The economics of crop rotations and land use: A fundamental study in efficiency with emphasis on economic balance of forage and grain crops

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The Economics of Crop Rotations and Land Use

A Fundamental Study in Efficiency with Emphasis on Economic Balance of Forage and Grain Crops

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SUMMARY

1. For largest profits a farmer must use each unit of resource where it will bring him the greatest return. He must decide whether to invest scarce capital in legume seed, fertilizer, brood sows, machinery, or some other alternative. He must decide whether a day of labor or an acre of land will bring greatest returns if used to grow alfalfa, clover, corn, soybeans, wheat or some other crop. He must make similar choices between crop and livestock enterprises. He must choose between different kinds of livestock. Rotations and cropping systems also must be considered in this light. The problems of the most desirable rotation or of the most profitable ration to be fed a given class of livestock are not distinct and separate problems. They are problems that must be considered together in order to get maximum farm profits. The analysis of this study relates mainly, however, to rotation economics alone.

2. Competitive and complementary enterprise relationships best explain the economic role of forage crops in the organization of a farm. These two general relationships help explain which farms should grow grasses or legumes, and they help determine how many acres of forage should be grown on any one farm. Enterprises are complementary with each other when the production of one increases the quantity of the other from given resources. The complementary nature of grasses and legumes is perhaps the most important reason why they are included in the farm organization.

Forage crops are complementary with grain crops when an increased acreage and production of these forage crops also increases the total production of grain from a given farm or area of land. The reasons why forage crops may serve in a complementary relationship to grain crops are outlined in other chapters. They are mainly these: (1) Legumes add nitrogen to the soil. This nitrogen is used by grain crops that follow. (2) Grasses and legumes improve soil tilth. This may increase the per acre yield of crops which follow in the rotation. The better soil tilth permits more timely planting and cultivation of the crop. Or it may have direct yield effects through the chemical and physical processes of the soil. (3) Forage crops grown in rotation may help control the corn root worm, or other crop pests and diseases. (4) Forage crops are especially effective in controlling erosion. Hence they tend to increase the relative acre yield of other crops over a period of time. In order to maintain a perfect and direct complementary relationship between forage and grain, the percentage increase in yield per acre of the grain must be greater than the percentage decrease in number of acres of grain, as land is shifted from grain to forage.
3. The costs of growing and harvesting the forages are greater than for corn, small grain and soybeans on most farms. However, the costs of growing forage are less than the costs of growing and harvesting most other Corn Belt crops. Thus, if fewer acres are devoted to grain while more land is planted to alfalfa or clover, total costs can be lessened if the forages are left unharvested or are plowed under. Profits will increase where costs can be lessened by growing more forage and at the same time increasing total grain production.

Where forage is complementary with grain in the rotation, price relationships are unimportant in determining the quantity of forage. Furthermore, it isn’t necessary for forages to be used by livestock. Forage production is not a utilization problem if it is complementary to grain. Yet profits may be increased even further by utilizing the forage through livestock. If the farmer has the capital and necessary fencing, he can harvest his forage crops as pasture and the only costs he needs to consider are the growing costs. He can go even further in increasing profits if the forage when harvested and fed to livestock adds more to gross income than it adds to harvesting and other costs.

4. Forage crops are competitive with grain or other crops on any one farm if growing more acres of forage reduces both the acreage and total output of the nonforage crops. Thus, in this situation, although grasses or legumes increase the per acre yield of other crops grown later on the same land, the increase is not great enough to more than offset the reduction in total yield owing to the fewer number of acres planted to the crops other than forages. On some soils, acreage and production of forage can be increased only at the expense of production of the nonforage crops. Here the two do not go hand-in-hand, and a competitive relationship alone exists. The relationship of grain and forage prices, or the relative returns which can be realized from grain-consuming as compared to forage-consuming livestock, becomes of first importance when forages are competitive with grain crops. Income actually will be largest when the forages and other crops are combined on an individual farm in such proportions that their substitution ratio is exactly equal to their price ratio. The substitution ratio must, of course, be figured from all the acres in grain and forage under the cropping systems being compared.

5. Forages are complementary to other crops only over time. Any increase in production of grain resulting from the added nitrogen, improved soil tilth, or other contributions of grasses and legumes must come from the grain crops which follow the forages in rotation. Grasses and legumes are always competitive with other crops in any single cropping season; a greater acreage of
grasses or legumes is possible only as both the acreage and total production of nonforages are reduced within the year.

As mentioned previously, in few if any instances are farm profits at a maximum over time if the acreage of forages is not extended through the entire range in which they are complementary to other crops. However, many farmers can make their crop plans for only one year and can view forages only as competitive crops. This situation is especially true for: (1) tenants who will be on a given farm for only one year; (2) tenants who are always faced with the expectation that they may have to move at the end of a year; and (3) beginning farmers, and others short on capital who plan largely in terms of the year ahead only, because of the uncertainty of price and the future.

The cash rent attached to forage acreages on many rented farms causes the cost of growing forages to be greater than the cost of growing and harvesting grain; it may then discourage forages in the rotation even where they are complementary with grain crops. Landlords and tenants can gain mutual benefits, however, if rental arrangements are devised which allow forages to be grown as long as they serve in a complementary capacity. The landlord might actually realize maximum returns if he were to charge no rent on the land producing forages, providing this action resulted in producing grasses and legumes as complementary crops. He would have more grain from fewer acres, and forage production also would increase. The landlord is justified in charging a rent on forages which will equalize their return with alternative crops, however, when grass and legumes are alone competitive, or if their acreage is extended beyond the complementary range into the competitive range.

6. The national pattern of forage crop production should conform to the comparative advantage of each particular production and soil area if (a) consumers of the nation are to realize the best use of resources from the standpoint of human wants and (b) farmers are to maximize returns from their resources. Forage crops, as well as other crops, should be grown where their relative advantage and not necessarily their absolute advantage is greatest. All areas in which forage is a complementary crop have some comparative advantage in grass and legume production.

7. Cropping and land use systems should be kept flexible to (a) conform to changes in consumer wants and national or emergency requirements, and (b) the position of individual farmers. Again rotation systems are possible which reconcile objectives between these different economic units or organisms.
Economics of Crop Rotations and Land Use

A Fundamental Study in Efficiency With Emphasis on Economic Balance of Forage and Grain Crops

By EARL O. HEADY and HARALD R. JENSEN

The economics of crop rotations is a research problem of central importance in Iowa agriculture. Although the major portion of Iowa cash farm income is derived from livestock, a greater share of the state's gross value of agricultural products is attributable to crops than to livestock and livestock products. Livestock and livestock products provide the greatest part of the total cash income since the major portion of the hay and feed grains is not sold in the market but is processed through livestock on the farms where the crops are produced. Livestock production adds 40 to 60 cents (depending on feed/livestock price ratios) to each dollar's worth of crops fed to livestock in Iowa. The importance of crop production economics in Iowa agriculture is thus apparent: Economic balance in the production of crops is of foremost concern (1) to the individual farm operator and farm owner in Iowa because of the large contribution of crops to total income and (2) to the nation's consumers since the output from any resources employed in the state's agricultural production represents an important part for the country as a whole.

Economic aspects of crop production (land use) have always been important considerations in the maximization of individual farm profits or in the most efficient utilization of the nation's resources. However, the question of which pattern of crop production is economic has taken on increasing importance during the last decade because of the large number of programs, popular movements and economic forces that impinge on crop production. Prior to the outbreak of World War II, farmers were being encouraged, through monetary and technical assistance of governmental action agencies and educational institutions, to increase the acreage of grasses and legumes (the so-called soil-saving crops) and to decrease the acreage of grain and similar crops (the so-called soil-depleting crops). Emphasis was shifted in the opposite direction during the war period as consumer demand and

1 Readers who are interested in further fundamentals of crop rotation economics may consult the following article which includes the original principles upon which the current study is based:

Heady, Earl O. The economics of rotations with farm and production policy applications. Jour. Farm Econ. 33:645-664. 1948.
Fig. 1. Acres of corn and soybeans, small grains, tame hay and plowable pasture as percentages of land in farms by counties in Iowa, 1943-47. (Acres of plowable pasture was listed only in the 1946 Iowa farm census. Thus the 1946 acreage was taken as representative for the period.)

national defense needs called for greater acreages of grain and fiber crops. Current uncertainties on the world political horizon suggest that cropping patterns may need to be geared in either one of two directions in the future depending on (1) the probability of world conflict wherein rotations must be rapidly adapted in the direction of high-calorie crops with a heavy drain on soil nutrients stored in an earlier period or (2) the probability of peace (or the absence of armed conflict) wherein relative consumer values represent the dominant factor in determining the optimum pattern of crop production. Monetary incentives and technical assistance have again been used in postwar years to effect a shift of acreage from grain to forage crops.

Too, the fluctuations in farm prices and costs over the last decade have provided a complex decision-making environment for farmers. Changes in prices and price relationships and the uncertainty attending these changes have tended to place a premium on crops which give a rapid return on investment. Beginning farmers and farmers who have recently purchased farms have also placed a premium on grain and related "quick-return" crops as compared to grasses and legumes. Many farmers have hoped to maximize either (a) the reduction in indebtedness or (b) the accumulation of capital, before prices fell in the postwar period.

The various programs and economic influences mentioned above emphasize the need for development of basic principles that apply to crop rotations and crop production. Not only do certain market influences (inflation, market uncertainty, acquisition of farms, etc.) on the one hand and action programs on the other conflict in the emphasis placed on the relative need for grain and forage crops, but also other long-standing problems in the economics of rotations are still unsolved. One of these is the problem of rotations for rented farms. Numerous customs have developed relative to the rentals to be paid for and the cropping systems to be followed on rented farms. These customs often give rise to conflict over rotations since the resulting rental returns are not mutually satisfactory to landlords and tenants. As a result, the cropping system on a very great number of rented farms includes a far smaller acreage of grasses and legumes than will suffice to produce the most efficient use of resources. Too, the grain acreage on many owner-operated farms is far greater than is recommended by agronomists. A large number of farm operators, whether owners or tenants, are simply concerned with the question, "What is the most profitable crop rotation?"

