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Chapter 13

Fertilization in Relation to Conservation Farming and Allocation of Resources Within the Farm

FERTILIZER has long been a resource of particular interest to agronomists and economists. Some of the better known historical literature has revolved around this resource, as a single category of input. Examples of classical studies include agronomic phases such as Liebig's law of the soil or law of the minimum and work by other early soil chemists such as Woolny and Mayer. Also included are economic phases, such as Ricardo's evaluation of rent; von Thunen's discussion of intensity; and Spillman's further development of the principle of diminishing returns. Most classical studies have tended to treat fertilizer and fertilizer use as a resource and practice apart from other resources and practices. While less prevalent than 100 years ago, this tendency still exists.

There are unique reasons why fertilization can be, and tends to be, treated as an isolated practice. From the standpoint of classical economics, fertilization fits remarkably well into conceptual frameworks including variable proportions, marginal analysis, fixity of particular resources, and others. This particular resource and its use serve well for classroom examples of several basic theorems: It is realistic to consider this resource as one which is variable and can be allocated in varying patterns relative to fixed resources. From the agronomic standpoint, fertilization allows expression of systematic biological laws, perhaps better than any other agricultural practice. Then, too, this important economic resource can be used conveniently without entanglement in the total organization of the farm and without requiring a large investment in complementary resources.

However, to view fertilizer as an isolated resource, with main relation only to soil management practices other than fertilization itself, causes the broader role and economic significance of fertilizer to be overlooked. Also, it causes some of the broader methodological problems to be overlooked. Over much of the nation, fertilizer (at least nitrogen) from chemical sources is a substitute for nutrients furnished by crops. Hence, the optimum combination of crops and the optimum fertilization plan must be determined jointly. The problem is hardly scratched in analyses such as have been made when designs, response surfaces, and optimum ratios and rates have been determined for a single crop. The big problem is still ahead, namely, the exploration of fertilizer use when crops and other enterprises are variable. A few examples can be used to illustrate some of the broader uses of fertilizer input-output data. Research needs will then be explained.

Fertilizer in the Total Farm Picture

Fertilizer is a resource which can give returns in a relatively short period of time. Because of this fact, it can be used advantageously as an *income complement* in those major farm adjustment ploblems, most of which involve a considerable time span for investment and before important increments are made to income. Most major farm adjustment problems involve several years of planning before they can be put fully into operation and the income flow can be increased. Some examples include:

1. Adjustment from cash crops to livestock farming in the Southeast. Not only is a large increase in funds needed for this type of change, but also, establishment of pastures, erection of buildings, and creation of livestock herds require from 5 to 10 years before operations can get into high gear.
2. Adjustment from exploitative to conservation farming systems in the Midwest.
   Plans commonly recommended by the Soil Conservation Service involve shifts from continuous row cropping, or rotations with only a small amount of meadow, to rotations including a considerable percentage of meadow. To get rotations into effect and obtain their yield benefits, cycles of rotations as long as 5 to 10 years are required. A similar time period is required in gearing livestock, buildings, and other investments to the new cropping system.
3. Adjustments from dry-land to irrigation farming.
   Leveling land, laying out ditches or sprinkler systems, putting new rotations into effect, and acquiring organizational and managerial skills ordinarily require 5 or more years before most dry-land farmers complete the shift to fairly efficient operations.

Other examples could be cited. However, most of these are the same, viz., several years is required before effective adjustment can be made in organization of the farm; capital investment must be built up over a considerable period and maintained at a higher level than previously; most major adjustments require some sacrifice in current income as the shift is made. Sacrifices in income are made as land is planted to forages or nurse crops, rather than to immediate cash return crops. Income is not replenished immediately by the livestock or soil development investments which require several years for their outturn of market product. In cases of some farm adjustment, income under the recommended system may never return as much as the current system. In other cases, however, income will be increased in the distant future, but with the sacrifice of income in the few years ahead.

