MARCH 1971

CAED 38

- **FOOD COSTS**
- **FARM INCOMES**
- **CROP YIELDS**

With Restrictions on Fertilizer Use

CENTER for AGRICULTURAL and ECONOMIC DEVELOPMENT
Department of Economics * IOWA STATE UNIVERSITY * Ames, Iowa 50010

PRELIMINARY

FOOD COSTS, FARM INCOMES, AND CROP YIELDS

With Restrictions On Fertilizer Use

by

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FOREWORD

Agriculture now serves in an increasingly interdependent role with other sectors of the economy. This increasing interdependence grows out of the rapid commercialization and technological changes in farming in the last three decades. As farms grow larger more highly capitalized and employ increasing quantities of inputs from other sectors, this interdependence will be accentuated.

In comparison with its present structure, farming once approached a closed system with respect to the majority of its inputs and a large portion of its output. As a reflection of this closed system, farms generated most of their own inputs. Energy was produced biologically on farms in the form of feed stuffs and animals. Fertility and pest control also were of on-farm, biological origin. Both were supplied mainly through cropping systems, variety adaptations, land use methods, and other on-farm practices. With this source and pattern of inputs, the agricultural sector imported a small proportion of inputs from the industrial sector. Its exports to other sectors were mainly food commodities.

Now, however, the major proportion of agricultural inputs is imported from the industrial sector in the form of power units, fuels, chemical fertilizers, pesticides and other materials representing advanced capital technologies. Because of the change in source and composition of its inputs, the nature of agricultural outputs and exports also has changed. The agricultural sector now exports a much larger supply of food at lower real cost to consumers. But it also exports a growing quantity of technological inputs which are unused in the agricultural production process and find their way into streams and water supplies as wastes and pollutants.

Through the vehicle of rainfall runoff, erosion and the transportation of silt from farms to streams, the technological inputs upon which modern farming is based now have great environmental impacts. Hence, the question arises: How would different levels and mixes of input use affect important variables of human concern? Included in this set of important variables are those of the ecosystem, farm income and food costs.

This study has been made accordingly. It concerns itself with a single major category of farm inputs; namely, chemical fertilizers. Since the demand for food is inelastic, a reduction in marketings causes revenue to increase. Federal farm programs of recent years have recognized this interrelationship of the farm sector with consumer markets. They have provided payments to farmers for idling land in order to reduce marketings and increase farm income. Hence, these questions arise: What would be the effect on farm income, consumer food prices, treasury costs of farm programs and the ecosystem if farmers were to use fewer industrial inputs? How would income of farmers in particular regions be affected if state legislators enacted pollution and conservancy restraints on their producers while other states do not?

The analysis which follows has been made to evaluate outcomes if lower levels of fertilizer were to be used. Would reduced levels of fertilizer have the simultaneous effects of reducing the pollution potential while either increasing farm income or reducing the level of treasury costs to attain a given level of farm marketings and income? And what are the trade-offs which might be reflected in the form of higher food costs to consumers and reduced fertilizer sales by the industrial sector?

This study is one of a series relating to policy alternatives for agriculture. Its purpose is to provide objective information indicating the consequences and trade-offs involved in selecting various alternatives. The relevant publics then have an improved basis for selecting policies which have differential impacts on various strata of society and which relate to particular goals for the farm sector and society at large.

Earl O. Heady
Executive Director
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Summary

This study analyzes the economic effects of placing public restrictions on the use of inorganic fertilizer in the production of six major crops -- corn, wheat, barley, oats, grain sorghum and cotton. The analysis focuses first on effects if all farmers in the nation are affected by the restriction and second, on effects if only a single state is affected by the restriction. Iowa was chosen for the individual state analysis.

Economic effects are measured for three alternative levels of fertilizer use assuming that U.S. farmers are restricted to each level over the period 1970 to 1980. The initial restriction level chosen (model analyzed) was based on 1969 average application rates of nitrogen and other inorganic fertilizers. This application rate was assumed to be the maximum allowed per crop acre for the next decade; the analysis then measures resultant shifts in resource use, changes in production levels, variation in farm prices and incomes, and increases in consumer food costs. The second model assumes fertilizer use is restricted to approximately one-half the previous rate of application. Economic effects are measured for the same farm indicators and consumer food costs over a similar time period. The final U.S. model assumes the elimination of inorganic fertilizer use for major crop production.

Economic effects are next measured for the same levels of fertilizer use assuming Iowa farmers are required to lower fertilizer use while other farmers can apply a rate similar to 1969. Results are projected for 1970, 1975 and 1980 with changes estimated in Iowa land use, crop yields, production levels, in-state feed supplies, feed prices, government payments and Iowa farm income.

Results of the analysis for the United States indicate that a wide range of substitution possibilities exists between cropland and fertilizer use for producing a given level of crop output. Limiting fertilizer use could result in the return to production of large acreages of cropland which have been annually diverted from crop production by government programs. A large potential exists for this type substitution since these programs have diverted over 50 million acres of cropland annually since 1961. Most of these acres remain readily available for crop production if the need arises.

A further result emphasized by this analysis is that any threat to domestic food supplies is clearly tempered by the large portion of U.S. farm production which is shipped to other countries under various export programs. There are wide substitution possibilities between levels of crop exports and required domestic food supplies. Any change in exports has a substantial effect on farm prices and income levels, unless offset by a change in domestic utilization. An attempt to keep exports rising

along past trends while applying restrictions to fertilizer use could result in rapidly rising food prices. A decision to cut back government supported exports too fast even with fertilizer use restricted could result in declining farm prices and incomes.

This study indicates that limiting fertilizer use on all farms of the nation can cause effects on farm prices and incomes similar to limits on total cropland. But the opposite effect is also true. The availability of large acreages of diverted cropland for expanding crop production tempers the possible upward pressure on farm prices that limiting fertilizer use might be expected to cause. If acreage diverted under government program is held constant, placing a restriction on fertilizer use can raise farm prices and incomes along with consumer food costs. But, a relaxation of government land retirement programs with fertilizer use restricted may or may not raise farm prices,

Summary of gains and losses from restricting fertilizer to various levels

Fertilizer Restriction Level	Change Measured from Actual 1969								
	Total Food Costs			Total Farm Income			Farm Program Costs		
	1970	1975	1980	1970	1975	1980	1970	1975	1980
				(billion dollars)					
110 lb max	+ 4.0	+11.6	+21.7	-1.1	-0.2	+1.6	-0.3	-0.5	-0.7
50 lb max	+ 4.4	+12.9	+23.4	-1.0	+1.0	+2.5	-1.2	-1.6	-2.3
0 lb max	+11.2	+27.1	+38.7	+0.5	+3.6	+6.8	-3.3	-3.3	-3.3

depending on (a) how restrictive is the limitation on fertilizer, and (b) how long a time period is considered -- that is, how much increase in domestic population and per capita income growth is taken into account.

We found in this study that limiting fertilizer to 1969 (110 pounds) rates of applications over the period 1970 to 1980 would not raise farm prices and incomes or the farm portion of consumer food costs <u>if</u> government land retirement programs are relaxed. Similarly, the reduction of fertilizer use to approximately one-half present levels could be offset through 1980 by a greater expansion of crop acreage but this policy alternative would be largely "used up" by 1980. The cropland which then remains available is of low productivity and high per unit costs. A continuation of this policy after 1980 without a reduction in exports could cause a rapid increase in prices and food costs.

The complete removal of fertilizer causes a sharp reduction in crop production which brings higher crop prices, reduced livestock production and a large cutback in exports even though all government diverted acres are released for crop production. Even with a 75 percent reduction in feed grain export in the initial year of the analysis, corn price jumps to $1.99 per bushel. Livestock prices are projected to increase along with crop production costs, and consumer food costs rise. Governments costs of land retirement drop, but the increase in consumer food costs is double the tax savings from reduced land retirement.

Restricting fertilizer use in an individual state has quite different consequences for the affected farm public as well as the food consuming public. And again the large producing potential of U.S. agriculture is of critical importance. With only Iowa farmers restricted in the use of inorganic fertilizer, corn and other crop production is sharply decreased in Iowa. If no offsetting expansion of crop production occurs in other states, national and Iowa farm prices would rise. However, with the large amount of cropland now diverted under government programs in other states, there is adequate production capacity to offset any reduction in Iowa crop production. Thus Iowa farm production is decreased but prices received by Iowa farmers, which are determined by aggregate supply and demand for a crop, do not rise by any substantial amount. Farm income drops. Limiting fertilizer use to a maximum of one-half present levels would only slightly affect Iowa farm income at first. However, these estimates suggest a reduction of $1,000 net income per farm by 1980. A much larger reduction occurs with the elimination of fertilizer use. Net income drops as Iowa farmers have smaller sales of crops, higher costs for purchases of feed for livestock (Iowa imports one-third of its feed grains by 1980 with fertilizer prohibited) and larger total production costs from farming more but less productive land. The outcome is characterized by reduced cash receipts, less income from government payments and sharply higher production costs. These trends cause almost a 60 percent reduction in net farm income for Iowa farm families. In actual figures, net income is estimated to drop from $8,388 in 1969 to $3,646 in 1975 (allowing for a further decline in farm numbers) with fertilizer eliminated. Only a slight improvement occurs thereafter; net income reaches $4,080 by 1980.

While a reduction in Iowa fertilizer use would lower incomes to farmers, no change would necessarily occur in consumer food costs. With production potential available in other states to keep food supplies adequate, the farm portion of consumer food prices need not change. Thus the major effect of a single state limiting the use of a particular production input is borne by that state's farmers. Neither farm prices in general nor the farm portion of consumer food costs is substantially affected by the restriction.

This study indicates opposite effects for the farm public if fertilizer is limited in one state or limited in all states. Also, consumer food costs are not affected by an individual state limitation but a nationwide limitation could drive food prices sharply higher -- if the limitation restricted fertilizer use by a substantial amount. These results reinforce the importance of inorganic fertilizer in crop production, its past role in holding down food prices, and the importance of an enlightened policy for continued use of fertilizer in food production.

Introduction

Technological innovation, capital intensification and improved labor productivity have combined to provide American food consumers an abundant supply of food at a cost which requires only 16 percent of their disposable incomes. Efficiency in food production and marketing has resulted from the efforts of U.S. farmers combined with those of the industrial sector which, on the one hand, provides new inputs to improve the farm production process, and on the other hand, purchases the commodities from the farmer and processes them into final food products. The farmer, for his part, has adopted the new inputs and rearranged his input mix to increase total output while employing a minimum of resources in the process.

These combined efforts have been quite successful; between 1950 and 1969 total farm output rose by 35 percent while total inputs increased only 11 percent, a 23 percent increase in productivity. To accomplish this, farmers substituted increased quantities of capital in the form of machinery, fertilizers and other inputs into the production process, thus reducing the man-hours of labor used. Output per man-hour more than doubled between 1950 and 1969.

Increased output, improved efficiency, lower cost food, and improved living standards have long been public goals in the U.S. In large measure, these goals have been achieved by a close interaction of all groups of the economy -- industry, agriculture, and marketing institutions. Industry produced and farmers adopted the new capital inputs which increased output and reduced production costs, especially costs per unit or per bushel. In turn the market system passed along much of the gain from lower production cost to consumers in the form of lower food costs.

So long as the goals of the nation regarding the agricultural sector remained those of improved efficiency and lower food costs, the adoption and increased use of new inputs meshed well with the farmer's desire to increase his income. Under these circumstances, the unlimited use of new inputs was accepted by the public as a means to achieve lower food costs and increased incomes for efficient farm producers. But once these goals had been largely achieved, it was only reasonable that that same public might turn its attention to any side-effects associated with the use of these new inputs in unlimited quantities. In the past, some attention has focused on items like pesticide residues in milk, growth stimulant residues in beef, effects of insecticides on bird population, and herbicide effects on fish in streams and reservoirs. In some of these cases, the magnitude of the problem has caused considerable delay in finding solutions to the problem. In other cases, the procedure followed was to establish tolerance levels to minimize any potential side-effects on the environment, on wildlife, or human population. These tolerance levels often times represented a compromise to achieve the conflicting goals of improved efficiency while meeting public health standards. Compromises of this nature are a natural part of a society which desires such things as rapid means of transportation but open and spacious countryside without billboards, and low cost fuel for automobiles but smog free air. Such compromises of necessity must emanate from the political process where the desires and objectives of millions of citizens are registered at each election.

Public attention has yet to turn its full gaze towards one of the factors responsible for a major portion of lower cost food and improved farm incomes -- that factor is inorganic fertilizer. But there are limited and somewhat distant rumblings that fertilizer use will not always escape this attention. A recent news article in the Des Moines Sunday Register reported that "A Chickasaw County (Iowa) water testing program completed here recently revealed that 30 percent of the private wells tested contained enough coliform bacteria or nitrate nitrogen to be labeled as 'unsatisfactory or unsafe' by U.S. Public Health Service Standards."[1/] The article went on to cite soil scientists at the University of Wisconsin who, it said ". . . encourage farmers who grow continuous corn not to apply more nitrogen than the crop can use -- in order to reduce the possibility of nitrate contamination of underground water." The article pointed up the importance of residue tolerances and the possibility of setting standards in the use of agricultural chemicals to reduce possible side-effects on the human population.

Residue tolerances for use of chemicals are usually established only after long and arduous evaluations of all aspects of their use -- and these include economic considerations as well as human well-being. To preclude the use of a chemical and raise the cost of food may reduce human well-being as much as allowing the unlimited use of the chemical. In all such situations, a balance must be struck between over use which may be harmful and elimina-

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1/ Charlie Nettles. "30% of Wells Flunk in Water Test." Des Des Moines Sunday Register, Section F, July 19, 1970.

tion of its use which also could be harmful, especially to those persons who spend a major portion of their incomes on food.

In the case of inorganic fertilizer, little evidence has yet been gathered to indicate the levels of application which might result in substantial side-effects. The process of gathering such data may be time consuming and require considerable time lag between any initial results and ultimate conclusive evidence to form a basis for tolerance levels. In the meantime, public activity could result in public action to assure that any hazard to public health is removed. Such action could have substantial effects on a whole set of factors -- including consumer food costs, farm family living standards, income flows in rural areas, exports of agricultural commodities, and the nation's balance of payments.

This study is undertaken in the interest of determining the economic costs associated with placing alternative limits on the use of inorganic fertilizer in crop production. Its purpose is to estimate the substitution possibilities which exist between fertilizer and cropland, the effects on farm returns of such substitutions and the effect on consumers' food costs, and other related variables.

Fertilizer Application on Major Crops

Commercial fertilizer use is so prevalent in U.S. agriculture today that it is difficult to realize that only two decades ago a significant number of commercial farmers were not using any inorganic fertilizer. In a study of acceptance and use of fertilizer in 1953, researchers at Iowa State College found that 31 percent of Iowa farmers were using no inorganic fertilizer on their farms. The study also reported that the adoption rate for fertilizer tended to be correlated with the entrance of younger and better educated farmers. The study suggested "a fertilizer user could be characterized generally as having more capital, a larger farm, more years of education and fewer years of farming experience, and being somewhat younger than the nonuser."[2/] As more of Iowa's farmland came under the control of this type of farm operator, the

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2/ Anderson, M. A., L. E. Cairns, Earl O. Heady, E. L. Baum. "An Appraisal of Factors Affecting the Acceptance and Use of Fertilizer in Iowa, 1953," Iowa Agr. Exp. Sta. Special Report No. 16. June, 1956.

proportion of acreage receiving fertilizer increased. By 1969, 92 percent of Iowa's corn crop received some fertilizer.3/ And Iowa farmers were not alone in increasing the proportion of corn land receiving fertilizer. As data in Table 1 indicate, approximately 60 percent of all corn grown for grain in the U.S. received some fertilizer in 1954 and this increased until, in 1969, some 92 percent of all acres of corn for grain received at least some nitrogen.

Fertilizing more and more of total crop land is only one of two types of changes that have been occurring. The other change has been in quantity of fertilizer applied per acre. Each acre of corn land fertilized in 1947 received 10 pounds of nitrogen (N), 23 pounds of phosphoric oxide (P_2O_5) and 12 pounds of potash (K_2O) (Table 1). By 1969, total pounds of N applied per acre of corn for grain averaged 109 pounds. The use of other types of fertilizer also increased, and as a result total fertilizer use on corn increased to 5.6 million tons from an estimated 836,000 tons of fertilizer in 1947.

Corn is not the only crop on which fertilizer use has increased. The average acre of wheat land received 5 pounds of nitrogen in 1947 but this increased to 39 pounds in 1969. Likewise, the proportion of wheat land receiving nitrogen rose from 18 percent in 1947 to 55 percent in 1969. Total fertilizer applied to wheat land increased from 279,000 tons in 1947 to 926,000 tons in 1969.

Soybeans have used a smaller amount of fertilizer than either corn or wheat. But total use of fertilizer on soybeans has grown over the last 15 years as total land area devoted to soybeans more than doubled. While 17.0 million acres were harvested in 1954, 40.9 million acres were harvested in 1969 and both the average application per acre and the proportion of acres receiving have increased, but not as dramatically as either corn or wheat. Between 1954 and 1969, the average application of nitrogen to soybeans rose from 4 to 11 pounds per acre. The proportion of acres receiving nitrogen rose from 17 to 19 percent but the latter is for a much larger acreage base. Total fertilizer used for soybean production increased from 114,000 tons in 1954 to 542,000 tons in 1969.