Figure 1 represents the general production pattern of intertiled, small grain and forage crops in Iowa for the period 1943-1947. Notable area differences are indicated in this pattern. For example, the north central area of Iowa reflects a heavy produc-
tion of intertilled crops, whereas southern Iowa evidences relatively heavy forage production. These, however, are broad and over-all area adjustments and the answer to the question of what is the most profitable rotation still remains an individual farm problem. The following pages will largely be addressed to the solution of that problem.

OBJECTIVES

Because of the maze of forces which affect cropping programs and condition farmer decisions on many individual farms, development of basic economic principles which apply to crop rotations and land use is greatly needed. Even though the problem of crop rotation economics has always been important in the management of an Iowa farm or in the best use of the nation's resources, little has been accomplished previously in the development and application of the economic principles of crop rotation. The specific objectives of this study are to develop and outline these fundamental economic principles. Principles, which are simple and which provide a sound framework for suggesting the cropping systems for individual farms and for establishing goals for national programs, are developed and applied to farm problems in the following discussion. While the study is nowhere complete in these respects, it does set forth the more elementary and fundamental relationships in crop production economics. It also provides models suggestive of the design for further economic and physical research aimed at providing data for decision-making, either at the individual farm or in respect to the national program level. The data employed in testing the models and in applying the principles are partly drawn from other economic and agronomic studies. Physical data from other states have been employed since the quantity of yield data available from Iowa experiments was not great enough to test and apply all of the principles. Then, too, the basic principles are of general application irrespective of particular soil types and climatic conditions; they apply equally whether moisture in the Great Plains or nitrogen in the Corn Belt is the limiting element in crop yields. The enterprise relationships and principles of choice that follow are relatively simple and can be illustrated and understood through use of simple examples in arithmetic and geometry. Again it should be mentioned that emphasis is on development of basic principles which apply to all farms and situations rather than to the prescription of practices to be followed on a limited number of individual farms. The general principles of enterprise combinations discussed on the following pages apply to all crops and livestock; they apply to crops grown in the Great Plains and other areas as well as in the Corn Belt. However, emphasis is on
the relationship of grain and forage crops grown in Iowa and the central Corn Belt.

ANALYSIS IN PRODUCTION ECONOMICS

The crop rotation which is economically efficient can be determined only within the framework of farm management and production economics. The particular cropping system which will give maximum returns on the individual farm is determined not alone by the yields to be obtained under different rotations. Other factors that especially must be considered include: (1) the amount of labor available on the particular farm and the seasonality of labor requirements for particular crops, (2) the prices for and the capital and labor costs of each crop, (3) the various kinds of livestock (a) which can be adapted to the cropping system or (b) to which the rotation can be adapted, (4) the alternative rations that can be fed to each class of livestock and the manner in which livestock rations and feed from the crop rotation can be adapted to each other, (5) the price and cost relationships for various classes of livestock, (6) the leasing system under which the farm is operated and (7) the capital position of the individual farmer and his ability to withstand risks and major fluctuations in income.

The economics of rotations is not simply a study in land use. Land is a single factor of production. Crops can be produced only by the use of capital, labor and management as well as land. Since production is forthcoming only when two or more factors of production are employed, economic study of land use can be made only within the framework of production economics which involves use of two or more factors of production. Studies dealing with a single production factor (as land or labor) involves only the physical aspects of the particular resource or crop.

The cropping pattern which is most desirable from the standpoint of either the individual farm or the national welfare can thus be established only in a framework wherein other farm enterprises and all production factors are included. The rotation which is best for one farm may well differ from the rotation which is most profitable on another farm because of differences in such items as labor supply, management skill, amounts and kinds of available capital, and leasing systems. Similarly, national programs touching upon cropping patterns must consider not only the differences in physical characteristics associated with each particular type of soil, but also must consider land use in the general framework of production economics wherein proper consideration is given to (1) the relative demand or prices for the alternative crops and (2) the degree to which capital, labor and land substitute for each other and the relative costs or scarcity of
each of these factors of production. The analysis which follows applies the basic principles of production economics to rotations and land use. The study does not, however, complete the development of principles of crop rotation economics. Neither does it completely interrelate problems of crop and livestock production. This analysis is to be made in a publication on livestock and feed utilization.

The two basic problems of cropping combinations relate to how many acres of various crops should be grown (1) on each individual farm and (2) in each agricultural area or region of the nation. The following section discusses principles of regional specialization in crop production. However, the major portion of the analysis that follows refers to the choice of crop combinations on specific soils and farms from the standpoint of both the individual farmer and the national welfare. The optimum regional specialization would be attained automatically were the optimum cropping pattern established on each individual farm from the standpoint of national welfare.

COMPARATIVE ADVANTAGE AND REGIONAL SPECIALIZATION IN CROPS

The amount of forage and grain crops produced per farm varies greatly between different localities. In some areas nearly all the land area is devoted to grasses and legumes. Some regions grow very little of these crops. In other areas a near-even balance exists between forage and grain or fiber crops. The areas which can produce the highest acre yields of grasses or legumes do not always specialize to the greatest extent in these crops. Regional specialization in forage production and utilization is illustrated in fig. 2.

The principle of comparative advantage is the economic law which helps explain this regional specialization. In general, this principle or law indicates that crops should not always be grown where absolute yields and income per acre are greatest. Rather they should be produced where relative or comparative yield and return are greatest.

For example, the yield per acre of both forage and grain crops is greater in the Corn Belt than in most of the Great Plains area. Certain sections of the Corn Belt, however, grow a greater acreage of grain than of grasses and legumes. At the same time in parts of the Great Plains practically all of the land is devoted to grasses and livestock grazing. As previously stated, the Corn Belt has an absolute advantage in both forage and grain crops. Yet the Great Plains grazing area has a “comparative or relative advantage” for grasses. The reason: Its yield disadvantage for
grass is less than for grain crops. In the same vein, the Corn Belt has a comparative advantage for grain, since its actual advantage for corn, oats and soybeans is greater than for the forage crops.

To illustrate: suppose that in region $A$, an acre of land along with the necessary capital and labor will yield either 2.5 tons of hay or 60 bushels of corn. In region $B$, the yields for hay and for corn are 1.5 tons and 30 bushels, respectively. Region $B$ has a comparative advantage in hay because the yield is 60 percent as great as in region $A$ while the corn yield is only 50 percent as great. Conversely, $A$ has the comparative advantage in corn.

It must be borne in mind, also, that consumers of commodities and services help establish the comparative advantage and the amount of specialization in any one crop or enterprise. The prices consumers are willing to pay tend to push each region into producing the product for which it has the greatest relative advantage. Market prices reflect the consumers' desires for different products. Aside from variations due to geographical distances, these market prices are about the same for all farmers. In effect, the consumer thus indicates that the farmer with the lowest relative costs (not always the lowest absolute costs) should produce a given crop.

Historically, broad regions with varying degrees of specialization in grasses and legumes have become established. Some re-
regions produce forages because the topography and climate make it impossible to produce any other crop. But mainly, forages are produced in areas where they have a comparative advantage over other crops.

Changes in comparative advantage are brought about especially by: (1) changes in consumers' tastes for different things, and hence the prices which they are willing to pay for them as compared to others; and (2) changes in the acre yield or costs of one crop as compared to that of other crops.

The American diet is fairly stable. The greatest opportunity, therefore, for increasing the comparative advantage of forage crops relative to grain and fiber crops is through increasing the relative acre return as compared with that of other crops.

BEST COMBINATION OF FORAGES AND OTHER CROPS

Very few farming regions in the United States have such a distinct advantage in grain, fiber, fruit or other crops that they cannot afford to devote any of their land to forage production. Generally, the problem is to get the best combination of forages with other crops.

The proper combination from a national economic standpoint is that one which gives both a maximum satisfaction to consumers and a maximum profit to farm operators. Once this balance has been struck, any major shift away from it is to the disadvantage of both farmers and consumers.

BASIC ENTERPRISE RELATIONSHIPS AND FARM SPECIALIZATION

Choice of the amount of capital, labor and land which should be employed in production of alternative crops or livestock enterprises depends especially on the relationships between enterprises. These enterprise relationships are explained in general form below and applied to crop rotation data in the following section. Knowledge of these basic concepts of enterprise relationships should be possessed by any economist or physical scientist who advises farmers and program administrators on crop or livestock combinations. Enterprises may bear either one of two general relationships: These relationships are (1) complementary and (2) competitive.

COMPLEMENTARY RELATIONSHIPS

Two crops are complementary to each other when an increase in output of one also results in an increase in output of the other
from given resources. When two crops are complementary, use of resources for two crops makes possible a greater production of one or of both crops than if each were grown independently. This relationship exists only when one crop enterprise furnishes an element of production required by the other. Thus grasses and legumes become complementary to grain crops when the former (a) furnish nitrogen, (b) control erosion, (c) eliminate diseases and pests and (d) maintain or improve soil tilth to an extent that a greater production of grain crops is possible over time from fewer acres.

Complementary relationship between two crops is illustrated in the example of fig. 3. This illustration refers to the possible combinations of crop A and crop B which might be produced from a given quantity of land and other resources. Each increase in production of crop B is associated with an increase in the output of crop A.