Time Effects

Time requirements of farm adjustments cause shifts, such as those outlined above, to be discounted in the farmer's decision-making process because of (a) a shortage of capital, (b) the opportunity costs of using funds, and (c) the uncertainty relating to outcomes in the more distant future. A resource such as fertilizer, with a relatively short period for transforming investment into profit, can help overcome some of these effects and facilitate adjustments.

However, before empirical examples of this process are given, the effects of time on the "current outlook" for profits spread over time are examined. Suppose that a budget to determine the "average expected income" of the farmer's *present system* is constructed. Income per year is predicted to be $3,000. Income under a *recommended farming system,* after it is put fully into effect, is predicted to be $4,000, with an added investment of $10,000. The *revised plan* appears most desirable, profitwise. However, no consideration has been given to the time required to get the plan into effect. Income may be lower than $3,000 at the outset and income of the distant future comes at the expense of income in the near future. Consequently, the stream of income under the old plan may be preferable to the stream of income for the revised plan.

This point can be illustrated by principles explaining the present (discounted) values of alternative income streams. Suppose that the farmer has limited capital, but that he can obtain funds for the increased investment required by the new plan. His task is to determine whether the "old" or "new" plan gives the greatest present (discounted) value of future incomes. (Future incomes relate to the length of period which is relevant for the farmer's decisions, i.e., until income of a particular year is discounted to zero). The present value (PV) of income under each plan, supposing that only time with no uncertainty is involved, can be defined by equation 1 where R

$$PV = \sum_{i=1}^{i=n} \frac{R_i - C_i}{(1 + r)^i} \qquad (1)$$

refers to the annual revenue of the i-th year, C refers to annual costs of the i-th year and r refers to the interest or discount rate. A dollar of income in the near future has much greater value than a dollar in the distant future, because the "discount coefficient" grows with time.

For example, a dollar forthcoming at the end of the next year has a present value of $\frac{\$1}{(1.10)^2} = \frac{1}{1.21}$, or 86 cents under a 10-percent discount rate. In other words, 86 cents invested at 10 percent will amount to $1 in two years. The 10 percent is the return which can be realized (or is sacrificed) from investments other than the one under consideration. A $2 amount forthcoming in 20 years, at the same discount rate, is worth only $\frac{\$1}{(1.10)^{20}}$ or 15 cents today. In other words, a dollar forthcoming in two years has a much greater present value than $2 forthcoming in 20 years.

Under the same discount levels, a farming system which returns $4,000 per year for the first 10 years and $1,000 per year for the next 10 years will average $2,500 over the 20 years. However, it has a higher present or discounted value than an alternative plan which returns $1,000 per year for the first 10 years and $7,000 per year for the second 10 years, an average of $4,000 over the 20 years. Thus, farming plans which include "quick turnover" investments, such as fertilizer and cash crops, have a strong economic advantage over long-time investments with delayed incomes. However, if capital is available, use of resources such as fertilizer can be added to "long-lived" plans to boost incomes in the near future, hence increasing the relative advantage of "long-time" plans which eventually increase returns.

All alternative resources and practices, even though some of these appear remote to the main adjustment in question, need to be considered in recommendations. Fertilizer can be important in this respect. Its increased use can serve as an "income catalyst" in adjusting to conservation farming in the Midwest, irrigation in arid regions, and other farming shifts. An empirical example in conservation farming is selected to illustrate this point.

Role of Fertilizer in a Conservation Plan Involving Time

An extreme problem in conservation is to be found on the Ida-Monona soils of western Iowa. The steep topography and the structure of these soils give rise to serious gully erosion. However, the shift toward soil-conserving farming systems has been small, even though education on needs has been fairly intensive and considerable public funds have been used on dams, conservation subsidies, and for Soil Conservation Service personnel in each county. As one travels through the area, he sometimes wonders if farmers have ever heard the word *conservation*. Of course, they all have, and they know the adjustments which are recommended to stop the extreme gullying found on most farms. But mainly they do not shift because, under their capital limitations and discounting, current farming systems have income advantages. Time-sequence budgets have been constructed on some of these farms to examine income prospects under current farming systems and those being recommended under educational and action programs. The purpose of these comparisons is to determine the length of time required for conservation systems to become profitable (and, as well, to determine if they are profitable), and the effect of different discount rates on the relative profitability of different plans.