3/ U.S. Department of Agriculture. Monthly Crop Production. January 12, 1970. p. 12.

Table 1. Estimated fertilizer use on major crops and percent of harvested acres receiving any fertilizer, U.S. data for available years, 1947-1969.[a/]

Year	Total Fertilizer Used	Ave. Rate Per Acre Receiving N	Ave. Rate Per Acre Receiving P_2O_5	Ave. Rate Per Acre Receiving K_2O	Pct. Harvested Acres Receiving N	Pct. Harvested Acres Receiving P_2O_5	Pct. Harvested Acres Receiving K_2O
	(Thousand Tons)	(Pounds)			(Percent)		
			CORN FOR GRAIN				
1947	863	10	23	12	44	44	44
1950	1,031	15	23	15	48	48	48
1954	1,763	27	26	21	60	60	60
1959	2,269	41	35	33	61	59	52
1964	3,027	58	41	35	85	78	72
1965	3,826	73	47	42	87	82	76
1966	4,665	84	55	51	91	85	30
1967	5,451	93	58	56	92	87	81
1968	5,610	103	53	60	92	88	84
1969	5,607	109	52	62	92	87	82
			WHEAT				
1947	279	5	25	11	18	18	18
1950	379	3	30	14	22	22	22
1954	336	15	21	8	28	28	28
1959	482	26	24	15	33	31	16
1964	648	28	28	16	47	37	17
1965	674	30	30	13	48	38	14
1966	720	32	31	14	48	38	14
1967	1,143	35	39	16	54	44	17
1968	1,029	37	33	14	56	43	15
1969	926	39	34	20	55	42	14
			SOYBEANS				
1954	114	4	40	37	17	17	17
1959	143	6	39	41	8	15	15
1964	135	13	29	37	7	12	12
1965	213	11	31	38	11	16	16
1966	383	14	36	39	19	26	24
1967	463	14	37	40	20	27	27
1968	488	11	38	43	21	27	27
1969	542	11	44	49	19	26	26

a/ Sources: U.S. Department of Agriculture, Fertilizer used on crops and pasture in the United States, 1954 estimates, Stat. Bul. No. 216, August, 1957; Commercial fertilizer used on crops and pasture in the United States, 1959 estimates, Stat. Bul. No. 348, July, 1964, Fertilizer use on selected crops in selected states, 1964-1969 published annually in monthly Crop Production. Estimates for 1947 and 1950 are USDA estimates; estimates for other years are weighted averages from state data published.

Economic consideration affecting fertilizer use

The quantity of fertilizer used per acre by farmers is determined by two sets of conditions. One set is the technical conditions of production -- that is, how crops respond to various levels of fertilizer application. The second set of conditions involves economic relationships -- that is, the price of fertilizer, the expected market price of the crop, and the degree of uncertainty involved in production and marketing decisions.[4] Crop response to fertilizer is affected by such things as the nutrient level in the soil, the availability of crop varieties which utilize heavier dosages of fertilizer, knowledge of the set of practices which maximize response to various levels of application, the interaction of fertilizers with other types of inputs, and the development of methods for ease of application of the various types of fertilizer. However, given knowledge of these kinds of considerations, economic conditions become important in determining the actual amount of fertilizer applied per acre. In essence, once the production response of a particular crop to various levels of fertilizer is established, the most profitable quantity of fertilizer to use becomes a function of the crop price and the price of fertilizer.

A simple example of fertilizer use and crop production may help explain the relationship between the technical and economic aspects of fertilizer use and also specify clearly why farmers have increased fertilizer use on crops. In this example, fertilizer is related to the yield of some crop (say oats) as follows: zero fertilizer gives a 40 bushel yield, a 10 pound application of fertilizer gives a 50 bushel yield, a 20 pound application a 58 bushel yield and so on. These are the technical conditions of production and indicate the crop response to fertilizer. In this example, (shown on page 7) each additional unit of fertilizer adds a smaller amount to yield.

To determine the most profitable level of fertilizer use requires knowledge of both the increase in crop yield and of prices -- that is, the price of fertilizer and expected price of the crop. In this example we assume a fertilizer price of 20 cents per pound and a crop price of 40 cents per unit. The initial 10 pound application of fertilizer costs \$2.00 (as do all

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4/ For a complete discussion of relationships between technical and economic conditions, see Earl O. Heady, Economics of Agricultural Production and Resource Use. Prentice-Hall, Inc. Englewood Cliffs, N.J. 1952. Chapter 3.

Total Fertilizer	Total Yield	Fertilizer Added	Total Increase	Marginal Cost of Fertilizer[a]	Marginal Value of Crop[b]
(lbs)	(bu)	(lbs)	(bu)	(dollars)	
0	40				
		10	10	2.00	4.00
10	50				
		10	8	2.00	3.20
20	58				
		10	6	2.00	2.40
30	64				
		10	5	2.00	2.00
40	69				
		10	4	2.00	1.60
50	73				
		10	3	2.00	1.20
60	76				

[a] The price of fertilizer is assumed to be 20 cents per pound.

[b] The price of the crop is assumed to be 40 cents per bushel.

remaining such units) and the 10 bushel increment in yield returns \$4.00. As additional units of fertilizer are applied, the added return declines, finally dropping to \$1.20 between 50 and 60 pounds of fertilizer. With 40 pounds of fertilizer the cost for the last 10 pounds of fertilizer is \$2.00 and the increment in yield returns \$2.00. Under these circumstances, this level of fertilizer use is most profitable and any greater use is clearly a losing proposition (the increase in fertilizer costs more than the added return in yield).

This example can be used to partially explain why fertilizer use has increased so substantially over the last two decades:

1. The technical conditions of production have changed, giving a larger yield per unit of fertilizer, thereby increasing the revenue from additional units of fertilizer and increasing the most profitable level of fertilizer use.
2. The price of fertilizer has decreased causing each

additional unit of fertilizer to cost less so that more units of fertilizer can be purchased with the same expenditure.

3. The price of a crop may have increased, thereby increasing the value of each additional unit of the crop produced.

Coupled with these three possible changes in technical or market conditions are two further possibilities. Producers may have discovered heavier fertilizer application to be profitable or the level of uncertainty over the effects of additional fertilizer use may have been reduced -- an improved knowledge effect. Finally, there may have been greater certainty of expected prices for the crop at the end of the production period as an outgrowth of government price support programs.

All of these changes, however, have a similar effect. With reduced uncertainty and increased profitability, producers are encouraged to apply more fertilizer per acre of cropland. As the per acre amount increases total quantity applied increases -- if total land use remains constant or does not decrease markedly.

Fertilizer use and cropland requirements

As fertilizer use increased over the last two decades, two major trends occurred in crop production in the U.S. First, crop yields per acre rose, thereby raising the total level of output from a given cropland base. Crop production per acre rose from an index of 84 in 1950 (1957-1959 = 100) to 129 in 1969, a 54 percent increase. Second, as total output rose at a more rapid rate than markets expanded, total acreage of cropland used in production was reduced. (See Figure 1.) Some 377 million acres of cropland were used for crop production in 1950 (including summer fallow and abandonment) but cropland use declined by nearly 50 million acres after 1954, to a low of 331 million acres in 1966. While total acreage expanded to 343 million acres in 1967, it was again reduced for 1968 and 1969 and remained at the lower level during 1970.

The necessity of reducing cropland harvested did not result from any one change in the agricultural situation. As usual with a phenomena as complex as agricultural production, there are several explanatory variables. But two aspects of the agricultural situation have had a major effect on cropland requirements. The first is the amount of fertilizer used in crop production and the second is the size of export markets for grain commodities. Lower exports were of major importance in reducing cropland needs

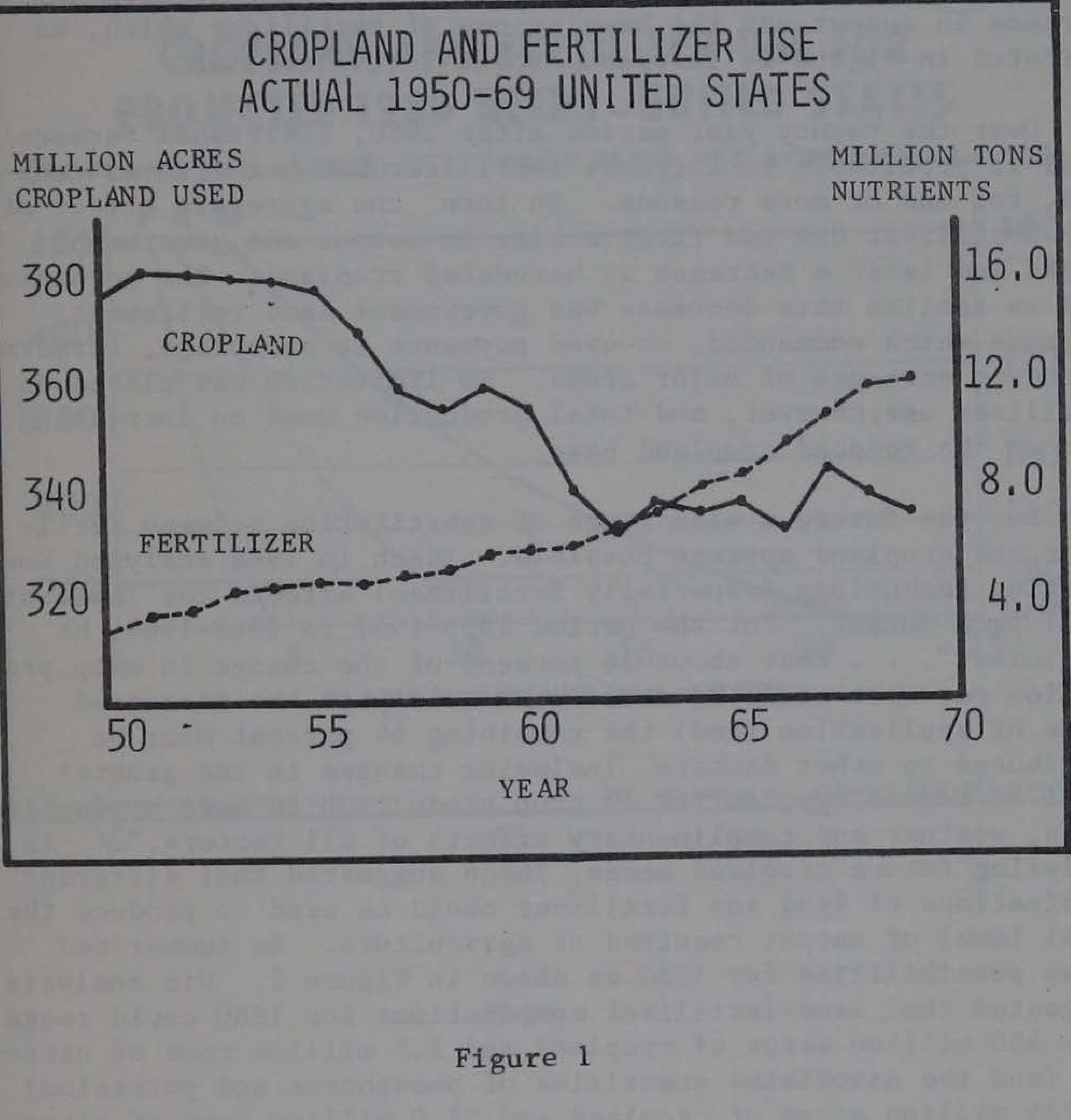
CROPLAND AND FERTILIZER USE
ACTUAL 1950-69 UNITED STATES
MILLION ACRES
CROPLAND USED
MILLION TONS
NUTRIENTS
380
360
340
320
16.0
12.0
8.0
4.0
CROPLAND
FERTILIZER
50
55
60
65
70
YEAR

Figure 1

after the Korean War in the early 1950's. But the export decline was the major causal factor for only a short period. Even after 1961 when exports increased, cropland harvested remained at a lower level. Total output increased, however, and even allowed for a sizeable increase in exports. A major factor explaining the increase in output was the heavier use of fertilizer which, as indicated in Figure 1, increased three fold after 1950.

Over the twenty year period after 1950, individual farmers found it profitable to increase fertilizer use per acre of cropland, for one or more reasons. In turn, the aggregate effect of more fertilizer use was first a rise in output and government stocks and later a decrease in harvested cropland. The mechanism used to realize this decrease was government land retirement programs which commanded, or used payments to encourage, farmers to reduce acreages of major crops. No limitation was placed on fertilizer use, however, and total production went on increasing even on the reduced cropland base.

For the future a wide range of substitution between fertilizer and cropland appears possible. Ibach in 1966 analyzed how changing technology (especially fertilizer) affects the level of total farm output. For the period 1955-1957 to 1960-1964, he concluded ". . . that about 36 percent of the change in crop production per acre could be attributed solely to the increased rates of application (and) the remaining 64 percent must be attributed to other factors, including changes in the general level of technology, shifts in crop production to more productive lands, weather and complimentary effects of all factors."5/ In analyzing future cropland needs, Ibach suggested that different combinations of land and fertilizer could be used to produce the total level of output required of agriculture. He summarized these possibilities for 1980 as shown in Figure 2. His analysis suggested that land-fertilizer combinations for 1980 could range from 450 million acres of cropland and 3.5 million tons of nitrogen (and the associated quantities of phosphorus and potassium) to 225 million acres of cropland and 21.0 million tons of nitrogen. The higher level of fertilizer use would result in a doubling of crop production per acre which for a fixed level of output halves cropland requirements.

5/ D. B. Ibach. Fertilizer Use in the United States, Its Economic Position and Outlook. Agricultural Economic Report No. 92. Economic Research Service, U.S. Department of Agriculture, Washington, D.C. 1966. p. 3.

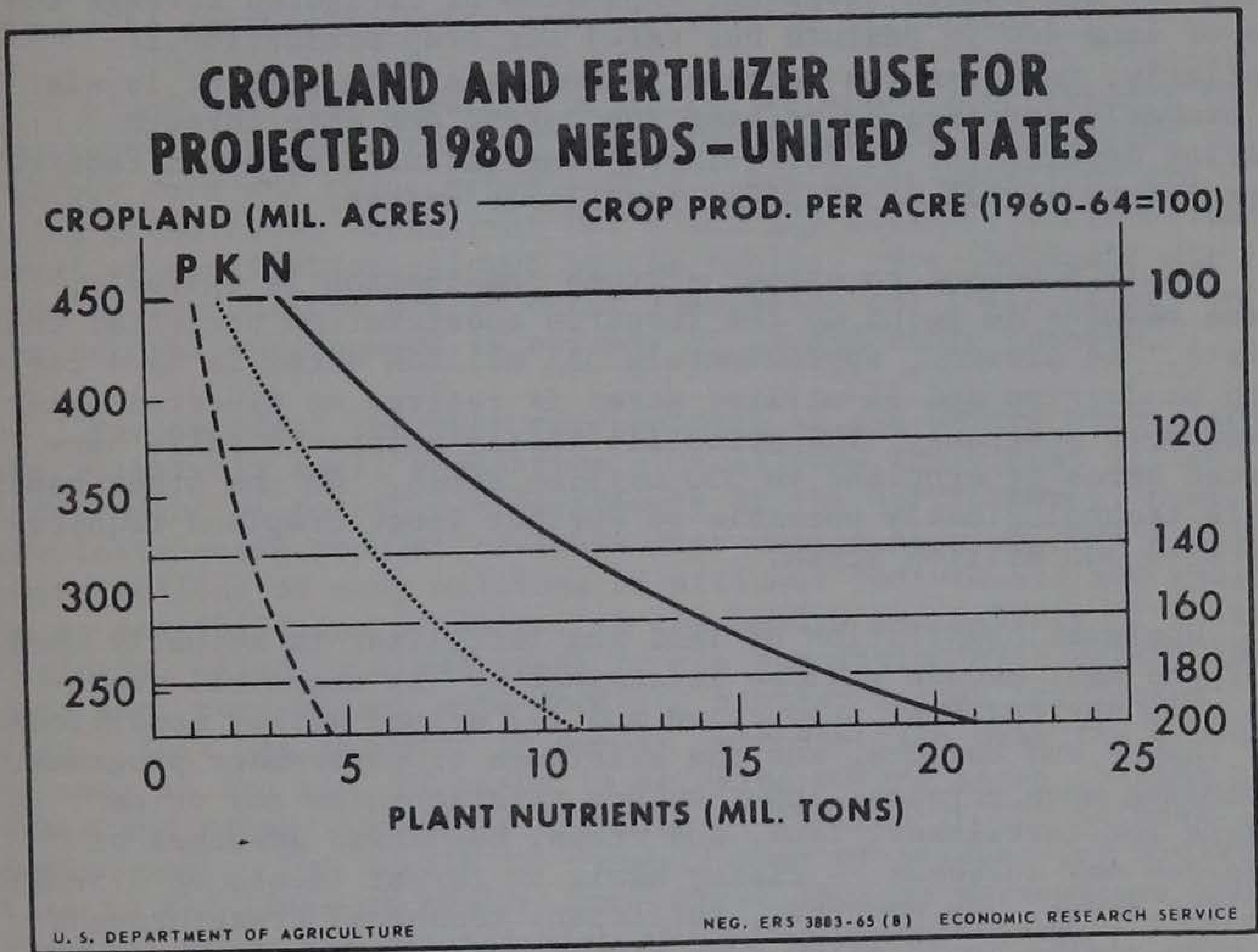
CROPLAND AND FERTILIZER USE FOR PROJECTED 1980 NEEDS–UNITED STATES
CROPLAND (MIL. ACRES)
CROP PROD. PER ACRE (1960-64=100)
P K N
450
400
350
300
250
100
120
140
160
180
200
0
5
10
15
20
25
PLANT NUTRIENTS (MIL. TONS)
U. S. DEPARTMENT OF AGRICULTURE
NEG. ERS 3883-65 (8)
ECONOMIC RESEARCH SERVICE

Figure 2

Ibach's results suggest that a wide variation in resource use is possible over the next decade. Use of 450 million acres of cropland implies some expansion from present levels of cropland use but this degree of expansion is probably possible given the potential for double cropping, expansion of irrigated acreage and use of land now in pasture but rated for crop production.6/ Similarly, reducing the necessary land base from present levels is probably possible by raising the output per acre through heavier application of fertilizer. The latter case would require appropriate levels of cropland fertilizer prices.