COMPETITIVE RELATIONSHIPS

Two crops are competitive when an increase in the total production of one is possible only as the output of the other is decreased. Competitive crops act as substitutes for each other in the use of given resources since the gain in output of one crop always necessitates a sacrifice in output of the other. Competitive crops may substitute for each other at either (a) a constant
marginal rate or (b) a declining marginal rate. Substitution at a constant rate is illustrated in the example of fig. 4. Here each successive increase in the output of crop \( D \) requires a constant reduction in the output of crop \( C \). Crops substitute for each other at a constant rate only when neither crop contributes to the production of the other (through addition of nitrogen, improvement in soil tilth, by control of erosion and pests, etc.) and when both require machinery, labor and power at approximately the same time of the year. Oats and barley are generally competitive at a constant rate within the rotation since neither adds to the yield of the other and both have similar tillage, planting and harvesting dates. Each acre of land on an individual farm which is transferred from barley to oats requires the same sacrifice in output of barley for equal gains in production of oats. Substitution at a diminishing marginal rate is illustrated in the example of fig. 5. Here each successive increase in the output of crop \( F \) requires increasingly larger sacrifices in the production of crop \( E \). Forage and grain crops substitute for each other at a diminishing marginal rate when the growing of forages makes possible greater yield per acre of grain but when the increase in yield per acre of grain is not great enough to offset the decline in the number of acres.

**ROTATION RELATIONSHIPS**

Forage and grain crops ordinarily have both a complementary and competitive relationship to each other even when grown on the same farm or same tract of land. If only one relationship is present, it is the competitive or substitution relationship alone. While it is true that two crops may be competitive alone, they are never complementary throughout all possible combinations. When both complementary and competitive relationships are present, the complementary relationship must occur first and is followed by the competitive relationship. The range of the complementary relationship extends as long as the increase in yield per acre of grain (resulting from the added nitrogen, improved soil tilth or from the increased control of erosion, pests, etc.) more than offsets the reduction in number of acres of grain. Grain production reaches a maximum from a given area of land or on a given farm when the forage-induced increases in per acre yields of grain are exactly offset by the effect of reductions in the acre-age planted to grain. When the per acre yield benefits to grain from forage can no longer offset further decreases in grain acre-

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2The term *marginal* refers to the rate at which each successive unit of one crop substitutes for the other. Marginal is used to denote that the important question of substitution is not that of averages throughout all ranges of crop combinations but how each successive change in output of one crop causes output of another crop to decline.
age, grain and forage become competitive and each acre shifted from grain to forage results in a decrease in the total grain production. Within the competitive range, substitution of forage for grain may be at either a constant or at a diminishing marginal rate, depending on whether or not grain and forage have any effects on the per acre yield of each other.

The general complementary-competitive relationship is illustrated by the example of fig. 6. As is suggested by the intersection of the curve and the vertical axis, some grain would be produced even in the absence of forage. The positive slope of the curve indicates that as production of crop G is increased (through an increase in acreage), the production of crop H is also increased. Total production of H reaches a maximum at point M and beyond this point any increase in the acreage and total production of crop G results in a decrease in total production of H. The points L, M, N, P and Q are equivalent to individual rotations containing various proportions of land devoted to forage or grain crops. Although each individual rotation represents a specific point (as L, M, N, P and Q) on the rotation curve, all points on the curve might be derived from one farm or a tract of land by increasing the number of rotations and by combining rotations in different proportions. The nature and slope of the rotation curve will vary between soils depending on topography, on origin and development of soil, and on climate and other physical considerations. On some soils the complementary relationship may end with a small proportion of the land in forage. On other soils, the complementary range may extend farther to the right thus denoting a larger possible proportion of the land in grass or legumes before
Examples of complementarity discussed above relate only to the effect of forage on grain (or one-way complementarity between any two crops). It is also possible that grain has a complementary effect on forage for some soils and under certain climatic conditions. Under this possibility, the total production of hay will be less if all of the land is planted to hay (hay grown continuously with none of the land devoted to grain). Possible reasons (hypotheses) explaining why grain may serve as complementary to forage include winter killing of grass and legume stands, emergence of native grasses and weeds to compete with hay in growth, depletion of soil moisture, development of plant diseases and pests, and other factors which may lower forage yields sufficiently to cause a lower total production when land is continuously devoted to hay or pasture. A rotation which includes row crops and small grains may eliminate these yield-reducing forces to an extent that hay production will be greater in a rotation which includes some acreage of grain as compared to one where the land is devoted entirely to hay (grassland farming). The rotation relationship takes the general nature of the example shown in fig. 7 when both forage and grain are complementary to each other. Under this situation grain production can be increased (starting from the intersection of the vertical or left-hand axis and the curve) as hay production is also increased. At the point $R$, maximum grain production is attained from given resources and further increases in forage production are possible only as total grain production is reduced. However, at point $S$, total hay production will decline along with total grain output as more resources (acres of land) are devoted to grass or legumes. Or, starting from the point where all resources are devoted to forage production (as denoted by intersection of the rotation curve and the horizontal axis) total hay production will increase within a given range by also increasing grain production (planting more acres to grain). However, at point $S$ the transfer of more

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3While complementarity is not to be found in standard dictionaries, the term is employed in this study as a noun to denote the conditions wherein one or more crops are complementary.
resources to grain production (fewer acres in forage) results in a smaller total output of forage since the percentage increase in the per acre yield of forage is less than the percentage decrease in forage acreage.

BASIC RELATIONSHIPS AND ROTATION DATA

The enterprise and rotation relationships outlined above include all of the possible situations into which various rotation and land use arrangements for individual farms and soils may fall. Each one of these specific relationships (1) competitive at (a) constant marginal rates or (b) diminishing marginal rates and (2) complementary of (a) forage with grain alone or (b) both crops to each other has its own special economic implications and requires a particular cropping pattern if farm returns or national welfare is to be maximized. Thus knowledge of these relationships and their quantitative application to individual soils is essential for farmers, educators, program administrators and others who are concerned with adaptations in cropping patterns. The exact implications of each of the individual relationships will be pointed out later.

BASIC INFORMATION

Recommendations for rotations on particular soils should consider especially the extent to which forage crops are complementary with grain crops. On bottomlands which are flooded frequently, it is possible that forage and grain crops are never complementary and hence any increase in forage acreage and production must be at the expense of grain acreage and production. On level soils, it is possible that forage remains complementary to grain only as a small amount of the land is planted to forage. Complementarity on level soils results mainly through the added nitrogen or improved soil tilth which grasses and legumes furnish for subsequent grain crops. On the other hand, the complementary range may be extensive and call for a large acreage of forage on rough land. Grasses and legumes not only furnish nitrogen and improve soil tilth on rough land but also control erosion which may affect long-run grain yields. As will be pointed out later, the rate at which grain and forage crops substitute within the competitive range is also important.

In order to determine under which conditions and the extent to which forage crops are complementary to grain crops on particular

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4An additional enterprise relationship is the supplementary relationship. It has not been discussed since it has no particular implications in crop rotations.
soils, information from crop rotation experiments has been brought together in table 1. While these data cover only a small range of soils, they represent an important portion of the long-run experimental data available in the Corn Belt. It should be remembered, of course, that they apply to particular soil types and cannot be used as inferences for all other specific soils. Too, the major portion of the experimental data is for level soils with high initial productivity. These represent only a fraction of the possible rotations and crop combinations possible for individual farms and soil types. Data are converted to the basis of 100 acres since farmers must view their cropping operations on the basis of alternatives on a given area of land.

**COMPLEMENTARY RANGE**

The data in table 1 indicate that a complementary relationship exists between forage and grain for some period on each of the soil types included. Complementary relationships are denoted in the columns showing total production (pounds) of grain. For the Illinois and Ohio rotation experiments, total production of grain for the entire experimental period was greater under rotations including some amount of hay than under a cropping system of continuous corn. Complementary effects are not expressed over the average of the experimental period for the data from Clarion-Webster soils nor from the Marshall soil in Iowa; however, in both instances, complementarity is manifested in the latter part of the experimentation periods.

In the Morrow Plot experiments in Illinois, the forage in the C-O-Cl rotation had a complementary effect on total grain production when compared to continuous corn, and even when compared to the C-Os rotation which included forage as a crop to be plowed under. In the Ohio experiment, 1937-1943, the forage in the C-C-W-A rotation had complementary effects on total grain output when compared to continuous corn. However, when the C-W-A rotation is compared with C-C-C-W-A, forage is competitive in the sense that a greater acreage and production of hay brings about a reduction in total grain production. The rate at which forage substitutes for grain diminishes even further between the C-C-W-A-A and the C-W-A rotations, and further still between the C-W-A-A and the C-C-W-A-A rotations—only 1.9 pounds of forage is gained for each pound of grain sacrificed.

As indicated previously, the complementary effects of forages on total grain production were expressed only in the latter portion of the experimental period for the rotation experiments on Clarion-Webster and on Marshall soils (1945-1948 for Clarion-Webster soils and 1941-1949 for the Marshall soils).
It is the figures on total production of the alternative crops rather than figures on yield per acre which are important in determining complementary or competitive relationships and in decision-making relative to the optimum cropping pattern. While corn and small grain yields per acre are sometimes greater for rotations which extend into the competitive range (the C-W-A rotation as compared to the C-C-C-W-A rotation on Canfield-Wooster soils, for example) the increase in yield per acre is not great enough to offset the decline in the number of acres in grain. Accordingly, total grain production eventually decreases as acreage and production of meadow is increased (between rotations). The range of rotations included in the various experiments is not great enough to determine whether grain also has a complementary effect on forage. Hay production increases on each soil type as grain acreage is reduced. However, since the experiments do not include continuous hay (no grain) or rotations which approach this extreme, possible complementary effects of grain on forage are not expressed.

While it is true that forage-grain complementarity is expressed for some time period on each of the particular soils, the experiments do not indicate exactly how far forage acreage can be extended in the rotation before the range of complementarity is exhausted and the range of competition begins. For the cropping systems on Marshall silt loam over the period 1941-49, for example, the C-O-M rotation yielded a greater grain production than did the continuous corn. Only 67 acres out of each 100 would be in grain under the 3-year rotation while the entire 100 would be in grain under the continuous cropping system. However, if these data are compared with the illustration of fig. 6, it cannot be determined whether the C-O-M rotation represents a point such as L, M or N. If it represents a point such as N, then forage acreage extends beyond that which would maximize grain production from a given farm acreage even though the 3-year rotation results in a greater total grain output than continuous corn. If the 3-year rotation represents a point such as L, forage acreage might be extended still further than that included in a 3-year C-O-M rotation before meadow crops become competitive with grain crops. If it falls at a point such as M in fig. 6, maximum total grain production for a given acreage has been attained and longer rotations (more acres of forage) would result in a smaller total grain production.

