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ECONOMICS OF CROP ROTATIONS AND FERTILIZER USE IN THE PALOUSE WHEAT-PEA AREA

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Fertilizer increases crop yields. It raises farm income. It shifts the relative income advantages of various alternative crop rotations. With the alchemy of fertilizer, soil-depleting crops can be transformed into soil-conserving crops.

These points are illustrated by a cooperative research study in the Palouse wheat-pea area of Washington and Idaho.[1/] In the last decade, the use of fertilizer and other new developments have revolutionized farming in that area.

The Palouse is one of the most productive wheat-farming areas in the Nation. The soil is rich, and precipitation is usually adequate. Nitrogen is the only major plant nutrient that is generally deficient. Sulfur, a minor plant food, is sometimes deficient for satisfactory crop production. The land is used principally for growing wheat, barley, dry peas, alfalfa hay, green manure crops, and for summer fallow and clean cultivation. Various alternative crop rotations are followed. These rotations differ as to the amount of income they produce. They differ also in the degree to which they conserve or deplete the productivity of the soil. In this steeply rolling area, soil erosion is a problem and soil organic matter is being depleted. The effect that each cropping system has on the future productivity of the land is, therefore, a factor to be considered by farmers in selecting a cropping system.

The incomes expected from various alternative cropping systems were calculated by the farm budgeting method. A main effort required with this research method is the assembly of accurate input-output data. Input requirements and production costs were determined from farm survey and other sources of data. These data were computed for each crop with various sequences of cropping and with varying amounts of fertilizer. The results of experiments conducted by State and Federal agricultural experiment stations in the area constituted a source of information on the effects on crop yields of the sequence of cropping, crop rotations, fertilizer

1/ Pawson, Walter W., Brough, Owen L., Jr., Swanson, Jay P., and Horner, Glenn M., Economics of Cropping Systems and Soil Conservation in the Palouse, Pacific Northwest Agr. Expt. Stas. Regional Research Bul. No. 2 (in process).

use, and other practices.[2] These data were supplemented by records of crop yields on more than 800 fields on farms during a 5-year period. For each individual field for which yield data were obtained, data were also obtained concerning the past cropping history, use of fertilizer, and other factors that influenced yields. The effects of these factors on crop yields on farms were analyzed by multiple regression techniques. The normal crop yields that an average farmer can expect to obtain with various farming practices were established jointly by agronomists and agricultural economists from an evaluation of the data from experimental plots and from farmers' fields. The cooperation of economists and physical scientists is important in this type of research. It is also desirable that experimental data on crop yield relationships be supplemented by similar data from farms. The levels of yields on experimental plots are generally higher than those attained by farmers, and there is no constant relationship between yields of different crops grown with specified practices on experimental plots and on farms.

Cropping Sequence, Rotation, and Fertilizer Influence Yields

One reason why farmers rotate crops is because of the effect on crop yields. This is illustrated by figure 1. When no fertilizer is used, yields of wheat grown in different sequences of cropping show wide differences. Normal yields range from 21 to 48 bushels per acre without fertilizer, depending on the previous use of the land. Nitrogen fertilizer increases markedly the yield of wheat and other small grains. It partly offsets the effect of the sequence of cropping. With heavy fertilization, the yield of wheat after grain or peas approaches the yield obtained after fallow, clean cultivation, alfalfa hay, or alfalfa green manure. The quantity of fertilizer that is required to correct the deficiency in available soil nitrogen differs according to the previous use made of the land.

Experiments have shown that a point is ultimately reached at which no further gain in yield occurs with the application of additional fertilizer; yields sometimes decline if a still larger quantity of fertilizer is applied. The maximum yield from the application of nitrogen fertilizer usually occurs at the point at which available soil moisture becomes the limiting factor, other nutrients become limiting, or lodging occurs. Yields of wheat with varying amounts of nitrogen fertilizer were calculated from the exponential equation shown in figure 1. This equation is similar to those used by Mitscherlich, Spillman, Ibach, and others.[3] Yields were not

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2/ Horner, G. M., Oveson, M. M., Baker, G. O., and Pawson, W. W., Effect of Cropping Practices on Yield, Soil Organic Matter, and Erosion in the Pacific Northwest Wheat Region, Pacific Northwest Agr. Expt. Stas. Regional Research Bul. No. 1, July 1960.

3/ Mitscherlich, E. A., Zum Gesetz von Minimum, Eine antwort an TH., Pfeiffer und seine mitarbeiter, Landw. Vers. Sta. 77: [413] - 428, 1912.

Spillman, W. J., Use of the Exponential Yield Curve in

Figure 1. Normal Yield of Wheat in Palouse Wheat-Pea Area as Affected by Cropping Sequence and Nitrogen Fertilizer Use

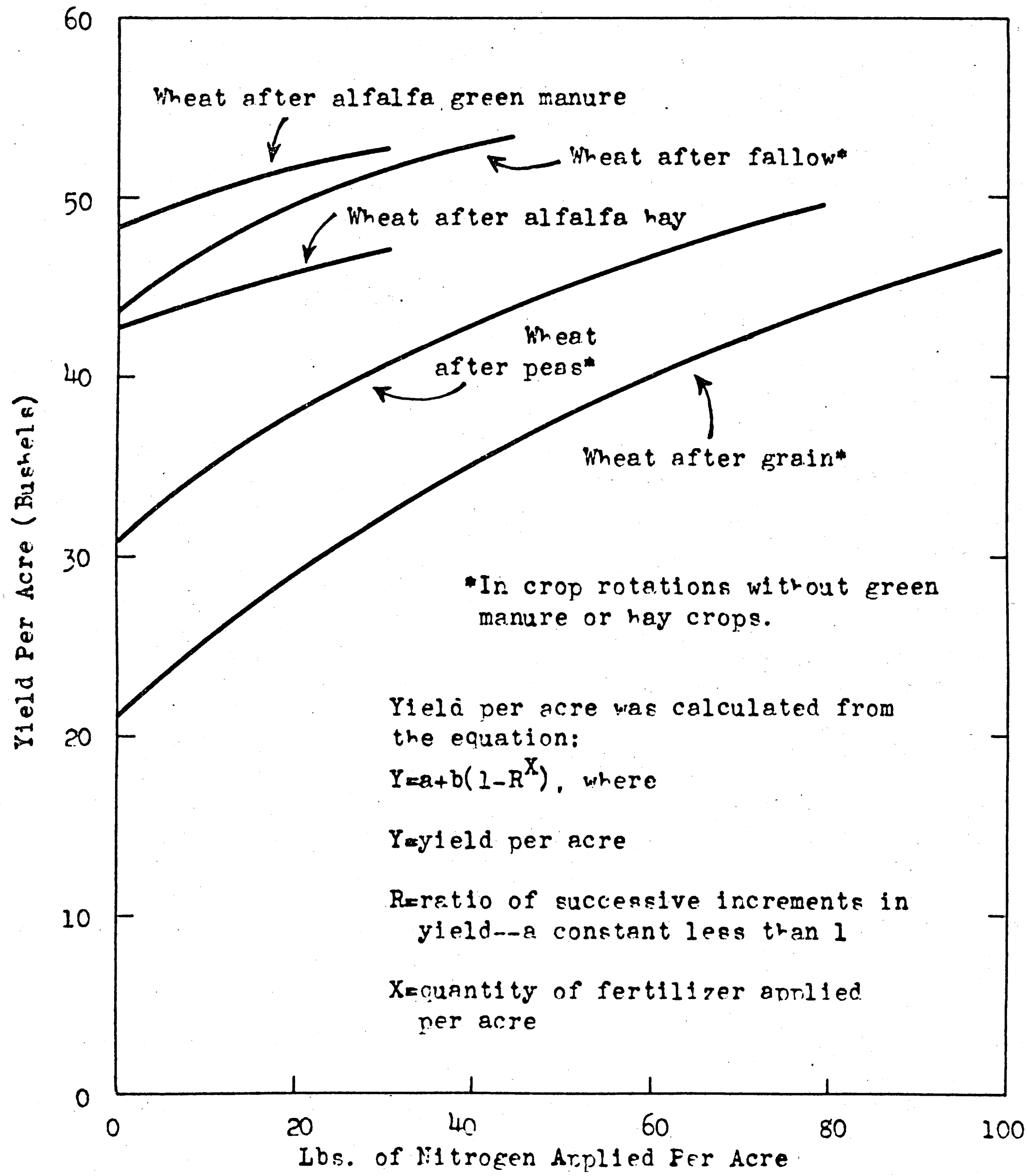


Figure 2. Normal Yield of Wheat After Peas in Rotations With Alfalfa Hay Compared With That in Rotations Without Green Manure or Hay Crops