There is, of course, no unique discounting rate for all farmers. While agricultural economists quite often use the market rate of interest for discounting calculations (i.e., land valuation, etc.), this magnitude applies only to a farmer with unlimited funds. It does not apply, as an opportunity cost, to the farmer who is limited on funds to invest in his own business because of either (a) capital rationing by lending firms, or (b) a risk aversion on the part of the farmer himself. The appropriate discount rate (i.e., opportunity cost rate) for this farmer is the return which can be earned within the year on some other enterprise.

An auxiliary objective of calculations was to determine planning procedures which would facilitate conservation farming systems by serving as "income complements" over time. Fertilizer was selected as one of the most promising opportunities in this respect.

Nondiscounted Incomes Under Two Alternatives

Budgeted incomes over a 15-year time period for one farm in the Ida-Monona soil association are presented in figure 13.1. The solid line shows predicted income, if the farmer continued to follow his current soil-exploitative farming system. Prices are assumed to be constant through the period and computations are based on average weather for each year. This farm is 160 acres and has soils typical of the area. It has several large gullies, also typical of the area. Budgets were made under assumptions of declining soil productivity, but these are not shown because of time and space limitations. General conclusions are not different, however, from those apparent in data of figure 13.1.

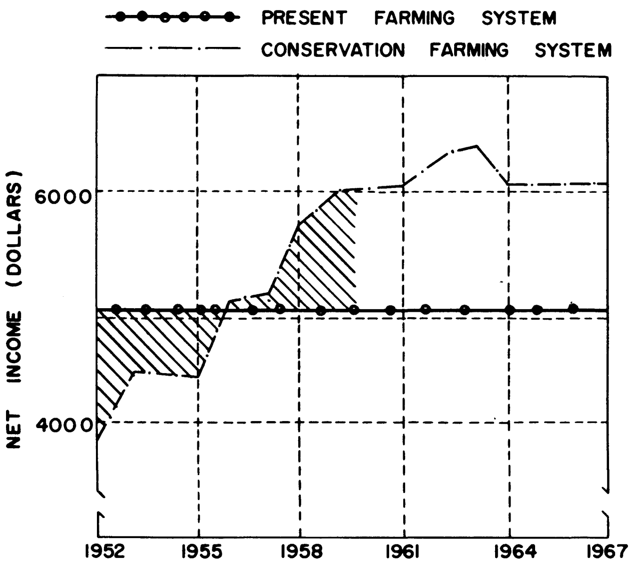

Fig. 13.1 — Net income predicted for typical 160-acre farm on Ida-Monona soils of western Iowa. (Actual income without discounting.)

The broken line shows the path of income predicted if the farmer were to follow the cropping plan suggested by the Soil Conservation Service, and if the farmer were to adapt livestock to it. The plan supposes that all farm-grown feed would be used under the revised plan. (Some was sold for cash under the existing plan). The revised plan averages about 40 acres of corn, 25 acres of oats, and 50 acres of hay. The existing plan included 66 acres of corn, 34 acres of oats, and 12 acres of hay. With terraces and contouring, per acre soil loss would be reduced to 6.63 tons; it was predicted to be 73.38 tons under the old system. The main livestock system for the new plan includes yearling steers wintered, grazed on pasture, and "fed out" in dry lot. Hogs are used as a supplementary enterprise to use the remaining corn. (Budgets were also made for nine other livestock systems, but are not presented because conclusions are similar).