Similarly, it is impossible to determine whether the particular rotations which indicate the greatest grain yields for other soil types fall before, after or exactly at the line (or point M in fig. 6 for example) which divides the complementary and competitive effects of forage with grain. Figure 8 which is derived from the Ohio experimental data corresponds to the basic rotation relationship illustrated in the example of fig. 6. Figure 8 displays both a
<table>
<thead>
<tr>
<th>Cropping system**</th>
<th>Acres of land out of 100 in</th>
<th>Per acre yields of:</th>
<th>Total production (lbs.)†</th>
<th>Rate of substitution of hay for grain (lbs. hay gained for each lb. of grain sacrificed) in competitive range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hay</td>
<td>Grain</td>
<td>Corn</td>
<td>Small grain</td>
</tr>
<tr>
<td>Drummer silt loam, Urbana, Illinois, 1904-1949</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>100</td>
<td>24.3</td>
<td>34.5</td>
</tr>
<tr>
<td>C-0s</td>
<td>33</td>
<td>67</td>
<td>51.1</td>
<td>49.8</td>
</tr>
<tr>
<td>C-O-Cl</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wooster and Canfield silt loams, Wooster, Ohio, 1937-1943</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>100</td>
<td>38.9</td>
<td></td>
</tr>
<tr>
<td>C-C-C-W-A</td>
<td>20</td>
<td>80</td>
<td>60.1</td>
<td>23.2</td>
</tr>
<tr>
<td>C-W-A</td>
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<td>67</td>
<td>70.0</td>
<td>41.5</td>
</tr>
<tr>
<td>C-C-W-A-A</td>
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<td>60</td>
<td>68.3</td>
<td>31.4</td>
</tr>
<tr>
<td>C-W-A-A</td>
<td>50</td>
<td>50</td>
<td>78.3</td>
<td>37.5</td>
</tr>
<tr>
<td>Clarion-Webster silt loam, Ames, Iowa, 1915-1948</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>C</td>
<td>0</td>
<td>100</td>
<td>40.0</td>
<td>56.5</td>
</tr>
<tr>
<td>C-C-O-Cl</td>
<td>25</td>
<td>75</td>
<td>59.9</td>
<td>50.1</td>
</tr>
<tr>
<td>C-O-Cl</td>
<td>33</td>
<td>67</td>
<td>59.5</td>
<td>50.1</td>
</tr>
<tr>
<td>Clarion-Webster silt loam, Ames, Iowa, 1945-1948</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>100</td>
<td>32.2</td>
<td>59.6</td>
</tr>
<tr>
<td>C-C-O-Cl</td>
<td>25</td>
<td>75</td>
<td>60.6</td>
<td>59.6</td>
</tr>
<tr>
<td>C-O-Cl</td>
<td>33</td>
<td>67</td>
<td>63.7</td>
<td>57.8</td>
</tr>
<tr>
<td>Marshall silt loam, Clarinda, Iowa, 1933-1949</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>100</td>
<td>28.02</td>
<td>25.35</td>
</tr>
<tr>
<td>C-O-Cl</td>
<td>33</td>
<td>67</td>
<td>64.27</td>
<td>25.35</td>
</tr>
</tbody>
</table>

* Total production figures based on 100 acres of land.
† Rate of substitution of hay for grain (lbs. hay gained for each lb. of grain sacrificed) in competitive range.
<table>
<thead>
<tr>
<th>Cropping system**</th>
<th>Acres of land out of 100 in</th>
<th>Per acre yields of:</th>
<th>Total production (lbs.)†</th>
<th>Rate of substitution of hay for grain (lbs. hay gained for each lb. of grain sacrificed) in competitive range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Hay</td>
<td>Grain</td>
<td>Corn</td>
</tr>
<tr>
<td>Marshall silt loam, Clarinda, Iowa, 1941-1949</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>0</td>
<td>100</td>
<td>21.2</td>
</tr>
<tr>
<td>C-O-Cl.</td>
<td></td>
<td>0.33</td>
<td>67</td>
<td>183,019</td>
</tr>
</tbody>
</table>


**C=corn; O=oats; s=sweetclover green-manure crop; Cl=clover; A=alfalfa.
†Corn, 56 pounds per bushel; oats, 32; wheat, 60.
complementary and competitive relationship. However, it again is impossible to determine whether the C-C-C-W-A rotation represents a point (a) exactly at, (b) to the left of, or (c) to the right of the complementary peak or rotation which gives the maximum grain production for a given land area. Data which indicate location of this particular point are more important in economic decisions relating to rotations than any other single aspect of rotation data. Additional experimental and record data for a wider range of rotations and for varying time periods will have to be obtained before the exact extent of forage-grain complementarity can be established for individual soils and farms.

RATES OF SUBSTITUTION

For those rotations where the number of crop combinations is sufficiently great for measurement, forage substitutes for grain at a diminishing marginal rate within the competitive range. Successive sacrifices in grain production add smaller and smaller quantities of hay to total production. On Clarion-Webster soils over the period 1915-48, for example, 8.0 pounds of hay are gained for each pound of grain sacrificed between the C-C-O-M rotation and continuous corn. One pound of grain substitutes for only 0.2 pounds of hay between the C-C-O-M and C-O-M rotations. Similarly, on the Canfield-Wooster soils over the period 1937-43, grain substituted for hay at the rate of 5.2, 4.6 and 1.9 between the pairs of rotations, C-C-C-W-A and C-W-A, C-W-A and C-C-W-A-A, and C-C-W-A-A and C-W-A-A, respectively. The fact that substitution is at a diminishing rather than a constant marginal rate has important bearing on the amount of forage which is optimum for any particular farm or soil. As is pointed out later, substitution at a constant marginal rate ordinarily specifies that one of two extreme quantities of forage should be produced. The causes of a

5Total grain production in the data of table 1 and fig. 8 includes both corn and small grain. Under historic market relationships corn and oats average approximately the same price per pound. Hence, gross income is affected similarly whether total grain production in pounds increases because of a greater proportion of oats or corn. Wheat has historically sold at a higher price per pound than corn. Hence as rotations include a greater proportion of wheat and as wheat production represents a greater proportion of total grain production, gross income will always increase as total grain output becomes greater.
diminishing rate of forage-grain substitution on Corn Belt soils are evidently these: (1) Yield per acre of grain still increases from a greater forage acreage (although not enough to compensate for the reduced acreage of grain). (2) Hay yield per acre tends to decline for rotations which include increasingly greater amounts of forage.

MAXIMUM RETURNS UNDER COMPLEMENTARIETY

Given the nature and extent of the complementary and competitive relationships, basic statements can be made about rotations and land use systems which will maximize farm profits and national welfare. The conditions defining maximum economic efficiency in the use of resources devoted to grain or forage crops can be outlined and ranges within which grain or forage acreage must fall can be delineated. The exact rotation or cropping system (within the delineated range) will vary at any one particular point in time depending on price relationships. Again, these conditions are highly dependent on the enterprise and rotation relationships previously outlined.

RETURNS IN THE COMPLEMENTARY RANGE

For an operator who will be on his farm during the period in which a forage-grain complementary relationship is expressed (and in the absence of the major fluctuations in grain-forage price relationships which are discussed in a later section) returns can never be maximized by a forage acreage short of that necessary to exhaust the complementary effect and maximize total grain production. (As examples, a forage acreage short of that necessary to attain the grain production represented either by (a) point \textit{M} in fig. 6 or by (b) the 5-year Ohio rotation, if the latter represents the greatest possible grain production, will never maximize profits.) Irrespective of prices for the crops, returns can always be increased by extending forage acreage as long as legumes or grasses are complementary to grain. Even if the price of forage is zero, its production is still profitable. The hay or pasture represents only one of the products of forages. Other important products are in the form of nitrogen, better soil tilth, erosion, pest and disease control, or other direct and indirect contributions of grasses and legumes to yield of subsequent grain crops.

When forage crops are complementary with grain in the rotation, a greater total production of both hay (or pasture) and grain can be attained through extending the acreage of grasses or legumes. The hay harvesting methods being used on some farms result in per acre costs of production for hay which are about equal to those
TABLE 2. PER ACRE COSTS OF GROWING AND HARVESTING SPECIFIED GRAIN AND HAY CROPS, 1940-44.*

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield per acre</th>
<th>Growing cost per acre</th>
<th>Harvesting cost per acre</th>
<th>Total cost of growing and harvesting per acre**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oats</td>
<td>42</td>
<td>$5.84</td>
<td>$4.09</td>
<td>$9.93</td>
</tr>
<tr>
<td>Corn</td>
<td>67</td>
<td>9.27</td>
<td>3.80</td>
<td>13.07</td>
</tr>
<tr>
<td>Soybeans</td>
<td>20</td>
<td>9.93</td>
<td>3.28</td>
<td>13.21</td>
</tr>
<tr>
<td>Wheat</td>
<td>20</td>
<td>7.50</td>
<td>6.72</td>
<td>14.22</td>
</tr>
<tr>
<td>Red clover hay</td>
<td>1.6</td>
<td>6.69</td>
<td>10.03</td>
<td>16.72</td>
</tr>
<tr>
<td>Alfalfa hay</td>
<td>2.7</td>
<td>6.71</td>
<td>12.62</td>
<td>19.33</td>
</tr>
</tbody>
</table>

*The cost figures do not include a charge for land or similar items which are the same regardless of the crop being grown. Since costs such as these are constant, their inclusion or exclusion does not affect the relative profitability of the different crops. These costs are based on survey, record, and other data which indicate the physical input-output requirements for various crops. Costs for the period specified have been applied to these physical inputs. Cost allowances include labor, machinery power and all other operating costs as well as seed, and fertilizer applied at the recommended rates on Clarion-Webster soils.

