Substituting FERTILIZER FOR LAND *in growing corn*

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SUBSTITUTING FERTILIZER FOR LAND IN GROWING CORN

By D. B. Ibach, Agricultural Economist
Farm Economics Research Division

Improved technology in agriculture has had a major influence on the size of the corn crop and on the competitive position of corn in farming systems. On some soils, farmers have found it profitable to substitute commercial nitrogen for legumes and to maintain a higher percentage of the land in corn. Increased use of fertilizer has taken the form of higher rates, higher percentages of acreages fertilized within areas, and extension of use to new areas (table 1).

ECONOMIC POTENTIAL STILL LARGE

Although the extent of use of fertilizer and the per acre rate at which it is applied have increased markedly, rates of application are lower than would be profitable for most farmers in most areas under conditions that make production of corn practicable. 1/ Table 2 shows estimated marginal returns at 1954 rates of application, by regions. It shows also estimated yields per acre at higher rates of application to obtain specified smaller marginal returns until the most profitable rates are reached--the rate at which marginal return is equal to marginal cost.

Although the greatest increases in use of fertilizer on corn have occurred in the Corn Belt and Lake States, the economic potentials for further increases in rates of application appear to be greatest in these regions. A marginal return of $3.78 is indicated for the Corn Belt. With nearly two-thirds of the acreage there fertilized, the estimated average yield per fertilized acre is nearly 10 bushels above the 1953-55 average yield for the region. This estimate is based on data published by the Crop Reporting Service. The estimated 1953-55 average yield on unfertilized acres in the Corn Belt is about 34.5 bushels.

For the United States corn crop as a whole, the rates at which fertilizer was applied in 1954 are estimated to have resulted in a marginal return of $3.06 with a yield of 48.4 bushels per fertilized acre. Sixty percent of the acreage in corn was fertilized. The estimated yield for unfertilized

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1/ Estimates of fertilizer practice in 1954 taken from "Fertilizer Used On Crops and Pasture", U. S. Dept. Agr. Statis. Bul. 216, 1957. Estimates of yield response to different rates of application of fertilizer are based in part on U. S. Dept. Agr. Agr. Handbook 68, "Fertilizer Use and Crop Yields in the U. S.", December 1954. Other general information on response was also utilized as a basis for this report. The estimates of response assume average weather and some improvement in other practices. These estimates are preliminary; they are subject to revision pending availability of more complete information on yield response.

Table 1.- Use of fertilizer on corn, regions and United States, 1947 and 1954

Region	Acreage fertilized		Percentage of acreage fertilized		Plant nutrients applied: Quantity		Plant nutrients applied: As a percentage of nutrients used on all crops		Plant nutrients applied: Per acre fertilized	
	1947	1954	1947	1954	1947	1954	1947	1954	1947	1954
	1,000 acres	1,000 acres	Percent	Percent	1,000 tons	1,000 tons	Percent	Percent	Pounds	Pounds
Northeast	2,454	2,665	83	89	83.0	131.4	17	23	68	99
Lake States	1/	5,843	1/	59	1/	198.3	1/	43	1/	67
Corn Belt	1/	20,414	1/	64	1/	809.4	1/	55	1/	79
Lake States and Corn Belt	17,284	26,257	42	63	294.6	1,007.7	37	52	34	77
Appalachian	6,600	5,751	82	83	202.1	289.4	30	34	61	100
Southeast	7,473	6,254	92	94	214.2	265.8	28	28	57	85
Delta	2,638	2,181	56	74	47.5	83.5	19	20	36	77
Southern Plains	777	632	19	30	11.3	24.2	12	12	29	77
Northern Plains	610	2,791	4	20	8.8	72.7	26	38	29	52
Mountain	73	164	6	22	1.0	5.6	2	4	30	68
Pacific	27	179	26	86	1.0	7.7	2/	3	72	85
United States	37,936	46,874	44	60	863.5	1,888.0	26	34	45	80

1/ Separate estimates for these regions not available for 1947.
2/ Less than one-half of 1 percent.