As the two lines of figure 13.1 indicate, a shift to the conservation plan entails a decline in income for the four years: 1952, 1953, 1954, and 1955. Then, income of the revised plan moves above income of the existing plan in the fifth year. The "eventually greater income" under the conservation plan comes mainly from two sources: (a) gains in yield from a complete rotation cycle, (b) a larger livestock program with lesser amounts of the crops sold for cash. (The latter represents the largest portion of the income increase). Under the revised plan, fertilizer is not used in a "commercial" manner, but only in quantity and kind needed to get forages under way in the rotation.

While *income under the conservation plan* moves above *income under the existing farming system* in the fifth year (1956), it requires until the ninth year (1960) for the yearly sums of incomes under the former to exceed the yearly sums under the latter. That is to say, the surplus of four more years is required to make up the deficit of the first five years under the conservation plan. (In figure 13.1 the shaded area between the lines before they cross is greater than the shaded area after they cross, up to 1960). Hence, a total of nine years is required before the farmer can "break even" on his conservation plan. If the farmer is paying off a mortgage and has a low equity, is pinched for living funds, or has educational and other emergencies to meet, nine years is a long time.

If he discounts incomes, the picture is even less encouraging, as is illustrated in figure 13.2. The lines in figure 13.2 represent the same incomes as in figure 13.1, except that they have been discounted at the rates indicated. Different discount rates have been used to represent the outcome for farmers with different degrees of capital limitations. At a 5-percent discount rate, the sum of the surpluses of the revised plan, over the existing plan, is greater than the sum of the deficits for the 15 years represented. At 30 percent, however, the opposite is true, even up to 20 years. At discount rates of 20 and 30 percent, those common for many farmers, emphasis must be placed on resources which give a quick return. Fertilizer, hogs, and similar alternatives with production periods of a year are examples.

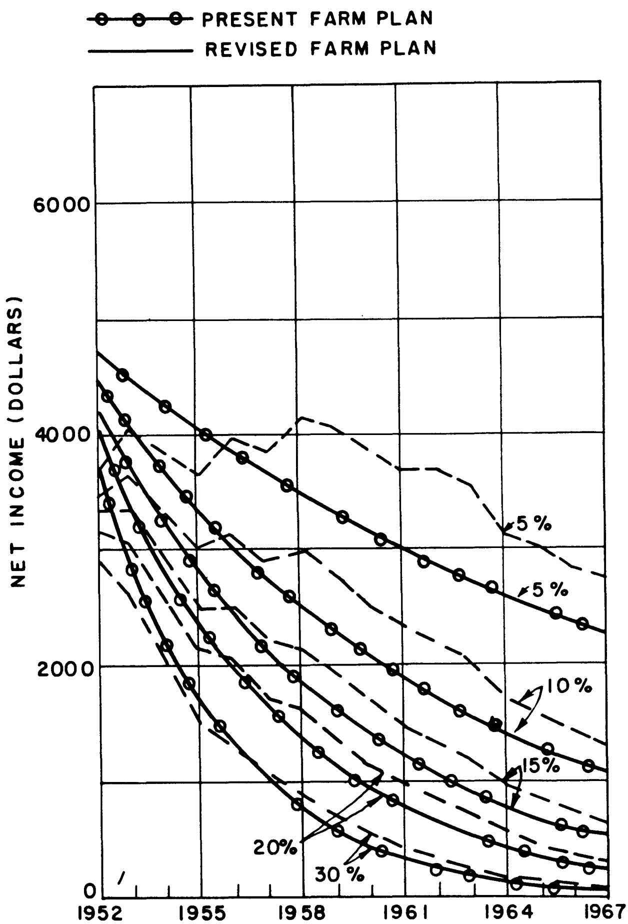

Fig. 13.2 — Net income on typical farm using variable discount rates.