While movement to either extreme combination is unlikely, these results do point up the resource substitution potential that exists. At present, approximately 335 million acres is used for crop production and 55 million acres is retired or diverted under government programs. The potential easily exists to raise harvested acres of cropland to 390 million acres. On the other hand, it is technologically possible to further lower cropland requirements to 300 million acres.

Whatever combination of land and fertilizer is actually used over the next decade will be determined by (a) technical conditions in agricultural production and (b) actual market conditions for inputs and outputs, and the existence of government programs. Depending upon physical input-output relationships and price levels for fertilizer, land, and crops, harvested acreages of cropland may increase -- rising again to former levels of 375-385 million acres. By contrast, sufficient technical breakthroughs in crop yields could allow even higher average fertilizer applications and a further reduction in cropland use. A large change in exports could change all these estimates considerably, however.

Potential problems of increased fertilizer use

The estimates cited above suggest that potential may exist for increasing the level of crop yields through heavier fertilization, even though the level of fertilizer application has already risen considerably in recent years. Other evidence also suggests that farmers are not using the maximum amount of fertilizer possible for greatest economic returns. One study found,

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6/ For estimates of land available but not now cropped, see Earl O. Heady, Leo V. Mayer, A. Gordon Ball. "Trends and Capacity of U.S. Agriculture: in North American Common Market, Iowa State University Press. Ames, Iowa. 1969. p. 70.

for example, that the average dollar spent on fertilizer in 1954 returned $2.93, and that by 1964 this had declined only $.43 -- to $2.50.7/ This level of return per dollar spent for fertilizer would seem to provide considerable incentive for the average farmer to further increase applications of fertilizer.

Given only the question of dollar returns, some farmers may continue to raise fertilizer usage in an attempt to increase output per acre and raise gross return. But other questions are being posed about fertilizer use which may ultimately affect the level of application allowed by the public. How chemicals are used in agriculture and in other industries and their effect on the natural environment is a topic of considerable concern.

For decades, the vast spaciousness of the United States and the relatively small population size allowed individual action independent of possible side-effects on the environment. Over the last decade population-land-water ratios have reached a point where actions of many millions of affluent individuals are adding up to possibilities of danger to the health and welfare of other citizens. Also, the awareness of the population with regard to pure air, pure water, pure food and similar issues has intensified. This has resulted in public introspection over the causes of smog in the air, nitrates in drinking water, algae choking up lakes and rivers and other examples of changes in the natural environment. The result is a questioning of present-day activities in all lines of production. These include agriculture where chemical usage has reached high levels in recent years.

While fertilizer is only one of several types of chemicals used in agriculture, it is of major importance in determining production potential, in holding down production costs, and in further lowering the cost of food to consumers. The possibility that it might represent a danger to the environment at heavier levels of application is of considerable importance and one the public has a particular interest in resolving. In a conference in 1967, the American Association for the Advancement of Science

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7/ For 1954 estimates see: D. B. Ibach and R. C. Lindberg. The Economic Position of Fertilizer Use in the United States. Agricultural Information Bulletin No. 202, November 1958. p. 7. For the 1964 estimates see: D. B. Ibach, op. cit., 1966. p. 3. Some later unpublished data suggests that each dollar spent on fertilizer returned $1.70 in 1969.

examined the relationship between Agriculture and the Quality of our Environment. In that conference, George E. Smith noted the special interest in fertilizer,[8]

> Public interest in water pollution has aroused speculation on chemical fertilizers as a possible source of contamination. Reports of fish-kill in streams from 'flushing' of large livestock feeding areas by heavy rains, or by 'leaking' lagoons, are becoming more numerous. It is recognized that, as the density of population increases, the possibility of nitrate, phosphate, and other ions from sewage entering water supplies becomes greater. The presence of foam on agitated water in some areas is considered to indicate sewage and household detergents containing phosphorous as the source. Sanitary engineers are concerned about increases in nitrate and phosphate contents of streams and lakes and the ultimate effect on water for domestic and recreational purposes. Frequently uninformed writers imply, without proof, that all the nitrates and phosphates entering water come from agricultural fertilizers. (p. 173)

Smith pointed up one of the major problems in analyzing the problems of pollution. There are many different sources of pollutants which may bring about contamination of ground water supplies. Few attempts have been made to determine the contribution of each source to any substantial change in the level of water purity. As a result, there is no agreement on the actual relationship between fertilizer usage and the concentration of nitrates in water. Some work has been done, however, on the build-up of nitrogen in soils which results from continuous cropping and applications of fertilizer. These data, cited in Table 2, tend to indicate a positive relationship between nitrogen availability in the soil and the level applied to a crop, given an application period as long as 17 years.

While little conclusive evidence exists regarding contamination of water supplies from application of fertilizer, there

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8/ George E. Smith. Fertilizer Nutrients as Contaminants in Water Supplies published in Agriculture and the Quality of our Environment, American Association for the Advancement of Science. Washington. 1967.

Table 2. Nitrate nitrogen in Putnam silt loam after 17 years continuous corn, zero nitrogen and 120 pounds of nitrogen (ammonium nitrate) per acre annually

Depth Inches	Zero Nitrogen lb. / acre	120 lb. Nitrogen lb./acre
0-24	41	90
24-48	27	70
48-72	38	65
72-96	29	90
96-120	13	45
Total	148	360

Source: George E. Smith, op. cit., 1967. p. 183.

is always the possibility that public reaction to further deterioration could encourage substantial restrictions on chemical use before adequate evidence is collected on these relationships.

One such set of restrictions would be reduction of fertilizer application for production of certain crops. Limits on fertilizer could be set at various levels below economic optimum rates to decrease or to minimize the run-off losses into streams and leeching losses into ground water. Any kind of control on fertilizer use would represent a significant change in philosophy for crop production for the nation. Under past conditions of production and environment, such controls would have been unlikely except in times of national emergency when fertilizer supplies were limited or unavailable. But the prospects of unsafe drinking water for any portion of the population represents a near-emergency situation -- one which could result in demands for restrictive action.

Objectives and Assumptions

The major objective of this study is to determine the economic effects which might result from limiting the use of fertilizer in crop production. It represents an initial effort to measure and quantify the economic outcomes for agriculture and the food consuming public of placing restraints on chemical fertilizer use in crop production. To estimate these effects, food needs and production potentials are projected for 1970, 1975 and 1980, assuming fertilizer use is restricted to three alternative levels. Estimates are prepared of effects on (a) cropland and fertilizer use, (b) prices and net incomes received by farmers, and (c) levels of consumer food costs. Estimates of production potentials take into account the 50 million acres of cropland which have been annually retired under federal farm programs since 1961. Farm level prices and incomes are estimated for each year and fertilization level. These prices are used to estimate consumer food prices and to estimate possible changes in consumer food budgets from restrictions on fertilizer use. In addition to effects when fertilizer use is restricted for all farmers in the United States, a second set of estimates was prepared when fertilizer use is limited for only one state. The state analyzed was Iowa and the same levels of restrictions on fertilizer use were assumed for this portion of the study as for the broader study -- the only difference is that only Iowa farmers would be affected at the two lower levels.

Three levels of restrictions on fertilization were assumed:

1. Farmers could continue to apply fertilizer up to 110 pounds of N (about equal to the 1969 average rate) with the proportion of acres fertilized continuing to increase.
2. Farmers must reduce fertilization rates so that no crop acre receives more than 50 pounds of nitrogen and the corresponding appropriate mix of phosphorous and potassium; the proportion of acres fertilized continues to increase along recent trends.
3. Farmers must remove all inorganic nitrogen from crop production with concurrent changes in crop rotations, available land base, etc.
4. Fertilization levels and corresponding crop yields assume normal weather. Crop yields and available cropland are estimated for 1970, 1975 and 1980.

In addition to assuming specific levels of fertilizer use, an assumption was necessary regarding land retirement programs and the level of agricultural exports. As pointed out previously, the possibility exists for substituting cropland for fertilizer in producing a given level of farm output. This possibility is especially true under present conditions where some 50 million acres of cropland are annually held out of production under government programs. This land could be returned to production if restrictions on the use of fertilizer lowered output per acre and required larger acreages of crops. For this reason, the analysis of this study is based on the assumption that if fertilizer use is limited, the government allows cropland in land retirement programs to return to production as needed to mesh production with demand. The objective of the analysis then becomes to estimate how many additional acres of cropland are required to produce the growing level of output required for the domestic population and its increasing per capita incomes. A further question posed is what levels of prices would be required to bring about this substitution of cropland for fertilizer.

The final assumption relates to the future level of agricultural exports. For this study exports are held constant over the 1970-1980 period at 1969 levels unless all cropland in agriculture is fully utilized whereupon exports are reduced to provide for the increase in domestic needs. Thus we assume that (a) relaxing government land retirement programs would be the initial step to satisfying domestic demand if a fertilizer limitation caused rising food prices in the United States, and (b) if that step is insufficient, we assume exports of major crops are then reduced. A third step would be to substantially increase the availability of cropland through expanded programs of reclamation and irrigation; this alternative is briefly analyzed under the final alternative set of restrictions on fertilizer use.

Projection of crop yields for alternative levels of fertilizer use

The major parameters in this study are the level of crop yield expected with each level of fertilizer use. Estimation of these parameters for the 48 individual states and for major crop production areas of these states is a large undertaking. Fortunately, a major state by state study was completed on Crop Yield Response to Fertilizer in the United States in August, 1968. In this study yield "estimates were developed for major crops in each state by parts of the 99 agricultural subregions in the United States."[9/] The study drew heavily upon estimates of individual

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9/ D. B. Ibach and J. R. Adams. Crop Yield Response to Fertilizer in the United States. Statistical Bulletin No. 431. U.S. Department of Agriculture, Economic Research Service and Statistical Reporting Service. August, 1968. p. 2.

state agronomic experts for developing the relationship between fertilizer and crop yields; to do so it included one or more consultants from each state who reviewed the estimates before final publication. According to the authors,

> The estimates represent an interpretation of experimental evidence and observations of farmer experiences, applied to the crops as grown in the area. . . . Because of the large number of crop-area combinations involved, the procedure used required an estimate of only one response curve for a crop. This curve indicated the yield at different rates of application of the nutrient to which yield response is greatest. The rates of the other nutrients needed are indicated at specified rates of the nutrient to which the curve was drawn" (pp. 3-6).

Using this procedure, tables were developed (as shown below) for each crop in each subregion when grown. All estimated yields were based on the expectation of normal weather.

To use the estimates for this study, yields were calculated for each level of fertilizer application and for each region using a linear extrapolation between the discrete quantities of fertilizer. Using the region in Table 3 as an example, the yield of corn in North Central Iowa with zero level fertilizer use is estimated at 70.4 bushels per acre. With 50 pounds of nitrogen (and corresponding rates of other nutrients) per acre, the yield is estimated at 88.7 bushels per fertilized acre. With 110 pounds of nitrogen, the yield is estimated at 99.7 bushels per fertilized acre. To use these estimates for this study to estimate actual yields in the production regions, it was necessary to weight these yields by the proportion of each crop actually fertilized. Data on fertilization of major crops have been published since 1964 by the U.S. Department of Agriculture.[10]

The proportion of acreage fertilized was projected to increase along trends established in each state between 1964 and 1969. Crop yields in each production region then become the yield per fertilized acre adjusted by the percent of acres fertilized in that region and the yield per unfertilized acre adjusted by the

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10/ U.S. Department of Agriculture. Crop Production, Published Annually in a Monthly issue under the title "Fertilizer use on selected crops in selected states," 1964-1969.

Table 3. Acreage, fertilizer practice, 1964 yields and crop response to fertilizer in Agricultural Subregion 71 (North Central Iowa)

Pounds/acre receiving					Yield/Acre Fertilized
N	P	P_2O_5	K	K_2O	Bu.
Estimated 1964 Rate and Yield with Normal Weather					
61.3	29.5	67.6	34.8	41.9	93.5
Estimated Alternative Rates and Yields with Normal Weather					
0	0	0	0	0	70.4
40.0	10.0	22.9	15.0	18.1	86.4
80.0	20.7	47.4	28.3	34.1	95.6
120.0	29.3	67.1	40.0	48.2	101.1
160.0	36.0	82.5	50.0	60.2	103.4
200.0	36.0	82.5	50.0	60.2	104.2

Source: Ibach and Adams, op. cit., p. 76.

percent of unfertilized acres. Finally, after observing these derived yields, our subjective judgment was that these yields were above normal for the projected years of this analysis.11/ Consequently, yields of each crop were reduced by a given percent across all regions. Corn was reduced 10 percent, wheat by 12 percent, other feed grains by 20 percent and cotton by 10 percent.12/ These yields were entered into a mathematical model and

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11/ There have been suggestions made that recent levels of crop yields have been above normal due to favorable weather. See Louis M. Thompson. A Case for a Land-Use Policy for Agriculture. Paper presented at the Annual Meeting of the Soil Conservation Society of America, Fort Collins, Colorado, August 13, 1969.

12/ These reductions across all regions were not entirely satisfactory because yields in (footnote continued on next page)

Table 4. Projected levels of various parameters required in the analytical framework.

Parameter	Unit	1970	1975	1980
Population	(million)	205.0	217.5	230.0
Income per capita	(dollars)	2,736	3,000	3,250
Per capita consumption				
Beef	(lbs carc wt)	109.6	118.6	127.3
Pork	(lbs carc wt)	62.2	60.2	58.3
Broilers	(lbs dressed wt)	39.5	43.2	47.0
Lamb	(lbs carc wt)	3.0	2.9	2.8
Eggs	(number)	290.0	290.0	290.0
Milk	(pounds)	566.0	566.0	566.0
Imports				
Beef	(mil lbs carc wt)	2,791	2,791	2,791
Pork	(mil lbs carc wt)	426	426	426
Broilers	(mil lbs carc wt)	-117	-117	-117
Exports				
Wheat	(mil bushels)	600	600	600
Feed grains	(mil tons)	18.5	18.5	18.5
Oilmeals	(mil tons)	23.3	23.3	23.3
Cotton	(mil bales)	2.0	2.0	2.0

Source: Estimates are based on data published by the U.S. Department of Agriculture and other official sources.

linear programming was used to solve for the total acreages and price levels necessary to provide the supplies of food commodities for domestic and export uses for each year.13/

Production costs per acre for alternative levels of fertilizer use

After yields were estimated for each crop and production region, the next step was to develop estimates of production costs per acre for each crop in each region. For this step we drew heavily upon previous research14/ and limited changes in projected costs to those associated with different levels of fertilizer use. Production costs per acre for each crop were adjusted to reflect the particular level of fertilizer use analyzed. Other costs for machinery, labor, seed, irrigation, interest costs and drying and storage costs were not adjusted between alternative fertilization levels. Production costs had been developed for all crops and regions in 1968 and required an immense set of computations. Also, cost relationships have not changed substantially over the past two years although inflation has adjusted all costs upward and this was taken into account.

Other parameters required for analyzing costs of limiting fertilizer use

Several other sets of data were required in order to complete projections of demand levels for U.S. agricultural commodities through 1980. The major parameters required were population size, per capita income levels and imports and exports of major commodities. The levels of each parameter for each of the years analyzed, 1970, 1975 and 1980 are specified in Table 4. These data were used to calculate total levels of demand for meat, milk and poultry commodities from which estimates were made of quantities of grains and oilmeals required. Estimates of demand for grain

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12/ (continued) some regions apparently had been based on experimental data and some on actual production conditions. In the latter case, the yields were underestimated after a flat percentage reduction. Iowa is an example where yields turned out too low as later results indicate.

13/ A detailed description of the mathematical model is given in the Technical Appendix.

14/ Mayer, Leo V., Earl O. Heady and Howard C. Madsen. "Farm Program for the 1970's," CAED Report No. 32, Center for Agricultural and Economic Development, Iowa State University. 1968.

commodities were based on constant rates of feed conversion over this period. To complete total demand for each commodity, exports were set near recent levels and assumed to be constant over the 1970-1980 period if adequate capacity is available to satisfy this level of total demand. These quantities of grains and oilmeals provided the basis for estimating acreages of cropland required for each fertilization level. While results in the following sets of tables are reported only for the United States, the analysis was developed around estimates of yields and costs of production for a total of 150 production regions in the United States. One breakdown of regional effects was made. The final set of tables in the report provide results for Iowa. These results were developed by summaring production and cost results for the seven production regions into which Iowa was divided for the analysis.