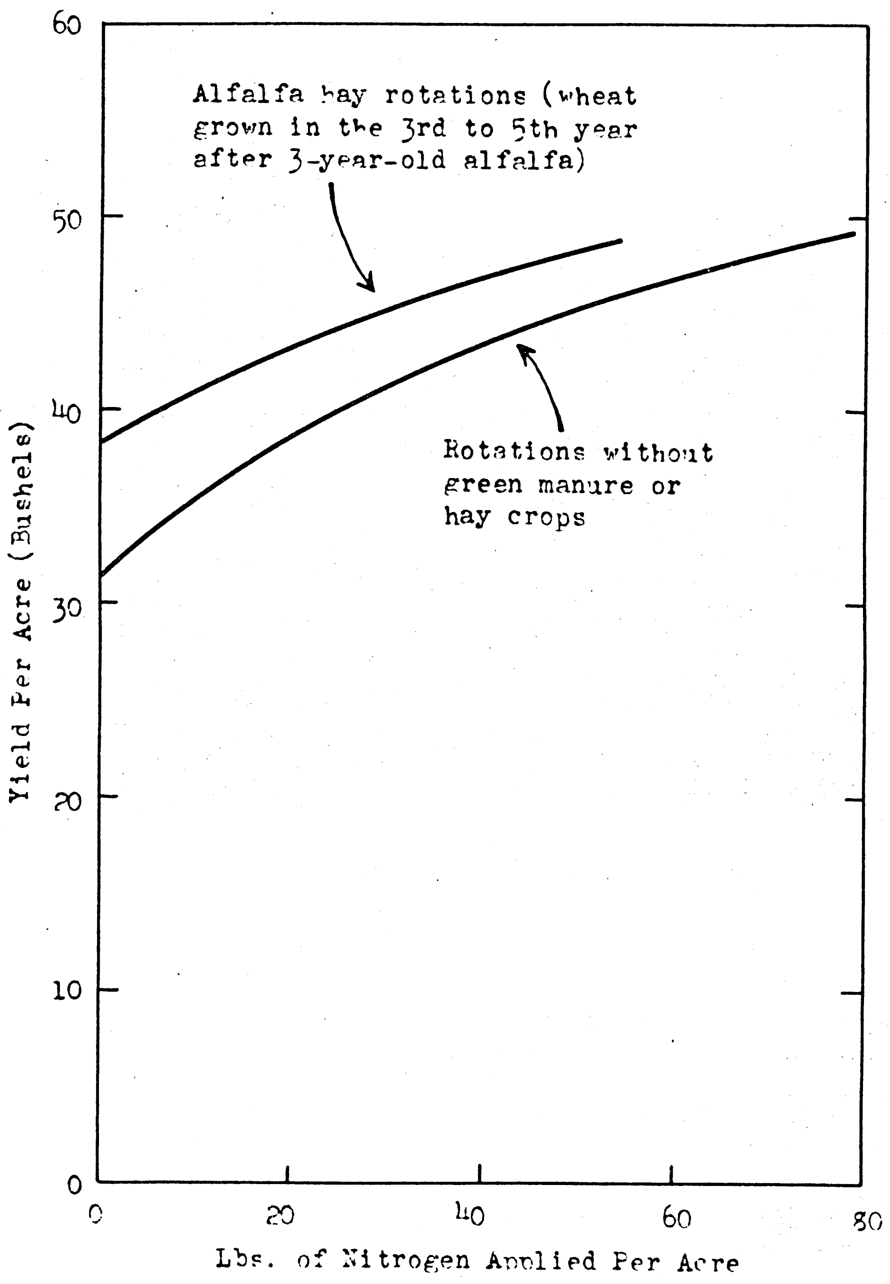
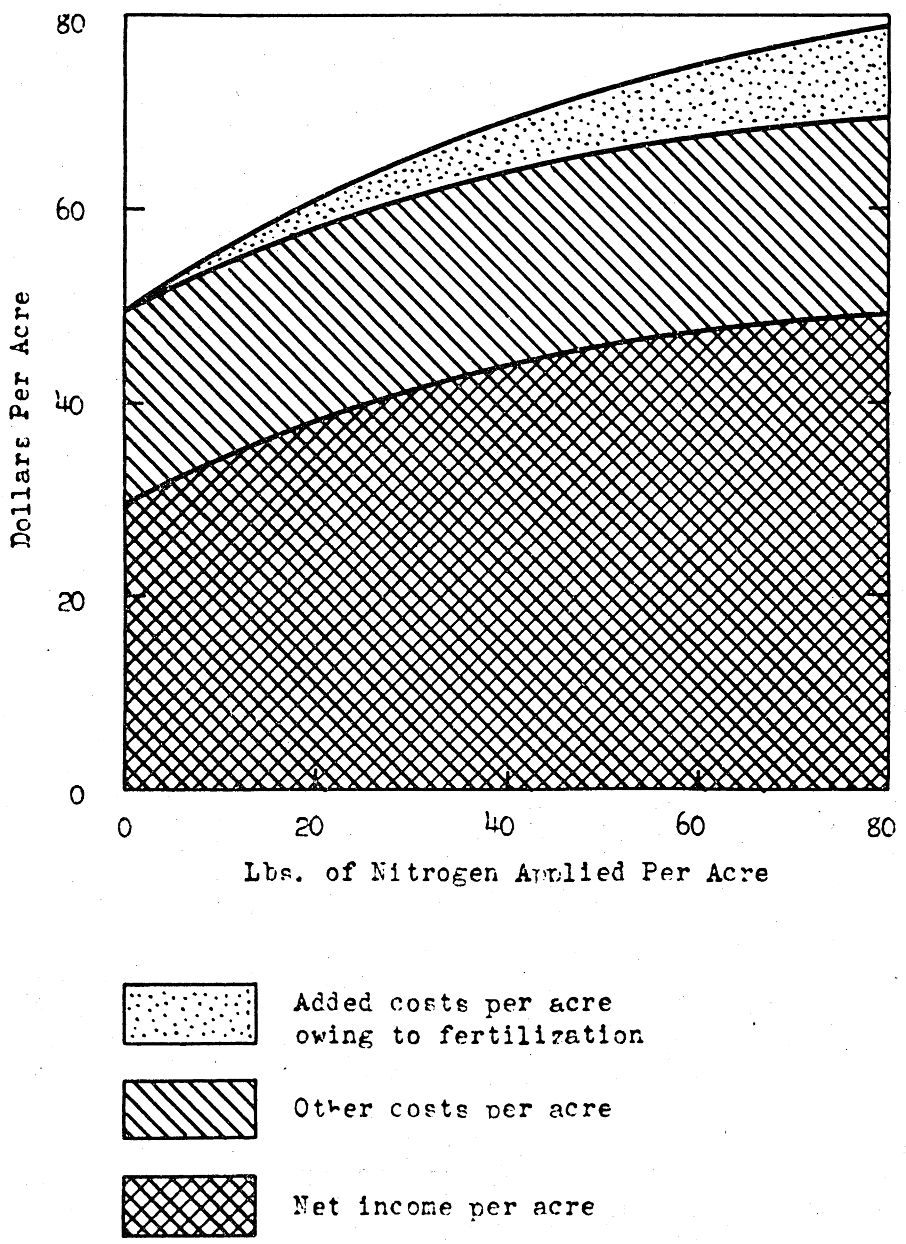


Figure 3. Effect of Nitrogen Fertilizer on Costs and Returns per Acre for Wheat After Peas in Crop Rotations Without Green Manure or Hay Crops in Palouse Wheat-Pea Area



extrapolated for rates of fertilization higher than the maximum rate that agronomists and others familiar with the area consider safe to apply in a normal year, based on presently available data.

No data are available on the effect of different quantities of sulfur fertilizer on yields. Where nitrogen fertilizer is applied, it is assumed to be supplemented by the application of sulfur in an amount that agronomists consider to be adequate for maximum yields.

Leguminous green manure or hay crops increase the yield of grain crops that follow them in the rotation (figure 2). Alfalfa that is at least 3 years old substantially increases the yield of succeeding crops of wheat for 10 or more years after the alfalfa is plowed up.