Estimates for 1947 from Fertilizer and Lime Used on Crops and Pasture, U. S. Bur. Agr. Econ., FM 86, June 1951. Estimates for 1954 from Fertilizer Used on Crops and Pasture in the United States, U. S. Dept. Agr. Statis. Bul. 216, August 1957.

Table 2.- Application of principal plant nutrients to corn and estimated yields per acre at different rates of marginal returns, regions and United States 1/

Region	With 1954 fertilizer practice 2/			With marginal return of -									
				$3.00		$2.50		$2.00		$1.50		$1.00	
	Marginal return 3/	Yield per harvested acre: Total	Yield per harvested acre: Fertilized	Rate per acre	Yield per acre	Rate per acre	Yield per acre	Rate per acre	Yield per acre	Rate per acre	Yield per acre	Rate per acre	Yield per acre
	Dol.	Bu.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.
Northeast	3.34	44.8	46.9	115	52.0	160	59.0	208	65.1	268	71.0	341	76.3
Lake States	3.57	49.6	57.5	138	76.1	192	88.5	249	98.9	320	108.8	407	117.9
Corn Belt	3.78	50.9	60.2	166	81.9	213	92.4	265	101.8	327	110.5	409	118.7
Appalachian	2.29	30.6	34.1	---	----	---	----	134	41.4	198	50.8	272	59.0
Southeast	3.04	21.8	23.0	---	----	210	44.1	271	53.6	336	61.7	421	68.9
Delta	2.47	22.3	26.9	---	----	---	----	144	36.9	210	45.2	282	51.9
Southern Plains	1.40	18.8	26.1	---	----	---	----	---	----	---	----	149	35.2
Northern Plains	1.38	24.9	36.0	---	----	---	----	---	----	---	----	74	38.0
Mountain	2.21	29.1	44.3	---	----	---	----	81	46.8	118	52.3	165	57.5
Pacific	2.96	55.8	60.1	---	----	102	65.6	130	71.3	164	76.8	212	82.2
United States	3.06	39.3	48.4	---	----	135	60.7	186	69.6	233	77.4	303	84.9

1/ Marginal returns based on projected "long-time" U. S. average net price of $1.37 a bushel after deducting harvesting cost with appropriate regional variations; and on estimated U. S. average cost (including application) of $0.1624, $0.1119, and $0.0693 per pound of N, P_2O_5 and K_2O, respectively, also with appropriate regional variations. Fertilizer prices based on relative quantities and costs to farmers of different grades and materials used by regions. Yields at specified marginal returns are per fertilized acre.

2/ See table 1.

3/ Return per additional dollar spent for fertilizer.

acres is about 25.5 bushels. The United States average yield per harvested acre in 1953-55 was a little more than 39 bushels.

In 1954, about 26 pounds of plant nutrients were used per acre of all cropland and improved pasture in the United States. This is about half the rate of usage per acre of arable land in Europe, excluding the Union of Soviet Socialist Republics.

EFFECT OF MAXIMIZING RETURNS PER ACRE

On the average, estimates of response of the United States corn crop to fertilizer indicate that with improvement in other practices and without regard for risk and uncertainty, profit per acre would be maximized at a rate of about 300 pounds of plant nutrients per acre. This is in contrast to about 80 pounds applied per acre fertilized in 1954. However, because of risk and uncertainty or capital limitations, many farmers need to obtain higher marginal returns, that is, to apply fertilizer at lower rates, than others.

Census data show that on the average, farmers in higher income classes fertilize a higher percentage of their acreages and use higher rates per acre than those in lower income classes. Dividing income classes of farms into 3 groups, and assuming that the needed marginal returns to fertilizer for farms in the high-, medium-, and low-income groups are $2.00, $2.50, and $3.00, respectively, the 1975 projected output of corn in the Corn Belt could be obtained from 1.3 million fewer acres than were harvested in 1953-55. This assumes the same percentage of acreage fertilized as in 1954.

Table 3 shows the substitution relationships, acreage, and plant nutrient requirements for 1975 needs if applications are made to obtain the indicated marginal returns for the United States as a whole and for the Corn Belt. The substitution relationships and marginal products shown in table 3 are point estimates, not averages between levels of use.

