Commodity Prices and Resource Use Under Various Energy Alternatives in Agriculture

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An interregional, large-scale linear programming model is used to evaluate the economic impacts of the energy crisis on U.S. agricultural production. The study examines the changes in crop production under energy minimization, an energy shortage, high energy prices, and high agricultural exports accompanied by high energy prices. Results indicate that reduced supplies or higher prices for energy will have important impacts on commodity prices, irrigated agriculture, and on rural communities.

Sunlight provides the energy for the biochemical process in plants that converts carbon dioxide, water, nitrogen, and other elements into the food building blocks of sugar, starches, and plant protein. However, sunlight is only a part of the total energy required in food production. Human energy, animal energy, and fossil fuel energy are as necessary as sunlight for efficient food production. Modern agriculture, such as that of the United States, typically uses a much larger proportion of fossil fuel energy than does traditional agriculture [Pimental, et al., 1974].

The sequence of events that led to the energy crisis was accompanied by a sharp decline in food reserves and a rise in worldwide food costs. At least in the forseeable future, the world is facing the problem of increasing food production while the fossil fuel energy supply is rapidly declining and energy prices are high and likely to increase further. This study does not provide a complete answer for this problem, but it does provide some insight as to how U.S. long-run food production may be affected by the energy crisis.

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Several studies have resulted from the growing interest in the economic implications of expanding use of fossil fuel energy in agriculture. Lack of space prevents an extensive review. Some of the important studies to which this one relates are Carter and Youde, Council for Agricultural Science and Technology, Economic Research Service (1974), Hill and Erickson, and Pimental, et al., (1973). An extensive list of publications on energy and agriculture is available from "Energy in U.S. Agriculture: Compendium of Energy Research Projects" [Economic Research Service, 1976].

This study uses an interregional linear programming model to analyze changes that could occur in the level and pattern of agricultural production under various future energy situations. The alternatives evaluated with the model are: (A) a base run, (B) the minimization of total energy used in crop production subject to point demands specified for agricultural commodities, (C) an energy shortage in the agricultural sector, (D) higher energy prices, and (E) a combination of high exports and high energy prices.

The Model

An interregional linear programming model developed at The Center for Agricultural and Rural Development, Iowa State University, is used for analysis.[1] The analysis

[1]For a more detailed explanation of the model see Dvoskin and Heady.

refers to the year 1985, a time period far enough in the future to allow farming methods to adjust to the changing energy situation. The model minimizes the cost of producing and transporting major U.S. crops for Alternatives A, C, D and E. Cost minimization is subject to a set of primary constraints corresponding to land, water, and energy supplies by regions, production requirements by location, and a final set of constraints controlling the demand sector through commodity supply-demand relationships. A fifth alternative (B), specifies an objective function that minimizes the total energy, measured in Mcal, used for crop production and transportation.[2] [3]

Activities in the model simulate crop rotations, water transfer and distribution, commodity transportation, and supplies of nitrogen and energy. Endogenous crop activities are specified for corn grain, sorghum grain, corn silage, sorghum silage, wheat, soybeans, cotton, sugar beets, oats, barley, legume and nonlegume hay. The projected production levels of all other crops are exogenously determined.[4]

Two sets of regions are utilized in the analysis, producing areas and market regions. These are outlined in Figures 1 and 2, respectively. The producing areas are derived from the Water Resource Council's 99 aggregated subareas (ASA's). Each producing area is an aggregation of contiguous counties approximating the ASA's boundaries. The boundaries of the market regions are defined from a compatible subset of producing areas and represent established commercial and transportation centers.

Two sets of constraints are defined for producing areas to control the availability of dryland and irrigated cropland. The land constraints assure that total cropland used in each producing area will not exceed total cropland available. The cropland available in each producing area is reduced by the acreage of the exogenous cropland requirements in 1985.

Two sets of constraints are defined in each of the western producing areas 48 to 105 to balance the regions water uses with its dependable water supply including interbasin transfers, natural flow, runoff and other water uses. An adequate water balance is obtained by requiring the water supply to at least equal the sum of the water required by livestock and crops included in the model.

Nine commodity demand constraints are defined in each market region. These constraints represent point demands for the following endogenous commodities: corn grain, sorghum grain, barley, oats, wheat, oilmeals, nonlegume hay, legume hay, and silage.[5] Commodity demand constraints in other market regions are linked together by commodity transportation activities.