Fertilizer to Close the Income Gap

The "income gap" in the first few years after adopting a conservation plan, prevents many farmers from shifting to an erosion control farming system. Hence, alternatives for removing this gap are examined. Two possibilities seemed important: (a) lengthening the expanse of time over which various practices are put into effect, and (b) using nitrogen fertilizer, or other farm practices, to give an immediate boost in production and income, where the practices themselves are profitable. Generally, these are practices which would be profitable even if the whole farm organization were not changed to a soil conservation system. The added income from them should not be viewed as resulting from the conservation plan. Along with conservation adjustments, these practices are simply part of the over-all farm management system. By offsetting income reductions due to shifts from grain to forage, these added practices may facilitate the adoption of conservation farming systems by a greater number of farmers.

Additional fertilizer was considered to be applied to corn acreage on the Ida and Monona soils of the farm so as to increase the annual yield to as much as 70 bushels per acre. No additional fertilizer was considered for Napier soil (although it could, perhaps, profitably use some). The yield increase in oats and hay (which would undoubtedly occur) was omitted in making calculations. Its value would more than counteract the cost of harvesting the additional corn yield. In spite of this conservative estimate of increases, net income can be increased considerably. Of equal or more importance to the farmer with a low income, is the fact that the increased income generally occurs in the year in which the fertilizer is applied.

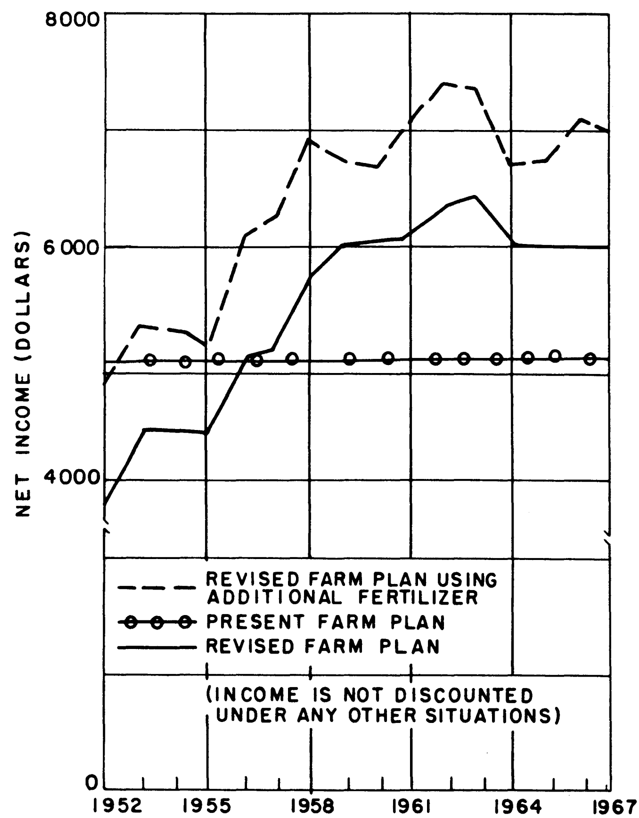

Fig. 13.3 — Use of additional fertilizer to reduce the income gap on farm shown in Figs. 13.1 and 13.2.