To obtain a marginal return of $2.00, the average application for the United States as a whole would be increased by about 100 pounds of plant nutrients per acre over that used in 1954. With this average increase in rate of application distributed among and within regions as in 1954, yields per harvested acre could be expected to rise from the 1953-55 average of about 39 bushels to about 52 bushels in 1975.

The estimated aggregate fertilizer-corn crop picture for the United States as a whole is indicated in figure 1. Different combinations of acreage and fertilizer can be used in obtaining the approximately 4.3 billion bushels estimated as needed in 1975. Combinations read from the upper curve assume no change from the 1954 percentage of acreage fertilized; those read from the lower curve assume that all acres will be fertilized, and that the response will be the same as that estimated for the acreage fertilized in 1954. Neither of these assumptions is appropriate as it is probable that in the future an increasing percentage of the acreage will be fertilized, and the rate of response may be altered as the extent of application increases. A more valid basis for estimating combinations of acreage and fertilizer needed for the indicated output would probably be described by some curve lying between the two indicated in figure 1.

Table 3.- Marginal return to fertilizer, and associated substitution rates, marginal products, and acreage and plant nutrients required for projected 1975 needs, United States and Corn Belt 1/

Marginal return to fertilizer (dollars)	With 100 percent of acreage fertilized				With percentage fertilized in 1954			
	Acreage replaced per ton of fertilizer	Marginal product per ton	Requirements for 1975 projected needs: Acreage 2/	Requirements for 1975 projected needs: Plant nutrients 3/	Acreage replaced per ton of fertilizer	Marginal product per ton	Requirements for 1975 projected needs: Acreage 2/	Requirements for 1975 projected needs: Plant nutrients 3/
	Acres	Bushels	1,000 acres	1,000 tons	Acres	Bushels	1,000 acres	1,000 tons
UNITED STATES								
3.06 4/	10.60	535	88,215	3,673	8.97	322	108,781	2,718
2.50	7.21	438	70,435	4,752	5.54	263	91,658	3,710
2.00	5.03	350	61,417	5,561	3.76	210	82,224	4,467
1.50	3.41	264	55,198	6,441	2.49	158	75,406	5,279
1.00	2.06	175	50,318	7,626	1.48	105	69,859	6,352
CORN BELT								
3.78 4/	10.25	619	37,294	1,645	8.67	396	44,086	1,245
2.50	4.41	407	24,288	2,590	3.41	261	31,376	2,141
2.00	3.20	326	22,048	2,922	2.44	209	28,944	2,455
1.50	2.20	245	20,310	3,321	1.65	165	27,004	2,826
1.00	1.37	163	18,916	3,862	1.02	104	25,408	3,320

1/ Projections of 1975 needs based on Farm Output, Past Changes and Projected Needs, U. S. Dept. Agr. Inform Bul. 162, August 1956. The projected needs assume a United States population of about 210 million. Needs from Corn Belt assumed to be in same proportion to total needs as production in recent years has been to total United States production.

2/ The 1953-55 average harvested acreage was 80,169,000 for the United States and 32,286,000 for the Corn Belt.

3/ In 1954, 1,888,089 tons of plant nutrients were used on corn in the United States; 809,413 tons were used on corn in the Corn Belt.

4/ Marginal return at 1954 rate of application.