Estimated Consequences of Restricting Fertilizer Use

The three sections which follow report national results of restricting fertilizer use to three alternative levels. In each section estimates are provided of the required crop acreages, the level of crop yields and total production to satisfy projected domestic and export demands. Cropland left over after total demands are satisfied is assumed to be retired by government programs -- if there is an excess. Estimates of production and idle land are followed by projected farm level prices which are used to estimate total and per farm income for each alternative level of fertilization. Finally, to indicate the effect of limiting fertilizer use on consumer food costs, retail prices and total food expenditures are estimated for each alternative. All results are projected for 1970, 1975 and 1980. Price and income estimates are measured in 1969-1970 dollars with no allowance included for inflation in the future periods covered.

Model I: Consequences of limiting nitrogen use to 110 pounds per acre

This section analyzes the future consequences of limiting nitrogen use for all farmers in the U.S. to a maximum of 110 pounds for any acre of cropland receiving fertilizer. This level was chosen because it approximates the average application rate per acre of corn receiving fertilizer in 1969. This restraint level is applied to each acre receiving any fertilizer; it does not restrict additional nonfertilized acres from receiving fertilizer. This assumption is important for certain crops of which less than 100 percent is fertilized. As noted in Table 1, 92 percent of corn received nitrogen in 1969, 55 percent of wheat and only 19 percent of soybeans. These proportions are assumed to continue increasing along past trends even though a maximum restraint is assumed per acre receiving fertilizer.

Fertilizer use per acre was estimated for 6 crops (corn, wheat, cotton, barley, oats and grain sorghum) for 150 different crop producing regions in the United States.15/ The resulting crop yields along with estimated production costs per crop acre were used to derive the location and total cropland required to satisfy total domestic and export demand levels for each year analyzed. The first set of results are specified for 1970, 1975 and 1980.

Acreages With a limit of 110 pounds of nitrogen per acre (and other nutrients limited to appropriate levels), exports constant and domestic demands increasing due to population and income growth, acreage of most major crops show increases over time. Corn acreage is estimated to increase, requiring 57.9 million acres for 1970 conditions, 58.8 million acres by 1975 and 60.7 million acres by 1980. Other feed grains (oats, barley and grain sorghum) remain fairly constant and near totals harvested in the 1967-1969 period. Soybean acreage increases slowly over the period and reaches 44.5 million acres by 1980. It is probable that soybean yields will increase somewhat more than we have assumed thus requiring less land. But offsetting that is the likelihood that exports will also increase more than we postulated, thus raising total demand and land required. We have assumed both yields and exports of soybeans constant.

Wheat acreage declines between 1970 and 1980, indicating two important consequences: One is that with exports held constant, as we assume here, total demand for wheat grows quite slowly. Yield increases raise production faster than demand, thus causing fewer acres of wheat to be needed. The second consequence is that wheat yields are less affected by the limit on nitrogen use per acre than are other crops. Wheat yields continue to increase as shown in Table 5, and rise from 31.6 bushels in 1970 to 34.8 bushels by 1980. Most of this increase occurs before 1975, indicating a rapid uptrend in both the percent of wheat acres

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15/ Soybeans were not included since the average acre of soybeans received only 11 pounds of nitrogen in 1969 and would be almost unaffected by any restriction on nitrogen use, except complete elimination of all fertilizer use.

Table 5. U.S. acreages, yields and production of major crops, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is limited to 110 pounds per crop acre.

		Actual[a]			Projected		
		1967	1968	1969	1970	1975	1980
				ACREAGES (000)			
Corn, grain		60,557	55,880	54,573	57,942	58,798	60,728
Other feed grains		40,193	41,237	40,854	40,365	40,865	41,115
Soybeans		39,767	41,104	40,857	41,397	42,808	44,510
Wheat		58,871	55,252	47,555	41,473	39,793	38,902
Cotton		7,997	10,160	11,094	10,174	11,742	12,785
Total		207,385	203,633	194,933	191,332	194,006	198,040
Acres retired		40,800	49,400	57,900	57,156	54,781	50,748
				YIELDS			
Corn	(bu)	78.6	78.6	83.9	81.9	84.2	85.8
Other feed grains	(ton)	0.98	1.03	1.04	1.00	1.12	1.19
Soybeans	(bu)	24.5	26.8	27.3	27.4	27.5	27.5
Wheat	(bu)	25.9	28.5	30.7	31.6	34.1	34.8
Cotton	(bale)	0.93	1.08	0.91	1.14	1.09	1.09
				PRODUCTION (000)			
Corn	(bu)	4,760,076	4,393,272	4,577,864	4,742,714	4,950,500	5,210,179
Other feed grains	(ton)	39,527	42,337	42,456	40,357	45,964	48,817
Soybeans	(bu)	976,060	1,103,129	1,116,876	1,134,867	1,178,503	1,226,089
Wheat	(bu)	1,522,382	1,576,251	1,458,872	1,312,063	1,357,206	1,353,130
Cotton	(bale)	7,458	10,948	10,080	11,621	12,771	13,921

a/ Source: U.S. Department of Agriculture, Crop Production, 1969 Annual Summary, December 1969.

receiving fertilizer and in the amount applied per acre.

Other crop yields show various effects of limiting fertilizer use. The response of other feed grain crops is similar to wheat. Yields rise from one ton per acre in 1970 to an estimated 1.19 tons per acre by 1980, nearly a twenty percent increase. Soybean yields remain relatively constant as noted before because we did not attempt to include them in the analysis. Cotton yields show an interesting trend of first rising and then dropping off and remaining relatively constant. This result occurs because cotton production is allowed to shift among different producing regions after 1970. The result derived here is that as these shifts occur, the average yield declines.

Total production levels shown in Table 5 indicate how large an increase will be necessary to satisfy domestic demand after 1970. Corn production increases from 4.7 to 5.2 billion bushels. Other feed grain production increases 8.5 million tons and soybeans, wheat and cotton all trend upward.[16/] The increases result from a larger population, higher per capita incomes and rising consumption levels for most meat commodities. Of course, if exports trend upward, even more production would be required than is shown.

Farm prices Crop and livestock price for these levels of production are shown in Table 6. These prices are derived as equilibrium level prices -- that is, these prices are estimated to cover costs of production for farmers and return the production expenses they would incur for producing the specified level of output. In this instance, these costs would include the cost for fertilizer up to a maximum level of 110 pounds of nitrogen per crop acre. Most crop acres receive less than 110 pounds and costs used reflect the lower level of fertilizer use. Other costs for machinery, seed, labor, insecticides, drying and storage are also included. Further, these prices are based on a distribution of production across states and regions as could exist with a set of government programs (similar to those of the recent past). Estimates of acreage bases and acreages retired were based on actual programs for these crops from the 1966 period.

16/ These production levels assume that exports remain constant over time, an assumption which makes it possible to clearly identify how much crop acreages would need to increase just to satisfy the expected increase in domestic demand.

Table 6. Prices received by farmers for major commodities, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is limited to 110 pounds per crop acre.

		Actual[a]			Projected		
		1967	1968	1969	1970	1975	1980
				CROPS[b]			
Corn	(bu)	1.03	1.08	1.12	1.09	1.03	1.04
Soybeans	(bu)	2.49	2.43	2.33	2.46	2.34	2.33
Wheat	(bu)	1.39	1.24	1.24	1.37	1.27	1.23
Cotton	(lb)	25.3	22.0	20.6	21.6	21.3	21.3
				LIVESTOCK[c]			
Beef	(cwt)	22.30	23.40	26.20	26.70	26.80	27.60
Pork	(cwt)	18.90	18.50	22.20	19.60	20.40	21.80
Milk	(cwt)	5.01	5.24	5.46	5.16	5.43	5.81
Broilers	(lb)	13.3	14.2	15.2	16.1	15.4	15.4

a/ Source: U.S. Department of Agriculture, Agricultural Prices, 1969 Annual Summary. June 1970.

b/ Units are dollars per bushel for corn, soybeans and wheat; cents per pound of cotton.

c/ Units are dollars per hundredweight of beef, pork, and milk; cents per pound of broilers.

The prices shown in Table 6 are highly dependent upon the level of farm programs assumed to exist. In the initial year considered, 1970, we assumed a program of equivalent size to 1969 when 57.9 million acres were retired from production. If a similar program had existed in 1970, and given normal weather, a limitation on fertilizer use of 110 pounds of nitrogen per crop acre could have resulted in the following crop prices: \$1.09 for cron, \$2.46 for soybeans, \$1.37 for wheat and 21.6 cents per pound of cotton. These prices could cover all costs of production indicated previously. Had demand slumped seriously because of unexpected factors, or had supply decreased substantially for some reason, these equilibrium prices would miss actual market price levels.

One of the major interests in this study was to determine what would happen to prices over time if fertilizer use was restricted. The data in Table 6 indicate that crop prices might not rise with fertilizer use restricted -- <u>if</u> government programs of land retirement are relaxed from year to year to allow an increase in acreages of these crops. If government programs are relaxed, then corn prices might continue near the \$1.05 per bushel level through 1980. But it should be stressed that relaxing programs too much could drive prices lower and relaxing not enough could drive prices higher.

Other crop prices similarly show no tendency to change sharply from recent levels. But the change that does occur is in total retired cropland acres which is estimated to decline from 57.2 million acres in 1970 to 50.7 million acres in 1980. (Table 5) This change along with continued increases in small grain crop yields would allow for the increase in output necessary to satisfy a rising domestic demand if exports remain constant as assumed. Mainly this analysis suggests that a limit on fertilizer use near present levels would provide adequate food supplies to maintain relatively stable farm prices through 1980. A reduction would occur however in the total capacity of the farm plant to produce crops and livestock.

<u>Farm income</u> Given the levels of farm production and farm prices shown, cash receipts of farmers were estimated for each year 1970, 1975 and 1980. Adding in estimated government payments from continuing government programs (at a declining level) as well as the value of home consumption and rental value of farm dwellings, total income of farmers is projected to increase through 1980 (Table 7). The rise is due mainly to increasing quantities

Table 7. Farm income received by U.S. farmers, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is limited to 110 pounds per crop acre.

	Actual[a/]			Projected[b/]		
	1967	1968	1969	1970	1975	1980
TOTAL FARM INCOME		(million dollars)				
Cash receipts	42,788	44,386	47,431	47,410	51,596	59,935
Government payments	3,079	3,462	3,800	3,459	3,294	3,132
Total	45,867	47,848	51,231	50,869	54,890	59,935
Home consumption	745	705	735	725	700	675
Rental value of farm dwellings	2,449	2,579	2,650	2,700	3,000	3,300
Total Income	49,061	51,132	54,616	54,294	58,590	63,910
Farm production expenses	34,820	36,346	38,751	39,159	42,529	46,102
Net Income [c/]	14,644	14,675	16,245	15,135	16,061	17,808
PER FARM INCOME		(dollars per farm)				
No. of farms (000)[d/]	3,147	3,054	2,971	2,768	2,492	2,248
Net income per farm (dollars)	4,654	4,805	5,468	5,468	6,445	7,992

a/ Source: U.S. Department of Agriculture. Farm Income Situation. February 1969 and February 1970.

b/ Projected values are measured in constant 1970 dollars. No allowance is included for inflation.

c/ Data for 1967-1969 include changes in farm inventories; data for 1970-1980 assume farm inventories are constant.

d/ Projected farm numbers are from: Earl O. Heady and Leo V. Mayer, Food Needs and U.S. Agriculture in 1980. Volume I, Technical Papers, National Advisory Commission on Food and Fiber. Washington, D.C. August 1967. p. 109.

of farm commodities, both crops and livestock, but some portion is due to the slowly rising level of farm prices for livestock products that was indicated in Table 6. Together with larger quantities required for a growing population, rising prices result in higher total incomes for farmers.

But the rise in gross farm income is largely offset by increased production expenses. Expenses increase for a number of reasons: Costs rise for purchasing larger quantities of livestock and purchased feed, costs increase for land taxes and interest payments, and by 1980 total crop acreages increase which raise costs for production. Together these several forces keep total production costs increasing along with total income received. But the indication is that if inflation could be controlled, as assumed here, net farm income, though estimated to be lower in 1970 than 1969, would rise thereafter through 1980.

One final calculation was made. Total net income for each year analyzed was divided among the projected number of farms in the U.S. The results indicate that real net income per farm could increase from an estimated \$5468 in 1970 to \$7992 in 1980. The number of farms is estimated to drop from 2.8 million in 1970 to 2.2 million in 1980. The major portion of the increase in net farm income comes from the lower total number of farms projected for 1980.

Consumer costs The next step in the analysis was to determine the relationship between what happens on the farms of the nation and what happens to consumer food costs. To evaluate this aspect of the food chain, we developed statistical relationships between farm level prices and retail level prices. These relationships, based on simple statistical techniques, were used to project retail level prices for each of the alternative fertilizer levels analyzed. Prices for this particular model -- where fertilizer use is limited to a maximum of 110 pounds of nitrogen per crop acre -- are shown in Table 8. In addition, total consumer expenditures based on the estimated retail prices, are also indicated in the table.

With nitrogen use limited to a maximum of 110 pounds per crop acre, retail beef price is projected to average 87.4 cents per pound in 1970 and rise to 97.5 cents by 1980. The 1970 price is substantially lower than the 1969 price. The normal relationship between corn price (\$1.08 per bushel in 1969 and projected \$1.09 for 1970 had these assumed conditions existed)

Table 8. Retail prices of specified food products and total consumer expenditures, actual 1967-1969 and projected 1970, 1975 and 1980 with fertilizer use limited to 110 pounds per crop in the United States.

		Actual[a/]			Projected		
		1967	1968	1969	1970	1975	1980
RETAIL PRICES							
Beef[b/]	(cts/lb)	82.6	86.6	96.3	87.4	91.8	97.5
Pork	(cts/lb)	67.2	67.4	74.3	68.8	72.9	78.0
Lamb[b/]	(cts/lb)	87.4	93.6	101.8	89.9	91.1	94.5
Chicken	(cts/lb)	38.1	39.8	42.2	42.8	42.7	43.8
Milk	(cts/qt)	25.8	26.8	27.6	27.2	28.2	28.8
TOTAL EXPENDITURES							
All Food	(bil. dol)	88.8	90.0	95.3	99.3	106.9	117.0
All Meat	(bil. dol)	25.1	26.7	28.5	28.6	31.8	37.1
Dairy	(bil. dol)	13.5	14.6	14.9	15.0	16.9	18.3
Poultry and Eggs	(bil. dol)	6.2	6.5	7.4	7.7	8.4	9.1
Other[c/]	(bil. dol)	40.0	41.7	44.5	47.0	49.8	52.5

a/ Sources: U.S. Department of Agriculture, Food: Consumption, Prices, Expenditures, Supplement for 1968 to Agricultural Economics Report No. 138. January 1970; Marketing and Transportation Situation, February 1969, February 1970 and August 1970.

b/ Choice grade.

c/ Includes fruits and vegetables, grain mill products, bakery products and miscellaneous.

and beef price, as determined through statistical techniques, is substantially different than that which existed in 1969.17/ These price levels are again reached only by 1980. A major portion of the projected increases comes from higher marketing margins which are projected to increase over time. Inflation, however, is assumed away.

Total expenditures for food rise from $95.3 billion in 1969 to $99.3 billion in 1970, $106.9 by 1975 and $117.0 billion by 1980. The largest part of this increase accrues to the larger population fed, the shift toward more meat consumption, and the larger cost of marketing. As consumers demand more and more processing with their foods, with preparation time in the home reduced to a minimum, processing costs continue to rise. But if farm prices also trend upward somewhat the portion of the food dollar going to farmers tends to remain relatively constant. The percent going to farmers has remained relatively constant over the past decade and unless farmers lose some of the bargaining power given them through past government programs, the proportion may remain relatively stable. Food costs will continue to rise, though, if both farm costs for food and marketing costs rise.

Model II. Consequences of limiting nitrogen use to 50 pounds per acre

The second restriction level assumes that a maximum of 50 pounds of nitrogen can be used per crop acre. This restriction was chosen in an attempt to determine the effects of "cutting the use of nitrogen fertilizer in half." The results are given in Tables 9, 10, 11 and 12.

Acreages Once again we assumed that if fertilizer use was restricted, the first response of government would be to relax land retirement programs and encourage increased acreages of major crops. A second strategy available would be to reduce agricultural exports, especially those moving with government subsidies, but this step was assumed to be secondary to reducing land retirement programs. In this particular alternative it was determined that exports could be held constant through 1980 without undue stress on land resources.

17/ In fact, a similar statement can be made about pork and lamb as well as beef. Only chicken and milk prices at the retail level appear not to have been abnormally high in 1969 relative to corn price.

Table 9. U.S. acreages, yields and production of major crops, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is limited to 50 pounds per crop acre.

