ALTERNATIVE SCENARIOS OF ENERGY USE IN U.S. CROP PRODUCTION*

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Agriculture has been among the most productive sectors of the U.S. economy. The agricultural sector uses only four percent of the labor force to produce food needed for both domestic use and export demand [31]. Consumers in the U.S. spend only about 17 percent of their disposable income on food, the smallest percentage of any country in the world [16].

That energy has been recognized as the propelling force for current and continuing agricultural productivity, along with the prospect of much higher costs, have given rise to a growing interest in technologies or systems of agriculture that are less energy intensive.[1] Possible future adjustments in agriculture may affect output levels, costs and conservation of land and water qualities.

In this paper, alternative scenarios providing an analytical framework for analyzing tradeoffs in the attainment of output levels, energy use and natural resource conservation are formulated in order to assess the likelihood of implementing new technologies and crop production systems.

STAGES OF ENERGY USE WITHIN AGRICULTURE

Three overlapping stages of energy use by agriculture may be discerned. The initial state (the "solar energy stage") started with the beginnings of agriculture and ended during the first decade of this century. Human and animal energy were derived from vegetation which, in turn was energized by the sun. Most of the world's peasant population still relies heavily on the sun, augmented by wind and water, to provide energy for agricultural activities.

The next stage (the "transitional stage") ended with World War II. Agriculture in developed countries and in the commercial agricultural subsectors of less developed countries shifted largely to fossil fuels for power and for manufacture and application of fertilizers and pesticides.

During this stage the number of tractors and motor trucks on U.S. farms increased more than 15 times from 1910 to 1930, but their numbers did not materially affect the way agricultural products were produced. Of the 330 million cultivated acres, about 50 million acres were still required to produce most of the power [31].

The third stage (the "fossil fuel stage") remains in effect, and is likely to continue until fossil fuels are exhausted, become too expensive, or substitute energy resources are developed to be used within agriculture. During this stage, capital intensive (energy intensive) technologies effectively substitute for labor, land, animal power and on-farm sources of plant nutrients following changes in relative prices.

Between 1955 and 1975, farm population declined by 11 million people and farm output rose 70 percent. Animal power made little contribution in producing farm output. Off-farm sources of energy took over. Decreasing real prices for petroleum products contributed to the dependence on ex-

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[1] Although energy used by agriculture represents about 13 percent of total energy consumption in the U.S. (crop production uses roughly four percent), concern exists regarding vulnerability of farm incomes and production to energy price and supply fluctuations [3, 4, 5, 6, 7, 8, 12, 13, 14, 18 and 30].

haustible stock energy resources. Commercial fertilizer use doubled over the period, reaching 48.9 million tons in 1976 [8]. The number of farms decreased from 4.6 to 2.8 million, and their average size increased from 258 to 385 acres [31]. Farmers became almost completely dependent upon tractors and tractor-powered equipment for cultivation, fertilization, pesticide application and harvest [8, 10].

Energy use on farms can be differentiated with regard to whether it is used by "fixed site power units" or by "mobile power units." Table 1 shows the pattern of energy consumption in agricultural production on farms, ranches and plantations, by uses and sources. Fixed site power units use a wide range of energy sources such as petroleum products, natural gas and coal. Mobile power units are totally dependent on petroleum products (Table 1). Tractors are the major on-farm users of fuel, consuming annually about 1.9 billion gallons of gasoline and 2.3 billion gallons of diesel fuel [11]. Therefore, mobile power units are dependent upon the least available energy sources and they are essential in extensive cultivation.

ALTERNATIVE SCENARIOS FOR ENERGY USE IN AGRICULTURAL CROP PRODUCTION

Decreasing energy supplies and increased costs of exhaustible energy resources, particularly petroleum and natural gas, have caused concern about the possibility of satisfying prospective increasing demands for energy by agriculture. Possibilities of modification in production practices have been suggested for saving fuels [16, 19, 21, 22, 24, 25, 26, 33 and 34]. However, substantial decreases in energy use by agriculture imply major shifts in agricultural production practices. Changes in relative prices of production inputs, as was the case in the past, will bring additional changes in the pattern of resource use. In analyzing and resolving conflicts between agricultural output, energy use and natural resource conservation, five scenarios for crop production, based on extensive and intensive systems of cultivation, are examined. These alternatives do not exhaust the possibilities for changing uses of energy by agriculture, but rather provide a qualitative framework for analysis and evaluation of future policies and research efforts to change patterns of energy consumption.