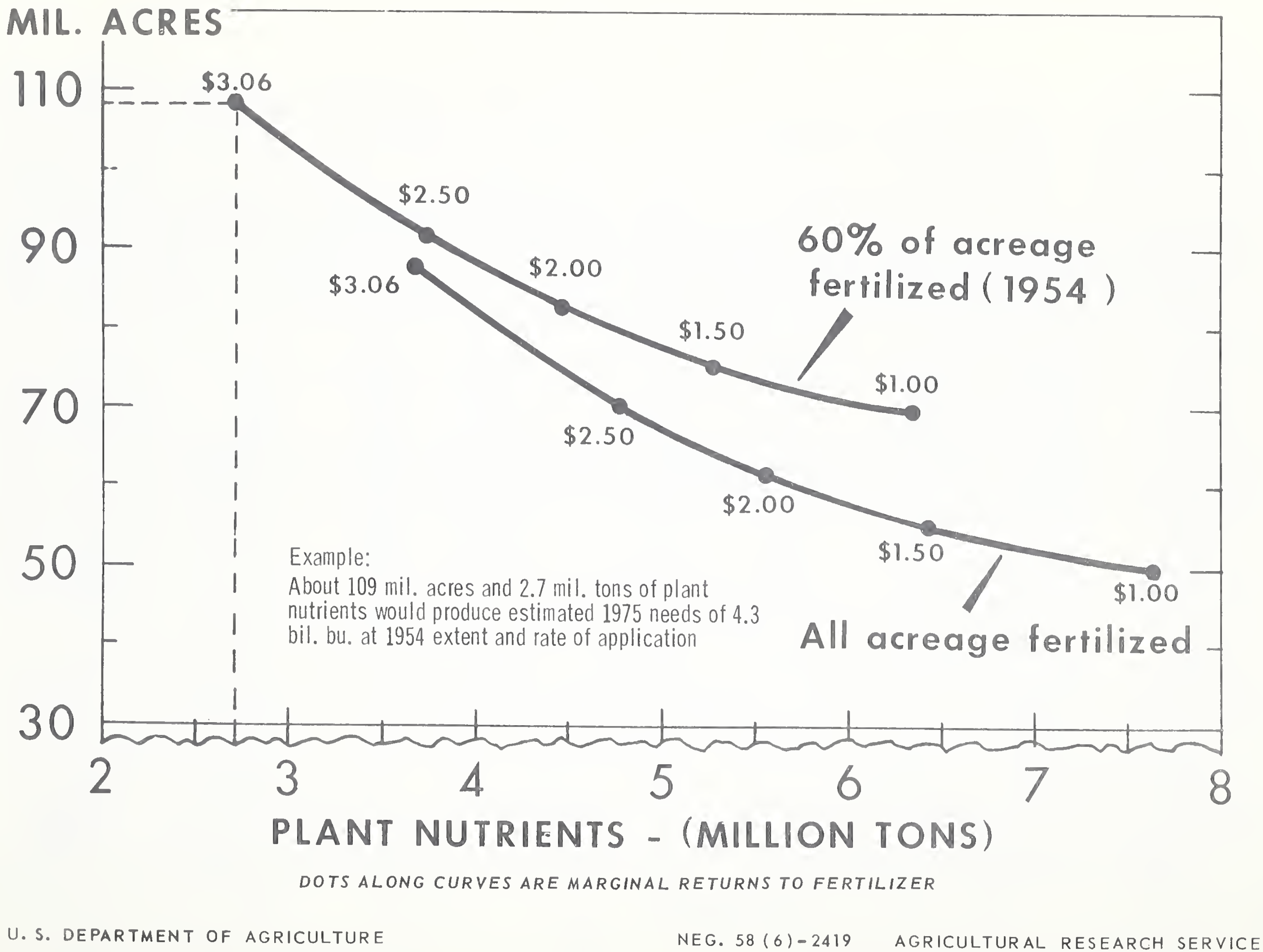

Figure 1.- Acreage-fertilizer combinations needed to produce the United States corn crop in 1975.

The substitution relationships indicated in table 3 and figure 1 are based on generalized estimates of response, and are subject to revision as new information becomes available. New information may consist of revised estimates of response based on existing information. Also, future developments in technology or in rate of adoption of improved practices would be expected to alter estimates of response and of the aggregate effects of different rates of application.

Estimates in table 3 indicate that with an average rate of application which would result in a marginal return of $2.00 distributed as in 1954, the annual corn crop needed by 1975 could be produced on about 2 million more acres than were harvested for the 3.1 billion bushel crops of 1953 to 1955. At this rate of application, a ton of plant nutrients substitutes for about 3 3/4 acres of land. But farmers fertilize other crops, and an average farmer whose funds are limited may need a marginal return of more than $2.00, particularly when risk and uncertainty are considered. Theoretically, the most profitable rate per acre is that at which the marginal return is $1.00, but this allows no margin for risk, uncertainty, or capital limitations. Farmers who are in a favorable situation might find it most profitable to obtain a marginal return approaching $1.00 from fertilizer applied on corn. They could afford to obtain similar marginal returns from use of fertilizer on other crops or from other farm expenditures. Other farmers may need to obtain a marginal return higher than the average return received at 1954 rates of use. Also, the shape of the response curve varies from farm to farm, so that while table 3 and figure 1 may express the average situation for the country as a whole, rates of substitution of fertilizer for land at specified marginal returns may differ greatly among farms.