**The harvesting figures are based on costs under baling. Under the conventional hay loader system, acre costs would be increased about $1.63 for clover and $2.75 for alfalfa.

for corn. *(In table 2, for example, the total costs per acre for clover are only slightly higher than those for corn.) Thus, as an acre of land is shifted from corn to hay, costs remain constant while grain production increases along with hay production. With hay costs equal to those of corn on the Marshall silt loam soils over the period 1941-49, an annual average of only 2,122 bushels of corn (from 100 acres of land) would be produced under the continuous corn rotation. However, with the same total costs under the C-O-M rotation, total grain production would amount to the equivalent of 3,201 bushels of corn. An annual average of 74 tons of hay would also be produced. Thus, net return must necessarily be greater for the meadow rotation as compared to continuous corn. Even if the hay brings only $1 (or less) per ton, gross income is greater while costs do not increase.

The haying methods employed on a very great number of farms result in greater per acre costs for hay than for the common grain crops. Yet even on these farms, returns can always be increased by increasing the acreage of forages if the grasses or legumes are complementary with grain. As is indicated in table 2, the total per acre costs of growing and harvesting hay are greater than those for the common grains of the Corn Belt. Yet the costs of growing hay are generally less than the total costs of growing and harvesting grains. Thus gross and net income can still be increased as forage acreage is increased within the complementary range, irrespective of the market price for forage or the return which can be realized on it through utilization by livestock. As is indicated in table 2,

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6Per acre costs are comparable on farms especially where hay is put up with a buck rake and stacked in the field. While this is not a practice common to all farms, the method is employed especially on farms in the southern and western edges of the Corn Belt.
TABLE 3. PRODUCTION, GROSS RETURN, NET VALUE OF GRAIN AND PRODUCTION COSTS FOR SPECIFIED ROTATIONS ON BASIS OF 100 ACRES OF LAND.

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Total production (lbs.)</th>
<th>Gross value of grain with zero value for hay*</th>
<th>Total costs of production**</th>
<th>Net value of production with zero value on hay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grain (corn equiv.) lbs.</td>
<td>Hay lbs.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-C-C-W-A</td>
<td>217,840</td>
<td>0</td>
<td>$3,579</td>
<td>$1,307</td>
</tr>
<tr>
<td>C-O-M</td>
<td>230,496</td>
<td>128,800</td>
<td>3,762</td>
<td>1,203</td>
</tr>
<tr>
<td>Marshall silt loam, Clarinda, Iowa, 1941-49</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>118,720</td>
<td>0</td>
<td>$1,611</td>
<td>$1,307</td>
</tr>
<tr>
<td>C-O-M</td>
<td>179,368</td>
<td>148,000</td>
<td>2,434</td>
<td>993</td>
</tr>
</tbody>
</table>

*Prices used include the average for Ohio and Iowa for the period of 1940-44. Only the value of corn and small grain has been included. Hay has been given a zero price for illustrative examples.

**Costs included are total growing and harvesting costs for grain and growing costs for forage.

the total cost of growing and harvesting alfalfa is greater than the parallel cost for any of the grain crops listed. Since the growing costs of alfalfa are less than the total of growing and harvesting costs of all grains listed, costs can always be reduced by shifting an acre from grain to alfalfa, if the hay is not harvested. For example, a shift of one acre from oats to alfalfa would lower costs by $3.22 while a shift from corn would save $6.36. Thus as long as forage is complementary to grain and with costs of growing forage less than the costs of growing and harvesting grain, income must always increase as more forage is grown. The shift of land from grain to hay which is not harvested must increase the total production and gross return from grain while total costs are lessened. These relationships are expressed in table 3 when the cost figures of table 2 are applied to the grain production figures of table 1 for the range of complementarity on Canfield-Wooster soils over the period 1937-43 and Marshall silt over the period 1941-49.

COMPLEMENTARITY AND FORAGE UTILIZATION

Since gross income from grain always increases and total costs can always be decreased, net income necessarily increases as land is shifted from grain to forage within the complementary range. Again, the price of hay or the returns to be realized from hay through livestock are unimportant. Production of more hay is always profitable whether the return per ton from hay is zero, $100, or another quantity. The hay can simply be turned under as a green manure crop and the growing costs alone are realized. Its profitability comes indirectly through increases in total grain production from a given land area.

Thus forage utilization is not a problem when grasses and legumes are complementary with grain and has no place in determining
which crop should be grown. A large number of individuals mistakenly pose forage utilization as a major obstacle to a greater acreage of grasses and legumes. Grass and legume production is not a utilization problem as long as forages are complementary. No direct return need be realized on these crops to make their production profitable. They need not be utilized and can simply be plowed under and the farm operator need not have capital invested in livestock to make complementary forage production profitable. It is true, of course, that any price or return that can be realized from forage represents an addition to net profit.

While utilization is not a factor determining which acreage of forage should be grown within the complementary range, there are few instances where utilization of the forages grown (for their complementary effect on grains) is not profitable if sufficient capital is available. Many farmers suggest that lack of capital and the risks associated with borrowing prevent them from utilization of grasses and legumes produced in rotation. However, utilization of some amount of complementary forages can generally be made profitable if only a very small amount of capital can be obtained. Too, this utilization need not entail any great risks. For example, most farm operators can get together enough capital to buy a beef heifer. The heifer can be grown on the grass and legumes which serve as complementary with grain and which might otherwise be plowed under as a green manure crop. As her eventual offspring are saved back (or steer calves are traded for heifer calves) a beef herd can be built upon a basis of feeds which would otherwise go unused. In this manner complementary forages can be transferred into capital over time and the capital so accumulated becomes a form of deferred income which would otherwise not be realized. A utilization system such as this not only allows capital accumulation to spring from complementary forages with a minimum outlay but also entails small risk. Even if the first heifer is bought immediately before a price decline, her original capital value can always be returned in a short period of years from feeds which would otherwise have no value.

There are also other methods by which all or part of the complementary forages can be profitably used under a small capital outlay and with little or no risk. These methods will be outlined in a later study dealing with forage utilization.

**RETURNS UNDER COMPETITION**

While the price for or returns from forage crops have no role in determining forage acreage when grasses or legumes are complementary with grain, they become extremely important in determining which rotation or combination of forages and other crops is most profitable when the relationship becomes one of competition.
When the crops are competitive, returns from grain are always sacrificed for any gains in returns from forages. Accordingly, income considerations require that the profitability of grain and grasses or legumes be compared. It is the relationship of forage and grain prices (or relationship of returns through livestock from forage and grain) along with the cost relationships and marginal rates of substitution between crops that define the optimum forage acreage when grasses or legumes are competitive with other crops. The extremely difficult decisions on the acreage of forage relative to other crops falls in the range of competitive relationships.

CONSTANT RATE OF SUBSTITUTION AND MAXIMUM RETURNS

Under competitive conditions and constant marginal rates of substitution between grain and forage throughout, the two types of crops generally should be combined in either one of two extremes. If crops are competitive for all possible acreage combinations (as illustrated in the example of fig. 4), returns can be maximized by devoting the entire acreage to either one or other of the crops. When the production costs per acre are equal for the two crops, direct comparison of the yield or substitution ratios and price ratios for the two crops indicate which is most profitable. Yield data for barley and oats in Cherokee County, Iowa, are employed in table 4 to illustrate this principle. The oat-barley substitution ratio used (the number of bushels of oats sacrificed for each bushel of barley gained per acre shifted from oats to barley) is held constant at 1.4:1.0 since the two crops are entirely competitive within the rotation. When the oat/barley price ratio is (inversely) greater (1.0:2.2) than the substitution ratio, gross and net returns are greater if the entire 100 acres were devoted to barley. When the oat/barley price ratio is (inversely) less (1.0:1.3) than the substitution ratio, returns are greatest for oats. A price ratio of 1.0:1.4 (exactly the inverse of the substitution ratio) causes both crops to be equally profitable.

The same conditions of profit maximization also hold true when crops compete at a constant marginal rate while costs per unit differ. The relevant comparison is then between the substitution ratio and the net price ratio (market price less cost per pound, or ton). Specialization again should be either in one or other of the crops alone.

While oats and barley have been used as an example of competitive crops which substitute at a constant rate, this relationship also holds true between forages and grain or other crops in some regions.

Footnote: Looking forward into an uncertain market, farmers may wish to plant some of both crops in order to avoid “having all eggs in one basket” should their price expectations be wrong. However, historical returns will always be less under this system than had expectations been formulated accurately and had specialization been in one crop.
TABLE 4. YIELDS, COSTS, GROSS AND NET RETURNS FOR 100 ACRES WITH VARYING COMBINATIONS OF OATS AND BARLEY, BASED ON YIELDS FOR CHEROKEE COUNTY, IOWA, 1936-45.*

<table>
<thead>
<tr>
<th>Acres in 100 planted to each crop and yield per acre</th>
<th>Total costs** (growing plus harvesting) per acre at $10 for each crop</th>
<th>Gross returns with prices† and price ratios as indicated</th>
<th>Net returns with prices and price ratios as indicated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oats</td>
<td>Barley</td>
<td>Oats 50¢ Barley 1.10 Ratio 1.0:2.2</td>
<td>Oats 90¢ Barley 1.20 Ratio 1.0:1.3</td>
</tr>
<tr>
<td>Acre</td>
<td>Yield</td>
<td>Acre</td>
<td>Yield</td>
</tr>
<tr>
<td>100</td>
<td>38</td>
<td>0</td>
<td>27</td>
</tr>
<tr>
<td>80</td>
<td>38</td>
<td>20</td>
<td>27</td>
</tr>
<tr>
<td>60</td>
<td>38</td>
<td>40</td>
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<td>60</td>
<td>27</td>
</tr>
<tr>
<td>20</td>
<td>38</td>
<td>80</td>
<td>27</td>
</tr>
<tr>
<td>0</td>
<td>38</td>
<td>100</td>
<td>27</td>
</tr>
</tbody>
</table>

*The yields have been obtained from Iowa County Assessors' Annual Reports.

