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Crop Rotation Studies

by

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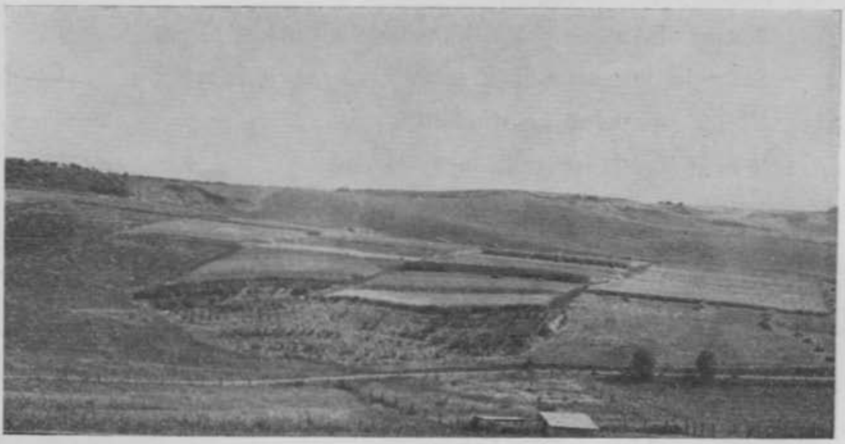

General view of rotation plats on the University Farm, Moscow, Idaho, established in 1915.

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G. ORIEN BAKER and K. H. W. KLAGES [2]

Introduction

THIS publication deals with the results of crop rotation experiments at four locations in Idaho, Moscow, Sandpoint, Aberdeen, and Tetonia. The results from the main station at Moscow are applicable to the Palouse and adjacent areas of northern Idaho with a fairly abundant precipitation. The limited results available from Sandpoint are applicable to the northern cut-over sections of the State. The results from the Aberdeen substation apply to the irrigated areas of southern, particularly southeastern Idaho. Conditions in the dry land areas of the eastern portion of the State are dealt with at the Tetonia substation.

Crop rotation experiments have been in progress on the University farm at Moscow since 1915; at the Aberdeen and Tetonia substations since 1929 and 1925, respectively; and at Sandpoint from 1920-1932. These experiments were laid out for the purpose of determining the effects of sequences of cropping on the yields of the important field crops in the various areas of the State.

Characteristics of Good Crop Rotations

A crop rotation may be defined as a more or less systematic recurrent succession of crops on the same land. A good rotation need not necessarily provide for the same acreage of a specified number of crops every year. Due to changing economic conditions, it is not practical to lay out a plan to be followed without minor or even major changes for the years to come. It is essential, however, that soil-improving crops or practices be rotated in time over the entire acreage of the farm in as regular a sequence as permissible by soil, climatic, and economic factors. Unless this is done, the system of cropping does not merit the term rotation. It is obvious that a practical program of crop production is dependent on entirely too many factors not within the direct control of the producer to make it either advisable or feasible to set up a plan of cropping for years to come in all its details with mathematical precision.

The main characteristics of good rotation systems are listed below; each factor will be discussed at some length. No effort is made to give these various factors in the order of their importance. Such a task would be impossible insofar as the relative importance of each separate factor is greatly influenced by specific local differences.

(1) The early work relating to the rotation experiments at Moscow was carried on under the supervision of P. P. Peterson, P. R. McDole, F. L. Burkhart, R. K. Bonnett, H. W. Hulbert, and R. E. Bell.

The authors wish to express their indebtedness to J. H. Christ, formerly of the Sandpoint substation, Ralph Knight, present superintendent of the Sandpoint substation; to A. E. McClymonds, formerly of the Aberdeen substation, John E. Toevs, present superintendent of the Aberdeen substation; and to W. A. Moss, superintendent of the high altitude substation.

(2) Soil Technologist and Agronomist, respectively.

1. The rotation system selected should be adapted to existing climatic, soil, and economic factors.
2. The rotation and system of cropping adopted for any specific area should be based on proper land utilization. The cropping enterprises should be so arranged in relation to the fields on the farm so that production can be maintained. Above all, soil losses through erosion should be reduced to a mimimum by the system of cropping adopted.
3. The rotation should contain a sufficient acreage of soil-improving crops to aid in maintaining the organic matter content of the soil.
4. In areas where legumes can be successfully grown, the rotation should provide for a sufficient acreage of this group of crops to help maintain the nitrogen supply of the soil.
5. The rotation should provide roughage and pasturage for the livestock kept on the farm.
6. The rotation should be so arranged as to aid in the control of weeds, plant diseases, and insect pests.
7. The rotation should provide for a maximum of acreage of the most profitable cash crops adapted to the area.
8. The rotation should be so arranged as to make for economy in production and labor utilization.