		Actual[a/]			Projected		
		1967	1968	1969	1970	1975	1980
			ACREAGES (000)				
Corn, grain		60,557	55,880	54,573	67,789	72,492	75,888
Other feed grains		40,193	41,237	40,854	40,365	40,865	43,365
Soybeans		39,767	41,104	40,857	40,981	42,565	44,322
Wheat		58,871	55,252	47,555	44,793	45,891	44,662
Cotton		7,997	10,160	11,094	12,123	12,837	13,699
Total		207,385	203,633	194,933	206,051	214,650	221,936
Acres retired		40,800	49,400	57,900	42,738	32,138	26,852
			YIELDS				
Corn	(bu)	78.6	78.6	83.9	70.8	70.5	70.2
Other feed grains	(ton)	0.98	1.03	1.04	0.85	0.90	0.95
Soybeans	(bu)	24.5	26.8	27.3	27.5	27.6	27.5
Wheat	(bu)	25.9	28.5	30.7	32.6	32.7	33.3
Cotton	(bale)	0.93	1.08	0.91	0.96	0.99	1.02
			PRODUCTION (000)				
Corn	(bu)	4,760,076	4,393,272	4,577,864	4,797,036	5,111,036	5,328,893
Other feed grains	(ton)	39,527	42,337	42,456	34,189	36,890	41,252
Soybeans	(bu)	976,060	1,103,129	1,116,876	1,128,876	1,172,846	1,218,230
Wheat	(bu)	1,522,382	1,576,251	1,458,872	1,459,619	1,502,508	1,487,778
Cotton	(bale)	7,458	10,948	10,080	11,621	12,771	13,921

a/ Source: U.S. Department of Agriculture. Crop Production, 1969 Annual Summary. December 1969.

As shown in Table 9, acreages of crops rise as fertilizer use is restricted. Corn acreage climbs to 67.8 million acres in 1970, 72.5 million acres in 1975 and 75.9 million acres in 1980. The decrease in fertilizer use from 110 pounds to 50 pounds causes an estimated 10 million acre increase in corn acreage if fertilizer had been restricted for 1970, 14 million acres for 1975 and 15 million acres by 1980. Other feed grain acreages show only a small change between the two levels of restriction; only by 1980 does the acreage of other feed grain show some competitiveness with increases in corn acreages.18/

Wheat acreages show an increase from the previous model. The major cause is that wheat becomes competitive with feed grains as corn yields decline with less fertilizer. The quantity of wheat used for feed is estimated to jump from 51.1 million bushels for the previous analysis to 198.6 million bushels for this model for 1970 conditions. The use of wheat for feed remains relatively constant after 1970, however. The 1980 quantities are 28.8 million bushels with the 110 pound restriction and 163.4 million bushels with a 50 pound restriction.

The increased use of wheat for feed is a direct outgrowth of the reduction in feed grain yields -- the U.S. corn yield declines from an estimated 81.9 bushels with a 110 pound limit to 70.8 bushels for this model for 1970. Other feed grain crops are also lower, dropping from 1.0 tons per acre to .85 tons per acre. The effect of less fertilizer is clearly apparent in these crop yields. But wheat yields are less affected and when coupled with increased production in higher yielding areas, wheat tends to substitute for feed grains in livestock rations. Wheat acreage increases as a result.

One other result is noticeable. Total acreage used for crops

18/ Our results consistently indicate that if farmers based crop planting decisions solely on costs and return per crop acre, fewer acres of other feed grains would be planted. Since it is evident that farmers include other considerations in crop planting decisions, as evidenced by Iowa farmers continuing to raise a large acreage of oats, we have adjusted our flexibility constraints in our mathematical model to assure that a minimum level of other feed grains is grown. In this particular model, the acreage of other feed grains exceeded the minimum in 1980, thus indicating that these crops become competitive as a stricter limit is placed on fertilizer use.

increases with less fertilizer. Substitution of cropland for fertilizer occurs as fertilizer is reduced, a reverse of the trend from the last decade. Total cropland used for the crops specified rises to 206.1 million acres in 1970, 214.7 million by 1975 and 221.9 million acres by 1980. Acres retired under government programs drop, declining from 42.7 million acres in 1970 to 26.9 million acres in 1980. The productive capacity of the remaining acreage is well below average, however, and the nation's protection against weather or other risks to adequate food production would be lower than at present.

Farm prices   Prices received by farmers tend to increase as additional cropland is substituted for fertilizer in crop production. Corn price, which in many ways is the bellwether of crop prices, is estimated at $1.15 for 1970, $1.19 for 1975, and $1.21 for 1980 (Table 10). All prices are higher than for the previous model. Reducing fertilizer use from a maximum of 110 pounds nitrogen per crop acre to 50 pounds raises the per unit cost of production, and prices must respond if farmers are to continue in production. Prices of soybeans also show a tendency to increase over time but wheat price remains relatively stable, indicating again the effect of holding wheat exports constant and the complementary effect of a slow growth in domestic demand for wheat. For some years, per capita consumption of wheat products has been falling. Thus an increasing population size does not increase wheat utilization by an equivalent amount. Consequently, when exports are held constant, growth in production must be less than population growth if market prices are to remain stable.

Livestock prices are somewhat higher with this model, reflecting the higher costs of corn fed. Beef price which is in some ways the bellwether of livestock prices, increases from an estimated $27.40 per hundred weight in 1970 to $29.50 by 1980. The rise in corn price accounts for a major part of the increase although processing costs also increase.

Farm income   Higher prices for farm commodities cause cash recepts from farm marketings to rise. But, since expanded acreages for crop production reduce total land retirement, government payments decline. The net effect is a small decline in estimated cash receipts for 1970 (Table 11) although cash receipts would tend to rise by 1975 as the full effects of reducing fertilizer use would be worked out in the market place. Income from other sources, home consumption and value of farm dwellings, remain the same as for the previous model. Thus total farm income follows

Table 10. Prices received by farmers for major commodities, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is limited to 50 pounds per crop acre.

		Actual[a/]			Projected		
		1967	1968	1969	1970	1975	1980
				CROPS			
Corn	(bu)	1.03	1.08	1.12	1.15	1.19	1.21
Soybeans	(bu)	2.49	2.43	2.33	2.34	2.55	2.52
Wheat	(bu)	1.39	1.24	1.24	1.31	1.34	1.35
Cotton	(lb)	25.3	22.0	20.6	22.2	22.5	23.3
				LIVESTOCK			
Beef	(cwt)	22.30	23.40	26.20	27.40	28.60	29.50
Pork	(cwt)	18.90	18.50	22.20	20.30	22.10	23.80
Milk	(cwt)	5.01	5.24	5.46	5.25	5.66	6.05
Broilers	(lb)	13.3	14.2	15.2	16.9	17.4	17.6

a/ Source: U.S. Department of Agriculture, Agriculture Prices, 1969 Annual Summary. June 1970.

Table 11. Farm income received by U.S. farmers, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is limited to 50 pounds per crop acre.

	Actual[a]			Projected[b]		
	1967	1968	1969	1970	1975	1980
TOTAL FARM INCOME	(million dollars)					
Cash receipts	42,788	44,386	47,431	48,022	54,006	59,689
Government payments	3,079	3,462	3,800	2,599	2,234	1,536
Total	45,867	47,848	51,231	50,621	56,240	61,225
Home consumption	745	705	735	725	700	675
Rental value of dwellings	2,449	2,579	2,650	2,700	3,000	3,300
Total Income	49,061	51,132	54,616	54,046	59,940	65,200
Farm production expenses	34,820	36,346	38,571	38,838	42,664	46,422
Net Income[c]	14,644	14,675	16,245	15,208	17,276	18,778
PER FARM INCOME						
No. of farms (000)[d]	3,147	3,054	2,971	2,768	2,492	2,248
Net income per farm (dollars)	4,654	4,805	5,468	5,494	6,933	8,353

a/ Source: U.S. Department of Agriculture. Farm Income Situation. February 1969 and February 1970.

b/ Projected values are measured in constant 1970 dollars. No inflation is included.

c/ Includes changes in farm inventories.

d/ Projected farm numbers are from Earl O. Heady and Leo V. Mayer, Food Needs and U.S. Agriculture in 1980. Volume I, Technical Papers, National Advisory Commission on Food and Fiber. Washington, D.C. August 1967. p. 109.

the decline in total cash receipts for 1970.

Production expenses have a tendency to offset the lower level of farm income for 1970. While production expenses rise from farming more acres, expenses for fertilizer decline. These offsetting tendencies coupled with changes in other expenses result in total production expenses of $38.8 billion and a net farm income of $15.2 billion in 1970, only a minor change from the previous model. Using the projected number of farms for 1970, income per farm is estimated at $5,494.

Trends in farm income after 1970 differ more between the two models. Restricting the level of fertilizer use for crops and thereby restraining farm output would result in rising farm prices and farm incomes after several production periods. This trend results because demand for farm products is inelastic -- that is, the consumer will purchase almost the same amount of food regardless of price. As the supply of farm products is restrained by less fertilizer, growth in domestic demand causes prices to respond positively.[19/] Farm income increases, reaching an estimated $6,933 per farm in 1975 and $8,353 in 1980. The latter is approximately $400 higher per farm than under the previous model.

Consumer costs The gain to farmers through higher incomes would come at the expense of consumers who would pay higher prices for food if fertilizer were reduced to half its present level. In the initial year or two, prices might not respond with any sizable increase, primarily because relaxation of government land retirement programs allow production of adequate supplies of grains and livestock commodities. But this level of production has higher per unit costs as average yields decline and additional cropland is returned to production. The additional land is in general less productive, with estimates varying from 90 percent as productive for diverted wheat land to 83 percent for land diverted

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19/ Livestock prices in the 1966-1969 period are an example of a favorable supply-demand balance for farmers. Similarly, the soybean market in recent years has responded to increases in demand, increases which shifted the demand curve to the right at a rapid rate and even though soybean production increased, soybean prices rose. This type of situation would exist if farm output was restrained by less fertilizer use.

Table 12. Retail prices of specified food products and total consumer expenditures, actual 1967-1969 and projected 1970, 1975 and 1980 with fertilizer use limited to 50 pounds per crop acre in the United States.

		Actual[a/]			Projected		
		1967	1968	1969	1970	1975	1980
		RETAIL PRICES					
Beef[b/]	(cts/lb)	82.6	86.6	96.3	88.6	95.1	101.1
Pork	(cts/lb)	67.2	67.4	74.3	69.9	75.7	81.2
Lamb[b/]	(cts/lb)	87.4	93.6	101.8	91.6	96.1	99.9
Chicken	(cts/lb)	38.1	39.8	42.2	43.9	45.7	47.1
Milk	(cts/qt)	25.8	26.8	27.6	27.4	28.6	29.7
		TOTAL EXPENDITURES					
All Food	(bil. dol)	88.8	90.0	95.3	99.7	108.2	118.7
All Meat	(bil. dol)	25.1	26.7	28.5	28.9	33.0	38.3
Dairy	(bil. dol)	13.5	14.6	14.9	15.7	16.5	18.2
Poultry and Eggs	(bil. dol)	6.2	6.5	7.4	8.1	8.9	9.7
Other[c/]	(bil. dol)	40.0	41.7	44.5	47.0	49.8	52.5

a/ Sources: U.S. Department of Agriculture, Food: Consumption, Prices, Expenditures, Supplement for 1968 to Agricultural Economics Report No. 138. January 1970; Marketing and Transportation Situation, February 1969, February 1970 and August 1970.

b/ Choice grade.

c/ Includes fruits and vegetables, grain mill products, bakery products and miscellaneous.

from corn.[20] The lower productivity results in higher per unit costs of production which ultimately must be repaid through the market place if these acres are to continue in production.

Although some lag may occur, higher prices at the farm level are eventually passed along to consumers through increases in retail food prices. Retail beef price is estimated at 101.1 cents per pound by 1980 compared to 97.5 cents per pound under the previous model, and 96.3 cents per pound in 1969. This increase along with similar increases for other meats raises 1980 consumer expenditures for meat products by $1.2 billion, compared to the previous model, from $37.1 billion to $38.3 billion. Limiting fertilizer to 50 pounds of nitrogen per acre causes total expenditures for all food to increase to $118.7 billion, a rise of $1.7 billion over the previous model. Approximately $1 billion of this increase is reflected in higher net farm income under this alternative.

As one can note in Table 12, the rise in food expenditures between 1970 and 1980 is at an increasing rate. Between 1970 and 1975, the increase is $8.5 billion in constant dollars while the increase is $10.5 billion between 1975 and 1980. As less and less land remains available for increasing production after 1980, expenditures would continue to rise. Of course, exports could be reduced as another means of temporarily reducing domestic price increases. But this again represents "a one time" solution and the general tendency would be for rising food prices if fertilizer were restricted and additional acreages of presently diverted cropland were required for production.

Model III. Consequences of eliminating nitrogen use on major crops

The final set of U.S. projections assume that nitrogen use is completely removed from major crop production. In turn, we assumed that farmers would go back to production methods which were common before inorganic fertilizer was widely used by farmers. Cropping patterns were assumed to return to those of previous periods when crop rotations were used to maintain a reasonable level of nitrogen fertility. With a return to rotation cropping, a smaller land base would remain available for major crops. For the analysis, estimates of available acreage were based on land use patterns of the early 1950's when only a small amount of

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20/ P. Weisgerber. Productivity of Diverted Cropland. ERS-398, U.S. Department of Agriculture. April, 1969.

Table 13. U.S. acreages, yields and production of major crops, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is prohibited on major crops.

		Actual[a]			Projected		
		1967	1968	1969	1970	1975	1980
				ACREAGES (000)			
Corn, grain		60,557	55,880	54,573	89,479	96,079	102,978
Other feed grains		40,193	41,237	40,854	40,365	40,865	41,115
Soybeans		39,767	41,104	40,857	26,800	25,823	24,725
Wheat		58,871	55,252	47,555	46,835	48,056	49,673
Cotton		7,997	10,160	11,094	14,842	16,094	17,656
Total		207,385	203,633	194,933	218,863	226,917	236,147
Acres retired		40,800	49,400	57,900	--[b]	--[b]	--[b]
				YIELDS			
Corn	(bu)	78.6	78.6	83.9	48.1	47.0	45.8
Other feed grains	(tons)	0.98	1.03	1.04	0.58	0.58	0.57
Soybeans	(bu)	24.5	26.8	27.3	27.0	27.1	27.4
Wheat	(bu)	25.9	28.5	30.7	20.5	20.5	20.7
Cotton	(bales)	0.93	1.08	0.91	0.70	0.68	0.66
				PRODUCTION (000)			
Corn	(bu)	4,760,076	4,393,272	4,557,864	4,306,250	4,514,000	4,719,036
Other feed grains	(tons)	39,527	42,337	42,456	23,555	23,780	23,582
Soybeans	(bu)	976,060	1,103,129	1,116,876	672,897	699,382	677,244
Wheat	(bu)	1,522,382	1,576,251	1,458,872	958,952	987,175	1,029,270
Cotton	(bales)	7,458	10,928	10,080	10,328	10,978	11,628

a/ Source: U.S. Department of Agriculture. Crop Production, 1969 Annual Summary. December 1969.

b/ No acres would be retired under government programs if fertilizer is eliminated but a portion of the existing land base would be required for soil building crops to maintain fertility of the soil. A ban on fertilizer use would encourage an expansion in the land base for crop production which for some period of time could allow additional acres of crops to be grown.

inorganic fertilizer was used per acre. These land use data indicated total acreages available for major crops similar to present crop acreages. The major difference is that a large number of cropland acres (similar in number to those presently retired under under government program) would have to be placed in legume crops to maintain nitrogen fertility rather than in government programs. For this alternative we assumed that all government land diversion or land retirement programs are terminated when inorganic fertilizer is banned for crop use.

Acreages Eliminating fertilizer use in the U.S. results in maximum use of cropland. Even with all cropland in use, total farm production would drop, prices would rise and cause a sharp reduction in exports and even some decline in domestic livestock production. Our findings are that corn acreage increases to 89.5 million acres (Table 13) with 1970 supply and demand conditions, but that exports of feed grains would have to drop to 5 million tons to allow for domestic livestock production.[21/] This acreage of corn coupled with other feed grain acres implies that total feed grains could again utilize nearly 125 million acres of cropland in the United States, a level reminiscent of the early 1950's. But the release of these acreages to corn production means that land used for other crops would have to decrease. The major crop affected is soybeans which has total acreage cut to 26.8 million acres. This results in declining exports of soybeans but no other alternative is feasible under these yield conditions. Both wheat and cotton acreage increase even though exports of these crops also decline substantially.

Yields of the crops analyzed show a sharp drop with the removal of inorganic fertilizer. A corn yield of 50 bushels per acre would be common across the Corn Belt. The average for the U.S. is estimated at 49.3 bushels for 1970. The average corn yield would continue to decline after 1970 as additional acres are required to meet expanding domestic demand. Wheat yield

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21/ Export levels for 1970 with this alternative are lower than the previous models. There is a further decline for 1975 and 1980 for feed grains and soybeans to allow for increased domestic utilization. The levels arrived at were:

	1970	1975	1980
Wheat (bu)	100,000,000	100,000,000	100,000,000
Feed-grains (tons)	5,000,000	2,500,000	0
Oil-meals (tons)	10,000,000	7,500,000	5,000,000
Cotton (bales)	1,000,000	1,000,000	1,000,000

Table 14. Prices received by farmers for major commodities, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is prohibited on major crops.