**Costs are based on the total growing and harvesting costs of $9.93 per acre for oats as indicated in table 3. For ease of computation this was rounded off to $10 per acre. Similar costs were assumed for barley.

†For the period 1935-1942 the oat-barley price ratio was 1.0:1.5 and in 1938 the ratio was 1.0:1.85 on the basis of Iowa annual prices. In July of 1949 the ratio was 1.0:1.72 on the basis of data from the Iowa Crop and Livestock Reporting Service.
Substitution at a constant rate is most common in the western Corn Belt and Great Plains areas where land is level, moisture is the limiting element in production, and grasses or legumes contribute neither directly nor indirectly to the yield of other crops. Under these conditions land should be devoted entirely to grass and grazing when the grain/grass yield or substitution ratio is low relative to the (inverse) grain/grass price or returns (including returns through livestock and associated costs) ratio. Land should be devoted entirely to grain when the grain/grass substitution ratio is higher than the (inverse) price or returns ratio. A similar situation (constant rate of substitution and the need for specialization entirely in grain or forage) exists on flooded bottomland soils of the Corn Belt where grass or legumes do not contribute significantly to grain yields.

Where forage crops first serve in a complementary capacity to grain, then compete at a constant rate of substitution, specialization should be either in (1) hay alone or (2) the combination of hay and grain which results in the maximum grain production (e.g. denotes the point of separation between complementary and competitive effects of forage on grain as point \( M \) in fig. 6. Again it is the substitution ratios as compared to the price or returns ratios which determines which one of the two extreme cropping systems will maximize returns.

**MAXIMUM RETURNS UNDER DIMINISHING RATES OF SUBSTITUTION**

In the central and eastern Corn Belt and other regions where rainfall is abundant or erosion is a definite hazard, those crops which play the same role in the rotation and do not have an interrelated yield effect tend to have similar costs per acre and substitute for each other at constant rates. This is true for barley as compared to oats, soybeans as compared to corn and red clover-brome as compared to alfalfa-brome hay or pasture mixtures. Accordingly, farms do and should produce one or other of the competing crops alone except where combinations are used to meet yield and price uncertainty. In these same regions, forage and grains or other crops not only tend to display complementarity but also to substitute for each other at a diminishing rate. (See table 1.)

Under conditions of diminishing rates of substitution, the optimum profit balance is again determined by the ratio of substitution as compared to ratios of costs and prices (or return through livestock if crops are not sold in the market). For competing crops the following conditions must hold true if income is to be maximized:

1. Gross returns can be maximized when the forage is extended to an acreage where the forage/grain substitution ratio is (inversely) equal to the forage/grain price ratio.
2. When costs per acre
### Table 5. Gross Income, Total Costs and Net Returns Per 100 Acres (for Rotations, Yield and Production Data of Table 2) for the Three Price and Cost Levels of 1940-1944, 1920 and 1947.*

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Gross income**</th>
<th>Total cost†</th>
<th>Net return</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1940-44 prices</td>
<td>1920 prices</td>
<td>1947 prices</td>
</tr>
<tr>
<td>Marshall silt loam, 1938-49</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C.........</td>
<td>$2,130</td>
<td>$1,429</td>
<td>$7,173</td>
</tr>
<tr>
<td>C-O-Cl....</td>
<td>2,709</td>
<td>2,857</td>
<td>6,984</td>
</tr>
<tr>
<td>Marshall silt loam, 1941-49</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C.........</td>
<td>$1611</td>
<td>$1,081</td>
<td>$5,427</td>
</tr>
<tr>
<td>C-O-Cl....</td>
<td>3,393</td>
<td>3,602</td>
<td>8,704</td>
</tr>
<tr>
<td>Clarion-Webster silt loam, 1915-48</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C.........</td>
<td>$3,080</td>
<td>$1,960</td>
<td>$10,200</td>
</tr>
<tr>
<td>C-O-Cl....</td>
<td>3,534</td>
<td>3,503</td>
<td>9,762</td>
</tr>
<tr>
<td>Clarion-Webster silt loam, 1945-48</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C.........</td>
<td>$2,479</td>
<td>$1,578</td>
<td>$8,211</td>
</tr>
<tr>
<td>C-O-Cl....</td>
<td>3,565</td>
<td>3,510</td>
<td>9,885</td>
</tr>
<tr>
<td>Clarion-Webster silt loam, 1937-43</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C.........</td>
<td>$3,579</td>
<td>$2,645</td>
<td>$8,402</td>
</tr>
<tr>
<td>C-C-W-A....</td>
<td>4,721</td>
<td>4,474</td>
<td>10,024</td>
</tr>
<tr>
<td>C-W-A......</td>
<td>5,186</td>
<td>5,866</td>
<td>10,193</td>
</tr>
<tr>
<td>C-W-A-A......</td>
<td>5,340</td>
<td>5,975</td>
<td>10,180</td>
</tr>
<tr>
<td>Drummer silt loam, 1904-49 (no treatment)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C.........</td>
<td>$2,117</td>
<td>$1,435</td>
<td>$5,641</td>
</tr>
<tr>
<td>C-O-Cl....</td>
<td>2,375</td>
<td>1,732</td>
<td>5,555</td>
</tr>
</tbody>
</table>

*Basic production data for this table are those set forth in table 1.

**Iowa Crop Reporting District 7 and District 5 prices were used in computing gross income for rotations on Marshall soils and on Clarion-Webster soils respectively. Ohio prices were used for rotations on Canfield-Wooster soils and Illinois prices for those on Drummer soils.

†Costs included were overhead and operating tractor costs, fixed machinery costs, seed costs, building costs, real estate taxes, operator labor costs, and those costs such as handling and hauling that vary with output.
are similar or identical, net income also can be maximized when forage is extended to an acreage where the substitution ratio is (inversely) equal to the ratio of market prices (or returns if the crops are fed to livestock). (3) When costs are not identical, the same conditions exist for profit maximization except the substitution ratio must be compared with the net price ratio (market prices less production costs per unit).

The conditions outlined above can be illustrated for gross returns with the data from the Clarion-Webster experiment (table 1) over the period 1915-48 when the average relationship between forage and grain was competitive. Under the substitution ratios realized for the entire period, gross income could be increased by a shift from the continuous corn to the C-C-O-Cl rotation as long as the price per pound of grain is not more than 8.0 times the price of hay. For example, with corn at $1.12 per bushel and hay at $18 per ton (a price of 2.0 cents per pound for grain and 0.9 cents per pound for hay, a grain/hay price ratio of 2.22:1.0) the C-C-O-Cl rotation would gross more than the continuous corn since 8 pounds of hay are gained for each pound of grain sacrificed (a grain/hay substitution ratio of 1.0:8.0). For each pound of grain sacrificed 2 cents (1.0 x 2.0) would be given up for a gain of 7.2 cents (8.0 x 0.9) from forage. However, at these same prices, the C-O-Cl rotation would always gross less than the C-C-O-Cl rotation. Giving up a pound of grain in this case would mean a gain of only 0.2 pound of hay (substitution ratio of 1.0:0.20). A gain of .18 cent from hay is realized for each loss in 2.0 cents from grain.

Similar relationships can be computed for net returns from the data of table 5. Three different price and cost levels were selected to illustrate varying grain-forage price relationships. In 1920, forage prices were high relative to grain prices; in 1947, the reverse was true. The grain-forage price ratios of 1940-1944 fall in between the 1920 and 1947 extremes and come fairly close to representing the longer-run grain-forage price ratios. As has already been pointed out, grain-forage price relationships are unimportant in instances where forage is complementary with grain output. This is illustrated by the rotations on Marshall soil, 1941-1949, on Drummer soil, 1904-1949, on Clarion-Webster soil, 1945-1948 where C-C-O-Cl is compared with continuous corn, and on the Canfield-Wooster soil where C-C-C-V-V-A is compared with continuous corn. At each of the three different price and cost levels (each char-

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8The grain/hay price ratio (2.22:1.0) is (inversely) less than the grain/hay substitution ratio (1.0:8.0). Therefore, a move from continuous corn to C-C-O-Cl would mean a larger gross income since the maximum gross income would be reached at a point where the substitution ratio just equaled the inverse price ratio.

9The grain/hay price ratio (2.22:1.0) is (inversely) greater than the grain/hay substitution ratio (1.0:0.20). Accordingly a shift from C-C-O-Cl to C-O-Cl would be a movement away from the maximum gross income.
acterizing a different grain-forage price relationship) C-O-Cl, in the first two instances and C-C-O-Cl and C-C-C-W-A in the third and fourth instances respectively, net higher returns than continuous corn. However, in all the other situations—Marshall soil, 1933-1949, Clarion-Webster soil, 1915-1948, and Canfield-Wooster soil, 1937-1943 (for rotation of C-C-C-W-A and those including a relatively larger proportion of forage crop) grain-forage price relationships and the costs of producing forage and grain do become important in determining the most profitable rotation. This is true since in all these situations forage output is competitive with grain production, i.e., total grain output is sacrificed for each expansion in forage acreage and output.

For Marshall soil, 1933-1949, C-O-Cl nets a higher return than continuous corn at both the 1940-1944 and 1920 price levels. This is the case since 14 pounds of clover hay is gained for every pound of grain sacrificed in a choice of C-O-Cl for continuous corn; and during neither price period is the price per pound of corn or oats 14 or more times that of the price per pound of clover hay, and the total costs for the C-O-Cl rotation are not enough higher than the total costs for continuous corn to make the 3-year rotation less profitable. In 1947, however, grain prices were high relative to those for forage (the price per pound of corn was almost eight times that of the price per pound of forage).

At first glance it would seem that the C-O-Cl rotation should still bring in a higher net return than continuous corn since only 1 pound of grain is given up for every 14 pounds of forage gained. However, within any one year it is seldom that two grains are priced the same per pound. When this is true the grains cannot be considered as a single crop under a single price. In 1947, the price per pound of oats was approximately only 0.6 times that of a pound of corn. In terms of corn thus only 16,338 pounds of oats are gained instead of 26,784. The total grain produced therefore (in terms of corn) from the C-O-Cl rotation is 138,709 pounds instead of 149,122. Thus the total grain sacrificed for the 110,880 forage is 18,203. Thus only 6.1 pounds of forage are gained for each pound of grain given up. The grain-forage price ratio is thus one of the reasons why continuous corn produces a higher net return; the other reason is that the total costs for C-O-Cl are relatively higher.