Eight constraints are defined at the market region level to provide for minimum and maximum levels of crop production within each region. These constraints reflect the limited adjustment of crop production to prevent diseases, distribution of work load over the entire growing season, and other noneconomic factors. Minimum and maximum production levels are specified for the following crops: corn grain, sorghum grain, barley, oats, wheat, soybeans, cotton, and sugar beets.[6] Both irrigated and dryland crops will satisfy the production constraints. A nitrogen fertilizer transfer constraint is de-

[2]Mcal is equal to one million calories or to 1,000 Kcal.

[3]There are 880 constraints and 10,700 activities in the model.

[4]In 1975, the endogenous crops in the model covered about 97 percent of the 327 million acres used by the principal crops [Statistical Reporting Service, 1977]. Endogenous crops are those that can be grown in many regions and are less dependent on specific regional weather or soil conditions.

[5]The commodity demands are exogenously determined from projected U.S. population by 1985 (232.2 million people), assumed levels of agricultural exports and livestock feed requirements.

[6]Each market region is required to maintain at least 70 percent of 1969 crop acres but not more than 250 percent of 1969 acres [U.S. Dept. of Commerce]. Such constraints allow some regions to increase their production substantially above 1969 level and assure a minimum of crop production in the less productive regions.

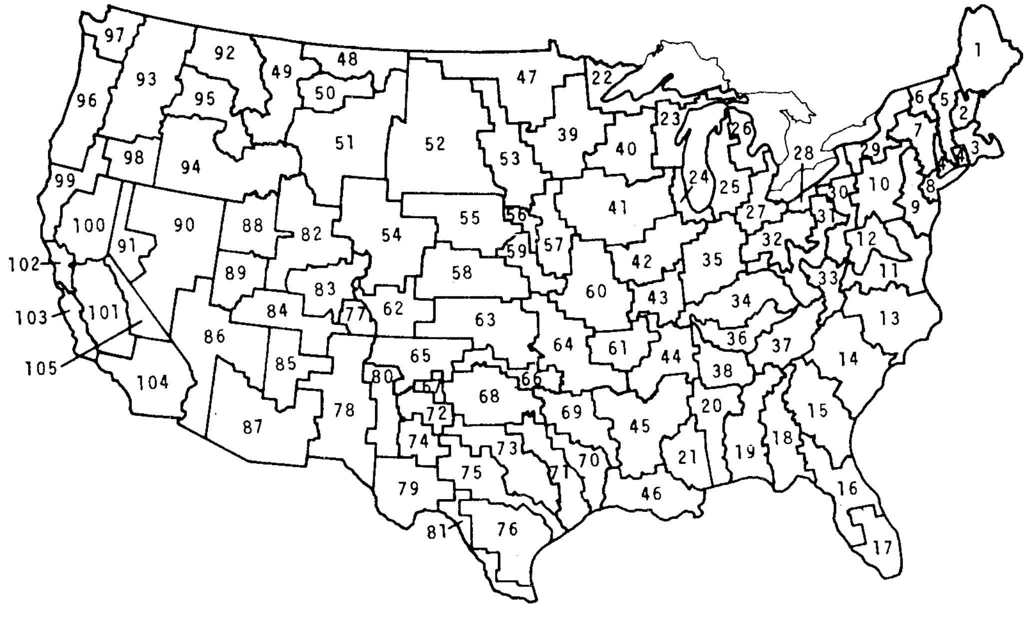

Figure 1. The 105 producing areas

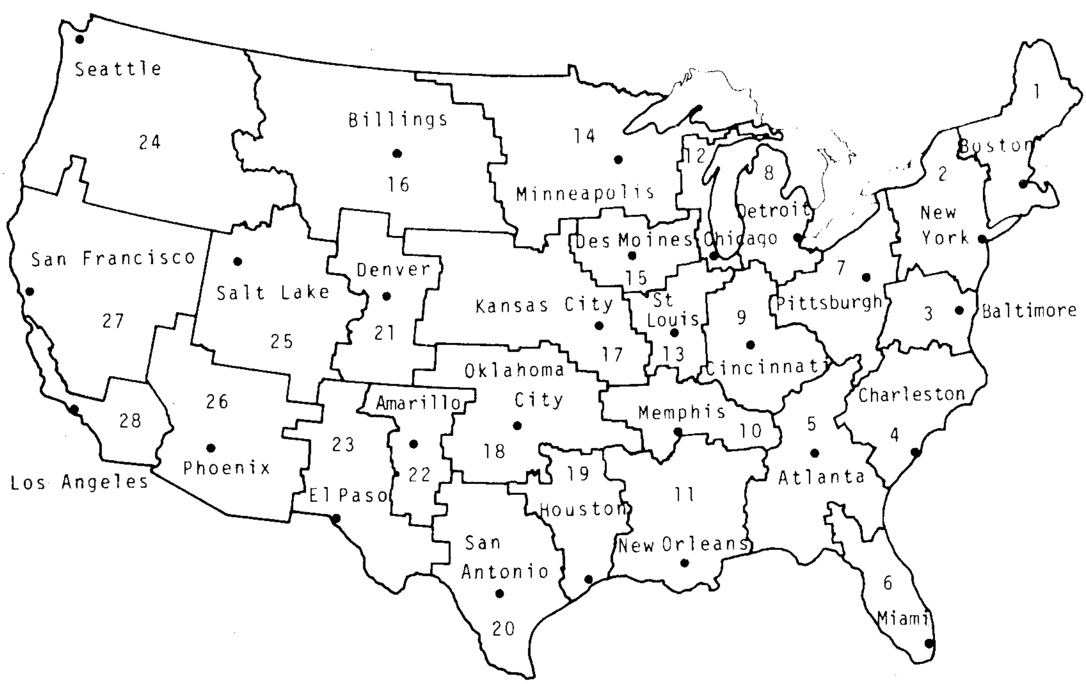

Figure 2. The 28 market regions

fined in each market region to balance the supply of and demand for nitrogen fertilizer used by the endogenous crop activities. Nitrogen fertilizer is supplied from livestock by-products, commercially produced fertilizers, and the fixation process of the legume crops. A predetermined amount of nitrogen is allocated to exogenous crops.