		Actual[a/]			Projected		
		1967	1968	1969	1970	1975	1980
				CROPS			
Corn	(bu)	1.03	1.08	1.12	1.99	2.13	2.30
Soybeans	(bu)	2.49	2.43	2.33	2.42	2.44	2.55
Wheat	(bu)	1.39	1.24	1.24	2.29	2.40	2.55
Cotton	(lb)	25.3	22.0	20.6	47.4	49.1	52.2
				LIVESTOCK			
Beef	(cwt)	22.30	23.40	26.20	36.78	39.09	41.80
Pork	(cwt)	18.90	18.50	22.20	29.60	32.58	35.90
Milk	(cwt)	5.01	5.24	5.46	6.45	7.01	7.61
Broilers	(lb)	13.3	14.2	15.2	27.4	29.1	31.3

a/ Source: U.S. Department of Agriculture. Agriculture Prices, 1969 Annual Summary. June 1970.

declines by one-third, stabilizing near 20 bushels per acre. Cotton yields of half a bale per acre in many regions would bring down the U.S. acreage yields to 0.7 bales initially and an additional decline would occur with further expansion in acreage.

Total production of major crops is substantially reduced even with larger acreages. Corn production totals 4.3 billion bushels and wheat less than a billion bushels for 1970 conditions. Other feed grain crops would provide only half as much feed as previously. Production levels of most crops would increase somewhat by 1975 and 1980. But contrary to past experience, the increase would not come from higher yields but rather from expanded acreages. Of course, as farmers adjusted their farm operations to the absence of fertilizers, yields might rise somewhat more than projected. There would likely be a tendency for livestock production to increase on individual farms to replace some of the loss in cash receipts from lower crop production. The organic manure produced would take on a higher value for crop production. There are other possible adjustments in farm operations which could raise yields somewhat if inorganic fertilizer were eliminated. But these would require time, first for research and development, and second for local adaptation and adoption by farmers.

Farm prices   As fertilizer is eliminated, prices received by farmers rise at a rapid rate, particularly for corn and wheat. The reduction in total output shifts the aggregate supply curve of these crops to the left thus intersecting the demand curve at a higher point resulting in a higher market price. Corn price in the absence of fertilizer initially jumps to nearly $2.00 per bushel (Table 14). A further downward adjustment in exports would slow the rise after 1970 but by 1980 the price of corn would be $2.30 per bushel. Soybean prices do not indicate a similar increase. A much larger portion of soybean production enters the export market and this demand is more elastic than the domestic demand for soybeans. As prices of soybeans initially rose, the more elastic demand would cause a cutback in the quantity of soybean exported. Of course, if the world market was highly dependent upon this source of oilmeals, that is if export demand is significantly more inelastic than we postulate, prices could climb more than shown.

With the large increase in corn price, production of all livestock commodities is reduced and prices increase significantly. Beef price is initially estimated at nearly $37.00 per hundred-

Table 15. Farm income received by U.S. farmers, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is prohibited on major crops.

	Actual[a]			Projected		
	1967	1968	1969	1970	1975	1980
TOTAL FARM INCOME	(million dollars)					
Cash receipts	42,788	44,386	47,431	53,336	60,388	67,784
Government payments	3,079	3,462	3,800	465	465	465
Total	45,867	47,848	51,231	53,801	60,853	68,249
Home consumption	745	705	735	725	700	675
Rental value of dwellings	2,449	2,579	2,650	2,700	3,000	3,300
Total Income	49,061	51,132	54,616	57,226	64,553	72,224
Farm production expenses	34,820	36,346	38,571	40,505	44,703	49,158
Net Income[b]	14,644	14,675	16,245	16,721	19,850	23,066
PER FARM INCOME	(dollars per farm)					
No. of farms (000)[c]	3,147	3,054	2,971	2,768	2,492	2,248
Net income per farm (dollars)	4,654	4,805	5,468	6,041	7,965	10,261

a/ Source: U.S. Department of Agriculture. Farm Income Situation. February 1969 and February 1970.

b/ Includes changes in farm inventories.

c/ Projected farm numbers are from Earl O. Heady and Leo V. Mayer, Food Needs and U.S. Agriculture in 1980. Volume I, Technical Papers, National Advisory Commission on Food and Fiber. Washington, D.C. August 1967. p. 109.

weight and climbs to $41.80 by 1980. Pork prices also jump upward, starting at $29.60 with 1970 conditions and reaching $35.90 by 1980. But even with the 1980 hog price, the hog-corn ratio would be only 15.6, well below the ratio of corn and hog prices for the 1967-1969 period. Prices for broilers and milk also rise but costs for producing these commodities would also increase.

Farm income Higher farm prices bring higher levels of cash receipts for commodities sold. Government payments drop, however, leaving only those payments for programs other than land retirement. But market receipts more than offset the decline in government payments and total cash income climbs some 2.5 billion dollars for 1970 (Table 15). However, total expenses for farming also climb reaching $40.5 billion. The climb of 2.5 billion in total income compares with an estimated increase of 2.0 billion in production expenses causes a half billion dollars extra net income for farmers. Income per farm climbs with the higher level of net income and the projected reduction in farm numbers. By 1980, income per farm is projected to reach $10,261, a level certain to improve living conditions on farms, raise land values and drive up costs of food for consumers.

Consumer costs Higher prices for farm commodities result in higher costs to consumers for food. Total expenditures for all food could rise to $106.5 billion dollars for 1970 conditions, compared to actual expenditures of $95.3 billion in 1969; total expenditures rise even further after 1970 and reach $134.0 billion in 1980 (Table 16) measured in constant 1969 dollars. If inflation should increase this cost by another 20 percent as occurred between 1960 and 1970, this would add another $40 billion dollars to 1980 food costs.

The largest increase in food costs is caused by higher cost of meat commodities. As production costs for these items rise in response to higher grain prices, supply is cut back and their market price increases. But in addition to higher prices, the importance of meat items in consumer food budgets affects total costs. Beef alone accounts for an estimated 11.8 percent of total food expenditures for the average family and all meats including fish and poultry make up 30.4 percent of food expenditures.[22/] Price changes in these commodities tend to affect consumer food

22/ U.S. Department of Agriculture. U.S. Food Consumption, Statistical Bulletin No. 364. pp. 8-10.

Table 16. Retail prices of specified food products and total consumer expenditures, actual 1967-1969 and projected 1970, 1975 and 1980 with fertilizer use eliminated on major crops in the United States.

		Actual[a/]			Projected		
		1967	1968	1969	1970	1975	1980
			RETAIL PRICES				
Beef[b/]	(cts/lb)	82.6	86.6	96.3	106.0	114.6	123.8
Pork	(cts/lb)	67.2	67.4	74.3	84.9	92.5	100.7
Lamb[b/]	(cts/lb)	87.4	93.6	101.8	118.0	125.8	134.5
Chicken	(cts/lb)	38.1	39.8	42.2	59.8	63.4	67.7
Milk	(cts/qt)	25.8	26.8	27.6	29.1	30.5	32.0
			TOTAL EXPENDITURES				
All Food	(bil. dol)	88.8	90.0	95.3	106.5	122.4	134.0
All Meat	(bil. dol)	25.1	26.7	28.5	32.0	42.0	47.2
Dairy	(bil. dol)	13.5	14.6	14.9	16.6	18.4	20.5
Poultry and Eggs	(bil. dol)	6.2	6.5	7.4	10.9	12.2	13.8
Other[c/]	(bil. dol)	40.0	41.7	44.5	47.0	49.8	52.5

a/ Source: U.S. Department of Agriculture, Food: Consumption, Prices, Expenditures, Supplement for 1968 to Agricultural Economics Report No. 138. January 1970; Marketing and Transportation Situation, February 1969, February 1970 and August 1970.

b/ Choice grade.

c/ Includes fruits and vegetables, grain mill products, bakery products and miscellaneous.

costs significantly. By contrast, other classes of food have less effect on food budgets. Fruits make up 8.0 percent of the average bood budget; vegetables 10.3 percent. Changes in the price of these latter commodities are not as noticeable to consumers because of a smaller total effect on their food budgets. But meats account for nearly a third of consumer food budgets. A rise in the price of these commodities causes a sharp increase in food costs as data for the 1967-1969 period indicates. These rates of increase would continue with elimination of fertilizers. It is likely that consumer response would be sharp and prolonged.

The elimination of fertilizer in crop production brings added costs which ultimately would have to be passed along to consumers in the form of higher food costs, just as past savings in farm production costs have held down food costs. Over the last several decades, the food consumer has received a significant share of the gains from improved efficiency of farm production. But a turn around in efficiency, such as elimination of fertilizer use or other chemicals for that matter would bring, would ultimately be paid for by the consumer. While it would be objected to by consumers, it should be clear that purifying the environment has costs associated with it. These costs must ultimately be paid by the consumer if environmental quality is desired.

With the present level of productive capacity in U.S. agriculture, a limit on fertilizer could be offset for some time by shifting additional acres of cropland back into production. But these acres are generally less productive and would have higher costs per unit of commodity produced. These higher costs must be recovered by farm operators if that land is to remain in production. To cover higher costs requires higher returns and these must come from either the market place where the farmer sells his product or from another source such as payments from the federal government. At the present time, public programs provide part of the returns to farmers through direct government payments. Such a policy could continue and increase if fertilizer use was limited thus shifting an additional part of food costs to the taxroll where it is perhaps less visible. Such a scheme could temporarily, at least, make higher cost food production less visible and perhaps more acceptable to the general public. It would not halt the loss of production efficiency which would be associated with such restrictions, however.

From the farmer's standpoint, limiting the use of these

Table 17. Iowa acreages, yields and production of major crops, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is limited to 110 pounds per crop acre in Iowa and the United States.

		Actual[a/]			Projected		
		1967	1968	1969	1970	1975	1980
			ACREAGES (000)				
Corn, grain		11,145	9,808	9,416	10,574	10,083	11,179
Other feed grains		1,912	1,858	1,881	277	277	277
Soybeans		5,246	5,561	5,283	6,347	7,020	6,403
Wheat		60	51	43	--	345	394
Total		18,363	17,278	16,623	17,199	17,725	18,253
Acres retired		1,959	3,721	3,889	3,163	2,636	2,109
			YIELDS				
Corn, grain	(bu)	88.5	93.0	98.0	83.3	85.3	85.6
Other feed grains	(ton)	0.81	0.88	0.75	0.71	0.72	0.79
Soybeans	(bu)	27.5	32.0	33.0	29.3	29.1	29.1
Wheat	(bu)	27.5	36.0	32.0	--	29.8	34.6
			PRODUCTION (000)				
Corn, grain	(bu)	986,332	912,144	922,768	880,607	860,107	957,143
Other feed grains	(ton)	1,546	1,628	1,408	198	200	218
Soybeans	(bu)	144,265	177,952	174,339	185,878	204,551	186,115
Wheat	(bu)	1,650	1,836	1,376	--	10,281	13,632

a/ Source: U.S. Department of Agriculture. Crop Production, 1969 Annual Summary December 1969; and Feed Grain and Wheat Programs -- Statistical Summary. April 1968, January 1969 and March 1970.

inputs could have a favorable impact on prices and incomes similar to reducing available cropland through land retirement programs. To farmers who place a high value on greater efficiency in farm production, higher yields per crop acre and minimum cost for finished animals in the feed lot, these kinds of restrictions could be socially and psychologically painful. It would be a long time before past corn yield records were broken although the record for net income per acre might be broken year after year. But these latter records would come at the expense of the consumer as we have stressed previously.

Estimated Consequences of Restricting Fertilizer Use on Iowa Farms

The second set of estimates focus on the question, "what would happen if only a single state decided to limit the use of fertilizer"? To evaluate the economic outcomes, restriction levels on fertilizer use similar to the previous analysis were applied only to Iowa. The effects on Iowa farm production, prices and incomes are summarized in the following three sections. To provide a set of estimates for comparison, the first section reports Iowa results if all farms in the nation, including Iowa, are limited to a maximum of 110 pounds of nitrogen per crop acre.[23] In the next section, a restriction of 50 pounds of nitrogen per crop acre is placed on Iowa farmers but other farms are allowed to continue the higher level. The final section analyzes the effects of eliminating inorganic fertilizer from Iowa farm production while other areas are allowed to use fertilizers. All Iowa results are projected for 1970, 1975 and 1980. Each alternative utilizes projected yield data discussed earlier. Also, since only Iowa would be affected, we assume government land retirement programs continue.

Model IV: Consequences of limiting Iowa farms to 110 pounds of nitrogen

Acreages, yields and production of major crops for Iowa, assuming a restriction of 110 pounds of nitrogen per acre, are reported in Table 17. These results are primarily for comparison with the other restriction levels analyzed in later sections.

23/ Not all crops or cropland would receive 110 pounds of nitrogen; rather, this is a maximum restraint. Crops using fewer pounds per acre are assumed to continue at the lower level with any increase following recent trends.

Acreages Total crop acreage in Iowa is closely determined by the size of government land retirement programs since high fertility and productivity assure crop production if no restraint is present. A decision by Iowa farmers to place more or less land in these programs leaves total acres to be planted accordingly. In this analysis we assume that the limitations on fertilizer use (since they affect all farmers in the U.S.) would restrain total output, thus requiring larger crop acreages and a reduction in land retirement programs. As land retirement decreases, Iowa corn, soybean and other crop acreage can increase if it is competitive with other regions. These results suggest that if fertilizer is restricted for all farms in the United States, Iowa would increase its corn and soybean acreage. These two crops alternate in size between 1970, 1975 and 1980. By 1980, the lower corn yields require larger acreages to meet quantities required for feeding livestock in Iowa and for shipment into the export market. Wheat acreage in Iowa also increases, with 345,000 acres projected for 1975 and 394,000 acres in 1980.

One other point should be noted. A minimum acreage of other feed grains in Iowa was established in the analysis; a larger acreage was allowed if competitive. For this level of fertilizer restriction, such a competitiveness was not evident; other feed grain acreage remained at the minimum (227,000 acres) throughout the period analyzed.

Iowa crop yields with this level of fertilizer use are lower than in the recent past. For the period analyzed, corn yield stabilizes near 85 bushels per acre showing a small increase over time due to the increasing proportion of acres fertilized. We noted earlier that 92 percent of corn acres in Iowa received some fertilizer in 1969, and this percent increases until all corn acres receive some fertilizer by 1980. Other feed grain yields also increase along with wheat yields. Soybean yields were not altered for this analysis although shifts in acreage between particular producing areas causes the average yield to vary.

With lower Iowa corn yields, corn production declines from 1967-1968 levels and remains lower until 1980 when larger acreages again raises production to nearly a billion bushels. The sharp increase in soybean acres raises total soybean production somewhat, although the weather-normal yields used in the study tend to be somewhat below recent years. The result is only slightly larger production levels. Production of other feed grain crops and wheat are relatively insignificant and show only minor change after 1975.

Farm prices   Crop and livestock prices for this alternative (shown in Table 18) change little from recent levels. These price levels are closely associated with those reported earlier for Model I, where national average prices are given for the same limitation on fertilizer. Both sets of prices are derived in a similar manner (based on costs of production). The level of prices is also similar since Iowa farm production is part of the total production for a national and international market for grain. Prices received by Iowa farmers are closely attuned to levels set in major terminal markets, although adjusted for transportation cost differentials. Should Iowa farmers suffer a sharp reduction in output, prices of grains may rise locally but not by as large an amount as if all farms in the U.S. were similarly affected by drought or other natural hazard. An individual state or producing area does not establish its own price for a commodity but rather is part of a larger trading area where total supply and demand for a commodity establishes the equilibrium price. Thus, any rise in Iowa prices would be limited by the supply of grain in other localities and the cost of transporting it to Iowa. This concept will become of greater significance in the later analysis as lower restrictions are placed on fertilizer use.

Farm income   Cash receipts for Iowa farmers with limited fertilizer are lower for 1970 than for 1969 (Table 19). Government payments are also lower as fewer acres are retired. Further, farm production expenses are higher. The remaining estimated net income for 1970 is 11.2 percent less than for 1969. On a per farm basis, net income is $7,383, a 12 percent reduction from 1969.

Total net farm income would rise after 1970 and reach the high set in 1969 by 1980. This increase, coupled with a further decline in farm numbers, would raise income per farm to $9,840 by 1980. While not shown here, the largest part of this increase comes from expanded livestock production and some increase in livestock prices which are projected to trend slowly upward over the period analyzed. Altogether, a limitation on fertilizer at this level would not greatly change economic conditions for Iowa farmers if other farmers are similarly restricted in fertilizer use. The general trend would be for expanded crop acreage, less land retired under government programs, a continued decline in farm numbers and an upward trend in income per farm. These latter

Table 18. Prices received by Iowa farmers for major commodities, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is limited to 110 pounds per crop acre in Iowa and the United States.

		Actual[a/]			Projected		
		1967	1968	1969	1970	1975	1980
				CROPS			
Corn		1.02	1.04	1.06	1.05	1.00	1.00
Soybeans		2.50	2.45	2.30	2.46	2.34	2.33
Wheat		1.43	1.22	1.17	1.35	1.25	1.21
				LIVESTOCK			
Beef	(cwt)	23.70	25.20	27.80	28.30	28.50	29.30
Pork	(cwt)	18.70	18.70	22.20	19.60	20.50	21.90
Milk	(cwt)	4.22	4.45	4.69	4.40	4.70	5.05
Broilers	(lb)	24.0	24.0	25.0	26.1	24.5	24.5

a/ Source: U.S. Department of Agriculture. Agricultural Prices. 1967, 1968 and 1969 Annual Summaries, June 1967, 1968 and 1969.