Effect of Nitrogen Fertilizer on Income Per Acre From Wheat

Figure 3 shows the effect of nitrogen fertilizer on gross income, costs, and net income per acre for wheat after peas. Net returns increase, but more slowly, as nitrogen applied per acre is increased. The maximum profit in all sequences of cropping is obtained with the highest rate of fertilization considered. Presently available experimental data are inadequate to determine the optimum economic rate of fertilization--the point at which marginal costs and returns are equal. In each sequence of cropping, however, the highest rate considered is more profitable than any lesser quantity of fertilizer would be. This is true not only with present price-cost relationships but also with a lower price for wheat and a higher cost for fertilizer. These rates, therefore, were used as the basis for determining the income potentialities of alternative crop rotations with nitrogen fertilizer.

Wheat is King

Wheat is by far the most profitable crop grown in the Palouse. At prices prevailing in recent years, the net income per acre from heavily fertilized wheat is two to six times greater than that from barley or peas and many times greater than the direct income from alfalfa hay. Wheat would need to be much lower in price than it is now to change this relationship.

Fertilizer Experiments, U. S. Dept. Agr. Tech. Bul. 348, 1933.

Ibach, D. B., and Mendum, S. W., Determining Profitable Use of Fertilizer, U. S. Bur. Agr. Econ., F. M. 105, June 1953.

Willcox, O. W., Agrobiologic Percentage Method of Evaluating Fertilizer Tests: I, Soil Science, 79:467-473, 1955.

Willcox, O. W., Agrobiologic Percentage Method of Evaluating Fertilizer Tests: II, Soil Science, 80:75-83, July 1955.

Farm Income From Alternative Crop Rotations

Six crop rotations adapted to the area were selected for study (table 1). These include an alternate wheat-fallow rotation and an alternate wheat-pea rotation. In a wheat-pea rotation or almost any other system of annual cropping, despite use of herbicides, it is necessary to clean cultivate the land intensively during the fallow season at intervals of years to control weeds. The recropped wheat rotation could otherwise be described as continuous wheat. Three rotations include alfalfa green manure or hay. Alfalfa is seeded with a companion crop of peas, and is plowed under for green manure the following year or cut for hay in 2 years. After alfalfa hay, the land is cropped for a number of years either to alternate wheat and peas or to recropped wheat.

Note the differences in the percentages of cropland in wheat in the various rotations when there are no acreage restrictions on wheat.

A farm of average size containing 520 acres of cropland is used to illustrate costs and returns under different crop rotations with and without the use of nitrogen fertilizer. Farm income was computed in terms of prices prevailing in recent years. The effect of higher or lower relative prices for different crops was also considered. Cropping systems were evaluated on two bases: (1) Without regard to current wheat acreage restrictions, and, (2) within the framework of present wheat acreage allotments.

Farm Income From Various Crop Rotations, Assuming No Wheat Acreage Restrictions

When nitrogen fertilizer is not used and there are no restrictions on the acreage of wheat that may be planted, a 12-year alfalfa hay rotation with wheat and peas produces the highest net income (table 2). The income from this cropping system is about 4 percent more than from a wheat-pea rotation. Although the direct income from alfalfa hay is low, alfalfa substantially increases the yield of and the net returns from crops that follow it in the rotation--especially wheat. The higher net income peracre from wheat tends to compensate for the smaller wheat acreage. Because of better weed control with alfalfa hay rotations, there are fewer acres of clean cultivation. A larger proportion of the land, therefore, is used for growing harvested crops from which an income is obtained.

Without fertilizer, a recropped wheat rotation is the least profitable system because the yield of wheat is so low that returns are small.

With nitrogen fertilizer and a favorable price for wheat, a recropped wheat rotation produces a greater income than any other cropping system (table 2). Assuming use of nitrogen fertilizer and no restrictions on wheat acreage, the net incomes produced by the various crop rotations are directly associated with the percentages of cropland in wheat. These range from about 33 percent with a 3-year alfalfa green manure rotation to nearly 86 percent with a recropped wheat rotation. With no wheat acreage

TABLE 1. Sequence of Cropping and Percentage of Cropland in Specified Uses for Six Selected Crop Rotations in the Palouse Wheat-Pea Area[a/]

Item	Rotations Without Green Manure or Hay Crops				Alfalfa Hay Rotation	
	Wheat-Fallow Rotation	Wheat-Pea Rotation	Recropped Wheat Rotation	Alfalfa Green Manure Rotation	12-Year Rotation with Wheat and Peas	12-Year Rotation with Re-cropped Wheat
	Yr. Land Use	Yr. Land Use	Yr. Land Use	Yr. Land Use	Yr. Land Use	Yr. Land Use
Sequence of Cropping	1 Fallow 2 Wheat	1 Peas 2 Wheat 3 Peas 4 Wheat 5 Clean Cult. 6 Wheat	1 Wheat 2 Wheat 3 Wheat 4 Wheat 5 Wheat 6 Clean Cult. 7 Wheat	1 Peas &Alf. 2 Alf. Green manure[b/] 3 Wheat	1 Peas &Alf. 2 Alf. Hay 3 Alf. Hay 4 Wheat 5 Peas 6 Wheat 7 Peas 8 Wheat 9 Clean Cult. 10 Wheat 11 Peas 12 Wheat	1 Peas &Alf. 2 Alf. Hay 3 Alf. Hay 4 Wheat 5 Wheat 6 Wheat 7 Wheat 8 Wheat 9 Clean Cult. 10 Wheat 11 Wheat 12 Wheat
Percentage of Cropland in Various Land Uses With No Wheat Acreage Restrictions:	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
Wheat	50.0	50.0	85.7	33.3	41.6	66.6
Peas	----	33.3	----	33.3	33.3	8.3
Alfalfa Hay	----	----	----	----	16.7	16.7
Green Manure Crops	----	----	----	33.4	----	----
Fallow or Clean Cult.[c/]	50.0	16.7	14.3	b/	8.4	8.4
Total	100.0	100.0	100.0	100.0	100.0	100.0
Percentage of Cropland in Grain With Wheat Acreage Allotments:						
Wheat	32.0	32.0	32.0	32.0	32.0	32.0
Barley	18.0	18.0	53.7	1.3	9.6	34.6
Total Small Grain	50.0	50.0	85.7	33.3	41.6	66.6

a/ "Alf." stands for alfalfa. "Clean Cult." stands for clean cultivation.
b/ Alfalfa green manure crop clean cultivated every third cycle of the rotation.
c/ Represents fallow in the case of a wheat-fallow rotation; clean cultivation in other rotations.

TABLE 2. Effect of Crop Rotations and Nitrogen Fertilizer Use on Yield of Wheat and Net Income on a Typical Farm in the Palouse Wheat-Pea Area

	Average Yield of Wheat Per Acre		Net Income Per Farm a/			
			With No Wheat Average Restrictions		With Wheat Acreage Allotments	
	Without Nitrogen Fertilizer	With Nitrogen Fertilizer	Without Nitrogen Fertilizer	With Nitrogen Fertilizer	Without Nitrogen Fertilizer	With Nitrogen Fertilizer
	Bu.	Bu.	Dol.	Dol.	Dol.	Dol.
Rotations Without Green Manure or Hay Crops						
Wheat-Fallow Rotation	44.0	53.5	10,026	12,584	7,301	9,289
Wheat-Pea Rotation	36.0	50.7	11,006	15,009	8,195	11,714
Recropped Wheat Rotation . .	25.2	48.2	7,807	10,039	9,432	9,397
Alfalfa Green Manure Rotation	48.0	51.5	9,433	10,039	9,220	9,817
Rotations With Alfalfa Hay						
12-yr. Rotation with Wheat and Peas	40.4	49.4	11,432	13,278	10,041	11,682
12-yr. Rotation with Recropped Wheat	32.1	47.9	10,574	16,229	6,827	10,039

a/ Refers to net income to capital and management. The figures are based on the following prices: wheat, \$1.60 per bushel; peas, \$3.50 per cwt.; barley, \$34 per ton; and alfalfa hay, \$15 per ton.

restrictions and at the assumed prices, all crop rotations that include recropped wheat are more profitable than crop rotations that include alternate wheat and peas. Rotations with green manure or hay crops produce less income than similar rotations without such crops.

Nitrogen fertilizer increases the income from some crop rotations more than others because it increases the yield of wheat in some rotations more than in others. The yields of wheat in rotations with leguminous green manure or hay crops--where a fairly high level of available soil nitrogen exists--are increased less by the application of nitrogen fertilizer than are yields in rotations without them (table 2). Therefore, incomes from crop rotations with green manure or hay crops rise relatively little as compared with those from crop rotations without green manure or hay crops. Nitrogen fertilizer more than doubles the net income from a recropped wheat rotation. Without nitrogen fertilizer, yields of wheat vary widely with different crop rotations, but with the use of fertilizer, yields of wheat differ little among various rotations. With adequate fertilization, high yields of wheat can be obtained with any crop rotation.