For the Clarion-Webster soil, 1915-1948, the continuous corn and C-C-O-Cl comparisons are exactly as those above. A C-C-O-Cl and C-O-Cl comparison shows that the former brings in a higher net return at all the given price levels and relationships. The reason for this is that such a small amount of forage is gained (0.2 pound) for each pound of grain given up when the C-O-Cl rotation is chosen instead of C-C-O-Cl and the price of forage relative to that of
grain is in no instance sufficiently high to compensate for this relatively low forage-grain substitution ratio even though the total costs for the C-O-Cl rotation are a trifle lower than for C-C-O-Cl. In a C-C-O-Cl and C-O-Cl comparison for the Clarion-Webster soil, 1945-1948, enough hay is gained (1.4 pounds) for every pound of grain given up when C-O-Cl is chosen for C-C-O-Cl so that the 3-year rotation nets the higher return in 1920 when forage prices were relatively high when compared to those of grain.

For the Canfield-Wooster soil, 1937-1943, C-W-A nets the highest return at the 1940-1944 price level. In all the other rotations that include a larger forage acreage and output, not enough forage is gained for the grain given up to offset higher prices for grain as compared to forage and the cost differences. However, at the 1920 price level and price relationships, the price of forage was sufficiently high when compared to grain prices to offset the diminishing marginal rate of substitution of forage for grain so as to make the C-W-A-A rotation the most profitable. At 1947 prices (when the prices of grain were high relative to forage prices) the C-W-A rotation again nets the highest returns. This is true even if some grain must be sacrificed for a gain in forage in a choice of C-W-A for C-C-C-W-A. The reason for this is that the price per pound of wheat was somewhat higher than for corn and the C-W-A rotation includes a larger acreage and output of wheat than does the C-C-C-W-A rotation.

It is relationships of the nature outlined above between substitution, cost and price ratios which cause any one particular rotation to be most profitable at any one price level.

While it is not a necessary condition, a pure grassland type of farming is generally most profitable only when substitution of forage for grain in the rotation is at a constant rate. When substitution rates diminish at a rapid rate such as for the Canfield-Wooster soils (table 1), maximum returns are expressed in rotations considerably short of continuous hay (a pure grassland system of farming with all land in hay). Where the substitution rate is extremely low, as for Clarion-Webster soils (between C-C-O-M and C-O-M) rotations, maximum profits come with a rotation which includes only enough hay that the complementary effect of grasses and legumes is exhausted (the rotation which allows maximum grain production from a given acreage of land).

It is true, of course, that the degree of complementarity or competition varies over time for a given soil type, as changes in soil tilth, virgin fertility and soil erosion occur under particular cropping systems. A changing economic premium is expressed for forage as compared to grain even for a given ratio of market prices or ratio of returns from grain and roughage when utilized through livestock.
THE ENDS OF SOCIETY AND MAXIMUM WELFARE

The use of resources which are economically most desirable from the standpoint of national welfare generally parallel those set out above.

From both the national (and most individual farmers’) standpoint, a particular cropping or land use pattern is not itself an end. Instead it is a means to an end. The end to which alternative cropping systems should be directed is that of maximizing the total satisfactions over the period which the individual or society deems relevant. The most efficient cropping pattern from the national standpoint is the one which provides the community of consumers with the range and quantity of farm products which it most desires relative to nonfarm products. Aside from market imperfections and uncertainty, the conditions which define the optimum cropping pattern for the nation’s consumers generally parallel those set out above. Over a period long enough that complementary effects can be expressed, the welfare of society can never be maximized with a forage acreage short of that necessary for complementary effects to be exhausted (point M in the example of fig. 6 or the C-C-C-W-A as compared to the continuous corn rotation for Canfield-Wooster soils in table 1). Rather than a forage acreage short of this quantity, society could always obtain a greater output of forages and grain from fewer acres of land and a smaller input or cost of capital and labor by extending forage on particular soils up to the point at which grasses and legumes become competitive with grain or other crops. Too, the quantity of forage which is optimum for society when crops are competitive is again that which equates price ratios and substitution ratios in the general manner outlined above.

Since forage and nonforage crops are complementary only over time (as grains, for example, have time to benefit from the improved soil tilth, and the nitrogen added or the erosion control provided by previous forage crops on a given piece of land), cropping systems should not be looked upon as fixed and inflexible. There are times when either a nation or an individual is faced with major emergencies which require that stores of fertility built up in previous periods be drawn upon to avert catastrophes. The need of a nation for food during war or the need of a farmer for income to meet sickness is for the point in time of the emergency rather than for a later point in time in which forage planted at the present can be reflected in grain or fiber production.

Flexibility in cropping patterns to meet changing requirements over time is especially important on those soils where the erosion hazard is not great and where permanent destruction of soil tilth is not a danger.

The introduction of flexibility considerations is consistent with
the conditions outlined previously of maximizing economic returns through equating substitution ratios with price, return and cost ratios. Under a changing economic environment, the price and cost ratios expressive of changes in market demand and national need also vary, thus causing maximum returns to be realized with a different cropping combination.

TIME AND DECISION-MAKING

Crops are complementary only over time. Within a single year, an increased acreage and production of forage crops can come only at the expense of both acreage and production of grain crops. This condition is parallel for that of grain or other crops which fill the same role in the rotation and do not contribute to the yield of each other. Grain crops benefit in yield only as they respond to the added nitrogen, the improved soil tilth, and the increased erosion control provided by previous seedings of grasses and legumes. Too, the degree to which forages are complementary with grain depends on the store of nitrogen already present and on the existing soil tilth, particularly on level soils. If these are originally high and if there is no serious loss of top soil through erosion, the complementary effect of forages will not be expressed until the fertility and soil tilth has been depleted to a level where grain crops respond sufficiently to the improved soil tilth and nitrogen added by forages. If the content of these is low on the farm when a particular operator moves on, forages may have a complementary effect on any one field immediately after one round of the rotation. As table 6 indicates, forages did not become complementary on Marshall silt loam until the tenth year. Of course, the length of time might well have been less for a farm or tract of soil which had been heavily cropped or under other weather conditions, while it might have been longer for soils where the original level of fertility and organic matter were higher and the degree of erosion was less. Under the experiment on Clarion-Webster soils, a complementary relationship was not expressed for 30 years.

Many farm operators make their decisions for a definite period of time. For a beginning operator whose ability to remain a farmer depends on his returns in the next 5 years or for an owner with a low equity in his farm and who must secure his capital position before prices fall, the relationship between crops over the next 5 years, for example, may be equally or more important than their relationship over the next 20 years. To illustrate with reference to table 6, the average net value of crops for the period 1933-1940 for continuous corn was $318 compared to $129 for C-O-Cl using actual prices and costs; using 1940-44 prices and costs, a similar comparison shows $1,081 for continuous corn and $404 for C-O-Cl. Thus during the first 8 years of the entire period continuous corn
### Table 6. Total Production of Crops and Costs and Returns Under Two Price Situations, Marshall Silty Loam, 1933-49. (100 Acres of Land.)

<table>
<thead>
<tr>
<th>Year</th>
<th>Total production of grain (corn equivalent)*</th>
<th>Gross value of crops**</th>
<th>Net value of crops</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Continuous corn rotation</td>
<td>C-O-CI rotation</td>
<td>Continuous corn rotation</td>
</tr>
<tr>
<td></td>
<td>Actual prices 1940-44 prices</td>
<td>Actual prices 1940-44 prices</td>
<td>Actual prices 1940-44 prices</td>
</tr>
<tr>
<td>1932</td>
<td>3,370</td>
<td>1,027</td>
<td>1,995</td>
</tr>
<tr>
<td>1933</td>
<td>5,700</td>
<td>2,535</td>
<td>912</td>
</tr>
<tr>
<td>1934</td>
<td>4,360</td>
<td>2,138</td>
<td>2,180</td>
</tr>
<tr>
<td>1935</td>
<td>1,350</td>
<td>472</td>
<td>1,477</td>
</tr>
<tr>
<td>1936</td>
<td>3,510</td>
<td>2,268</td>
<td>1,615</td>
</tr>
<tr>
<td>1937</td>
<td>5,090</td>
<td>2,464</td>
<td>2,036</td>
</tr>
<tr>
<td>1938</td>
<td>4,080</td>
<td>2,477</td>
<td>1,958</td>
</tr>
<tr>
<td>1939</td>
<td>3,480</td>
<td>2,767</td>
<td>1,636</td>
</tr>
<tr>
<td>1940</td>
<td>1,740</td>
<td>3,182</td>
<td>1,079</td>
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<td>1941</td>
<td>2,040</td>
<td>2,359</td>
<td>1,510</td>
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<tr>
<td>1942</td>
<td>2,570</td>
<td>3,261</td>
<td>2,570</td>
</tr>
<tr>
<td>1943</td>
<td>1,870</td>
<td>3,548</td>
<td>1,814</td>
</tr>
<tr>
<td>1944</td>
<td>2,430</td>
<td>3,611</td>
<td>2,454</td>
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<tr>
<td>1945</td>
<td>2,720</td>
<td>3,150</td>
<td>3,074</td>
</tr>
<tr>
<td>1946</td>
<td>4,198</td>
<td>2,146</td>
<td>6,866</td>
</tr>
<tr>
<td>1947</td>
<td>1,770</td>
<td>3,693</td>
<td>2,159</td>
</tr>
</tbody>
</table>


**Iowa Crop Reporting District 7 prices were used to compute gross values. Costs included were similar to those indicated in footnote 3, table 5, this bulletin.
averages a higher net return than C-O-Cl, whereas for the period as a whole C-O-Cl averages relatively higher net returns. Individuals operating on a farm with a high state of fertility, a small erosion hazard and under these economic circumstances outlined above may more nearly attain the short-run goal by growing a large acreage of grain (even if forages and grain are complementary in the long run). A greater acreage of forage can then be included as the relevant period of short-run decision-making has passed and fertility and soil tilth has dropped to a level where grasses or legumes benefit grain yields to an extent that complementarity is expressed in a short time period. At the other extreme, the operator who buys a farm that has been heavily cropped, has a large equity and is concerned with planning over a 20- or 30-year period may well realize greatest returns by an immediate shift to a rotation which allows full expression of forage complementarity.