Projected domestic and export demands for U.S. crops for the target years of 1980 and 2000 are provided by the U.S. Departments of Commerce and Agriculture.[2] The five scenarios of energy use developed herein, and which are designed to meet these demands are:

A. reversion to on-farm sources of energy

B. simple extrapolation from present energy uses

TABLE 1. PRESENT PATTERN OF FUEL USE IN AGRICULTURAL PRODUCTION, 1976

	Gasoline	LP Gas	Diesel	Distillate & Residual	Natural Gas	Coal	Electricity	Total
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fixed Site Power Units								
Crop drying	--	90	--	--	10	--	--	100
Structures (includes livestock)	40	10	32	--	4	--	14	100
Irrigation								
Surface	10	25	11.4	--	30	--	23.6	100
Sprinkler	10	25.7	10.8	--	30	--	23.5	100
Chem. manufacturing (pesticides)	--	--	--	13.7	62	15.4	8.9	100
Equipment manufacturing	--	--	--	5.7	63.3	17	14	100
Food and kindred products	0.5	1.2	--	10	48.3	9.9	30.1	100
Processing								
Input industry (seed feed, fat & oils)	0.9	2.4	--	8.4	56	0.4	31.9	100
Fertilizer industry	--	--	--	4	78.5	2	14	100
Mobile Power Units								
Highway vehicles	99	0.5	0.5	--	--	--	--	100
On farm vehicles	50	5	45	--	--	--	--	100

SOURCE: Economic Research Service [11] and Walker [37].

[2]OBERS' "E" projections of per capita commodity demands and normal grain exports represent desired output for U.S. agriculture in the formulation of the scenarios [35]. Applying these projections, the projected crop production index for 1980 is 125 (the 1967 production index equals 100). This index increases to 153 for the year 2000.

C. land-using energy scenario
D. land-conserving energy scenario and
E. technological breakthroughs.

Although a time lag would be required for necessary adjustments for each scenario, it is assumed that these adjustments can be made by the years 1980 and 2000.[3] For scenarios B, C and D present technology and availability of necessary production inputs are assumed. The possibility of technological advancements is allowed in the last scenario.

A. Reversion to On-Farm Energy Sources

With on-farm energy sources and reversion to animal power (horses and mules), projected demands for agricultural crops in 1980 would require more than double present tillable land acreage, or 687.5 million acres in 1980. An additional 75 million acres of land would be needed to feed the more than 60 million mules and horses needed to provide necessary horsepower. By the year 2000, crop production estimates would require more than 839 million acres with an estimated 100 million acres to feed the work animals. Vital cropland needs would reach the limit of land presently in farms.[4]

The relationship between output per acre, energy and research and extension was estimated with time series data (1940-1970) to provide guidance in the calculations. The ordinary least squares (O.L.S.) estimates of the equation are:

$$\text{Output/acre} = -17.6 + 0.037\ \text{Energy} + 0.098\ \text{Research}$$

$$R^2 = 0.91 \qquad (15.2)\ (0.012) \qquad (0.017)$$

The values in parentheses are standard errors and data are from [13, 23 and 28]. The index of average yield per acre needed for the calculations was adjusted to reflect lower per-unit costs of production than those prevailing prior to World War II. Adjustments for decreased productivity, because of the use of marginal and fragile lands and possible increased crop losses due to natural drying, were made. Manure produced in confinement, crop residues, crop rotations, organic materials and inorganic minerals (phosphate) that have not been chemically treated are assumed to substitute for commercial fertilizers and pesticides [1, 2, 9, 15 and 16].[5]

Soil erosion could become a more severe problem in nonmechanized agriculture because expanded acreage would include more fragile land. With no tractors and associated equipment to perform most heavy farm work, farm population would increase to about 30 million persons. Agricultural labor would climb to 10 million jobs from the present four million. Attracting laborers would require higher wage rates and contribute to substantial cost increases as well as to higher prices of agricultural commodities.[6]