Too much cannot be said about the necessity of selecting crops and practices to fit the particular climatic and soil conditions under which they are to be grown. Likewise the crops selected must have a market value in line with their costs of production. In other words, the crops selected must be adapted to their physiological and social environment. For example, the prevailing climatic conditions in the dry land areas of the State do not meet the growth requirements of sugar beets. One of the necessary factors of the physiological environment, moisture, is not present in a sufficient quantity. Again the sugar beet cannot become an important crop in the irrigated sections, with a sufficient water supply, unless a proper social environment is provided in the form of availability of labor, equipment, and marketing facilities.

No rotation system should be laid out without due regard to proper land utilization of the region or the specific farm. In the past, this important factor has been frequently disregarded. Large acreages of native grasslands have been plowed when, frequently too late, it was discovered that the destroyed native vegetations were better adapted to existing conditions than any crop plant that could be substituted for them. Such errors of the past should not only be avoided in the future, but should be corrected as soon as conditions permit. Lands in the drier portions of the State subject to severe wind erosion, must be so handled that erosion will be controlled. In extreme cases, the only solution is in the return of the land to native and introduced grasses. In the northern area of the State, steep slopes must be protected from erosion by keeping them more or less permanently in grass. The natural limits of production must be recognized in order to prevent soil exploitation with its disastrous effects on, not only the abused, but also on adjacent areas. Plant nutrients are lost from the soil in a number of ways. They are removed of necessity by plants. If the entire growth of a crop is moved from the farm, this source of loss may be considerable; on the other hand, if the crop residues or the manure resulting from the feeding of the crops are returned to the soil, then the loss will be much less. Another source of loss in the irrigated areas in places where water is used injudiciously is the leaching out of the soil of elements of nutrition. Where excess water is allowed to percolate through the soil, it carries with it such elements of nutrition as are in a soluble form. These elements are then lost in the drainage water. Greater than all of these losses is the removal of soil from the fields by erosion. Furthermore, if through careless land utilization, this soil loss is allowed to continue, the rates of loss become increasingly greater as time goes on. This emphasizes the fact that the cropping system and practices adopted should give due consideration to soil erosion control.

The organic matter content of the soil may be designated as the keystone of soil fertility insofar as it is associated with the nutrition of plants, and the physical condition of the soil. A high organic matter content and plant cover offer effective protection against soil losses through erosion. The organic matter content of the soil may be maintained or even increased by applications of barnyard manure, return of crop residues, or by the growing of biennial and perennial legumes and perennial grasses. The utilization of legumes, since they supply not only organic matter but also nitrogen, is especially recommended. Where climatic or soil conditions are such that legumes cannot be grown, then grasses should be produced. In sections where more roughage or pasturage is produced by the legumes or grasses than can be utilized to advantage by the livestock on the farm or in the community, the production of these crops for seed production purposes merits attention.

In this publication are presented some rather outstanding increases in the yields of crops resulting from application of manure. These results are not given for purposes of recommending the use of manure on all the crop land of Idaho. That is not practical; not enough manure is produced to do this. Nevertheless, the experimental increases in crop yields resulting from such applications of manure show clearly the beneficial effects of the organic matter and plant nutrients it supplies.

Legumes are outstanding in their ability to fix atmospheric nitrogen and for that reason have a very definite place in rotation systems. The fixation of nitrogen is possible only when these leguminous plants are properly inoculated and have proper soil conditions. Legumes have several distinct advantages over nonleguminous plants for purposes of supplying organic matter to soils.