EFFECT OF MINIMIZING COST PER UNIT

Assuming a fixed acreage of land, farmers obtain highest net return per acre when they distribute their expenditures so that marginal return from each variable outlay is the same, but this may not result in highest profit per unit of production. The concept of maximum profit per acre assumes a fixed acreage with levels of fertilizer and other variables carried to the point at which marginal revenue equals marginal cost for these inputs.

Farmers obtain minimum cost per unit of production when they vary all resources, including land, so that the marginal return from each outlay is the same, and marginal cost is equal to average cost. If all resources including land and management were variable and priced according to their marginal productivities, highest profit from a specified total expenditure would occur at the combination that results in least cost per unit of product.

Using cost data for different inputs obtained from various sources, total cost per bushel of corn in the Corn Belt has been estimated for different rates of application of fertilizer, covering the range from 1954 practice to the rate at which marginal revenue would equal marginal cost.

All costs per unit of the crop except those of fertilizer decline as higher yields are obtained. The minimum cost combination occurs at the point at which the additional cost of fertilizer just equals the reduction in other costs per unit of output. In the illustration and with the assumed factor prices, minimum cost per bushel occurs when the application is such that the marginal return is $2.50 (fig. 2). The marginal return to each input is equal at the minimum cost combination. At the lowest cost combination, therefore, the additional return from an additional dollar spent for each input is $2.50.

The effect on the minimum cost combination of changing unit costs of the different inputs is shown in figure 2. Curve A represents estimated costs of all inputs except management. Curves B, C, and D show the effect of doubling the cost of labor, power and machinery, and land respectively, with all other costs unchanged. Total costs would be increased but the combination of resources that would give the lowest total cost would be changed little if any as a result of doubling the costs of labor or power and machinery. But doubling the cost of land would shift the low cost combination toward more intensive use of fertilizer and fewer acres to obtain a given production. The effect of changes in the cost of fertilizer is not shown in figure 2 because, as fertilizer costs rise, different rates of application and different yields are associated with a specified marginal return. However, the total cost per bushel with cost of fertilizer doubled and other costs unchanged would be about $1.02 at the minimum cost combination.

Substitution of capital, such as power machinery or fertilizer, for labor, increases the advantage of large-scale operation and permits lower unit costs. Thus family-operated farms are becoming larger. Farmers who want to enlarge their operating units account for a large percentage of the land transfers.

RELATION TO AGRICULTURAL POLICY AND THE SURPLUS PROBLEM

In the long run, improvements in technology tend to become capitalized at least in part into increased land values. At present, land in the Corn Belt appears to be undervalued relative to fertilizer. With cost of land double that estimated currently, minimum cost per unit would occur at a lower rate of application than would maximize profit per acre. But if the price of a crop (with or without supports) exceeds substantially the minimum cost per unit of production in an area, the net result will be a bidding up of land values by farmers and other investors. Some farmers will use the increased income to improve levels of living. But to the extent gains in income are reflected in higher land values, reduced net returns from land would offset the short-time benefit of a supported price.