TABLE 13.1. Description of Processes or Activities

Activity or Process Number	Enterprise	Description: Types of Rotation Supplying Hay Requirement[a]	Description: Types of Pasture Used
P1	Renting out unimproved pasture		
P2	Beef cow-calf	CCOM	Unimproved Kentucky bluegrass
P3	Beef cow-calf	CCOM	Improved Kentucky bluegrass
P4	Beef cow-calf	CCOM	Phosphate-lespedeza impr.
P5	Beef cow-calf	CCOM	Renovated pasture
P6	Beef cow-calf	CCOMM	Unimproved Kentucky bluegrass
P7	Beef cow-calf	CCOMM	Improved Kentucky bluegrass
P8	Beef cow-calf	CCOMM	Phosphate-lespedeza impr.
P9	Beef cow-calf	CCOMM	Renovated pasture
P10	Beef cow-calf	CCOM+F	Unimproved Kentucky bluegrass
P11	Beef cow-calf	CCOM+F	Improved Kentucky bluegrass
P12	Beef cow-calf	CCOM+F	Phosphate-lespedeza
P13	Beef cow-calf	CCOM+F	Renovated pasture
P14	Beef cow-calf	CCOMM+F	Unimproved Kentucky bluegrass
P15	Beef cow-calf	CCOMM+F	Improved Kentucky bluegrass
P16	Beef cow-calf	CCOMM+F	Phosphate-lespedeza
P17	Beef cow-calf	CCOMM+F	Renovated pasture
P18	Yearlings fed in drylot	CCOM	None
P19	Yearlings fed in drylot	CCOMM	None
P20	Yearlings fed in drylot	CCOM+F	None
P21	Yearlings fed in drylot	CCOMM+F	None
P22	Yearlings full fed on pasture	CCOM	Unimproved Kentucky bluegrass
P23	Yearlings full fed on pasture	CCOM	Improved Kentucky bluegrass
P24	Yearlings full fed on pasture	CCOM	Phosphate-lespedeza
P25	Yearlings full fed on pasture	CCOM	Renovated pasture
P26	Yearlings full fed on pasture	CCOMM	Unimproved Kentucky bluegrass
P27	Yearlings full fed on pasture	CCOMM	Improved Kentucky bluegrass
P28	Yearlings full fed on pasture	CCOMM	Phosphate-lespedeza
P29	Yearlings full fed on pasture	CCOMM	Renovated pasture
P30	Yearlings full fed on pasture	CCOM+F	Unimproved Kentucky bluegrass
P31	Yearlings full fed on pasture	CCOM+F	Improved Kentucky bluegrass
P32	Yearlings full fed on pasture	CCOM+F	Phosphate-lespedeza
P33	Yearlings full fed on pasture	CCOM	Renovated pasture
P34	Yearlings full fed on pasture	CCOMM+F	Unimproved Kentucky bluegrass
P35	Yearlings full fed on pasture	CCOMM+F	Improved Kentucky bluegrass
P36	Yearlings full fed on pasture	CCOMM+F	Phosphate-lespedeza
P37	Yearlings full fed on pasture	CCOMM+F	Renovated pasture
P38	Deferred feeding of yearlings	CCOM	Unimproved Kentucky bluegrass
P39	Deferred feeding of yearlings	CCOM	Improved Kentucky bluegrass
P40	Deferred feeding of yearlings	CCOM	Phosphate-lespedeza
P41	Deferred feeding of yearlings	CCOM	Renovated pasture
P42	Deferred feeding of yearlings	CCOMM	Unimproved Kentucky bluegrass
P43	Deferred feeding of yearlings	CCOMM	Improved Kentucky bluegrass
P44	Deferred feeding of yearlings	CCOMM	Phosphate-lespedeza
P45	Deferred feeding of yearlings	CCOMM	Renovated pasture
P46	Deferred feeding of yearlings	CCOM+F	Unimproved Kentucky bluegrass
P47	Deferred feeding of yearlings	CCOM+F	Improved Kentucky bluegrass
P48	Deferred feeding of yearlings	CCOM+F	Phosphate-lespedeza
P49	Deferred feeding of yearlings	CCOM+F	Renovated pasture
P50	Deferred feeding of yearlings	CCOMM+F	Unimproved Kentucky bluegrass
P51	Deferred feeding of yearlings	CCOMM+F	Improved Kentucky bluegrass
P52	Deferred feeding of yearlings	CCOMM+F	Phosphate-lespedeza
P53	Deferred feeding of yearlings	CCOMM+F	Renovated pasture
P54	Spring farrowed hogs	CCOM	None
P55	Spring farrowed hogs	CCOMM	None
P56	Spring farrowed hogs	CCOM+F	None

TABLE 13.1 (Continued)

Activity or Process Number	Enterprise	Description	
		Types of Rotation Supplying Hay Requirement[a]	Types of Pasture Used
P57	Spring farrowed hogs	CCOMM	None
P58	Fall farrowed hogs	None	None
P59	Laying flock	None	None
P60	CCOM, entire production sold on market	None	None
P61	CCOMM, entire production sold on market	None	None
P62	CCOM+F, entire production sold on market	None	None
P63	CCOMM+F, entire production sold on market	None	None

[a]A +F sign on the rotation indicates fertilization has been included as a practice. If this sign does not follow a rotation notation, fertilization is not included on the field crops.