Five constraints in each market region balance the supply of and demand for energy. These constraints are defined for diesel fuel, natural gas, liquid petroleum gas, electricity, and total energy measured in Mcal. Regional energy needs are supplied by five energy buying activities which withdraw energy from the national energy constraints at 1974 energy prices. Energy is used by activities for crop production, transportation, and purchasing of commercial nitrogen fertilizer. Two constraints control national supplies and demands for cotton and sugar beets. These commodities are supplied directly into a national demand constraint, hence, no transportation activities are defined for these commodities. Five energy constraints also are defined at the national level and act as national energy markets for each energy source. Energy for each of the national markets is obtained from national energy buying activities.

Crop production activities simulate rotations for barley, corn grain, corn silage, cotton, legume and nonlegume hay, oats, sorghum grain, sorghum silage, soybeans, sugar beets, and wheat. These activities represent various regional crop management systems incorporating one to four crops and covering from one to eight years. Each crop activity is defined as conventional or reduced tillage. Two levels of fertilizer applications are specified for crop activities. The first level assumes farmers apply the optimum amount of fertilizers reflecting equality between fertilizer costs and marginal value product of fertilizer.[7] The second level assumes farmers apply only two-thirds of the optimum level, reflecting a fertilizer shortage. Crop costs are defined in terms of 1972 farm input prices.

Transportation routes for endogenous commodities are defined between market regions. All grain and soybean products are assumed to move by railroads as is the case with most long hauls of more than 200 miles [ERS, 1974]. The costs per ton-mile of grain and soybean transportation are obtained from the Federal Railroad Administration. Energy requirements for rail shipment are assumed to be one gallon of diesel fuel per 235 ton-miles of shipment [ERS, 1974].

Three water transfer activities are defined in the water supply regions: downstream flows, interbasin flows, and water-buy activities. The downstream flows are bounded to a maximum of 75 percent of the available water upstream. The interbasin flows are bounded to a maximum of the water transfer system's capacity. Water-buy activities are bounded by the maximum available water supply in each water supply region.