B. Simple Extrapolation from Present Energy Uses

Extrapolation of the present structure of crop production to meet future demands results in energy consumption levels of 2,446.7 trillion BTUs of energy in 1980 and 3,112 in 2000. This scenario could be characterized as both labor and land conserving but energy intensive. The following nonlinear relationship was estimated with time series data as an aid to the calculations projecting aggregate energy use. Resulting estimates with O.L.S. are:

$$\text{Energy} = 550.9 + 56.8\ \ \text{Time} - 0.23\ \text{Time}^2$$

$$R^2 = 0.96\ (107.1)\ (14.9) \qquad (0.15)$$

Allocation of aggregate energy consumption to fixed and mobile power units is then performed through the output per acre information obtained above, and percentages are presented in Table 1.

Under the simple extrapolation of present energy uses, land requirements would increase three percent by 1980 and 10 percent by 2000 with present levels of output per acre. Therefore, land erosion might be comparable to current erosion rates, but the intensiveness of production would imply increased environmental damages from agricultural chemicals.[7] The most likely constraint of this scenario seems to

[3] For scenario A with regard to required animal stock, it is calculated that it would take 17 years to breed 60 million animals from the three million on hand [15].

[4] The cropland segment of the national land base currently consists of 427 million acres. An additional 264 million acres (representing a 56 percent expansion of current cropland) could be converted to cropland if improved and managed properly to prevent erosion and deterioration. This expansion consists of Class I, II and III land which is presently used mostly as forest land and pasture [8, 31, 32, 34].

[5] For quantification of trade-offs there is need for more survey and census data, rather than engineering estimates, linking energy use to actual operations. In particular, knowledge of the direct relationship between agricultural chemicals and yield improvements is needed in reducing their usage.

[6] Human labor at $3 per hour costs $6,000 per million BTUs and is the most expensive energy source [28].

[7] Concern exists that increased productivity on extensive and intensive margins of cultivation could lead to greater levels of erosion [20, 34], as well as residuals of fertilizers and pesticides which, combined with eroded soil and water runoff from intensively farmed cropland, may pollute ground and surface waters [1, 20, 29, 36].

be availability of specific sources of energy.[8] Substitution among possible energy sources would probably ensure a continuous flow of needed energy but at a high cost of capital stock adaptations.

C. Land-using Energy Scenario

This scenario of crop production assumes very little commercial fertilizer, agricultural pesticides or irrigation. Fixed site power unit requirements for energy would be substantially reduced, while mobile power unit requirements would be substantially increased.

Potential energy savings from the reduced need of certain farm implements (because of no agricultural chemical application activities), along with the increased use of mobile-power units needed to cultivate and harvest an enlarged land base, are considered. Assuming a yield per acre index of 70 (1967 = 100), 518 million acres of land would be required by 1980 for crop production and 634 million acres by 2000. An overall energy reduction of almost 50 percent would be achieved. Energy requirements would be 1,223.3 trillion BTUs by 1980 (equal to the 1951 level of energy consumption) and 1,556 trillion BTUs by 2000 (equal to the 1961 level of energy consumption).

A reduction of natural gas consumption by about 60 trillion cubic feet by 1980 is achieved, but increased gasoline consumption comparable to the straight extrapolation scenario would be required. Despite the overall decrease in energy consumption, labor would substitute only partly for energy from fossil fuels. Hand weed control, crop rotations and additional acres might offset production attributed to the use of agricultural chemicals.[9] Average size of farms would increase under this scenario.

D. Land-conserving Energy Scenario

This scenario assumes intensive agricultural production with less mobile power than presently used and an expanded use of energy for fixed site power units, particularly for fertilizer production and irrigation. A 20 percent increase in energy for the fixed-site power units results in an increase of 30 percent in yields. Energy consumption reaches 2,752.4 trillion BTUs in 1980 and 3,501.0 trillion BTUs by 2000. Crop acreage requirements are the lowest of the alternative scenarios. Only about 294 million acres by 1980 and 340 million acres by 2000 would be required. Although soil erosion with this alternative is substantially decreased, other environmental effects from sediment and salinity would be expected to decrease environmental quality.