As figure 13.3 illustrates, fertilizer used in conjunction with a conservation plan eliminates, from the very outset, the drop in income which would otherwise accompany the adjustment. The amount of fertilizer, now included as a resource in corn production rather than alone for establishing forages in the rotation, is not yet at the most profitable level (i.e., where MC=MR for fertilizer investment). However, enough is used to cause a plan which might not otherwise appear economically desirable to be adopted. Of course, other short-lived investments, such as more hogs, could serve similarly. However, the data suggest that "adjustment practices" of the farm business should not be treated in isolation, but should be treated in the fashion of over-all farm organization and resource allocation. Fertilizer has an important role in this over-all planning of farms in about all but the arid regions of farming. Even with discounting as high as 20 and 30 percent, our figures show that by using fertilizer as an income complement, conservation can be made *currently profitable* with the addition of fertilizer on corn.

Other Aspects of Over-All Farm Planning

Fertilizer also fits into the total farm program in other ways. It is one of many alternatives in which the farmer can invest. If profits are maximized, each dollar of capital and unit of other resource should be used where it gives the greatest marginal return. In other words, profitable fertilizer use cannot be established apart from the rest of the farm. In many cases, the return on fertilizer can outcompete many other investments in adding profit to the farm; at some level of fertilization, other investment opportunities may have profit priority over fertilizer. The farmer must decide whether scarce funds will add the most to profits if used for breeding stock, livestock feed, more buildings, new crop varieties, or fertilizer.

Linear programming provides a convenient method of testing the best investment plan for the farm, and in deciding what proportion of scarce funds should be invested in fertilizer. For example, a linear programming study for beginning farmers on Clarion-Webster soils in Iowa shows this: With very limited funds, a beginner would be better off to farm 80 acres and grow a corn-corn-soybean rotation fertilized at an intermediate level, rather than to farm 160 acres without fertilization. He would invest nothing in livestock if he maximized profits. With an intermediate amount of capital, he would farm 160 acres, grow a corn-soybean-corn-oats-meadow rotation fertilized to an intermediate level; he would raise 40 litters of pigs. With a larger amount of capital, he would use a corn-corn-oats-meadow rotation fertilized to a somewhat lower level per acre; he would raise 30 litters of pigs and feed out a carload of cattle.

Another study can be cited to illustrate a role of fertilizer in the program of the farm as a whole. This linear programming solution was worked out for a 160-acre farm in Clark County, Iowa, with associations of Grundy-Shelby-Haig and Seymour-Edena as the main soils. Limitational resources include labor of the operator and family, capital at various levels, building space for poultry and cattle, and cropland and pasture land. Considering two rotations of corn-corn-oats-meadow

TABLE 13.2. Optimum Plans Under the Various Capital Situations[a]

Investment Capital Situations	Optimum Program
$1,000	110 acres CCOM+F rotation; 38 acres unimproved pasture rented out; 148 hen laying flock; 10 litters of spring hogs. ($3286 net return)
$2,000	110 acres CCOM+F rotation; 38 acres unimproved pasture land rented out; 148 laying flock; 15 litters of spring hogs; 5 litters of fall hogs. ($4481 net return)
$4,000	110 acres CCOM+F rotation; 9 acres unimproved pasture rented out; 148 hen laying flock; 15 litters of spring hogs; 10 litters of fall hogs; 10 yearling steers on a deferred feeding program with unimproved pasture. ($5526 net return)
$8,000	110 acres CCOM+F rotation; 148 hen laying flock; 15 litters of spring hogs; 10 litters of fall hogs; 31 steers full fed on pasture; part of pasture improved, and part left unimproved; 6 steers on a deferred feeding program. ($6718 net return)
$10,843	110 acres CCOM+F rotation; 148 hen laying flock; 15 litters spring hogs; 10 litters fall hogs; 20 steers deferred feeding program;[b] 19 steers full fed on pasture.[b] ($4917 net return)

[a]All values have been rounded to nearest whole number.