Five activities allow for the control of the total amount of energy consumed in agricultural production. Energy prices are specified for 1974, as compared to the 1972 prices used for other inputs. This change reflects the more than doubling of gasoline and diesel fuel prices between 1972 and 1974 while the index of prices paid by farmers rose by only 40 percent [Statistical Reporting Service, 1975]. The total cropland acreage available in each producing area is determined from the Conservation Needs Inventory Committee. An adjustment is made for projected changes in exogenous land uses and irrigation development by 1985. Demands for all commodities in the study are exogenously determined. Final commodity demands include domestic demands, net exports and livestock demands (Table 1).

Model Variations

The base run in Alternative A is the control alternative used for comparison with the results of the other alternatives. The base run represents normal long-run adjustments of

[7]The optimum level of fertilizer application is determined from a set of Spillman production functions defined by crop and producing areas.

TABLE 1. Crop production in 1975 and assumed total crop demands in 1985

Crop	Unit	1975[a]	Alternative A,B,C,D	Alternative E
			(Thousand Units)	
Corn grain	bushels	5,809,637	5,800,197	6,598,797
Sorghum grain	bushels	758,454	1,043,516	1,375,269
Barley	bushels	382,980	1,045,602	1,124,363
Oats	bushels	656,862	952,847	1,013,885
Wheat	bushels	2,133,803	1,709,475	2,306,715
Soybeans	bushels	1,521,370	1,613,103	2,565,568
Hay	tons	132,917	342,775	373,743
Silage	tons	120,595	125,709	74,113
Cotton	bales	8,327	10,911	11,015
Sugar beets	tons	29,270	33,583	33,583

[a]SOURCE: Statistical Reporting Service (1976).

agriculture if relative energy prices remain at 1974 levels, restrictions are not imposed on energy used in agriculture, and exports remain "normal."[8] The energy minimization solution in Alternative B, minimizes total fossil fuel energy required by crops for field operations, irrigation, fertilizers, drying, transportation, and pesticides regardless of increases in other production costs. Alternative C, minimizes the cost of producing food and fibers under a 10-percent reduction in overall energy. This alternative restricts the amount of energy available to agricultural production to 90 percent of the Mcal in the base run. The very likely situation of much higher relative energy prices in the future is examined in Alternative D under the assumption that costs per Mcal are double those of the base run. Alternative E retains high energy prices and also assumes 1985 exports of agricultural products to increase substantially from the base run.[9]

Model Results

The model results demonstrate differences in effects on commodity prices between an energy reduction policy and a high energy price policy. Even a 10-percent national energy reduction for agricultural production leads to a sharp increase in programmed supply prices. Doubling energy prices results, however, in a much smaller increase in supply prices. This phenomenon is explained by a very inelastic demand for energy. Doubling energy prices causes only a 5-percent reduction in the total energy used in agricultural production. The derived demand curve for energy in agricultural production becomes more inelastic as energy use declines. Hence, additional energy reductions can be achieved only by successively larger increases in commodity supply prices (Table 2). The weighted shadow prices of the various commodities are termed supply prices. They indicate the price levels necessary to attain the domestic and export commodity demands specified in the model.

The changes in energy supplies and prices have major impacts on agricultural resource use and costs. The most important energy saving "devices" identified through model results are reduction in energy used for irrigation and for commercial nitrogen. Irrigated agriculture uses energy very intensively. The 10-percent energy reduction in Alternative C is accompanied by a 41-percent reduction in irrigated acres. The 5-percent energy reduction resulting from a doubling of energy prices in Alternative D leads to a 22-percent reduction in irrigated acres. The outcome differs substantially, however, under high export demands for U.S. agricultural products.

[8]"Normal" increase in exports in 1985 refer to U.S. export experience prior to 1972-1973.

[9]Total exports of grain under the base run are assumed to be 76.7 million tons and 4.1 million bales of cotton. Under the high export alternative, grain exports are assumed to be 118.4 million tons and cotton exports are assumed to be 4.2 million bales. These two export levels are obtained from ERS, USDA. See Dvoskin and Heady for more details.