Because of higher energy costs, production costs would be higher than for the straight extrapolation scenario. Labor inputs would be reduced and average size of farms would increase.[10]

E. Technological Breakthroughs

Ongoing research suggests energy conservation practices ranging from minimum tillage to genetic maniuplation of plants, reduced crop drying, improving energy efficiency in crop farming and in livestock production or even bypassing animal production in the supply of food, and use of machinery precisely scaled for specific operations. [17, 21, 22 and 24].[11]

Technological breakthroughs in developing energy resources, particularly resources based upon solar energy, might be possible. New technologies on energy demand and supply can change agricultural production relationships dramatically. Calvin's research on two species of the genus Euphorbia is of particular importance [27 p. 46].

Calvin [27] suggests these plants might produce between 10 and 50 barrels of oil per acre per year and would regrow from the stumps, so replanting might be necessary only once every 20 years or so. He optimistically estimates the cost of these crude hydrocarbons (virtually free of sulfur and other contaminants) be somewhere between $3 and $10 per barrel, but a substantial initial investment would be

[8] This analysis assumes that agriculture would be sufficiently competitive with sectors of the economy to obtain needed energy resources.

[9] This scenario resembles "organic farming" which does not rely on chemical fertilizers or pesticides but uses the same mechanized methods of crop production as conventional farming. Competitiveness of organic farming with conventional farming was studied by Klepper, et. al. who concluded that organic farming had about the same net returns but lower crop output per acre of cropland [18].

[10] Current and projected demands for agricultural products premised upon continuing and expanded effective demands are fraught with uncertainties rooted in natural, economic and political conditions. The possibility of reduced international demands for agricultural products and return to agricultural surpluses reminiscent of the 1960s should be considered.

[11] Some very large tractors and other machinery will do more work per unit time, but this efficiency is offset by greater fuel requirements during operation. In addition, increasing the number of acres per tractor would help reduce this input. A more efficient use of sunlight has also been suggested. Solar energy potentially available to U.S. cropland varies from a high of 260 watts/m^2/yr in most of New Mexico, Arizona, and parts of California, to a low of 150 watts/m^2/yr in dairy regions of upstate New York, Vermont and Oregon [16]. Areas with maximum sunlight are characterized by scarce water supplies. In these areas, agriculture must compete with manufacturing industries yielding much greater returns and making water prohibitively expensive for agriculture [16, 17].

required.[12] Such a technological breakthrough would make agriculture a major supplier of energy using the inexhaustible flow of solar energy through the medium of vegetation.

SUMMARY AND CONCLUSIONS

Five scenarios were developed in an effort to suggest bounds on energy use by agricultural crop production. Potential impacts of alternative structural scenarios on energy consumption, on specific sources of energy, labor, output per acre and land and water quantities and qualities are summarized in Table 2. Figure 1 compares alternative energy scenarios with respect to future energy use in crop production. Scenario E, technological breakthroughs, yields the lower bound of energy use and scenario D, land-conserving energy structure, represents the upper bound. Remaining scenarios point to tradeoffs between intensive farming, land and water resource deterioration, extensive farming and losses of soil productivity.

Less energy intensive agricultural systems seem desirable for the future, given potential resource use conflicts arising from them. Yet, outright energy minimization may lead to undesirable results in crop production. For the quantification of relevant tradeoffs, more forward-looking research must concentrate on resource substitution. Opportunities for adjusting