The large fleshy roots of biennial and perennial legumes, such as the clovers and alfalfa, have the ability to penetrate deep into the soil. This deep penetration of their root systems opens up relatively impermeable layers of soils and serves to add organic matter to the lower levels, thus facilitating the downward percolation of moisture and increasing the extent of the feeding areas of the root systems of the plants following them. Again, due to their relatively high nitrogen contents, leguminous residues decompose in a shorter period of time than those of grasses. Cereal straws decompose slowly due to their high carbon and low nitrogen contents. The rapid decomposition of the remains of leguminous plants prevents the excessive accumulation of partly decomposed crop residues in the surface areas of soils. An accumulation of such partially decomposed plant remains is desirable from the standpoint of erosion control. When, however, the amounts of such materials in the surface areas of the soil becomes too great, it results in excessive aeration and drying. When plant residues with a high carbon and low nitrogen content decompose, the nitrogen requirements of the organisms working on the decomposition of such materials is taken in part from the available nitrates in the soil. This results in an active competition for nitrates between the cellulose decomposing organisms and the plants growing on such soils. This condition accounts in part for depressed yields following the plowing under of large amounts of straw. In the case of leguminous materials, the plant residues being high in nitrogen, decomposition progresses rapidly so that additional amounts of nitrates are available for the use of plants following the legumes. In areas with insufficient moisture this abundance of available nitrates not infrequently leads to complications. Available supplies of nitrogen stimulate the vegetative development of plants and may bring about uneconomical utilization of available moisture insofar as the stimulated production of stems and leaves during the early phases of development may not leave a sufficient amount of moisture in the soil for the normal completion of the growth cycle. This condition is commonly referred to as firing or burning. Due to the above factors and the greater difficulties encountered in establishing stands of perennial legumes than drought resistant grasses, such as crested wheat and smooth brome, the use of such grasses is recommended for areas too dry for the establishment of legumes for purposes of maintaining or increasing the organic matter content of soils.

The rotation adopted should provide roughage and pasturage for the livestock kept on the farm or in the area. On most farms, hay crops but not pastures are often rotated over the acreage. It is recognized that often the special topography of the pasture area or its location in relation to the buildings on the farm make it necessary to utilize certain areas exclusively for pasturage. Insofar as other factors permit, the pasture acreage should become a part of the rotation system. The inclusion of pastures in rotation system calls for a long time and a not-too-systematic rotation.

The rotation system offers one of the best means of controlling weed and insect pests. As a matter of fact, in many areas, the necessity of weed, insect, and disease control, more than any other single factor, has been instrumental in forcing producers to rotate their crops. Legumes and grasses are very effective in smothering annual and some perennial weeds. Canada thistles can be effectively kept under control—and with proper methods eradicated—by a rotation containing alfalfa and cereals. If the region is adapted to the production of a cultivated crop, such a crop should be included in the rotation for purposes of eliminating weeds. In the strictly grain producing portions of the State, the place of intertilled crops can in part be taken by summer fallow. It has been demonstrated by Shirck and Lanchester ([1]) that the growing of red clover in southern Idaho increases greatly the population of wire worms in the soils.

One of the most important features of a good rotation is that it provides for a maximum acreage of the most profitable cash crop adapted to the area. No crop rotation is suited to a given area unless it makes for a system of cropping capable of showing a profit to the producer. An unprofitable system of cropping leads invariably to soil exploitation, exhaustion, and eventual abandonment. The acreage of the main cash crop should be consistent with good farm practices with due emphasis on the maintenance, even increase of soil fertility, and a minimum of soil loss. Stimulated production at the cost of soil depletion leads to agricultural disaster. It is well in this connection to point out that a change in a system of cropping with the aim of maintaining or increasing the fertility of the soil is best made at a time when the native fertility of the soil is still high. It is at best difficult to improve an impoverished agriculture.

A crop may have a place in rotation, not because of the fact that it is on its own account the most profitable crop that can be grown for the time being, but rather due to the fact that it either leaves the soil in good condition for the crops to follow or makes it possible to prepare the seedbed for the next crop in the cropping sequence at a low cost. The production of peas in northern Idaho offers a good example of this kind. During the past several years this crop has, due to low prices, not been especially profitable. Yet the crop more and more has taken the place of summer fallow. It will be shown in a later discussion that peas can be used to advantage for replacing the summer fallow without greatly reducing subsequent winter wheat yields. Furthermore, and this is especially important, the cost of preparing the seedbed for the winter wheat following the pea crop is in most instances no greater than if the field were left in fallow prior to the seeding of the winter wheat. Frequently the growing of crops in definite sequences makes it possible to grow at least two crops following one plowing, thus materially serving to cut down the costs of production.

([1]) Shirck, F. H. and Lanchester, H. P., Wireworm infestation trends accompanying certain crop rotations in the Pacific Northwest, U.S.D.A. Cir. 408. 1936.

TABLE 1.—Summary of climatic conditions at Moscow, Sandpoint, Tetonia, and Aberdeen, Idaho, for the periods covered by rotation experiment at each of the respective locations.