TABLE 2. Endogenous commodity shadow prices for the base run and changes from the base run alternative in 1985

Commodity	Unit	Base Run Alternative A	Energy Min. Alternative B	Energy Cut Alternative C	High Energy Prices Alternative D	High Exports Alternative E
		Dollars per unit		Index of Commodity Prices (A=100)		
Corn	bushel	.94	N.A.	164.89	113.83	230.85
Sorghum	bushel	.90	N.A.	177.78	118.89	271.11
Barley	bushel	1.19	N.A.	142.02	110.08	220.17
Oats	bushel	.94	N.A.	139.36	107.45	268.09
Wheat	bushel	1.45	N.A.	148.97	113.10	284.14
Soybeans	bushel	3.17	N.A.	169.09	117.67	237.22
Hay	ton	29.66	N.A.	165.58	115.95	190.09
Silage	ton	7.37	N.A.	150.75	112.35	189.82
Cotton	pounds	.27	N.A.	151.85	111.11	151.85
Sugar beets	ton	15.23	N.A.	141.17	107.49	133.55
Total commodity cost	million $	4,223	N.A.	154.68	112.62	216.24

TABLE 3. Energy sources use, changes from the base run (Model A), and prices under different alternatives in 1985

Fuel Source	Unit	Base Run Alternative A[a]	Energy Min. Alternative B	Energy Cut Alternative C[b]	High Energy Prices Alternative D[c]	High Exports Alternative E[c]
			Energy Use			
Diesel	million gallon	5,377	5,179	5,340	5,407	5,964
Nat. gas	million ft.^{3}	180,060	111,198	124,332	152,966	400,458
LPG	million gallon	657	534	571	625	740
Electricity	million kwh	12,014	5,738	7,607	8,915	13,025
Total Mcal	10^9	292.438	249.622	263.194	277.354	377.544
			Index of Energy Use (A=100)			
Diesel	A=100	100.00	96.32	99.31	100.56	110.92
Nat. gas	"	100.00	61.76	69.05	84.95	222.40
LPG	"	100.00	81.28	86.91	95.13	112.63
Electricity	"	100.00	47.76	63.32	74.21	108.42
Total Mcal	"	100.00	85.36	90.00	94.84	129.10
			Shadow Prices			
Diesel	¢/gallon	35.614	N.A.	136.829	68.267	77.858
Nat. gas	¢/100 ft.^{3}	62.554	N.A.	240.333	119.906	136.753
LPG	¢/gallon	30.008	N.A.	115.291	57.521	65.602
Electricity	¢/kwh	2.387	N.A.	9.171	4.576	5.218
Total Mcal	¢/Mcal	.858	N.A.	3.505	1.716	1.716

[a]Energy prices are based on 1974 prices.
[b]Energy shadow prices.
[c]Energy cost (Mcal) is set at twice the cost of Alternative A.

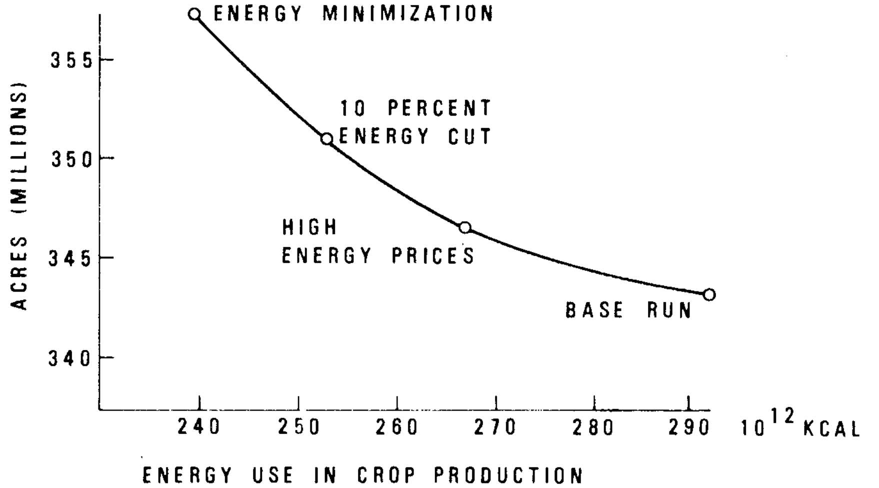

Figure 3. Energy-cropland substitution among different alternatives

Under high exports, irrigated acres increase 12 percent above the base run, even when energy prices are doubled.