[b]These enterprises utilized completely renovated pasture. Beef enterprise in preceding plans were on unimproved Kentucky bluegrass pasture.

and corn-corn-oats-meadow-meadow (both with and without a *discrete* amount of fertilizer), fall pigs, spring pigs, chickens, and four beef cattle systems, there are 63 possible activities when pasture can be (a) rented out as unimproved bluegrass, (b) used as unimproved bluegrass, (c) used as improved bluegrass, (d) improved with lespedeza and phosphate fertilizer, and (e) completely renovated with a pasture mixture and fertilization; and crops can be sold for cash. These 63 activities (processes or investment opportunities) are shown in table 13.1.

The linear programming solutions are shown in table 13.2 for different capital situations. These quantities refer to funds available beyond that required for land and building machinery, and regular cropping expenses for the rotation land. With funds very limited (i.e., $1,000 in capital beyond the amounts mentioned above), profits are greatest if the farmer uses a CCOM rotation with fertilization, and rents his pasture out. He would keep 148 hens, and raise 10 litters of pigs, but the greatest proportion of the farm's crop production would be sold for cash. Fertilization of rotation crops would, in fact, be more profitable than investment in any livestock practices. As capital availability increases, it becomes profitable to invest in more livestock and, finally, to use pasture improvement, or renovation. However, pasture renovation does not come in partially until capital is at $8,000. Pasture is completely renovated with $10,843 in capital.

Since pasture renovation also requires fertilization, an important point has been illustrated: Fertilizer use is a practice giving both a higher (i.e., on field crops) and a lower (i.e., on pasture) return than alternative investments at low capital levels. Hence, its optimum use cannot be determined without planning or programming of the farm as a whole. These programming analyses need to go even further than illustrated here, and allow consideration of different rates of fertilization on different crops.

Research Needs

The "farm solutions" mentioned above suggest some of the kinds of research information for farm-and home-planning programs, or other recommendations fitted into the farm as a whole. To be certain, they present difficult research problems, but they are much needed for the types of educational programs being intensified today.

One major problem is to determine the time effects or response for fertilizers, including:

1. The response sequences for fields or farms where a fertility build-up is taking place. If rates of 40, 80, and 120 pounds of nitrogen are applied in the first year, what will be the marginal products in the second year if these same three rates are superimposed on each of the same three rates of a previous year? What happens if this process is continued over several years? How much time is required and what are the effects of different rates in moving from a low fertility level to a level of economic maintenance?

2. The residual response functions for fertilizer applied at different rates. How much response can be expected in the second, third, and later years? What rates of discount should be used in figuring optimum fertilizer programs where incomes extend into the future?

3. What variations in response and incomes can be expected from weather variations as a farmer shifts between major organizations and uses fertilizer as an income complement?

To analyze the role of fertilization in the total farm program, research data are needed which predict the effects of different nutrient rates and ratios for different rotations. If the farmer can select among five different rotations such as CSC, CCOM, CSCOM, COM, or CCOMM, several rates and ratios of nutrients are needed on each crop in the rotational sequence (and on the first and second year of particular crops) before it can be determined which rotation and fertilization program is best. Of course, the optimum plan for the farm as a whole cannot be determined until the response functions for fertilizer are known, when this resource is varied in relation to other management practices or inputs such as livestock and, hence, manure, crop varieties, seeding rates, etc. The problem is only begun after having decided on the best empirical designs for determining the response function for a single crop, entirely apart from other inputs, other crops, and other management practices.

PART V

Trends in Use and Manufacture of Fertilizer

- **Quantity and Costs**
- **Sources of Nutrients**
- **Processes for Fertilizer**
- **Future Trends and Problems**