The crop rotation that is most profitable depends, of course, on the relative prices of different crops. Incomes from some cropping systems are affected more by a change in the price of wheat than those from other systems (figure 4). The lower the price of wheat the less the income advantage that a recropped wheat rotation with fertilizer holds over other rotations. With a very low price for wheat, other rotations return as much or more net income than a recropped wheat rotation.

Figure 5 is a price map which shows the most profitable crop rotation with any specified combination of prices of wheat, peas, and alfalfa hay. This chart assumes heavy use of nitrogen fertilizer and no restrictions on the acreage of wheat. For example, as you will note from that part of the chart with alfalfa hay at $20 per ton, if wheat is priced at $1.60 per bushel and peas at $5 per cwt., "X" marks the spot that is in the area in which the most profitable crop rotation is recropped wheat. If the price of peas were a little higher or the price of wheat lower, a wheat-pea rotation would maximize profits. With wheat at less than $1.25 per bushel and other prices constant, a 12-year alfalfa hay rotation with wheat and peas would be most profitable.

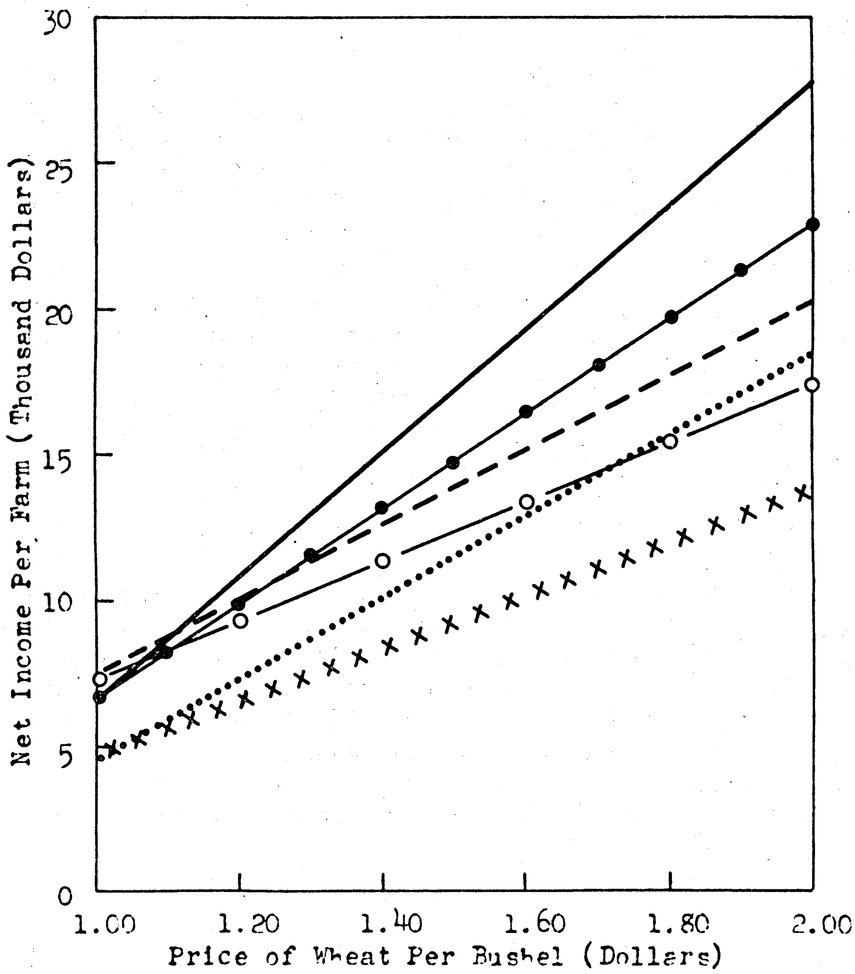
Heady, Buddemeier, and others[4] have set forth economic principles

4/ Heady, Earl O., and Jensen, Harald R., The Economics of Crop Rotations and Land Use, Iowa Agr. Expt. Sta. Res. Bul. 383, 1951.

Heady, Earl O., Economics of Agricultural Production and Resource Use, Prentice-Hall, Inc., New York, 1952, pp. 201-275.

Buddemeier, W. D., Heady, E. O., Janssen, M. R., Jensen, Harald R., and Ottoson, Howard W., Economics of Cropping Systems in the Corn Belt, Nebr. Agr. Expt. Sta. Bul. 429, 1955.

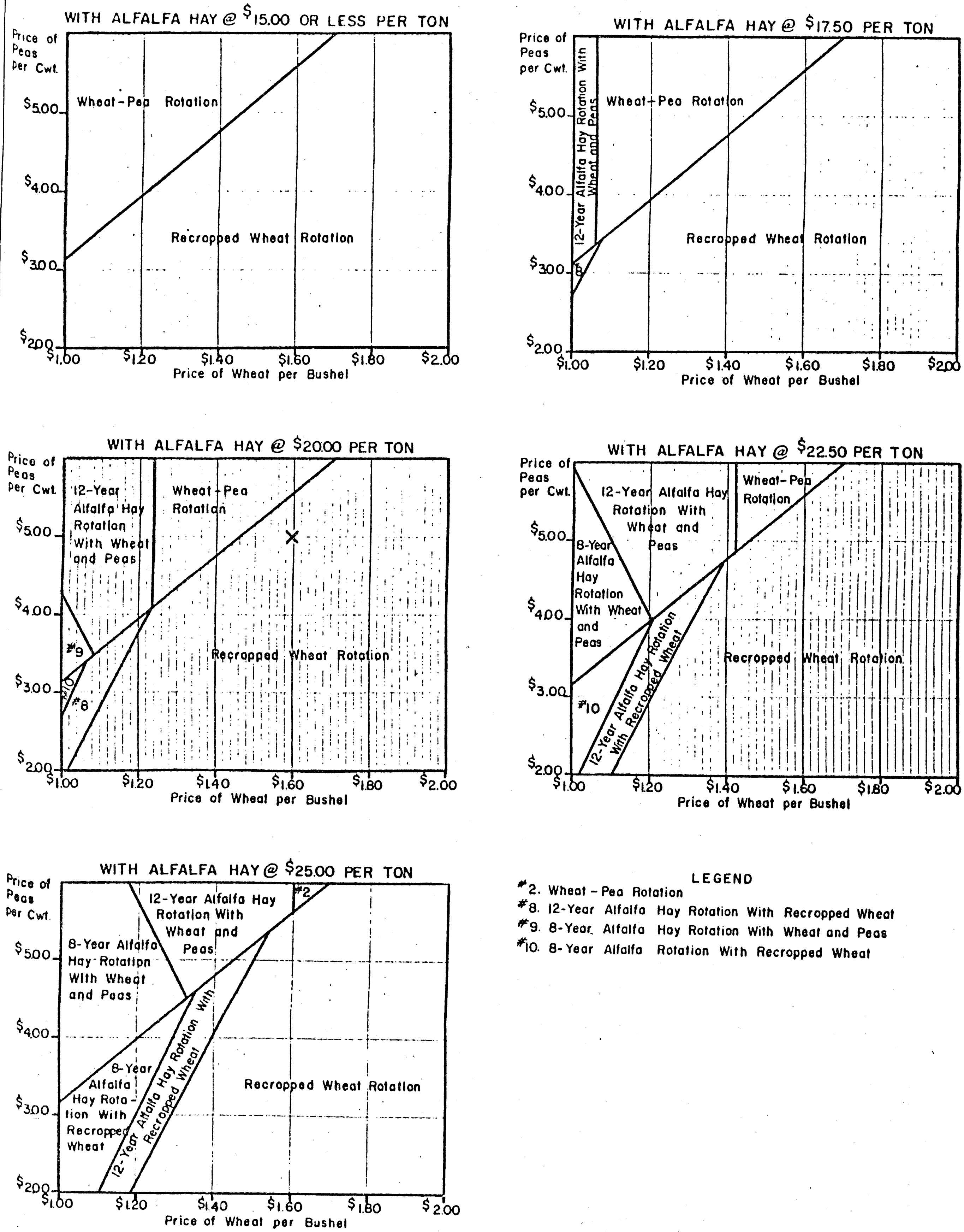
Figure 4. Effect of Price of Wheat on Net Income From Selected Crop Rotations in the Palouse Wheat-Pea Area, Assuming Fertilizer Use and No Wheat Acreage Restrictions, and Constant Prices for Crops Other than Wheat



Rotations without green manure or hay crops:
1 ············ Wheat-fallow
2 — — — — Wheat-peas
3 ———— Recropped wheat

4 x x x x x x Alfalfa green manure rotation

Rotations with alfalfa hay:
5 o———o 12-year rotation with wheat and peas
6 •——•——• 12-year rotation with recropped wheat



Most Profitable Crop Rotations With Various Prices for Wheat, Peas, and Alfalfa Hay, Assuming High Fertilizer Use and No Wheat Acreage Restrictions.

relating to crop rotations. They bring out that the most profitable cropping system depends on whether crops are complementary or competitive with each other, on how the outputs of different crops change when they are substituted for each other, and on the ratio of product prices. I shall illustrate these points by data from the Palouse wheat-pea area.