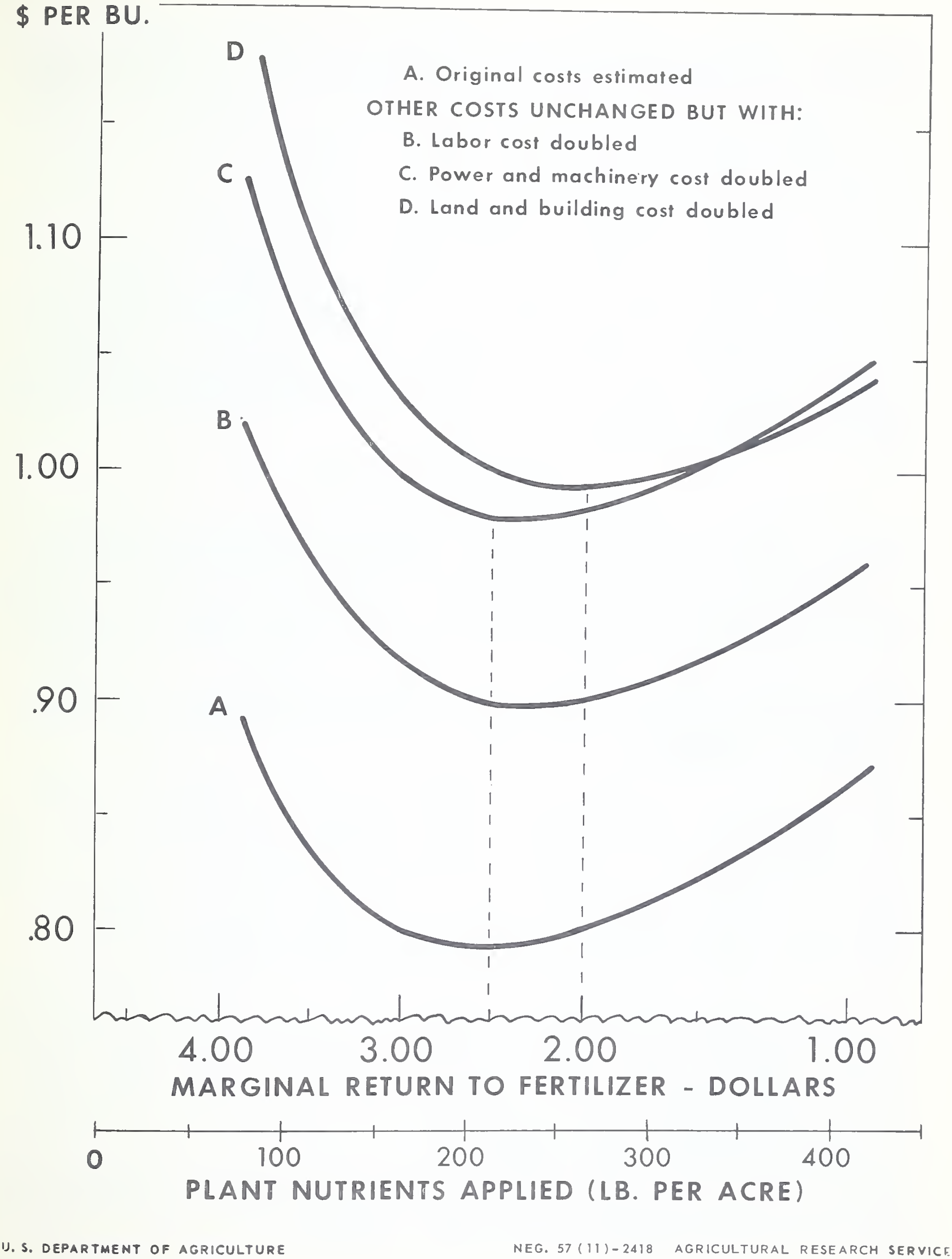

Figure 2.- Production costs per bushel of corn in the Corn Belt.

The prime managerial function is to maximize total returns from all resources. A farmer's interest lies in intensifying use of variable inputs to the point of maximum total return over total cost, with due consideration for risk and uncertainty. With advances in applied technology, this leads to an ever-expanding total output. When "surplus" situations develop, farmers who do not readily adopt the new lower unit-cost methods find themselves in an even more unfavorable economic position than before. General attempts to control output by reduction of acreage may not improve the ability of farmers to adopt improved methods. But those who are in position to do so may offset reduced acreages with higher yields per acre and may often increase their total output. Thus, by encouraging intensification on the part of those who can afford it, a program of acreage restrictions may further impair the competitive position of those farmers who cannot or do not adopt methods that give them high yields. Because the acreages of operating units are relatively fixed in the short run, acreage restrictions and price supports tend to widen the gap between highest profit and least-cost resource combinations.