Table 19. Farm income received by Iowa farmers, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is limited to 110 pounds per crop acre in Iowa and the United States.

	Actual[a/]			Projected		
	1967	1968	1969	1970	1975	1980
TOTAL FARM INCOME	(million dollars)					
Cash receipts	3,406	3,445	3,788	3,677	4,005	4,428
Government payments	143	246	260	214	181	148
Total	3,549	3,691	4,048	3,891	4,186	4,576
Home consumption	33	35	37	39	44	48
Rental value of dwelling	70	73	78	81	92	99
Total Income	3,651	3,800	4,163	4,011	4,322	4,723
Farm production expenses	2,678	2,794	2,888	2,970	3,197	3,493
Net Income[b/]	1,016	1,045	1,200	1,041	1,125	1,230
PER FARM INCOME	(dollars per farm)					
No. of farms (000)	150	147	143	141	133	125
Net income per farm (dollars)	6,771	7,108	8,388	7,383	8,458	9,840

a/ Source: U.S. Department of Agriculture. Farm Income Situation, State Estimates, 1949-1969. August, 1970.

b/ Includes changes in farm inventories.

conditions have generally existed for the last decade in Iowa.

Model V. Consequences of limiting Iowa farms to 50 pounds of nitrogen per acre

Acreages Reducing the level of fertilizer use by one-half while holding the rest of the nation at 110 pounds initially has little effect on the acreage of corn grown in Iowa. But some shift away from corn and toward soybeans and wheat does occur. Acreages of soybean increases by 1.6 million acres from 1969 levels (Table 20) and by 0.5 million acres from the previous model. The implication of these results is that soybean acreage may have been below optimum levels for Iowa under recent levels of prices and production costs. One explanation may be the rapid expansion of soybeans over the past two decades, and the general tendency of farmers to maintain past cropping patterns. Large shifts in production patterns thus tend to occur only as inter-generational transfer of farms take place. Younger farmers with heavier indebtedness may shift toward more intensive cropping patterns and maximum profit crops. According to these results the latter incentive could bring a further expansion of soybeans at the expense of other feed grain crops under recent price and productivity relationships. With limits placed on fertilizer use, as assumed here, the shift toward soybeans might occur more rapidly and at the expense of some corn acreage. In the past these shifts have occurred at the expense of other feed grain crops.

Iowa crop yields drop significantly with reduced fertilizer use. Corn yield stabilizes near 75 bushels per acre. While these results suggest that corn yield would drop significantly in the initial year of any restriction on fertilizer, these estimates do not take into account the carryover effect of past fertilizer use. The yield estimates of this study for each of the 150 producing regions assume that adjustment to limited fertilizer use is immediate, that is, these yields are those which would be possible after several production periods have elapsed with a constant level of fertilizer use.

Production levels for corn are substantially reduced as yields decline. Soybean production, on the other hand, increases as total acres increase. Wheat production also is substantially higher but no wheat is used for livestock feed in Iowa. Other feed grain production remains at a minimum level, showing no tendency to increase or become more competitive as corn production is restricted by fertilizer use.

Table 20. Iowa acreages, yields and production of major crops, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is limited to 50 pounds per crop acre in Iowa and 110 pounds in the remainder of the United States.

	Actual[a]			Projected		
	1967	1968	1969	1970	1975	1980
ACREAGES (000)						
Corn, grain	11,145	9,808	9,416	9,674	9,790	11,135
Other feed grains	1,912	1,858	1,881	277	277	277
Soybeans	5,246	5,561	5,283	6,810	7,226	6,403
Wheat	60	51	43	438	433	438
Total	18,363	17,278	16,623	17,199	17,726	18,253
Acres retired	1,959	3,721	3,889	3,163	2,636	2,109
YIELDS						
Corn, grain (bu)	88.5	93.0	98.0	74.0	75.3	75.3
Other feed grains (ton)	0.81	0.88	0.75	0.72	0.72	0.79
Soybeans (bu)	27.5	32.0	33.0	29.2	29.1	29.1
Wheat (bu)	27.5	36.0	32.0	27.7	29.8	31.1
PRODUCTION (000)						
Corn, grain (bu)	986,332	912,144	922,768	715,876	737,393	838,796
Other feed grains (ton)	1,546	1,628	1,408	199	200	218
Soybeans (bu)	144,265	177,952	174,339	198,802	210,156	186,122
Wheat (bu)	1,650	1,836	1,376	12,127	12,902	13,616

a/ Source: U.S. Department of Agriculture, Crop Production, 1969, Annual Summary. December, 1969; Feed Grain and Wheat Programs -- Statistical Summary. April 1968, January 1969 and March 1970.

Table 21. Prices received by Iowa farmers for major commodities, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is limited to 50 pounds per crop acre in Iowa and 110 pounds per acre in the remainder of the United States.

		Actual[a]			Projected	
	1967	1968	1969	1970	1975	1980
			CROPS			
Corn	1.02	1.04	1.06	1.07	1.03	1.02
Soybeans	2.50	2.45	2.30	2.50	2.38	2.34
Wheat	1.43	1.22	1.17	1.40	1.27	1.24
			LIVESTOCK			
Beef (cwt)	23.70	25.20	27.80	28.50	28.80	29.50
Pork (cwt)	18.70	18.70	22.20	19.80	20.80	22.10
Milk (cwt)	4.22	4.45	4.69	4.40	4.70	5.10
Broilers (lb)	24.0	24.0	25.0	26.4	25.9	25.8

a/ Source: U.S. Department of Agriculture. Agricultural Prices, Annual Summary. June 1967, 1968 and 1969.

One final result should be mentioned. There is no tendency evident for idle acres to increase in Iowa with the more restrictive restraint on fertilizer. The productivity of cropland in Iowa appears adequate so that a cutback in fertilizer use does not greatly reduce its competitiveness with other producing regions. Instead there is a shift of acreage among crops. But no land remains out of crop production except as required by government programs which might or might not increase if fertilizer was restricted.[24]

Farm prices The significant factor about estimated farm prices with only Iowa farmers facing a limit on fertilizer use is the small increase from the previous model. The smallness of the increase is important because per unit costs of production would increase for Iowa farmers with lower crop yields. But Iowa prices are determined by the aggregate supply of farm products in the U.S. and the cost of transportation to major markets. Thus, since adequate production capacity is available elsewhere in the U.S. to offset the reduced level of production from Iowa, prices of farm commodities do not rise much, either from the previous model or over the period from 1970 to 1980 (Table 21). Corn price remains slightly above $1 per bushel and soybeans fluctuate near $2.50 per bushel. Wheat price shows a downward trend over time.

Livestock prices are only modestly higher than under the previous model. This outcome could be expected because livestock prices are dependent in this analysis upon the level of crop prices and crop prices are similar. The method used assumes a cost of production approach to pricing of livestock, that is, if feed input prices rise, the cost of producing the animal increases and this cost is ultimately passed along to the consumer or the feeder must take a smaller return on his labor and other inputs. In the short term, the feeder may have no choice but take a lower return, but over a longer period, a lower level of returns will be reflected by a reluctance on the part of some farmers to produce livestock. At that point, the supply of livestock will

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24/ We were unable to determine in this analysis whether Iowa farmers, if given the opportunity, would place larger acreages in government programs at recent levels of direct payments. This alternative could not be examined under the framework used for this analysis. But we were able to determine that if idling land without payment was the alternative to cropping, cropping would still be profitable for Iowa farmers even with restricted use of fertilizer.

Table 22. Farm income received by Iowa farmers, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is limited to 50 pounds per crop acre in Iowa and 110 pounds per acre in the remainder of the United States.

	Actual[a/]			Projected		
	1967	1968	1969	1970	1975	1980
TOTAL FARM INCOME		(million dollars)				
Cash receipts	3,406	3,445	3,788	3,617	3,902	4,293
Government payments	143	246	260	214	181	148
Total	3,549	3,691	4,048	3,831	4,083	4,441
Home consumption	33	35	37	39	44	48
Rental value of dwelling	70	73	78	81	92	99
Total Income	3,651	3,800	4,163	3,951	4,219	4,688
Farm production expenses	2,678	2,794	2,888	2,946	3,200	3,472
Net Income[b/]	1,016	1,045	1,200	1,005	1,019	1,116
PER FARM INCOME		(dollars per farm)				
No. of farms (000)	150	147	143	141	133	125
Net income per farm (dollars)	6,771	7,108	8,388	7,128	7,662	8,928

a/ Source: U.S. Department of Agriculture. Farm Income Situation, State Estimates, 1949-1969. August, 1970.

b/ Includes changes in farm inventories.

be cut back, prices will rise and the higher costs of feed inputs will be passed along to the consumer. The process is of a long term nature but we have assumed it to occur immediately in this equilibrium model.

Farm income The lack of increase in prices Iowa farmers would receive shows up in income levels estimated for this type of restriction. The initial impact is small with the first year, 1970, showing only a small change in gross and net incomes. Government payment and nonmoney income from perquisites remain the same as under the last model. Farm production expenses are slightly lower due to the use of less fertilizer. For 1970, net income is estimated at $1.0 billion (Table 22), not greatly different from the previous model (Table 19). But by contrast, there is almost no rise after 1970 with this limitation while the previous model showed an increase. By 1980, lower income per farm is clearly apparent in these estimates. With this more restrictive limitation on fertilizer use, income per farm is nearly $1,000 less by 1980 than under the previous model. Higher production costs and a smaller increase in gross sales cause a slower rise in income per farm. By 1980, the effects of limiting fertilizer to 50 pounds of nitrogen per acre only on Iowa farms would be clearly evident in the level of income received by Iowa farm families.

Model VI. Consequences of eliminating nitrogen on Iowa farms

Acreages Discontinuing the use of all fertilizer from major crops in Iowa causes a more serious shift in crop acres than the previous limitation (Table 23). Corn acreage declines with a shift to other feed grain crops. Soybeans increase from recent levels and continue increasing over the period analyzed. Wheat acreage is not competitive with feed grains initially, an outcome partially explained by the large need for feed grains in livestock rations. The data for 1975 show a temporary shift toward wheat based on cost-returns considerations, but by 1980 these acres return to feed grains (Table 23).

But an interesting result is that there is again no tendency for idle acres to increase under this alternative. Even with the great reduction in yields, with the state average corn yield at 58.9 bushels per acre, and other feed grain crops reduced to 0.56 tons per acre, our compititive equilibrium model indicates that all cropland remains competitive for production of these crops. Productivity of this land is greatly reduced, however, and total production of corn falls to half the recent level. Soybean

Table 23. Iowa acreages, yields and production of major crops, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is prohibited in Iowa and limited to 110 pounds in the remainder of the United States.

		Actual[a/]			Projected	
	1967	1968	1969	1970	1975	1980
			ACREAGES (000)			
Corn, grain	11,145	9,808	9,416	8,021	7,867	7,598
Other feed grains	1,912	1,858	1,881	1,312	688	1,177
Soybeans	5,246	5,561	5,283	7,856	8,605	9,468
Wheat	60	51	43	0	576	0
Total	18,363	17,278	16,623	17,189	17,716	18,243
Acres retired[b/]	1,959	3,721	3,889	3,163[c/]	2,636[c/]	2,109[c/]
			YIELDS			
Corn, grain (bu)	88.5	93.0	98.0	58.9	59.1	59.2
Other feed grains (ton)	0.81	0.88	0.75	0.56	0.56	0.56
Soybeans (bu)	27.5	32.0	33.0	29.4	29.4	29.3
Wheat (bu)	27.5	36.0	32.0	0	22.4	0
			PRODUCTION (000)			
Corn, grain (bu)	986,332	912,144	922,768	472,407	464,715	449,750
Other feed grains (ton)	1,546	1,628	1,408	739	376	663
Soybeans (bu)	144,265	177,952	174,339	230,856	252,584	277,835
Wheat (bu)	1,650	1,836	1,376	0	12,889	0

a/ Source: U.S. Department of Agriculture. Crop Production, 1969 Annual Summary, December 1969.

b/ Source: U.S. Department of Agriculture. Feed Grain and Wheat Programs -- Statistical Summaries -- April 1968, January 1969 and March 1970.

c/ These acres are assumed to be retired under a government program although elimination of inorganic fertilizer would require crop rotations to maintain soil fertility. These acres would likely be planted to soil building crops even if a diversion program was available.

production jumps upward, reaching 231 million bushels in 1970, and 277 million bushels by 1980. Other grain crops contribute a small amount to total feed supplies.

With these levels of production, large changes would occur in Iowa agriculture. The state would become an importer of feed grains, if total livestock production were to remain stable. In an attempt to offset losses growing out of the lower crop sales, farmers might substantially increase total livestock production. To do so would require large imports of feed grains. We estimate that with 1970 demand and supply conditions and no fertilizer, 4.2 million tons of feed grains would have to come from outside the state. By 1975, this tonnage would climb to 6.3 million tons and to 7.9 million tons by 1980. On-third of all feed grains fed in the state in 1980 would be shipped in from other production areas. The state would shift from a major exporter of corn to a major importer of this same commodity. Soybean exports would increase somewhat to offset part of this loss but the net impact would be highly negative on farmers and the Iowa economy.

Farm prices   Iowa corn price initially is recorded at $1.14 per bushel for 1970 but as government programs are relaxed in Iowa and elsewhere to assure an adequate food supply, the tendency is for corn price to slowly decline (Table 24). A similar trend is evident for soybeans and wheat. Added acres of production located outside Iowa cause this decline. It means the following: there is adequate production capacity in the U.S. so that a reduction in farm output in one state can be offset by increased production in other states. As other states expand production, the average market price for all states would be held down or if production were increased adequately, there could be a decline in grain prices. Thus production is reduced in the state affected but prices do not rise to offset the loss in production.

This outcome grows out of the large magnitude of excess production capacity which exists in U.S. agriculture, expecially the cropping portion. With over 50 million acres of cropland annually held out of production in the United States, reducing Iowa corn production by one half does not raise national prices for long. Production of corn increases in other states and national prices again stabilize (and even decline in real terms, a process that has been going on since 1961). Without a large increase in corn price, cash grain farmers in Iowa would suffer immense losses. Livestock feeders who purchase corn would not be greatly affected although there would be some inconvenience with the need to

Table 24. Prices received by Iowa farmers for major commodities, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is prohibited in Iowa and is limited to 110 pounds per acre in the remainder of the United States.

		Actual[a/]			Projected	
	1967	1968	1969	1970	1975	1980
			CROPS			
Corn	1.02	1.04	1.06	1.14	1.08	1.05
Soybeans	2.50	2.45	2.30	2.59	2.41	2.34
Wheat	1.43	1.22	1.17	1.44	1.29	1.22
			LIVESTOCK			
Beef (cwt)	23.70	25.20	27.80	29.30	29.40	29.80
Pork (cwt)	18.70	18.70	22.20	30.60	21.40	22.50
Milk (cwt)	4.22	4.45	4.69	4.50	4.80	5.10
Broilers (lb)	24.0	24.0	25.0	27.3	26.5	26.1

a/ Source: U.S. Department of Agriculture. Agricultural Prices. 1967, 1968 and 1969 Annual Summaries. June 1967, 1968 and 1969.

purchase a large supply of corn from outside the state. Costs for this corn would be higher, of course, because transportation costs would have to be paid. The smaller grain sales by cash grain farmers coupled with increased purchases of grain at higher prices by livestock feeders would have some significant effects on farm income.

Farm income Cash receipts from farming show a decline from recent levels in the initial year without fertilizer. The decline is relatively small because most cash receipts come from livestock sales in Iowa (75.4 percent was from livestock products in 1969). These sales are assumed to continue even though fertilizer is limited and crop production reduced. With government payment and other sources of farm income added in, total income of Iowa farmers is below recent levels. But the worst part of the income picture is yet to come. Production expenses take a significant jump upward as larger acreages are farmed, and more feed is purchased at higher prices to feed livestock. Production expenses are estimated to climb to $3.4 billion in 1970, to $3.6 billion by 1975 and $4.0 billion by 1980 (Table 25). Total production expenses in Iowa were $2.9 billion in 1969.

With the large increase in production costs without any offsetting increase in cash receipts, total net income for Iowa farmers is reduced to one-third the former level. Total net income is estimated at $462 million in 1970, compared to $1.2 billion in 1969. The average farm would have only $3,277, compared to $8,388 in 1969. While a small improvement would occur in the future as farm numbers decrease, these estimates suggest that even by 1980 per farm income would be only $4,080. This level of income could result in a speed up in migration from the farm for farm families in lower income levels.

This analysis indicates that some severe effects would grow out of any limitation on fertilizer use by an individual state. With present levels of unused and available crop acres in land retirement programs, the cutback in crop yields and production by a single state could be offset in a fairly short time period by increased production in other states. Since price levels relate closely to aggregate supply and demand conditions, and not to conditions within any single state, farm prices would not rise any substantial amount. Thus the state faced with reduced crop yields would suffer significant losses of crop production without offsetting increases in crop prices. The result would be sharply lower incomes for the farmers affected and

Table 25. Farm income received by Iowa farmers, actual 1967-1969 and projected 1970, 1975 and 1980 assuming nitrogen use is prohibited in Iowa and limited to 110 pounds per crop acre in the United States.