In this area, practically all uses of the land are competitive. Crops are competitive when from a fixed area of land the total output of a given crop is decreased by shifting some of the land resources to another crop. Crops are competitive if the yield per acre is not affected by substitution of crops or is not increased enough by crop rotation to offset the decrease in acreage. Figure 6 shows the total output of wheat and peas on a 520-acre farm in the Palouse when these crops are grown singly or in various proportions. The slope of the transformation function is changed by the use of nitrogen fertilizer. Nitrogen fertilizer increases the output of wheat, whereas the output of peas remains constant with any specified proportion of the land in peas. Nitrogen fertilizer causes wheat to compete more strongly with other land uses.

Whether profits will be maximized when competitive crops are produced in combination or whether specialization in one crop or the other will be most profitable depends on the ratio of product prices and on whether the crops substitute at constant, decreasing, or increasing marginal rates.

The marginal rate at which wheat substitutes for peas is shown in figure 7. If the transformation function is linear, the marginal rate of substitution is constant. Broadly speaking, wheat and peas substitute for each other at increasing marginal rates when the whole range of substitution possibilities is considered. However, the change takes place in "kinked" or "stairstep" stages; between points, the marginal rate of substitution is constant. The kink in the marginal substitution ratio is caused by the shift in the sequence of cropping from alternate wheat and peas to wheat after wheat or peas after peas, which occurs when either more or less than 50 percent of the acreage is planted to wheat.

When crops substitute at a steadily increasing marginal rate, the maximum profit combination of the two crops occurs when the marginal rate of product substitution is inversely equal to the ratio of product prices adjusted for unit marginal costs. At this point, the net marginal value product of a unit of land allocated to one crop is equal to the net marginal value product of a unit of land allocated to the other crop. A small change in the price ratio shifts the optimum combination of crops.

When two crops substitute for each other at a constant marginal rate, specialization in one or the other ordinarily maximizes profits. There is, however, an indifference price ratio at which either crop or any combination of the two crops produces the same net returns. This point occurs when the ratio of product prices, adjusted to take into consideration unit marginal costs, is inversely equal to the product substitution ratio.

Figure 6. Transformation Function for Wheat and Peas on a Typical 520 Acre Farm in Palouse Wheat-Pea Area, With and Without Nitrogen Fertilizer on Wheat

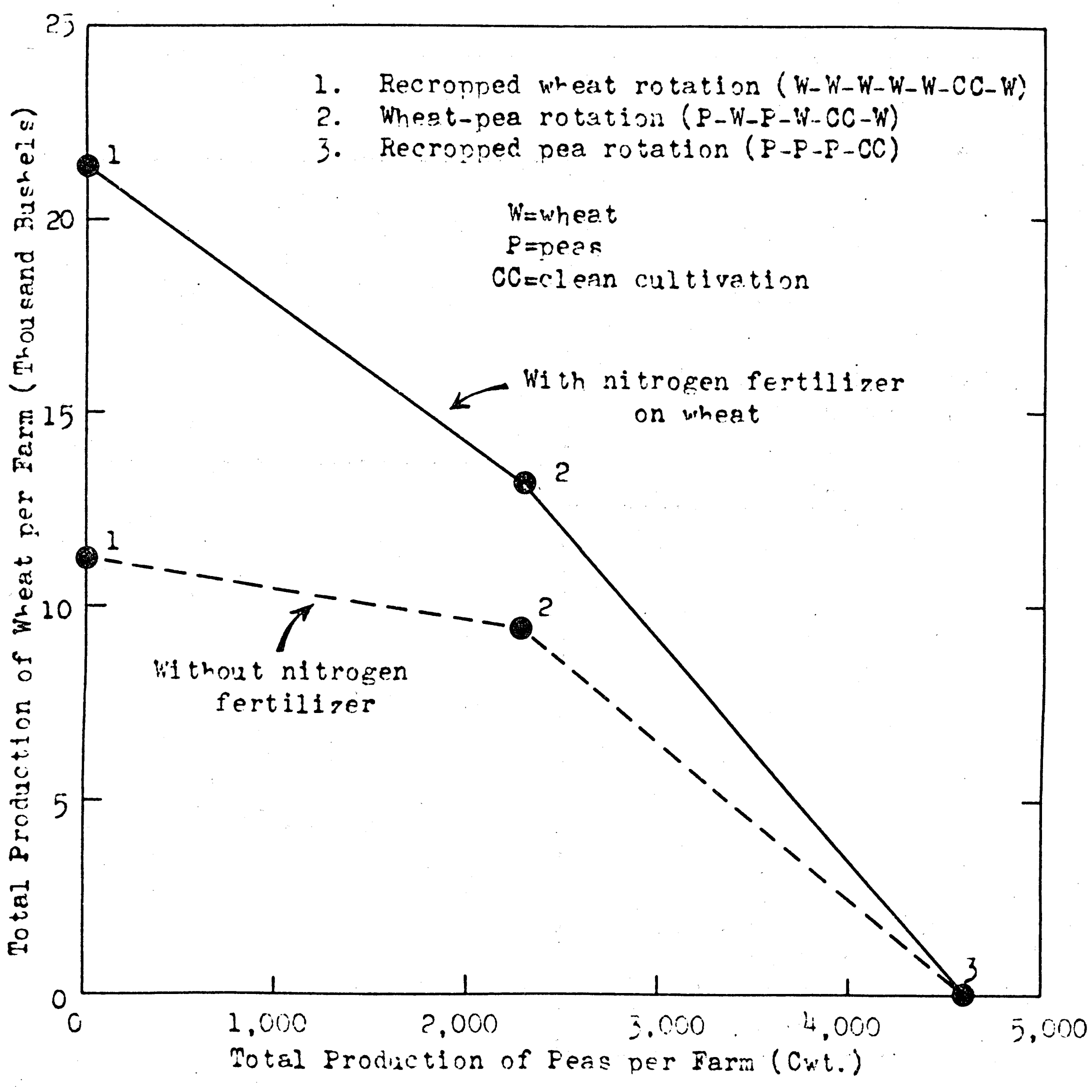
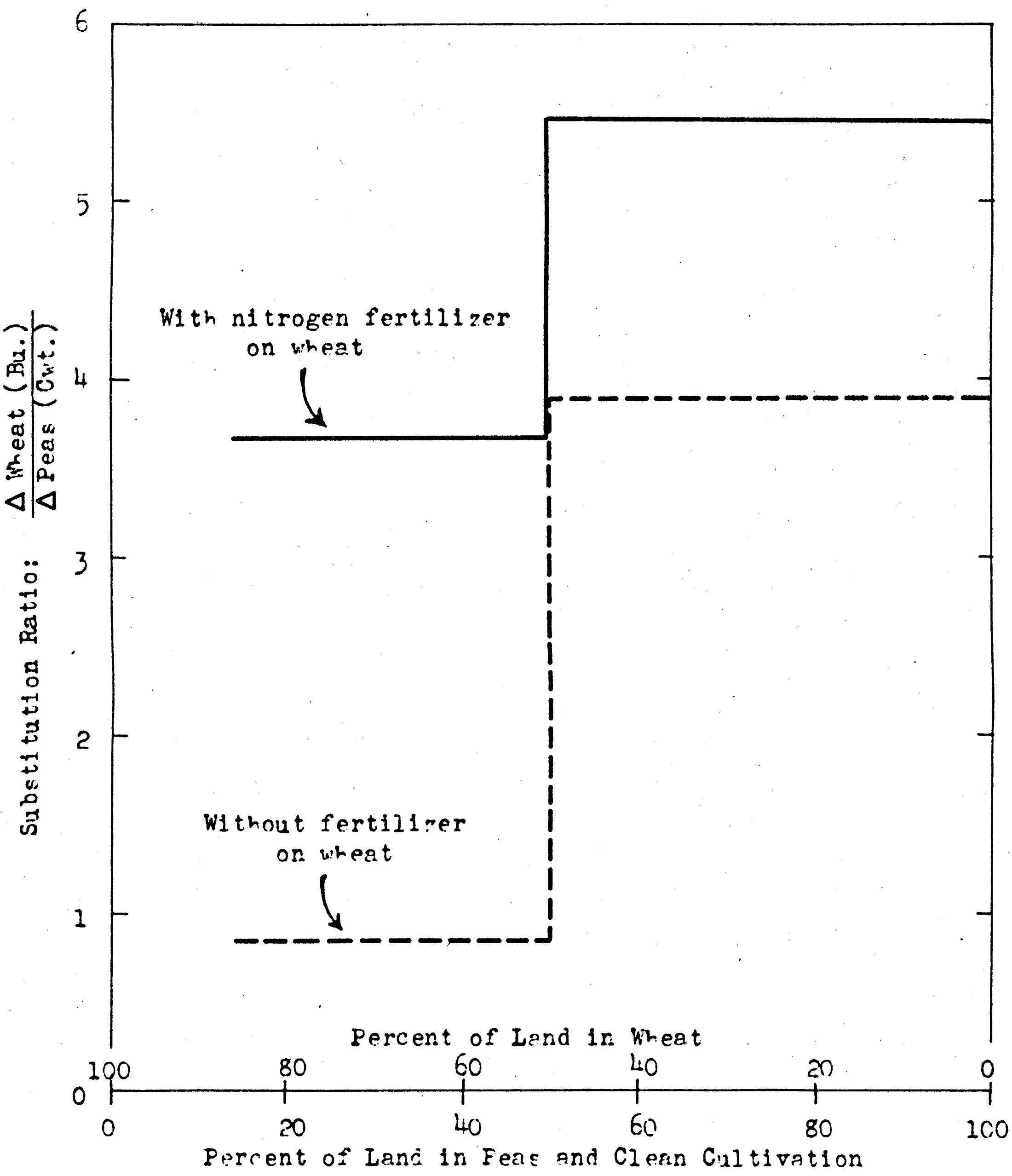