Climatic features	Moscow 1915–1937	Moscow 1923–1937	Sandpoint 1924–1932	Tetonia 1925–1937	Aberdeen 1929–1937
Annual precipitation in inches	21.37	21.78	29.52	13.34	7.65
Precipitation from Apr. 1 to Aug. 31	5.37	5.15	6.67	6.26	3.62
Percentage of annual precipitation falling between Apr. 1 to Aug. 31	25.1	23.6	22.6	46.9	47.3
Average frost free period in days	144	145	109	56	116
Average date of last frost in spring	May 10	May 6	May 29	June 28	May 23
Average date of first frost in fall	Sept. 30	Sept. 28	Sept. 15	Aug. 23	Sept. 17
Annual mean maximum temperature	57.1	58.0	57.7	52.6	60.4
Annual mean minimum temperature	37.0	37.4	33.1	23.7	29.9
Mean annual temperature	47.1	47.7	45.4	38.7	45.2
Mean maximum temperature, Apr. 1 to Aug. 31	71.5	72.6	73.9	68.4	78.3
Mean minimum temperature, Apr. 1 to Aug. 31	45.7	46.2	41.6	36.8	42.7
Mean temperature, Apr. 1 to Aug. 31	58.6	59.4	57.8	52.6	60.5
Longest frost free period	192	192	155	85	134
Shortest frost free period	83	83	85	12	93

Summary of Climatic Conditions at Moscow, Sandpoint, Tetonia, and Aberdeen

Table 1 gives the outstanding features of the climates at the four locations in the State from which yield data of rotation experiments will be reported for the periods covered by these experiments. Since the experiments on the University farm at Moscow extend over the periods from 1915 to 1937 and from 1923 to 1937, inclusive, the averages of climatological factors are presented for both of these periods.

The climate of the Palouse area, represented by the data from Moscow, as well as that of the cut-over section of northern Idaho, represented by the data from the Sandpoint substation, is characterized by low summer precipitation. This means that crop growth is to a high degree dependent on moisture stored in the soil during the fall and winter months. The rather moderate amounts of average annual rainfall is compensated for by the relatively low temperatures prevailing and by the low rates of evaporation especially during the moisture accumulating months.

The Tetonia substation is located in eastern Idaho at an elevation of 6200 feet above sea level. Both rainfall and temperatures are low, but it will be observed that a relatively high percentage of the annual precipitation can be expected during the growing season.

At the three stations indicated above, crop production is carried on under natural rainfall conditions. The climate at Aberdeen is typical of that of the upper Snake River Plains where due to the low rainfall, intensive crop production is dependent on irrigation.

Rotation Studies on the University Farm at Moscow

History of Rotation Plats

Investigation on crop rotations on the University farm have been in progress since 1915. The land on which the present rotation studies are being conducted was cropped uniformly to corn in 1913. No yields, however, were taken that year. In 1914 the area was laid out into 63 one-tenth acre randomized plats. The following rotation systems were established in 1915. A preliminary report of these rotations may be found in Idaho Agricultural Experiment Station Bulletin 118 (1919.) (1)

1. Wheat, oats, peas—with and without applications of manure.
2. Wheat, oats, fallow—with and without applications of manure.
3. Wheat, oats, corn—with and without applications of manure.
4. Wheat, oats, potatoes.
5. Continuous wheat—with and without applications of manure.
6. Wheat, timothy and clover, timothy and clover, oats, corn.
7. Wheat, barley, potatoes, oats.
8. Wheat, barley, oats, corn.

These rotations were built around the prevailing systems of cropping of that time, namely two years of cereals followed by one of fallow. The purpose of the various cultivated crops in the rotation system was to test such cultivated crops against the fallow in their effects on the crops in the rotation and to compare the effects of fallow with annual systems of cropping.

The rotations established in 1915 were modified in 1923. The ones not applicable to conditions in the Palouse area were eliminated. Those to which manure was applied were numbered as separate rotations. Since 1923 they have been continued without change. Table 2 gives a list of the long-time rotations established in 1915, and the so-called short-time rotations established in 1923, together with the crops included and the sequences of cropping and practices for each rotation. Each of the crops listed was grown every year for the period given. The yield data are presented for the 23-year period, from 1915 to 1937 inclusive, for the long-time rotations and for purposes of making comparisons with the short-time rotations for the 15-year period, 1923 to 1937, inclusive.

In 1936, the size of the plats was reduced from one-tenth to one-twelfth of an acre in order to increase the width of the alleys between the plats and the roadways between the ranges. This facilitates working the plats.