QUANTITY ALLOTMENTS 2/

Although there are advantages and disadvantages in quantity-allotment programs not enumerated here, a program of this kind would appear to offer greater opportunities to reduce surpluses than an acreage-allotment program. It would operate in harmony with economic decisions of farmers, who when in possession of the facts that influence costs and returns would attempt to obtain equal marginal returns from all inputs. Unless prices and marginal productivities of factors are in equilibrium, the point on the production surface at which marginal returns are equalized is associated with lower yield than the point at which marginal revenue equals marginal cost with reference to fertilizer.

Table 4 presents a comparison of the application of a quantity allotment program to 3 farms, each of which normally produces 10,000 bushels of corn. The farms are operated at different levels of fertilizer use. A 15-percent reduction in output is required. The fertilizer practice on farm 1 is the same as the 1954 average for the Corn Belt. Many farmers are using less, but also many are using more fertilizer than farm 1. Farm 2 represents a higher rate of application--a rate associated with minimum unit cost as indicated by curve A, figure 2. Relatively few farmers are following the fertilizer practice represented by farm 2. Farm 3 illustrates the situation for farms on which corn would be fertilized at a rate that would result in maximum profit per acre. Only very few farmers would follow the fertilizer practices represented by farm 3 because of the risk and uncertainty. Of course, on some farms, the rate shown for farm 3 might result in a higher marginal return than $1.00.

2/ The illustration of the application of a quantity-allotment program for corn to hypothetical farm situations is not necessarily to be regarded as an endorsement of such a program, nor does it consider comparisons of administrative problems connected with different programs.

Table 4.- Effect of program requiring a 15-percent reduction from a 10,000-bushel corn base on farms operated at 3 different levels of fertilizer application, Corn Belt

Item	Farm 1	Farm 2	Farm 3
Plant nutrients applied per acre-----pounds-	1/ 78	2/ 213	3/ 409
Marginal return to fertilizer-------dollars-	3.78	2.50	1.00
Yield per acre---------------------bushels-	60.17	92.39	118.69
Acreage needed to produce 10,000 bushels----------------------------acres-	166.20	108.24	84.25
Acreage diverted----------------------do---	24.93	16.24	12.63
Acreage needed to produce 8,500 bushels------------------------------do---	141.27	92.00	71.62
Net return per bushel 4/-----------dollars-	0.53	0.61	0.54
Net value of 8,500 bushels------------do---	4,505	5,185	4,590

1/ 1954 average rate per fertilized acre.
2/ Rate for least cost per bushel.
3/ Rate for maximum profit per acre--marginal return equal to marginal cost.
4/ Price of $1.40 a bushel less production cost at the different rates of application.

Irrespective of a program, operators of farms 1 and 3 could achieve minimum cost production by using more or less fertilizer, respectively. The most profitable combination for corn would include the rate indicated for farm 2 and whatever acreage would be required at that rate to result in the desired production. Thus in the absence of any control program, if the operator of farm 1 wanted to produce 10,000 bushels he could profitably shift up to 57.96 acres from corn (166.20 - 108.24). Once the decision to produce 10,000 bushels is made, the complete shift to the combination of farm 2 would result in the greatest gain even though the diverted acreage were left idle. Departure from this combination would be justified only if there were other alternatives on the farm that would be more profitable than production of the 10,000 bushels of corn.

Farmers who apply fertilizer up to or near the intensive margin illustrated by farm 3 usually do so because of lack of available land. If more land is not available, the best alternative for producing 10,000 bushels on farm 3 is to continue the indicated rate of application and grow 84.25 acres. But if enough land were available, the most profitable alternative would be to add 23.99 acres (108.24 - 84.25). As with farm 1, the real question would be one of how to distribute available resources among different farm enterprises. If enough additional land were available, the most economical way to obtain any desired production of corn would be to apply the rate of fertilizer associated with lowest production cost to whatever acreage is required.

If a quantity-allotment program were in effect, farm 1 could adjust resources to the combination represented by farm 2. To the extent to which additional land is available, farm 3 could to the same. The net value of any quantity of the crop could be increased by allowing this freedom of adjustment. This means that farmers could reduce production at less sacrifice in income under a quantity-allotment program than under a program of acreage control. A quantity-allotment program would encourage farmers to adjust toward the minimum cost combination.