Figure 7. Marginal Rate of Substitution of Wheat for Peas
in Palouse Wheat-Pea Area,
With and Without Nitrogen Fertilizer on Wheat



When the product substitution ratio is kinked, as in the case of wheat and peas and most other crops in the Palouse, there are three zones of production possibilities that will maximize returns, depending on the ratio of product prices. These zones are: (1) Specialization in crop A, (2) a specific combination of crops A and B, and (3) specialization in crop B. A considerable shift in the product price ratio can occur before an adjustment in the enterprise combination is necessary in order to maximize returns.

Let us look at the situation with wheat and peas without nitrogen fertilizer, as shown in figure 7. Let us assume that the costs of producing wheat and those of producing peas are equal. The ratio of the price of peas to the price of wheat has never been as low as 1:1; hence, without use of nitrogen fertilizer, a recropped wheat rotation does not pay. If the price ratio is more than 1:1 but less than about 4:1, a wheat-pea rotation with 50 percent of the cropland in wheat, will maximize income from among these enterprises. If the price ratio exceeds 4:1--which it did during World War II--recropping to peas will produce the highest income.

If a farmer uses nitrogen fertilizer on wheat, more bushels of wheat must be sacrificed to produce 100 pounds of peas than when wheat is grown without fertilizer. In order for a wheat-pea rotation and a recropped wheat rotation to produce the same gross revenues, 100 pounds of peas must sell for 3.7 times as much as a bushel of wheat with nitrogen fertilizer applied, compared with a 1:1 price ratio when nitrogen is not used. Taking into consideration the differential in costs, the "break-even" or indifference price ratio at which these cropping systems are equally profitable when nitrogen fertilizer is used is actually about 3.0 - 3.5 to 1, depending on the level of prices. 5/

5/ The differences in crop production and in total costs as between these cropping systems on a farm of average size, with the price of wheat (P_w) at $1.60 per bushel and an equally profitable price for peas (P_p), are as follows:

Item	Production: Wheat (W) (Bu.)	Peas (P) (Cwt.)	Costs (C) (Dol.)
Wheat-pea rotation	13,172	2,253	14,475
Recropped wheat rotation . .	21,466	0	15,174
Difference	+ 8,294	- 2,253	+ 699

The marginal cost of producing a bushel of wheat is $0.084 + 0.27 cwt. of peas. The indifference price for peas (P_p) is calculated as follows:

Figure 8 illustrates two complementary uses of land--summer fallow and unfertilized wheat. Land uses are complementary when from a fixed area of land the total output of a given crop is increased by shifting some of the land resources to another use. To be complementary, the yield per acre of a given crop must be increased sufficiently by rotation of crops to more than offset the reduction in acreage caused by the substitution of one crop for the other. More bushels of wheat are produced from a given area of land with an alternate wheat-fallow rotation than with a recropped wheat rotation when no fertilizer is applied. Crops that are complementary to each other are complementary only within a certain range of substitution; they become competitive as the range of substitution is extended. It pays to combine two land uses if they are complementary to each other, unless total costs are thereby substantially increased.

You will note that the use of nitrogen fertilizer on wheat changes the relationship between summer fallow and wheat from complementary to competitive. Although a wheat-fallow rotation produces a greater net income than a recropped wheat rotation when fertilizer is not used, the reverse is true when nitrogen is applied.

Farm Income From Various Crop Rotations, Assuming Wheat Acreage Allotments

With acreage allotments in effect, a typical Palouse farmer can harvest wheat from only about 32 percent of his cropland. When wheat acreage is restricted, the problem is to find other profitable uses for the land. At prices prevailing in recent years, the most profitable cropping systems when nitrogen fertilizer is used are a wheat-pea rotation or a 12-year alfalfa hay rotation with wheat and peas (table 2). With a wheat-pea rotation, much acreage that would normally be seeded to wheat is diverted to barley. Instead of diverting a large acreage to barley, it is just as profitable to shift to an alfalfa hay rotation.