All plats except those that are fallowed or those that produced a cultivated crop are fall plowed as soon as practical after the removal of the preceding crop. The fall seeded cultivated plats are disked and harrowed. The spring seeded plats are left rough over winter. The disk and harrow are used in seedbed preparation. Seeding is done as early as the soil can be put in shape both in

(1) Peterson, P. P. Soil and climatic factors in relation to crop production in the Palouse silt loam of Idaho. Idaho Agricultural Experiment Station Bulletin 118. 1919.

TABLE 2.—List and average yields of crop rotations conducted on the University farm, Moscow, Idaho, for a 23- and a 15-year period of comparison.

Rotation No.	Crops and sequence	Average yields	
		23-year period 1915-1937	15-year period 1923-1937
1	Winter wheat	52.9 bu.	59.6 bu.
	Oats	63.5 bu.	72.1 bu.
	Peas plus manure	20.0 bu.	17.9 bu.
2	Winter wheat	43.0 bu.	46.5 bu.
	Oats	47.1 bu.	50.0 bu.
	Peas	20.3 bu.	19.3 bu.
3	Winter wheat	56.4 bu.	63.5 bu.
	Oats	56.1 bu.	61.5 bu.
	Fallow plus manure	....	....
4	Winter wheat	52.5 bu.	56.7 bu.
	Oats	42.3 bu.	42.0 bu.
	Fallow	....	....
5	Winter wheat	50.0 bu.	55.6 bu.
	Oats	59.7 bu.	64 9 bu.
	Corn for silage plus manure	7.82 tons	7.70 tons
6	Winter wheat plus 200 lbs. $NaNO_3$	47.4 bu.	48.2 bu.
	Oats	48.3 bu.	47.9 bu.
	Potatoes 1916-1922	120.7 bu.	....
	Corn for silage 1923-1937	....	5.51 tons
7	Winter wheat	34.3 bu.	35.5 bu.
	Oats	42.4 bu.	43.0 bu.
	Corn for silage	5.61 tons	5.35 tons
8	Winter wheat	49.2 bu.	50.7 bu.
	Oats	47.1 bu.	46.0 bu.
	Potatoes	84.5 bu.	68.5 bu.
9	Winter wheat	....	25.9 bu.
	Oats	....	45.5 bu.
	Sunflowers for silage	....	13.31 tons
10	Winter wheat	....	28.7 bu.
	Peas	....	19.5 bu.
	Sunflowers for silage	....	16.77 tons
11	Continuous winter wheat plus manure	33.4 bu.	35.5 bu.
12	Continuous winter wheat	22.6 bu.	23.0 bu.
13	Peas	....	23.1 bu.
	Winter wheat	....	39.4 bu.
	Winter wheat	....	25.2 bu.
	Winter wheat	....	24.7 bu.
14	Winter wheat	....	42.3 bu.
	Barley	....	33.1 bu.
	Oats and peas for hay	....	2.50 tons
	Peas	....	18.7 bu.
15	Sweet clover and peas (nurse crop)	....	16.3 bu.
	Sweet clover for hay	....	2.56 tons
	Oats	....	66.0 bu.
	Corn for silage	....	6.33 tons
	Winter wheat	....	42.2 bu.
16	Sweet clover for hay	....	1.41 tons
	Sweet clover for hay	....	3.40 tons
	Oats	....	67.8 bu.
	Winter wheat	....	29.7 bu.
	Corn for silage	....	5.92 tons
	Barley	....	57.0 bu.
17	Alfalfa and peas (nurse crop)	....	16.1 bu.
	Alfalfa for hay	....	1.95 tons
	Alfalfa for hay	....	1.97 tons
	Alfalfa for hay	....	2.03 tons
	Spring wheat	....	37.1 bu.
	Winter wheat	....	38.4 bu.
	Corn for silage	....	6.24 tons
	Barley	....	60.7 bu.

fall and spring. The cereal crops are harvested with a binder; no crop residues except the stubbles are returned to the land.

The general arrangement of the present plats is shown in Figure 1. The irregular arrangement of the separate series of plats is accounted for by the topographical features of the area and the location of the various plats on approximately comparable slopes. The general slope of the area is to the west. The soil is a Palouse silt loam.