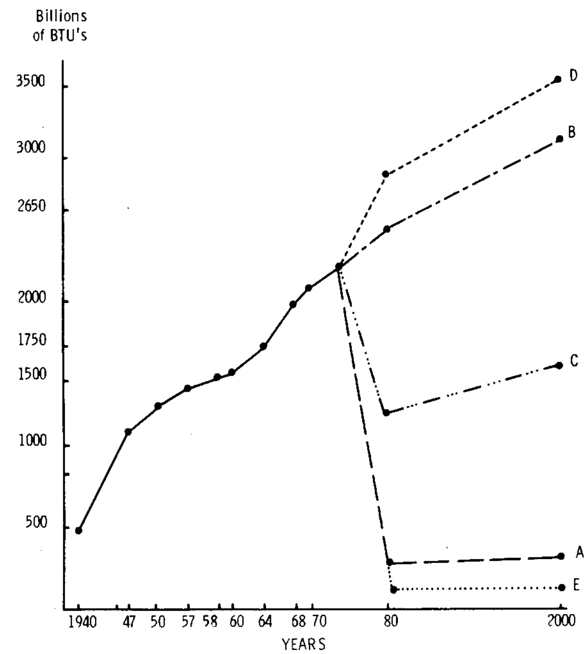

FIGURE 1. ENERGY CONSUMPTION UNDER ALTERNATIVE STRUCTURES OF CROP PRODUCTION[a]

[a]A. Reversion to on-farm energy sources; B. Extrapolation of present energy structure; C. Land-using energy use; D. Land-conserving energy use; E. Technological breakthroughs.

TABLE 2. COMPARISON OF ALTERNATIVE SCENARIOS IN CROP PRODUCTION[a]

	A[b]	B[c]	C[d]	D[e]	E[f]
Energy requirements	minimal	high	low	high	very low
Natural gas	zero	high	low	high	very low
Petroleum products	zero	high	high	high	very low
Land requirements	impossible	low	high	low	low
Output per acre	low	medium	medium-low	high	high
Environmental deterioration	minimal	very high	high	medium	low
Land erosion and deterioration	very high	medium	high	low	low
Employment	high	very low	medium	medium	high

[a]Ordinal comparisons are expressed as zero, minimal, very low, low, medium-low, medium, high and very high.
[b]Reversion to on-farm energy sources.
[c]Extrapolation of present energy structure.
[d]Land-using energy use.
[e]Land-conserving energy use.
[f]Technological breakthroughs.

[12]A major advantage of these plants is that they should grow well in dry regions on land not suitable for growing food. With a yield of 40 barrels per acre, an area the size of Arizona would be necessary to meet current requirements for gasoline.

factor ratios in response to changing factor price ratios exist even within the employment of present technologies. As the real price of energy increases, land, labor, capital, water and other inputs will be substituted for energy. Relative scarcity of individual forms of energy will cause divergent energy price ratios to develop which will induce shifts from one energy form to another. In particular, adjustments will arise as those commodities heavily dependent on scarcer energy forms are replaced by other commodities within the limits of production alternatives and consumer demand. Also, as transportation costs rise, present location of agricultural production may change with important effects on land use patterns for agricultural and nonagricultural purposes. These factor employment shifts need to be assessed and projected to smooth the adjustment process.

Although scenario A, complete reversion to on-farm energy sources, frees farm production from dependence on exhaustible stock energy resources, it becomes impossible to meet land requirements generated with this solution. If all potential cropland in the U.S. were used, enough output would be generated to meet estimated domestic demand in 1980, but only a portion of estimated export demand. By the year 2000, crop output would not be enough to meet estimated domestic demands. Furthermore, additional acres must be drawn from other uses, and land brought into cultivation would be marginal in productivity and fragile in terms of conservation and environmental quality. Projected output levels for the target years 1980 and 2000 are met by the remaining scenarios.

Scenario B, extrapolation of present energy use, results in very high levels of energy consumption which implies substantially higher costs for crop production. Furthermore, energy resource availability makes implementation of such a scenario unlikely. Scenario D, land-conserving energy use, is constrained by availability of inputs and prices and costs favorable to using additional energy needed. Soil productivity is preserved at the expense of high energy use levels and, in particular, high natural gas and petroleum requirements.

Scenario C, land-using energy use, leads to an overall reduction in the use of fossil energy, specifically natural gas, but an increased dependence on petroleum products owing to the extensive margin of land cultivation. Water quality deterioration is reduced, but additional expenditures for management of the increased land base are needed. This scenario resembles organic farming which is already in effect on a small scale. But a move to less intensive agricultural systems will need the consideration of the mix of products demanded and how this demand might require allocation of more land for crop production. The tradeoff of land resources for chemical inputs will need to be investigated in deciding to move to less energy intensive systems.