But if an acreage-allotment program were in effect, operators of farms 1 and 2 could reduce acreage and increase the rate of application of fertilizer to maintain output, or, as indicated in table 4, they could reduce both acreage and output. In the former instance, the acreage-allotment program would not achieve production control. The operator of farm 3 could not reduce his acreage of corn without a corresponding reduction in output, as he is already operating at the intensive margin with reference to fertilizer. For farm 3, compliance with either program would mean some reduction in output. But very few farmers are in this position.

In general, farmers are adopting improved technology and are substituting capital for labor and for land when it is profitable to do so. As most farmers are operating at the level of intensity of farm 1, few at the level of farm 2, and still fewer at the level of farm 3, there is in general a profitable opportunity to further increase yields per acre. Table 5 presents the effect of an acreage-allotment program on farms 1 and 2 when they: (1) Maintain production through increasing yields while reducing acreages; or (2) reduce both acreage and production.

The net value per bushel for any level of output of farm 2 is reduced by departure from the combination involving the use of 213 pounds of plant nutrients per acre. But the operator of farm 2 could afford this reduction in net return per bushel because the total net return from a 10,000-bushel crop would be $715 more than from an 8,500-bushel crop. Thus, even for farmers whose rate of application of fertilizer is such that they are obtaining production at minimum cost per bushel, an acreage-allotment program makes it profitable to comply acreage-wise but at the same time to maintain output.

Under an acreage-allotment program, the operator of farm 1 could not only increase his total net return--he could increase net return per bushel by applying more fertilizer to maintain output under an acreage-allotment program.

Table 5.- Alternative rates of application, yields, production, and returns under an allotment program requiring a 15-percent reduction in acreage

Item	Farm 1 1/		Farm 2 2/	
	Production of 10,000 bushels	Production of 8,500 bushels	Production of 10,000 bushels	Production of 8,500 bushels
Plant nutrients applied per acre----------------pounds-	118	78	310	213
Marginal return to fertilizer----------------dollars-	3.50	3.78	1.62	2.50
Yield per acre-----------bushels-	70.79	60.17	108.20	92.39
Net return per bushel 3/-dollars-	0.54	0.53	0.59	0.61
Net value of production----do----	5,400	4,505	5,900	5,185
Sacrifice in income--------do----	---	895	---	715

1/ Acreage diversion of 24.93 acres as in table 4.
2/ Acreage diversion of 16.24 acres as in table 4.
3/ Price of $1.40 a bushel less production cost at the different rates of application.

Returns in table 5 relating to the 8,500-bushel level of production are the same as those in table 4 so that the effect of the two types of programs would be the same for farmers who reduced production in the same proportion as they reduced acreage. The sacrifice in income is less for farmers who are operating at the minimum cost combination.

CONCLUSION

Use of fertilizer on corn in the United States has expanded markedly in recent years but considerably higher rates of application would be profitable on most farms in the principal corn-producing areas. In the Corn Belt, at projected crop price-fertilizer cost relationships used in this analysis, rates per acre could be increased nearly threefold before passing the point of minimum total cost of production per bushel. The corn crop estimated as needed by 1975 could be produced on fewer acres than were harvested during the World War II years of 1943 and 1944, if fertilizer were applied on the same acreage that was fertilized in 1954 at rates that would result in a marginal return of $2.50. For the Corn Belt, this rate would be associated with minimum cost of production per bushel. In terms of plant nutrients, fertilizer used on corn would need to be about double that applied in 1954.

Information on crop yield response by areas within which response is generally similar, is useful in estimating aggregate effects of levels of use of fertilizer associated with different economic returns. These estimates are useful as guides to research programming and general agricultural adjustment programs.

Estimates of average production cost for most of the "surplus" crops in reasonably homogeneous producing areas may be developed from costs and returns data applicable to different type-size farms. These estimates of cost of production of the different inputs, together with information on response to fertilizer applicable to these areas, can be used to estimate the minimum cost combination for production of a crop for the area as a whole. Information on input combinations for minimum cost per unit of production would encourage profitable changes in farming.

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