$$\frac{P_p}{P_w - C_w} = \frac{\Delta W}{\Delta P}$$

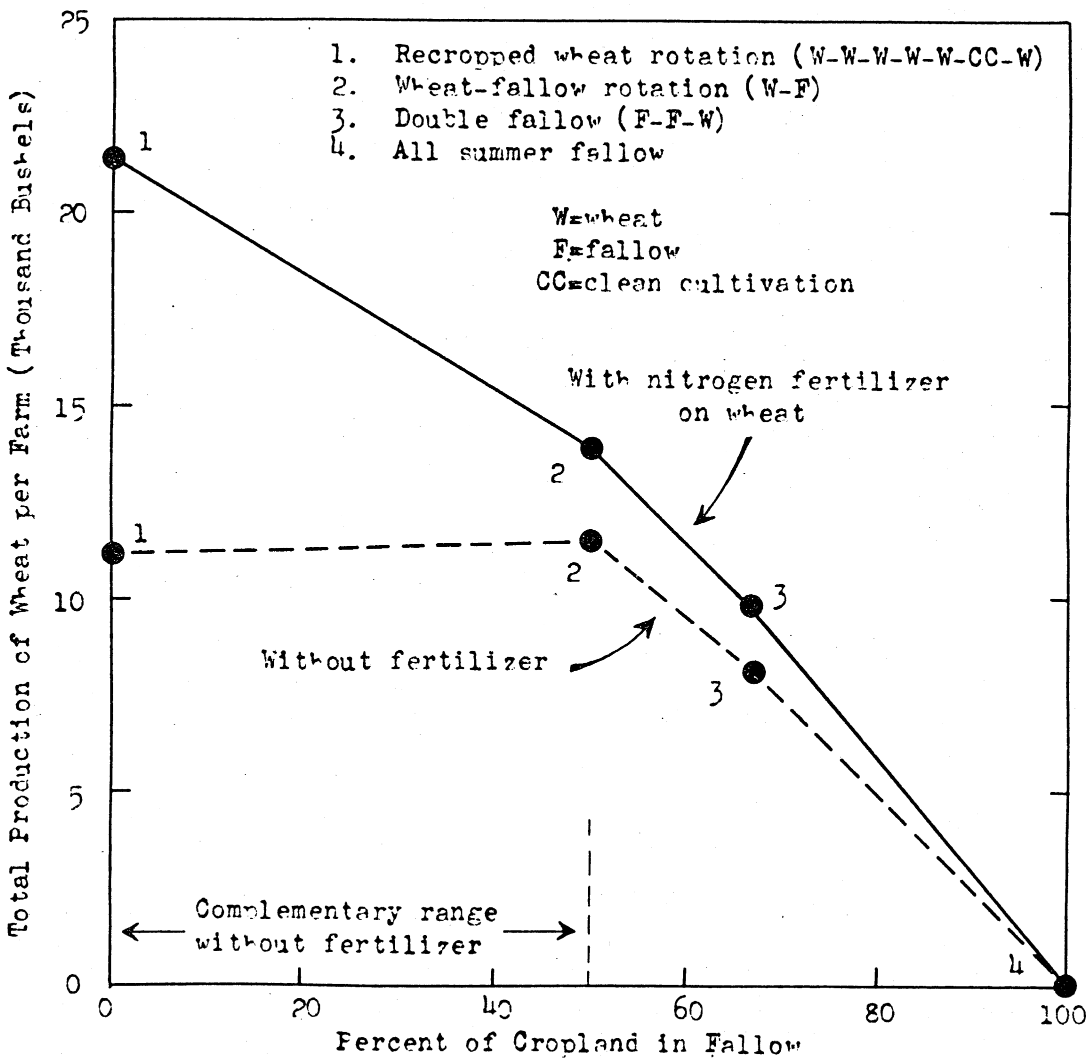
$$\frac{P_p}{\$1.60 - \$.084} = 3.68$$

$$P_p = \$5.58 \text{ per cwt.}$$

The indifference price ratio is 3.5 to 1.

With wheat at $1.00 per bushel and peas equally profitable, total costs for the two cropping systems would be $13,700 and $14,893, respectively, and the indifference price ratio would be 3.15 to 1.

Figure 8. Transformation Function for Wheat and Summer Fallow on a 520 Acre Farm in the Palouse Wheat-Pea Area, With and Without Nitrogen Fertilizer



With wheat acreage allotments, a recropped grain rotation is one of the least profitable cropping systems, even though fertilizer is applied. This is because a large acreage of recropped barley, a low-value crop, must be substituted for recropped wheat in this rotation. With wheat acreage allotments, all crop rotations that include wheat and peas are more profitable than those with recropped wheat and barley.

When nitrogen fertilizer is not used, an alfalfa hay rotation produces a much higher net return than a wheat-pea rotation, because of the higher yields of grain crops following alfalfa. An alfalfa green manure rotation also produces a higher net income than a wheat-pea rotation, because of the higher yield of wheat obtained. This differs markedly from the situation when nitrogen fertilizer is used or when there are no restrictions on the acreage that may be planted to wheat. In these instances, an alfalfa green manure rotation produces a low income compared with most other cropping systems.

When the acreage planted to wheat is restricted by acreage allotments and nitrogen fertilizer is used, the price of wheat has no significant effect on the relative net income from various alternative cropping systems. Under these conditions, the relative net income from the various crop rotations is determined largely by the relative prices for barley, alfalfa hay, and peas.

Effect of Crop Rotations and Fertilizer On Maintenance of Soil Productivity

Crop rotations have an effect on soil erosion losses (table 3). To maintain the productivity of the land, excessive soil erosion must be avoided and the soil organic matter or humus content of the soil must be maintained.

Nitrogen fertilizer and crop rotations have a marked effect on the maintenance of soil organic matter (table 3). Maintenance of soil organic matter depends upon the return to the soil of carbonaceous material and nitrogen in the form of crop residues, green manures, and fertilizers. Without nitrogen fertilizer, soil organic matter is depleted by most of the rotations, especially those without leguminous green manure or hay crops. A 3-year alfalfa green manure rotation builds up organic matter. Nitrogen fertilizer improves organic matter maintenance with all rotations, especially those without green manure or hay crops. With good farming practices, including the heavy use of nitrogen fertilizer, wheat is not a soil-depleting crop. The "black eye" which continuous one-crop cultivation has received is based on experiments and observations of continuous cropping without adequate fertilization. Experiments in the Palouse in which wheat, heavily fertilized with nitrogen, has been grown continuously on the same land for 25 years and the straw returned to the soil show that soil organic matter has not been depleted; it has increased.[6] This corroborates a

6/ Smith, Henry W., Vandecaveye, S. C., and Kardos, L. T., Wheat Production and Properties of Palouse Silt Loam as Affected by Organic Residues and Fertilizers, Wash. Agr. Expt. Sta. Bu. 476,

TABLE 3. Effect of Crop Rotations and Nitrogen Fertilizer Use on Soil Erosion

TABLE 3. Effect of Crop Rotations and Nitrogen Fertilizer Use on Soil Erosion Losses and Soil Organic Matter Trends in the Palouse Wheat-Pea Area

Crop Rotation	Average Annual Soil Losses Per Acre a/	Percentage Change in Soil Oragnic Matter Per Year b/	
		Without Nitrogen Fertilizer	With Nitrogen Fertilizer
	Tons	Pct.	Pct.
Rotations Without Green Manure or Hay Crops			
Wheat-fallow rotation	6.2	-0.65	-0.40
Wheat-pea rotation	5.6	-0.50	-0.10
Recropped wheat rotation	4.7	-0.51	-0.04
Alfalfa Green Manure Rotation . . .	4.5	-0.26	-0.28
Rotations With Alfalfa Hay			
12-year rotation with wheat and peas	3.9	-0.20	-0.07
12-year rotation with recropped wheat	3.4	-0.22	-0.14

a/ Data apply to situations without wheat acreage allotments. They differ just slightly with acreage allotments.

b/ Refers to the annual rate of change expressed as a percentage of thepresent level of soil organic matter.

growing body of similar evidence concerning continuous corn in the Corn Belt.[7]

It is estimated that without the use of nitrogen fertilizer the yield of wheat in a recropped wheat rotation in the Palouse would decline 15 percent in a period of 50 years, and net income per farm, 35 percent, assuming constant technology, prices, and costs. On the other hand, with heavy use of nitrogen fertilizer in conjunction with the use of straw for soil-conservation purposes, no significant change in the productivity of the land will occur with a recropped wheat rotation.

It has been generally considered that land must be in leguminous green manure or forage crops a substantial portion of the time to maintain its productivity and to obtain high yields. Technology is changing this. Advances such as the use of commercial fertilizers, selective herbicides, new insecticides, and modern machinery place a new light on crop rotations.

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DISCUSSION: ECONOMICS OF CROP ROTATIONS AND FERTILIZER USE IN THE PALOUSE WHEAT-PEA AREA

By

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First, I should like to state that we in the Pacific Northwest are pleased to have this excellent material on the economics of conservation farming which Mr. Walter Pawson has developed over the past ten years. We have already used this data a great deal, and we shall find it increasingly useful in the future.

Mr. Pawson has made a very important contribution to knowledge in this area. Especially valuable is the large amount of basic data on yields and costs and returns which he has synthesized. This may be used by all of us to weigh decisions concerning cropping practices and crop combinations.

We all have a great deal of respect for Mr. Pawson's thorough job of accumulating and analyzing this cropping data. None of the Pacific Northwest states could have accomplished the task alone. With Mr. Pawson's leadership and with some cooperation from the individual states, a fine body of information has been secured.

I will discuss, largely, the implications of some of the material which Mr. Pawson has presented. I shall be especially concerned with the impact of (1) commercial fertilizer, and (2) wheat acreage restrictions on legume and non-legume rotations. I shall disagree on a few minor points, but on the whole, I shall support Mr. Pawson's presentation.

I would divide the problem to be solved into two parts:

(1) What amount of commercial fertilizer is optimum for the several cropping sequences.

(2) Using these optimum quantities of commercial fertilizer, what crop rotations will result in the maximum net returns in the long run.

The presentation by Mr. Pawson is confined largely to a comparison of the returns from typical rotations with and without commercial fertilizer and with and without wheat acreage restrictions. This is the second part of the problem as I have outlined it. The first part of the problem--how much fertilizer should be used--is discussed only briefly.

Pawson states that he had not carried fertilizer applications to the point where marginal costs are equal to marginal returns. Rather, he has used as his fertilizer input, "the maximum rate that agronomists and others familiar with the area consider safe to apply in a normal year, based on presently available data." My conversations with Mr. Pawson would indicate that he accepts these maximum rates only because experimental data is lacking at the higher rates of nitrogen application. He has, therefore, confined his analysis to the inputs of fertilizer use for which there is adequate experimental data. It is highly likely, therefore, that heavier rates of fertilizer use than those shown by Pawson are feasible.

This points up an area where further investigations are needed. We should have better information on the optimum rate of fertilizer use for the different cropping sequences. Individual farmers and fertilizer consultants have stated that higher rates are feasible than those used in fertilizer experiments. The experiment stations should carry inputs of fertilizer to the point where they are sure no further yield increases will result.