Except in the case of the potato plats, the same varieties were used throughout the course of the rotation experiments. Since the long-time rotations will be analyzed on the basis of the trends shown by the yields over the period of years that the experiment has been conducted, this is important. Obviously, the substitution of varieties with differing yielding capacities may materially influence trend relationships. The varieties used were Red Russian winter wheat, Swedish Select oats, Alaska type peas, Rustlers White

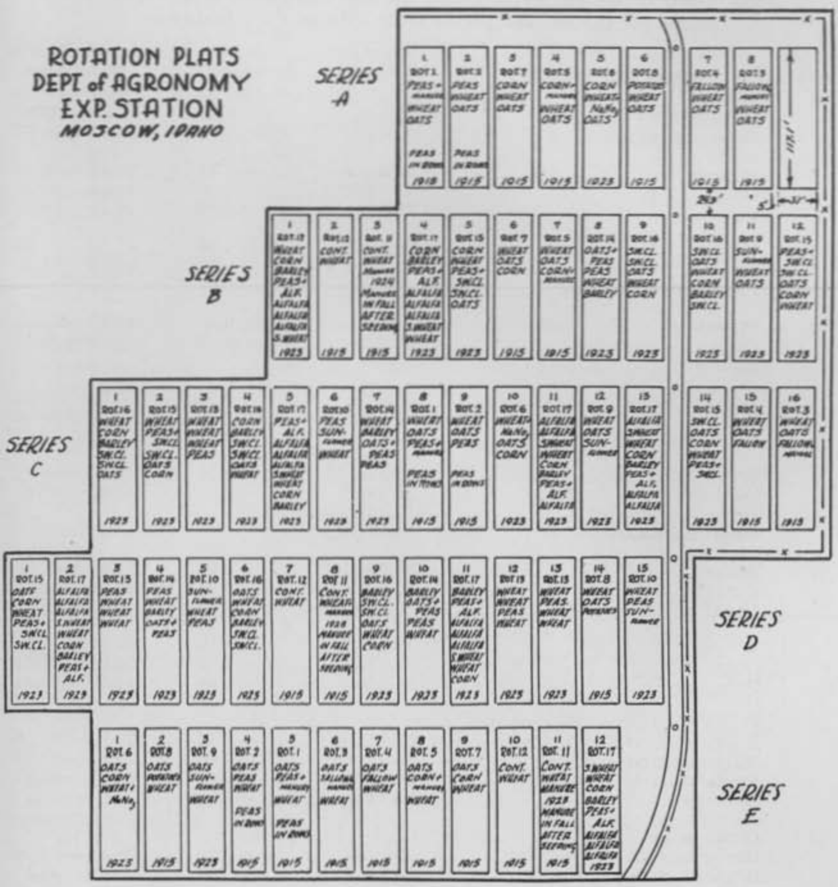

Figure 1.—Arrangement of old rotation plats on the University farm, Moscow, Idaho.

Dent corn, Winter Club barley, Red Bobs spring wheat, and Gold Coin, Early Ohio, Bliss Triumph, and Katahdin potatoes.

In view of the fact that the rotations here to be discussed do not include some of the practices in use at the present time, a new series of rotation plats was established in 1937 for purposes of evaluating these newer practices, embodying the use of more modern implements, and especially for purposes of studying the effects of adding varying amounts of crop residues as in the case of actual farm practice in territories using the combine method of harvesting.

Trends of Yields in the Long Time Rotations

Yield performances may be analyzed on the basis of averages and by the trends shown. When an experiment involving yield test extends over a sufficiently long period of years, the trend relationships shown will be of considerable value in the interpreta-

TABLE 3.—Average yields, yield trends, and extremities of trend lines of the separate crops grown in designated rotations on the University farm, Moscow, Idaho, for the 23-year period from 1915 to 1937, inclusive.