In order for a pure grassland or a grazing type of farming to be more profitable than a system of farming which includes both grains and forages, the ratio at which forage substitutes for grain between rotations (a low grain yield as compared to forage yields) must be extremely high relative to price ratios which have existed in the past. (See table 7.)

**ROTATIONS FOR RENTED FARMS**

A large amount of grain is grown relative to the acreage of forage on many rented farms. This tendency is expressed for one soil area in the data for tenant and owner-operated farms (table 8). Numerous forces tend to explain the difference in cropping patterns on rented and owner-operator farms. One force, the tendency of beginning operators to be short on capital and hence to operate rented farms on a short-run basis, has been mentioned above. Farmers operating under these conditions generally have less roughage-consuming livestock and hence require less forage on the basis of farm organization. However, two properties of leasing systems themselves cause smaller acreage of hay or pasture on rented farms than on owner-operated farms. One of these is short-term leases. Forage can never be viewed as a complementary crop by the tenant who will be on a farm for a single year since the yield-effects of grasses or legumes on grain come only in later years. The other is the attempt of some landlords to equalize returns per acre between crops by placing a cash rent on hay or pasture which will bring income up to that realized from the share of grain crops. In many instances the cash rent is so high that it penalizes production of

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10 Again, the conditions which give rise to the necessity of short-run decisions are those stemming from market imperfections and uncertainties. Adjustment of cropping systems to meet risk and uncertainty do cause inefficient use of resources for the nation as a whole and perhaps over time for the individual farmer. However, these imperfections are those to be improved through market analysis.
TABLE 7. PRICES FOR SPECIFIED GRAIN AND HAY CROPS, IOWA, 1910-44,
1910-29, 1930-39 and 1940-44.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Price per ton or bushels</th>
<th>Grain/hay price ratio (price per pound of grain divided by price per pound of hay)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn ...........</td>
<td>.716</td>
<td>.771</td>
</tr>
<tr>
<td>Oats ............</td>
<td>.387</td>
<td>.413</td>
</tr>
<tr>
<td>Soybeans ..........</td>
<td>1.53*</td>
<td>2.42**</td>
</tr>
<tr>
<td>Wheat .............</td>
<td>1.07</td>
<td>1.23</td>
</tr>
<tr>
<td>Alfalfa hay .......</td>
<td>14.17</td>
<td>16.44</td>
</tr>
</tbody>
</table>

*1923-1944.
**1923-1929.
Source: Records of Iowa Crop and Livestock Reporting Service.

TABLE 8. CROPPING PATTERN ON A RANDOM SAMPLE OF FULL OWNER AND SHARE RENTED FARMS IN THE IDA-MONONA SOIL AREA OF IOWA.

<table>
<thead>
<tr>
<th>Tenure</th>
<th>Percent of farm in grain</th>
<th>Percent of farm land in forage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Share renters</td>
<td>69.8</td>
<td>30.2</td>
</tr>
<tr>
<td>Full owners</td>
<td>50.6</td>
<td>49.4</td>
</tr>
</tbody>
</table>


forages even where they are complementary with grain. The possible outcome here can again be illustrated with the yield and cost data of tables 1 and 2, respectively. As already pointed out the owner-operator (or cash tenant) can always increase gross income (even with no return from hay), lower costs, and hence net income by switching from a continuous corn to a C-O-Cl rotation where forage is complementary to grain as is true in the period 1941-49 on Marshall silt loam. Even if he gets no return from hay, he can lower his total costs and increase total grain production by shifting land from grain to hay and leaving the hay down as a green manure crop. Yet this method of lowering costs is not always open for the tenant. With a growing cost of $6.69 and a cash rent of $15.00, the cost of growing an acre of hay is greater than the growing and harvesting cost of corn. He can grow hay profitably only if the increase in return from grain and hay is greater than the increase in costs associated with the cash rent. Evidently many tenants feel that returns are greatest when the hay acreage is small.

These characteristics of leasing systems need not penalize forage production on the rented farm, however. In the first place, returns to both the tenant and landlord can be increased by removal of arrangements which restrict forage acreage within the complementary range. For example, rather than restrict hay acreage to 20 acres on a farm through a cash rent for hay and pasture of, say, $20.00 per acre, where 40 acres can be grown before the limits of
complementarity have been reached, the landlord could get a greater return if he were to charge a flat cash rent of $300.00 and encourage the tenant to include 40 acres of hay in the cropping system. He would realize the same cash rent yet would receive a share of a greater total grain production (as in moving from the continuous corn to the C-C-C-W-A rotation on Canfield-Wooster soils in table 1). The tenant would pay out the same cash rent and also would share in a greater total grain production.

It is doubtful that landlords should ever attempt to equalize returns from grain shares and cash rent on hay or pasture when the forages are still complementary with grain. Rental arrangements should be of a nature to equalize returns between hay or pasture and other crops only when the forage acreage has been extended to the stage of enterprise competition. Too, if the landlord and tenant together plan a cropping system with a forage acreage never short of the complementary limits, the difficulty of short-term leases can be alleviated. If this quantity of forage, aside from fluctuations due to seeding failures, is a minimum specification for the farm and for all tenants, the gain to the oncoming tenant always compensates him for any return he might forego in his last year in leaving meadows down.

SUBSTITUTION OF FORAGES IN EROSION CONTROL OR FOR OTHER SOURCES OF NITROGEN AND ORGANIC MATTER

Forage crops may be grown either for (1) the direct return which can be realized from their sale and utilization through livestock as competitive crops, or (2) the indirect return which can be realized from them through their contribution as complementary crops to the yield of grains. When grown as complementary crops, grasses and legumes can serve as substitutes for or can be replaced by other forms and sources of nitrogen and organic matter, especially on level soils. For example, the intensive livestock farm which buys a large amount of feed may be able to provide more organic matter and nitrogen from the manure than would result from the growing of legumes. Grain yields may be maintained at an economic level even by continuous grain cropping if supplies of manure are abundant. The farmer living near a stock yard may be able to buy both (1) manure for its organic matter and fertility content and (2) commercial fertilizers. If the supply is adequate, all farmers have the opportunity to buy commercial fertilizers. When organic matter and fertilizer can be obtained and applied in sufficient quantities to grain crops, forages may no longer have a complementary effect on grain production. This fact is illustrated in table 9 for the Illinois Drummer silt loam. While the C-O-Cl rotation yielded more grain than either continuous corn or corn
and oats with a catch-crop plowed under without treatment, it did
not even yield as much total grain as the continuous corn with
treatment of manure, lime and phosphate. Forages are no longer
complementary to grain under similar treatment for all crops.

On rough and hilly land, it is possible for terraces, contouring
and similar practices to serve as a partial substitute for grasses and
legumes in controlling erosion. For example, in 1943, it was esti­
mated$^{11}$ that with practices then current the upper limits of in­
tertilled crops on Iowa's Marshall silt loam of 7-13 percent slope was
40 percent of the rotational acres if the soil was not to be perma­
nently impaired. Of the balance of the rotational acres, it was
estimated that 20 percent could be in small grain and 40 percent
in soil-conserving crops—hay or rotation pasture. With conserva­
tion practices, such as contouring and strip cropping, it was esti­
mated that the acreage of intertilled crops on rotation land could
be increased by 20 percent and that the acreage of soil-conserving
crops could be reduced by 20 percent. The complementary effect
of forages on grain yields then comes mainly through the addition
of fertility and improved soil tilth.

When other sources of nitrogen or organic matter are available,
the question then arises whether these should be furnished through
forages in the rotation or through commercial sources. If profits
are to be maximized, the source should be employed which pro­
vides organic matter and nitrogen at the lowest cost. The cost of
providing home-grown nitrogen and organic matter through rota­
tional arrangements can be computed as the difference in return
to be realized on an acre of hay as compared to grain or other crops.
For example, if a 50-bushel grain yield can be obtained either (a)
through the addition of purchased fertilizer and organic matter or
(b) through addition of forage to the rotation, the costs to be com­
pared are these: (1) the total costs of the commercial sources and

$^{11}$See Englehorn, A. J. and A. C. Bunco. Adjusting crop acreages for war pro­
(2) the total difference in net return from the acres planted to forages rather than grain.

CROPPING SYSTEMS TO MEET RISK AND UNCERTAINTY

Many farmers, especially operators with low equities or beginners with a small supply of capital, are concerned with combining enterprises in a manner which will give the most certain and steady flow of income possible. Some are willing to exchange a combination of enterprises which gives high but highly fluctuating returns for a combination which may give lower but more stable returns. This can be the goal particularly where a farmer "cannot stay in the game" if losses are too great in any one or two years.

Livestock enterprises may especially be selected for purposes of stability. However, crop combinations are also important. Variability in crop returns may be lessened through two general methods including (1) combinations of competitive crops which give more stable returns since all may not be affected equally by price changes or unfavorable weather in a given year, (2) combinations of forages and grains in order that the better soil tilth and nitrogen added by grasses and legumes will prevent yields from dropping so low in years of extremely wet or dry weather, and (3) selecting crops which have low yield or price variability. While price variability may be similar for all crops, yield variability and risk may differ materially between crops. In some areas the risk involved in getting hay stands is great. In other areas hay production represents one of the more stable crops from a yield variability standpoint. A study dealing with the degree of risk and uncertainty involved in Iowa crop production is now under way and will provide information on the manner in which different rotations and cropping systems can reduce the risk and uncertainty of farming.