At Idaho after a number of cooperative experiments in which agronomists and economists jointly participated, the agronomy fertilizer experiments now include applications up to 250 pounds of actual nitrogen. Previously they stopped at 80 to 120 pounds of nitrogen. At these higher rates, it is more likely that a deficiency of other fertilizer elements may limit the response to nitrogen. It is important then to include in the experiments such other elements. In 1956 and again in 1960, marked responses were obtained in Idaho by adding sulphur to the nitrogen applications. Phosphorus may be a limiting element on some fields. The yield of peas is increased on some fields by adding molybdenum. As the soils are depleted by the increasing yields that are being obtained, other elements than nitrogen will become more necessary. However, the major added element will probably continue to be nitrogen.

The problem of how much fertilizer to use is one of the more important problems in agriculture today. We need better research data to guide farmers who must make this decision.

The second part of the problem--the choice of a rotation--is really a highly complicated problem. It is no wonder that farmers are baffled by it. As well as considering the expected future prices of crops and the costs of growing them, the farmer must decide what crop combination will maintain productivity and soil structure, what weed control measures are needed, what feed crops are needed for livestock, what crop combinations will eliminate peak labor demands and result in the lowest added expense for labor and machinery, what rotation is preferred by the landlord, and what rotation will fit the farmer's ability to bear risks.

Furthermore, the decision of what rotation to use makes a big difference in the returns to the operator. For the rotations using fertilizer considered by Walter Pawson, this difference amounts to $9000 for rotations without restrictions in wheat acreage, and to $2500 with limited acres in wheat.

In his comparison of the returns from rotations with and without commercial fertilizer, Pawson brings out the fact that the yields of the non-legume rotations are increased more by fertilizer than the legume rotations. This is a change that farmers have been somewhat slow to accept. For good reasons, farmers formulate future plans on the basis of past experience. The results of rotations take ten to 20 years, usually, to be fully effective. Therefore, farmers as yet have little conclusive past experience on the effects of commercial fertilizer on different types of rotations.

Pawson's data points up the need for recognizing the increased returns from non-legume rotations with the advent of commercial fertilizer. The rotations we have considered to be exploitive in the past appear less so in the light of his material. For example, Pawson shows that the continuous wheat rotation, with liberal amounts of commercial fertilizer, actually increases organic matter content in the soil. Results in many parts of the country show that commercial fertilizer increases yields at a phenomenal rate. The increased yields result in large additions to crop residues. These augmented crop residues can maintain organic matter content as effectively as legumes in many places. This point is of special significance in the Palouse area of Idaho and Washington as only small numbers of livestock are kept in the area. The legumes are not used to any extent as livestock feed.

It is true, of course, that legumes in the rotation will be profitable in many situations. Their advantage is lessened, however, by the advent of commercial fertilizer. I think many of us have been slow to realize the implications of this change. I find many older farmers quite unwilling to believe that fertility can be maintained without legumes.

I should like now to discuss some of the implications of the second comparison--the returns to a typical 520 acre Palouse farm with the current wheat acreage restriction and without such restrictions. I shall limit my discussion to the situation where commercial fertilizer is used as I consider this to be the pertinent comparison.

Below, the average net returns to the operator's capital and management for the three non-legume rotations (continuous wheat, wheat-peas, and wheat-fallow) are compared with the average net returns for the three legume rotations. The comparison is made both with and without wheat acreage restrictions; and, in all cases, with maximum inputs of commercial fertilizer.

Capital and Management Returns

	With wheat acreage restrictions	Without wheat acreage restrictions
Three non-legume rotations	$10, 133	$15, 588
Three legume rotations	$10, 513	$13, 182

We note first the appreciable increase in returns when wheat acreage limitations are removed. This comparison assumes constant prices in all situations--an assumption that would not be realistic unless support levels were maintained.

The policy implications of this comparison are interesting. With no restrictions on wheat acreage, the non-legume rotations return appreciably more to the operator. On the other hand, the legume rotations are slightly superior when wheat acreage is controlled. This suggests that the continuation of the wheat control program will encourage the selection of legume rotations, while its discontinuance would favor the choice of non-legume rotations. Legumes become more advantageous when a part of the wheat acreage must be replaced by less profitable alternatives.

From a policy viewpoint, the results of the typical 520 acre unit do not apply to all farms in the Palouse. Some farms are larger, some smaller. Some farms will have higher costs than those used, others lower costs. Crop yields and fertilizer response will vary from farm to farm. The more level farms with only minor erosion problems will have a greater advantage with the non-legume rotations. The operators of the steeper farms, with serious erosion and run-off losses, should adopt rotations that increase water holding capacity of the soil. They will favor the rotations that add large amounts of organic matter. So, for the total Palouse area, we need models for the variety of conditions found in the area, rather than for the typical unit alone.

Although constant yields have been assumed for all of the rotations, one would expect slight increases in yield for those rotations that have increasing organic matter content. The added organic matter will provide more fertility and greater water holding capacity and less erosion damage. Likewise, the rotations with decreasing organic matter could show slight decreases in yield because of the loss.

Figures given by Mr. Pawson on erosion losses and on changes in organic matter content are helpful in considering the merits of the several alternative rotations. However, we are all aware that we cannot put price tags on these physical losses. In the Palouse area with its deep loessial soils and its low intensity of rainfall, erosion losses are less significant than in areas of shallow soils and of heavy, washing rains. We can measure these physical soil losses, but we have not yet found a way to adequately value them in monetary terms.

I have two comments regarding the budgets used to represent the various rotations. The alfalfa hay rotations seem to be resisted by Palouse farmers and may not be realistic for the larger acreages of hay. Part of the resistance is due to the conflict between haying and other farm jobs--weedsspraying, clean cultivation for weeds, and preparations for harvest. Part of it may be due to the limited market for alfalfa hay in the area. Relatively few livestock are found in the Palouse. Farmers also undoubtedly hesitate to invest in the added haying equipment that would be needed and to commit themselves to the harder work necessary when raising hay. In other areas farmers resist adding milk cows for this same reason. Therefore, I believe, that Palouse farmers would be slow to adopt rotations with sizeable acreages of alfalfa hay.

Secondly, costs as listed by Pawson include a charge for all labor, including that of the operator. For typical rotations I calculate from $1400 to $1700 charge for operator's labor in Pawson's budgets. I question whether this is an adequate charge for the major part of the operator's labor on these farms. I would prefer to omit any charge for operator's labor and attempt to maximize the returns to the operator's total resources--his labor, capital, and management. Farmers earn widely differing amounts for their labor and capital. I believe a standard charge for any of the farmer's resources is too arbitrary to be of value.

I admit that the comparisons made by Pawson would be affected very little by omitting a charge for operator's labor. I mention it only because I believe it is better procedure to consider operator's labor as a residual.

One is impressed in studying these rotations with the comparative advantage of growing wheat in the Palouse. Using a price of $1.60 for wheat, as Pawson does, the net returns per acre of wheat after peas is about $50. Barley or peas, at the prices assumed, return about one-third as much as this. The price of wheat would have to fall to about 90 cents per bushel to have equal net returns to the barley or peas.

At present prices for land and equipment, one can assume a capital investment of about $180,000 for a 520 acre Palouse farm. The returns shown by Pawson with wheat acreage allotments and nitrogen fertilizer range from $9289 to $11,714 or a return of 5.2 percent to 6.5 percent on the $180,000 investment. These are reasonably good returns on capital, but the amount deducted for the operator's labor, as stated previously, is too low to represent the full value of the operator's labor. If another $2500 was deducted for operator's labor, the amount remaining for capital would be reduced to a return of 3.8 to 5.1 percent on the investment. One could, of course, alter these returns drastically by changing the size of the unit, the prices of crops, or the expected yields.

Looking ahead for the Palouse, we can expect continually increasing yields. The soil is physically capable of producing more. For example, we have sampled parts of farmers' fields that have yielded from 100 to 150 bushels of wheat per acre. New varieties with less susceptibility to lodging, greater amounts of commercial fertilizer, and improved methods of weed control will help to obtain this increased production. Probably crop residues will form a more important source of organic matter and legumes a less important source. The better farmers who now average 50 bushels of wheat per acre will probably average 60 to 70 bushels or more in the future. The advantage for wheat in the area can be expected to continue--perhaps to increase. But we can certainly expect to continually reassess:

(1) How much fertilizer we shall use and

(2) What rotation will maximize returns with these amounts of fertilizer. Mr. Pawson has presented an excellent discussion of factors influencing these decisions.