Rotation Number	Crops and sequence	Average Yield	Yield trend	Extremities of trend lines
1	Wheat	52.9 bu.	+1.26	38.97 —66.69
	Oats	63.5 bu.	+1.26	49.60 —77.32
	Peas plus manure	20.0 bu.	—0.51	25.15 —14.95
2	Wheat	43.0 bu.	+0.47	37.82 —48.16
	Oats	47.1 bu.	+0.20	44.96 —49.36
	Peas	20.3 bu.	—0.42	24.50 —16.10
3	Wheat	56.4 bu.	+0.96	45.86 —66.98
	Oats	56.1 bu.	+0.46	51.04 —61.16
	Fallow plus manure	----------	----------	-------- --------
4	Wheat	52.5 bu.	+0.63	45.67 —59.53
	Oats	42.3 bu.	—0.52	48.00 —36.56
	Fallow	----------	----------	-------- --------
5	Wheat	50.0 bu.	+1.18	37.03 —62.99
	Oats	59.7 bu.	+0.62	52.84 —66.48
	Corn plus manure	7.82 tons	—0.11	8.96 —6.65
6	Wheat plus 200 lbs. $NaNo_3$	47.4 bu.	+0.10	46.27 —48.47
	Oats	48.3 bu.	—0.67	55.65 —40.91
	Potatoes 1916-1922	120.7 bu.		
	Corn 1923-1937	5.51 tons		
7	Wheat	34.3 bu.	+0.24	31.75 —37.03
	Oats	42.4 bu.	—0.24	45.06 —39.78
	Corn	5.61 tons	—0.12	6.87 —4.35
8	Wheat	49.2 bu.	+0.17	47.30 —51.04
	Oats	47.1 bu.	—0.51	52.64 —41.42
	Potatoes	84.5 bu.	—3.36	119.71 —49.12
11	Continuous wheat plus manure			
	Replication A	29.5 bu.	+0.15	27.84 —31.14
	Replication B	35.9 bu.	—0.06	36.60 —35.28
	Replication C	34.7 bu.	—0.002	34.71 —34.67
	Average	33.4 bu.	+0.03	
12	Continuous wheat			
	Replication A	20.1 bu.	—0.15	21.76 —18.46
	Replication B	24.1 bu.	—0.09	25.09 —23.11
	Replication C	23.7 bu.	—0.28	26.75 —20.59
	Average	22.6 bu.	—0.17	

tion and practical application of the results. Table 3 gives the average yields and straight-line trends of the yields of the separate crops in the rotation systems conducted on the University farm for the 23-year period, from 1915 to 1937, inclusive.

Klages (1) discussed the analysis of yield data of rotation experiments on the basis of trend relationships. Straight-line trends calculated by the method of least squares were found to be of most practical use in the analysis and presentation of the data. It will be noticed from Table 3 that the "yield trend" of the wheat in rotation 1 was +1.26 bushels. This indicates that the yield of wheat in rotation 1 showed a tendency to increase, on the average, at the rate of 1.26 bushels per year, the extremities of the trend line extend from 39.97 to 66.69 bushels from 1915 to 1937. This is shown graphically in Figure 2. By way of comparison, it will be observed that the yield trend of the wheat in rotation 4 is positive, that is, the yields of the wheat show a tendency to increase at the average rate of 0.63 bushels per acre, while the oats yields in this same rotation, since they show a negative trend, decreased at an average rate of 0.52 bushels per year. The extremities of the trend line for the oats in rotation 4 extend downward from 48.00 to 36.55 bushels from 1915 to 1937. The trend relationships of the oat yields in rotation 4 are shown graphically in Figure 3.

The trend data here presented cannot be used for purposes of predicting the future yields of the plats on which they are based. They do, however, give a definite indication of yield expectations with the inauguration of similar sequences of cropping under the conditions under which the yields here reported were obtained. It cannot be expected that the high upward, and, in some instances, downward yield trends will continue at their former rates. Sooner or later, a state of equilibrium will be reached in the yields of these crops. Studies on parabola trends of the yield data give some evidence that this point has already been reached in the case of some of the rotations. The exact position of this yield equilibrium will be determined by the climatic conditions under which the crops are grown and by the soil changes induced by the different systems of cropping. Progressive soil changes brought about by the incorporation of organic matter or other factors can, in turn, be expected to modify the response of plants grown to the particular climatic features of their environment. Figures 2 and 3 show beside the calculated straight-line trends the parabola trends of the annual yield data. The parabola trends indicate that the upward trends, and, in some instances, the negative ones, were not at the same rate throughout the entire period covered by the experiment. This brings out one of the short-comings of straight-line trends insofar as they bring out an average or general trend only. On the other hand, parabola trends, when applied to rotation yield data, have one decided fault in that they produce curves tending to swing downward at increasing rates towards the end of their

(1) Klages, K. H. W., Trend studies in relation to the analysis of yield data from rotation experiments, Journal American Soc. Agronomy 30: 624-631. 1938.

cycles. The actual yield data give no evidence of the occurrence of such increasing dips, but rather show that they may be maintained at around their present level upon reaching the equilibrium point.