In all the alternatives, unused cropland is substituted for water, fertilizer, and especially energy when it is short in supply or high in price (Figure 3). An important part of the shift is the conversion from irrigated to dryland crop production. For example, under the 10-percent energy reduction in Alternative C, irrigated crops decline by 9.4 million acres while dryland crops increase by 17.5 million acres. Undoubtedly, such changes will have a great impact on irrigated farming and rural communities in the western states.

One interesting result is the energy shadow price (Table 3) derived in Alternative C. The price per Mcal more than quadruples from 0.858 cents in the base run to 3.505 cents per Mcal. If we assume that relative fuel prices remain at 1974 levels, the latter shadow price is equivalent to diesel fuel at $1.37 per gallon, natural gas at $2.40 per 1,000 cubic-feet, LPG at $1.15 per gallon, and electricity at 9.2 cents per kwh.[10] Energy shadow prices would be substantially higher if an energy shortage coincided with high exports because agriculture requires much more energy under the high export alternative.

The distribution of energy use among different agricultural inputs for each alternative is shown in Table 4. Tractors, combines, and other self-propelled farm machinery consume about two-thirds of all the energy used. The amount required for fertilizers varies according to the energy and export alternatives. Under energy minimization in Alternative B, energy for nitrogen fertilizer declines sharply because the model substitutes manure and legume crops for commercially-produced nitrogen. However, the high export alternative uses about 262 percent more energy for nitrogen fertilizers than does the base alternative (A). Energy for field operations is reduced under energy minimization because of a larger acreage of reduced tillage. However, this alternative increases energy use for pesticides by 28 percent. Therefore both input substitution within the industry and possible increased use of inputs by other industries related to agriculture should be considered in the development of an energy saving program in agriculture. For example, under the energy-minimization program, crop production becomes more geographically dispersed and total energy for transportation increases accordingly.

[10]This assumption implies no deregulation of natural gas prices.

TABLE 4. Energy use in crop production and percent distribution for different alternatives in 1985

Inputs	Base Run Alternative A	Energy Min. Alternative B	Energy Cut Alternative C	High Energy Alternative D	High Exports Alternative E
			10^9 Mcal		
Fuel for machinery	169.573	164.956	169.435	171.520	184.465
Pesticides	7.374	9.405	7.896	7.518	7.875
Nitrogen fertilizers[a]	36.455	11.969	26.904	31.363	95.563
Nonnitrogen fertilizers[b]	7.207	7.287	7.036	7.060	8.019
Crop drying	13.056	12.148	12.610	12.933	14.320
Irrigation	41.456	.416	21.737	29.849	44.862
Transportation	17.317	43.441	17.576	17.110	22.440
Total	292.438	249.622	263.194	277.353	373.544
			Percent Distribution		
Fuel for machinery	57.99	66.07	64.38	61.84	48.86
Pesticides	2.52	3.77	3.00	2.71	2.09
Nitrogen fertilizers	12.47	4.79	10.22	11.31	25.31
Nonnitrogen fertilizers	2.46	2.92	2.67	2.55	2.12
Crop drying	4.46	4.87	4.79	4.66	3.79
Irrigation	14.18	.17	8.26	10.76	11.89
Transportation	5.92	17.41	6.68	6.17	5.94
Total	100.00	100.00	100.00	100.00	100.00

[a]Energy for nitrogen fertilizers indicates energy for production of chemically produced fertilizers.
[b]Energy for nonnitrogen fertilizers includes the energy required in production of phosphorus and potassium fertilizers.

Impacts on Western Irrigated Farming

Reduction in energy supplies, as well as higher energy prices, have an important impact on western irrigated farming. The main reason for a decline in irrigated acres under changed energy supplies and prices is the high energy intensity of irrigated crops (Table 5). Crop yields on irrigated land average higher than those for dryland. However, energy used for irrigation generally increases more than in proportion to increases in yields. Under unrestricted energy supplies in Alternative A, the amount of energy per unit of output for irrigated crops is about double that of dryland crops. An energy shortage, as simulated by Alternative C, leads toward a more efficient utilization of energy both for dryland and irrigated crops.[11] High energy prices (Alternative D) result in very minor changes in energy requirements per unit of output for both dryland and irrigated crops. These changes are small because the high energy prices induce relatively small changes in reduced tillage, fertilizer application, and in improved interregional production patterns.