Scenario E, technological breakthroughs in developing energy resources, or ways of utilizing energy more efficiently, is associated with most uncertainty. Yet, it would make some of the other scenarios feasible and possibly make agriculture a net energy producer. Mobile power unit requirements of energy would be met through either coal (coal gasification and liquefaction) or electricity which can be produced by a variety of energy sources. Adaptations in the machine stock of farm vehicles can reduce overall dependence on exhaustible stock energy resources and, in particular, make scenario C the most desirable. Increased research effort in technology assessment is essential.

Energy intensive scenarios like B and D could be implemented only if new energy sources are developed and costs of production are favorable so that, given consumer purchasing power and prices of agricultural crops, the present standard of living can be maintained or improved. Research efforts should be directed not only toward a more efficient use of energy, but to a more efficient use of all scarce natural resources used in farming with attending implications for environmental quality and resource conservation.

REFERENCES

[1] Aldrich, S. R. "Perspectives on Nitrogen in Agriculture: Food Production and Environmental Implications," Paper presented at the American Association for the Advancement of Science meeting, Boston, Mass., February 20, 1976.

[2] Beasley, R. P. *Erosion and Sediment Pollution Control,* Ames, Iowa: Iowa State University Press, 1972.

[3] Berry, John H. "The Energy Problems and Agricultural Production," Proceedings of the Forty-Seventh Annual Meeting of the Western Agricultural Economics Association, Moscow, Idaho, 1974, pp. 195-200.

[4] Brandow, G. E. "The Distribution Among Agricultural Producers, Commodities, and Resources of Gains and Losses from Inflation in the Nation's Economy," *American Journal of Agricultural Economics,* Volume 53, December 1971, p. 913.

[5] Bromley, D. W. "The Food System and Project Independence: Economic Issues and Research Opportunities," Proceedings of the Western Agricultural Economics Association, Moscow, Idaho, 1974, pp. 129-137.

[6] Carter, H. O. and J. G. Youde. "Some Impacts of the Changing Energy Situation on U.S. Agriculture," *American Journal of Agricultural Economics*, Volume 56, December 1974, pp. 878-887.

[7] Commoner, B., M. Gertler, R. Klepper and W. Lockeretz. "The Effect of Recent Energy Price Increases on Field Crop Production Costs," Center for the Biology of Natural Systems, Report No. CBNS-AE-1, Washington University, 1974.

[8] Cotner, M. L., M. D. Skold and O. Krause. *Farmland: Will there be Enough?* U.S.D.A., E.R.S.—584, January 1975.

[9] Dvoskin, Dan and Earl O. Heady. "U.S. Agricultural Production Under Limited Supplies, High Energy Prices, and Expanding Agricultural Exports," Center for Agricultural and Rural Development, Ames, Iowa, 1976.

[10] Economic Research Service, U.S. Department of Agriculture. *Commercial Fertilizers*, Statistical Reporting Service, Washington, D.C., June 1976.

[11] Economic Research Service, U.S. Department of Agriculture. *Farm Income Statistics*, Statistical Bulletin No. 557, Washington, D.C., July 1976.

[12] Economic Research Service, U.S. Department of Agriculture. *Handbook of Agricultural Charts*, Agriculture Handbook No. 491, Washington, D.C., 1975.

[13] Economic Research Service, U.S. Department of Agriculture. *The U.S. Food and Fiber Sector: Energy Use and Outlook*, Prepared for the Committee on Agriculture and Forestry, U.S. Senate, Washington, D.C., 1974.

[14] Federal Energy Administration. *Energy Use in the Food System*, Office of Industrial Programs, Washington, D.C., May 1976.

[15] Gavett, Earl E. "Can 1918 Farming Feed 1975 People?" *Farm Index*, U.S.D.A., E.R.S., Washington, D.C., August 1975, pp. 10-13.

[16] Heichel, G. H. "Agricultural Production and Energy Resources," *American Scientist*, Volume 64, January-February, 1976, pp. 64-72.

[17] Heichel, G. H. and C. R. Frink. "Anticipating the Energy Needs of American Agriculture," *Journal of Soil and Water Conservation*, Volume 30, 1975, pp. 48-53.