	Actual[a/]			Projected		
	1967	1968	1969	1970	1975	1980
TOTAL FARM INCOME	(million dollars)					
Cash receipts	3,406	3,445	3,788	3,500	3,808	4,210
Government payments	143	246	260	214	181	148
Total	3,549	3,691	4,048	3,714	3,989	4,358
Home consumption	33	35	37	39	44	48
Rental value of dwelling	70	73	78	81	92	99
Total Income	3,651	3,800	4,163	3,824	4,125	4,505
Farm production expenses	2,678	2,794	2,888	3,372	3,640	3,995
Net Income[b/]	1,016	1.045	1,200	462	485	510
PER FARM INCOME	(dollars per farm)					
No. of farms (000)	150	147	143	141	133	125
Net income per farm (dollars)	6,771	7,108	8,388	3,277	3,646	4,080

a/ Source: U.S. Department of Agriculture. Farm Income Situation, State Estimates, 1949-1969. August 1970.

b/ Includes changes in farm inventories.

reduced business transactions for the rest of the state's economy.

Extended Effects of Reduced Fertilizer

The reduction or elimination of inorganic fertilizer could have some substantial long run effects on the U.S. economy, both farm and nonfarm. The productivity of U.S. agriculture has contributed to an abundant supply of food commodities -- so abundant that a significant proportion of total capacity remains out of production each year and an additional portion of total farm production is annually exported. These exports offset the large amount of imports of other kinds of goods which each year enter the United States. With imports offset by agricultural exports, foreign trade flows are more nearly balanced and less worry is necessary over gold stocks and international monetary problems. The whole foundation for a strong and stable U.S. dollar is the ability of this nation to "balance its books." A sharp reduction in commercial farm exports as a result of restricting inorganic fertilizer use could result in a disequilibrium with international consequences. However, insofar as our exports have been at the expense of our natural resources, these are unaccounted costs associated with their international position.

There are other consequences which would affect the farm sector under a policy of restricted fertilizer use. The price of farmland would rise or decline depending on changes in land use, farm price levels and net farm incomes. To the extent that government programs change and allow increased farm output and reduced prices and incomes, a corresponding effect can be expected on land value. Any change in land market value might require a decade to measure but such changes would eventually occur. In the 1950's, farm incomes (especially in real terms) declined rather significantly over the period 1954-1960. It was not until 1960, however, that land values fell. Until that point, other factors tended to push land values upward more effectively than declining farm income pressed downward. The net effect was rising land values over a significant period of falling farm incomes.

While economic factors have received the major emphasis in this report, other aspects could also receive greater attention by other disciplines. The matter of public health and welfare is not the sole responsibility and discipline of economists. Many other aspects need to be examined and clarified. In the end the general public must decide which set of consequences are acceptable. For intelligent public decisions, a flow of information is essential. This report has brought forth one set of estimates. Other sets are possible and may be needed in the long term process of decision-making on issues of critical importance to future generations.

Technical Appendix

The Model

This study employed a cost minimizing linear programming model of U.S. agriculture. The continental United States was divided into 150 spatially delineated agricultural production regions. These regions were delineated such that reasonably homogeneous production possibilities existed within each region, subject to the condition that production regions followed country and state boundaries. The U.S. was not completely covered by the 150 regions, but those areas not included were analyzed separately and account was taken of this production in the consumption levels for each commodity.

Consumption of agricultural commodities was also considered in a spatial framework. The U.S. was divided into 31 consuming regions containing the 150 production regions. The consuming regions covered the U.S. completely following state boundaries. Demand for wheat, feed grains, and oil meals was calculated for each consuming region, while demand for cotton was calculated nationally.

Production activities were defined for each production region to satisfy demand in a consuming region:

(a) Wheat production which was credited against wheat demand;
(b) Corn production which was credited against feed grain demand;
(c) Other feed grains production (a weighted average of grain sorghum, oats and barley) which was credited against feed grain demand;
(d) Soybean production which was credited against oil meal demand;
(e) Cotton lint production which was credited against national cotton lint demand and cottonmeal which was credited against oilmeal demand.

Transfer activities were defined for each consuming region so that wheat could be used to satisfy the feed grain demand.

Transportation activities were defined between each pair of consuming regions for three commodities: wheat, feed grains, and oil meals.

Land retirement activities were defined for each production region for the retirement of wheat, feed grain, or cotton land. Bounds were placed on these activities to correspond to past levels of land retirement under federal farm programs.

The <u>variables</u> of the model are divided into activities, costs of activities, and demand and land restraints. <u>Activities</u> are:

X_{ij} = crop production activity level

P_{ij} = yield per unit of crop production

T_{kmn} = transportation activity level for the n^{th} commodity from the m^{th} to the k^{th} consuming region

WF_k = wheat-feed grain transfer activity level

RW_i = wheat land retirement activity level

RF_i = feed grain land retirement activity level

RC_i = cotton land retirement activity level

<u>Activity costs</u> are:

c_{ij} = crop production activity cost

d_{kmn} = transportation activity cost

v_i = cost per unit of wheat-feed grain transfer activity

<u>Activity restraints</u> are:

L_i = land restraint for land using activities

D_{mn} = demands for commodities

where the subscripts are as follows:

i = index of crop production regions: i = 1, 2,···, 150

j = index of crop production activities:

j = 1 for wheat

j = 2 for corn

j = 3 for other feed grains

j = 4 for soybeans

j = 5 for cotton

k,m = indices of consuming regions: k,m = 1, 2,···, 31;

k,m = 32 is the identification of the national cotton region.

n = index of agricultural commodities:

n = 1 for wheat

n = 2 for feed grains

n = 3 for oilmeals

n = 4 for cotton lint

The objective function is:

$$\text{Min} \sum_{i=1}^{150} \sum_{k=1}^{5} c_{ij} X_{ij} + \sum_{k=1}^{31} \sum_{m=1}^{31} \sum_{n=1}^{3} T_{kmn} d_{kmn} + \sum_{k=1}^{31} WF_k v_k$$

Land restraints are:

$$\sum_{j=1}^{5} X_{ij} + RC_i + RW_i + RF_i \leq L_i \qquad i = 1, 2, \cdots, 150$$

Demand restraints are:

(a) Wheat

$$\sum_{i \in k} X_{i1} P_{i11} - \sum_{m=1}^{31} \left(T_{km1} - T_{mk1}\right) - WF_k \geq D_{k1} \quad \text{1/} \qquad k = 1,2,\cdots,31$$

(b) Feed grains

$$\sum_{i \in k} \sum_{j=2}^{3} X_{ij} P_{ij2} - \sum_{m=1}^{31} \left(T_{km2} - T_{mk2}\right) + WF_k \geq D_{k2} \qquad k = 1,2,\cdots,31$$

1/ $\sum_{i \in k}$ indicates that the summation is over all producing regions (i) within the k^{th} consuming region.

(c) Oilmeals

$$\sum_{i \in k} \sum_{j=4}^{5} X_{ij} P_{ij3} - \sum_{m=1}^{31} \left(T_{km3} - T_{mk3} \right) \geq D_{k3} \qquad k = 1,2,\cdots,31$$

(d) Cotton lint

$$\sum_{i=1}^{150} X_{i5} P_{i54} \geq D_{32,4}$$

Activity bounds

Activity bounds include both lower bounds and upper bounds. Land retirement activities were controlled by lower bounds; crop activities were subject to upper bounds as necessary.

Non-negativity

Activity levels of the variables were restricted to values greater than or equal to zero.

Yield Coefficients

Yields of the various crops were calculated for each value of time (t = 6, 11, 16 as the year was 1970, 1975, 1980 respectively) and maximum fertilizer level M (M = 0, 50, 110). It was assumed that use of nitrogen fertilizer is a function of time and yield is a function of nitrogen fertilizer use. The functional relationships used to predict yield for each level of nitrogen use are given in Crop Yield Response to Fertilizer in the United States.[2/] Given these production functions, the major task remaining was to predict nitrogen fertilizer use. This estimation was carried out in two distinct steps:

(1) estimation of the amount of land receiving any nitrogen for each region and each crop, and
(2) estimation of the amount of nitrogen applied to land receiving any nitrogen for each region and crop.

2/ D. B. Ibach and J. R. Adams. Crop Yield Response to Fertilizer in the United States, Statistical Bulletin No. 431, U.S. Department of Agriculture. August 1968.

Proportion of land receiving any N

The amount of land receiving any nitrogen can vary in response to (a) a change in the production function $Y = Y(A, L)$, where A is the application rate of nitrogen fertilizer and L is land; (b) a change in output prices, and/or fertilizer prices relative to other input prices; and (c) a learning or adoption process. In this study the prices of inputs were held constant at 1969 prices; the production function was held constant at the specified level given. The use of nitrogen fertilizer was assumed to be profitable, at least at low levels, for all farms, in all areas for all crops. Thus, failure to fertilize a crop was hypothesized to result from incomplete adoption based on a lag in the learning and awareness process. The process of adoption of technical innovations is widely held to be a function of time as well as economic and demographic characteristics of the subject population. The assumption made was that the adoption rate of fertilizer use in any area for any crop is a simple function of time.

The function selected for estimation is intuitively the following:

$$N_T = K\, N_{T-1}$$

where N_T is the proportion of cropland not receiving any nitrogen for a given crop and year;
T is the time index (years since 1964);
K is a constant over time, but may vary between crops and/or regions.

An example might be "Of the corn land not receiving nitrogen in Iowa in 1969, 20% will receive some nitrogen in 1970." The function actually used was the continuous form

$$N_T = e^{\alpha + \beta T}\, N_0$$

where α and β are constants over time but may vary by crop and/or region. Using published estimates of fertilizer

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3/ George M. Beal and Joe M. Bohlen. The Diffusion Process. Iowa Coop. Ext. Serv. Special Report 18. 1957.

use,[4/] ordinary least squares estimation was used to project the proportion of land receiving any nitrogen.

Rate of application of N

The possible motivations for changing application rates are similar to those for adjusting the proportion of land receiving any N:

(a) changed physical productivity of nitrogen,
(b) changed price relationships, or
(c) changed user adoption.

In this study it was assumed that the dominant motive in level of fertilizer use is described by a simple time trend. The relationship assumed was:

$$A_T = (a + bT)\ A_0$$

where A_T is the application rate in pounds of nitrogen per acre for each acre receiving any N;
T is a linear time series of years since 1964;
a and b are parameters of the model and are constant over time but may vary between states and/or crops.

Using published estimates of fertilizer use,[5/] ordinary least squares estimates of the parameters were obtained. These equations were state-specific and estimated for thos crops for which data are published. It was necessary to infer parameters for oats, barley and grain sorghum crops since no data were available for them. Examination of the fertilizer data for cotton indicated no significant time trend. It was therefore assumed that, for cotton, $A_T = A_0$. The fertilizer limitations imposed by our study took the form

$$A_T = \text{Min}\left\{(a + bT)\ A_0;\ M\right\}$$

where M is the maximum application rate allowed, M = 0, 50, or 110.

4/ Crop Reporting Board, "Fertilizer Use on Corn Acreage Harvested for Grain, Selected States" and "Fertilizer Use on Wheat Acreage Harvested for Grain, Selected States," Crop Production, Feb. 1966, Feb. 1967, Jan. 1968, Jan. 1970.

5/ Ibid.

The values of α, β, a, b, for each state and crop were then applied to the percent fertilized and rate of application data supplied by Ibach and Adams[6/] for each production region within each state. The yield coefficient for a crop in a region was the average of $Y_t = Y(A_t, L)$ and Y_0, where Y_0 is the yield with no nitrogen applied; the weights were as follows:

$$P = F_T Y_T + (1 - F_T) Y_0$$

where P is the yield coefficient used in the mathematical model,

F_T is the proportion of land receiving any nitrogen at time T, for a given crop and production region.

The combination yield for oats, barley, and grain sorghum -- the other feed grains -- was derived after the individual yields were calculated.

Production Cost Coefficients

Production costs were primarily based upon previously established budgets for representative farms by region, but were modified to account for changes in fertilizer cost. The established budgets were divided into labor, power and machinery, fertilizer, lime, seed, pesticides, irrigation, interest and insurance, and drying costs.

The modification for fertilizer costs proceeded as follows:

(1) prices were calculated for elemental nitrogen (N), elemental phosphorous (EP), and elemental potassium (EK) on the basis of weighted averages of prices of their normal forms of application by states for 1969. These prices were held constant. The prices are given by PN, PP, Pk for N, EP, and EK respectively.

(2) Nitrogen cost (CN) for a particular crop in a region was estimated by

$$CN = PN\,(A_T)\,F_T$$

(3) Phosphorous costs (CP) and potassium costs (CK) were estimated by

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6/ Ibach and Adams, op. cit.

$$CP = \text{Max} \left\{ PP\ (EP_T)\ F_T\ ;\ \ PP\ (\overline{EP}_T)\ F_T \right\}$$

$$CK = \text{Max} \left\{ PK\ (EK_T)\ F_T\ ;\ \ PK\ (\overline{EK}_T)\ F_T \right\}$$

where EP_T and EK_T are the rates of application of EP and EK at time T given by $EP_T = P(A_T)$ and $EK_T = K(A_T)$ as given by Ibach and Adams[7/]

$\overline{EP}_T$ and $\overline{EK}_T$ are rates of application of EP and EK associated with $M = 50$.

CP and CK were held greater than or equal to the level associated with $M = 50$ since it was assumed that, while crop rotation could maintain an acceptable level of soil nitrogen, EP and EK would still need to be applied inorganically. This minimum level of EP and EK was deemed essential for consistency with the assumption of a constant production function over time.

(4) Fertilizer cost then equals CN + CK + CP. Total production cost c_{ij} for the mathematical model equals the sum of the other cost components with the new fertilizer cost component adjusted as shown. All other cost components are held constant.

Demand Constraints

The demands for agricultural commodities by consuming region are based on historic patterns of commodity use. The major consumer of feed grains and oilmeals is the livestock producing sector of the economy. This sector is not explicitly defined in the L.P. model, but it is represented in the allocation of demand for the grain and oilmeal commodities defined.

Total livestock demand is based on:

(1) Beef per capita demand which is a function of real per capita personal income, time, real price of beef, real price of pork;

7/ Ibid.

(2) Pork per capita demand which is a function of real per capita personal income, time, real price of beef, real price of pork;
(3) Broiler per capita demand which is a function of time, real price of beef, real price of pork, real price of broilers;
(4) Lamb and mutton per capita demand which is a function of time, real price of lamb, real price of beef, and real price of pork;
(5) Turkey per capita demand which is a function of time, real price of beef, and real price of pork, and real price of broilers.

Total demand for these five products is the product of per capita demands and projected population, less projected imports. Other livestock products include:

(6) Milk national demand which is a projection of historical demand less projected imports;
(7) Egg national demand which is a projection of historical demand for eggs less projected imports.

Levels of population and real per capita personal income were projected for 1970, 1975 and 1980.

Wheat demand

The demand for wheat in each consuming region is composed of three parts:

(1) Food demand is the product of historical per capita wheat consumption, total population, and the historical proportion of flour milling in that region.
(2) Seed and other demand is the product of historical levels of seed and other uses for the nation and the historical proportion of total wheat acreage in that consuming region.
(3) Export demand is the product of projected total wheat exports and the historical proportion of exports originating in that consuming region.

Total wheat demand is the sum of food, export, seed and other demands, less historical production of regions not included in the 150 production regions.

Feed grain demand

The demand for feed grain is calculated in six parts:

(1) Livestock demand is the product of (a) the sum of projected production of seven classes of livestock products

times their respective feed grain requirements per unit of product, and (b) the historical proportion of concentrates fed in the consuming region.

(2) Export demand is the product of projected feed grain exports and the historical proportion of feed grain exports originating in the consuming region.

(3) Food demand is the product of historical per capita human food demand, the projected total population, and the historical proportion of population in the consuming region.

(4) Seed demand is the product of historical seed demand and the historical proportion of total feed grain acreage in the consuming region.

(5) Horse and mule demand is the product of historical total horse and mule use and the historical proportion of horse and mule population in the consuming region.

(6) Other demand is the historical residual demand allocated evenly across the 31 consuming regions.

Total feed grain demand for each consuming region is the sum of the six components above less the historical feed grain production of areas not included in the production model.

Oilmeal demand

The demand for oilmeals is calculated in four parts:

(1) Livestock demand is the product of (a) the sum of projected production of seven classes of livestock products times their respective oilmeal requirements per unit of product, and (b) the historical proportion of concentrates fed in the region.

(2) Seed demand is completely analogous to the feed grain seed demand.

(3) Export demand is completely analogous to the feed grain export demand.

(4) Other demand is completely analogous to feed grain other demand.

Total oilmeal demand for each consuming region is the sum of these four components less the historical production of areas not included in the production model.

Cotton demand

The demand for cotton lint is calculated in two parts:

(1) Domestic demand is the product of projected population and historical per capita use. It is not allocated regionally.

(2) Export demand is an extrapolation of historical levels of exports.