These various energy situations also have important impacts on the level and regional distribution of farm income. Whether farmers are better off under an energy crisis depends, in part, on export levels and increases in input prices due to higher energy prices. In general, the inelastic demand for agricultural commodities implies that higher commodity prices will increase farm income under either higher prices or an energy reduction. Reduced supplies or higher prices of energy are likely to reduce irrigated acres and nitrogen applications. Both factors would reduce crop yields and total agricultural production. Lower agricultural production generally means higher farm prices and, because of inelastic demands, higher farm income. These income increases, however, would not be distributed equally among regions. Western irrigated regions would be relatively worse off and eastern and mid-western regions would be relatively better off in terms of farm income. These shifts would reflect changing comparative advantages in favor of dryland farming regions. These changes

[11]A more efficient utilization of energy is assumed to occur when less energy is required to produce a given output.

TABLE 5. U.S. average fossil fuel (Mcal) required to produce a unit of output by crop for different alternatives in 1985

Crop	Unit	Base Run Alternative A	Energy Min. Alternative B	Energy Cut Alternative C	High Energy Prices Alternative D	High Exports Alternative E
				Dryland crops		
Barley	bu.	13.093	13.005	13.791	13.141	15.574
Corn grain	bu.	16.415	15.536	15.846	16.083	19.203
Corn silage	ton	116.588	106.174	111.034	112.270	127.459
Cotton	bale	1,675.731	1,627.045	1,588.794	1,620.599	1,812.957
Legume hay	ton	346.705	345.480	343.669	346.355	340.331
Nonlegume hay	ton	555.992	545.749	547.774	550.171	616.492
Oats	bu.	11.368	10.251	10.325	10.685	11.995
Sorghum grain	bu.	19.096	16.057	17.529	19.056	24.540
Sorghum silage	ton	109.746	106.649	106.839	107.576	127.739
Soybeans	bu.	17.127	15.775	16.410	17.019	17.361
Sugar beets	ton	87.365	79.747	87.503	85.047	93.253
Wheat	bu.	20.856	19.301	20.227	20.240	25.915
				Irrigated crops		
Barley	bu.	30.027	10.879	22.356	24.124	25.132
Corn grain	bu.	30.832	13.868	16.234	28.963	26.604
Corn silage	ton	154.162	71.650	131.712	133.861	189.566
Cotton	bale	2,963.243	1,088.160	3,004.383	2,913.593	3,049.113
Legume hay	ton	632.963	181.042	562.969	582.293	608.226
Nonlegume hay	ton	656.716	360.896	444.221	451.954	491.037
Oats	bu.	26.333	13.166	22.678	28.983	30.927
Sorghum grain	bu.	32.182	10.527	31.410	30.587	32.351
Sorghum silage	ton	122.062	56.152	125.884	111.387	131.345
Soybeans	bu.	59.806	10.142	57.958	57.277	70.155
Sugar beets	ton	131.855	68.690	123.346	130.569	133.909
Wheat	bu.	37.435	14.424	30.731	33.786	42.990

could be extremely important for some crops. For example, production of cotton which previously shifted to the Southwest would partly shift back to the South Atlantic region because the irrigated cotton in the Southwest uses substantially more energy per acre.

The increased farm income of the dryland areas would have a positive economic interaction with rural communities. At a given level of exports, reduced supplies or increased prices of energy would have a negative impact on rural community income and employment in irrigated areas of the West.

Summary

Model results indicate that reduced supplies or higher prices for energy will have important impacts on U.S. agriculture and food production. Domestic consumers and foreign purchases of U.S. farm products would experience higher commodity prices as reflected in the shadow prices of the programming model. The nation's agriculture could absorb a 10-percent reduction in energy supplies but only with a substantial increase in commodity prices. The reduction in energy supplies would result in a conversion from irrigated to dryland crop production. Under reduced supplies and higher prices for energy, crop production would shift eastward from irrigated to dryland farming regions.

These shifts in production would also redistribute farm income away from irrigated regions to dryland regions. These shifts would also have an impact on income and employment in rural communities. The negative impacts in western states could be partially overcome by increased irrigation efficiency as well as reduced levels of water application. However, the main hope for prosperity of irrigated agriculture, particularly that drawing from groundwater supplies, depends on high exports and abundant energy supplies.

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