[18] Klepper, R., W. Lockeretz, B. Commoner, M. Gertler, S. Fast, D. O'Leary and R. Blobaum. "Economic Performance and Energy Intensiveness on Organic and Conventional Farms in the Corn Belt: A Preliminary Comparison," *American Journal of Agricultural Economics*, Volume 59, No. 1, February 1977, pp. 1-12.

[19] Lockeretz, W. "Agricultural Resources Consumed in Beef Production," Report No. CBNS-AE-3, Center for the Biology of Natural Systems, Washington University, St. Louis, Missouri, 1975.

[20] Meister, A. D., E. O. Heady, K. J. Nicol and R. W. Strohbehn. "U.S. Agricultural Production in Relation to Alternative Water, Environmental, and Export Policies," Center for Agricultural and Rural Development, Iowa State University, Ames, Iowa, 1976.

[21] Musser, W. N. and U. Marable, Jr. "The Impact of Energy Prices on Optimum Machinery Size and the Structure of Agriculture: A Georgia Example," *Southern Journal of Agricultural Economics*, Volume 8, No. 1, July 1976, pp. 205-211.

[22] National Academy of Sciences. *Agricultural Production Efficiency*, National Research Council, Washington, D.C., 1975.

[23] Pavelis, George A. "Energy, Natural Resources and Research in Agriculture," E.R.S., U.S.D.A., Washington, D.C., 1973.

[24] Perelman, M. J., "Farming with Petroleum," *Environment*, Volume 14, No. 8, October 1972, pp. 8-13.

[25] Pemental, D., W. Dritschils, J. Krummel and J. Kutzman. "Energy and Land Constraints in Food Protein Production," *Science*, Volume 190, November 21, 1975, pp. 754-760.

[26] Rappaport, R. A. "The Flow of Energy in an Agricultural Society," *Scientific American*, Volume 225, 1971, pp. 117-132.

[27] Science. "The Petroleum Plant: Perhaps We Can Grow Gasoline," *Science*, Volume 194, October 1, 1976, p. 46.

[28] Steinhart, J. S. and C. E. Steinhart. "Energy Use in the U.S. Food System," *Science*, Volume 184, May 17, 1974, pp. 307-316.

[29] Taylor, R. C. and K. K. Frohberg. "The Welfare Effects of Erosion Controls, Banning Pesticides, and Limiting Fertilizer Application in the Corn Belt," *American Journal of Agricultural Economics*, Volume 15, No. 1, February 1977, pp. 25-36.

[30] Tweeten, L. and L. Quance. "The Impact of Input Price Inflation on the United States Farming Industry," *Canadian Journal of Agricultural Economics*, Volume 19, November 1971, pp. 35-48.

[31] U.S. Bureau of the Census. "Statistical Abstract of the United States," Washington, D.C.: U.S. Department of Commerce.

[32] U.S. Department of Agriculture. *Cropland for Today and Tomorrow*, E.R.S. Agricultural Economics Report No. 291, July 1975.

[33] U.S. Department of Agriculture. *Minimum Tillage: A Preliminary Technology Assessment*, U.S. Senate Committee on Agriculture and Forestry, Office of Planning and Evaluation, Washington, D.C., September 1975.

[34] U.S. Department of Agriculture, Conservation Needs Inventory Committee. *National Inventory of Soil and Water Conservation Needs, 1967*, U.S.D.A. Statistical Bulletin 461, January 1971.

[35] U.S. Water Resources Council. "1972 OBERS Projections of Regional Economic Activity in the U.S. Agricultural Supplement," U.S. Department of Agriculture, Washington, D.C.: Government Printing Office, May 1975.

[36] Wade, J. C. and E. O. Heady. "Controlling Nonpoint Sediment Sources with Cropland Management: A National Economic Assessment," *American Journal of Agricultural Economics*, Volume 59, No. 1, February 1977, pp. 13-24.

[37] Walker, John N. "Energy Usage in Crop Systems," in *Energy in Agriculture*, Proceedings of Conference of the Southern Regional Educational Board of the Council of Higher Education in the Agricultural Science, Atlanta, Georgia, 1975.