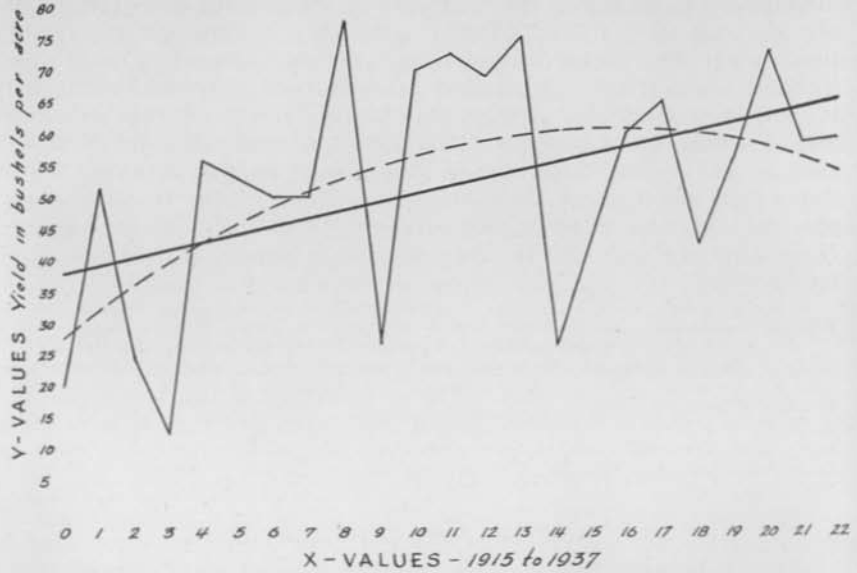

Figure 2.—Straight line and parabola trends of the seasonal yields of wheat in rotation 1 on the University farm, Moscow, Idaho, from 1915 to 1937, inclusive.

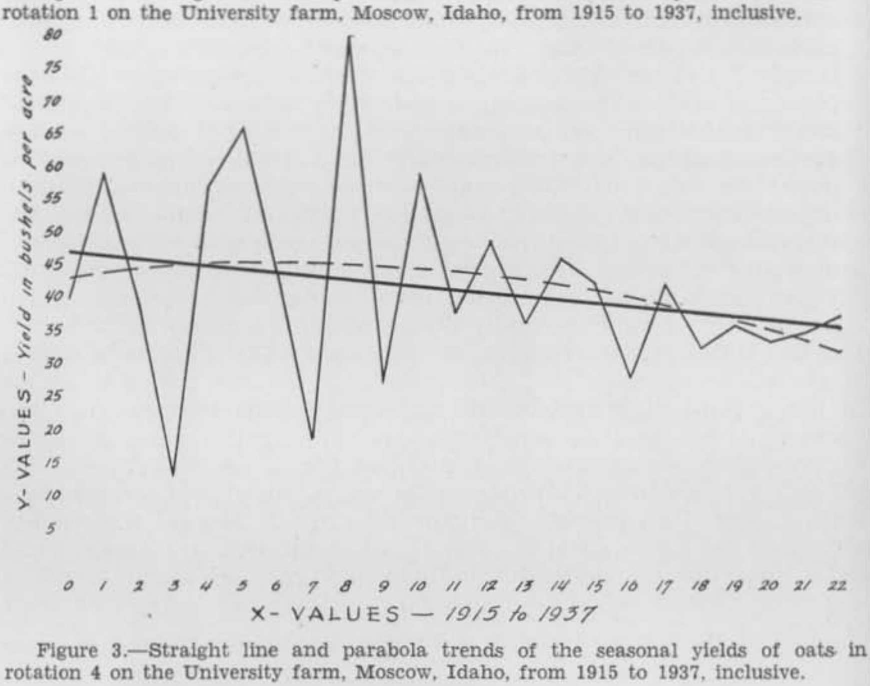

Figure 3.—Straight line and parabola trends of the seasonal yields of oats in rotation 4 on the University farm, Moscow, Idaho, from 1915 to 1937, inclusive.

Straight-Line Yield Trends in Relation to Rainfall Trends

The yield trends exhibited by crops in a series of rotation experiments may be due either to induced soil changes or to variations in climatic conditions, especially moisture relationships, over the period of the test. The influence of moisture relationships will be especially disturbing in the event of progressive changes in a given direction. That such progressive changes did not play a significant part in the trends of the yields shown by the crops in the rotation systems under discussion is brought out in Table 4, giving the annual and seasonal trends in precipitation at Moscow for the period of 1915 to 1937. The most significant positive trend is exhibited for the winter months of December to March, inclusive. The annual precipitation shows but a slight positive trend, while the August to November, as well as the April to July, trends show slightly negative trends.

TABLE 4.—Annual and seasonal trends in precipitation at Moscow, Idaho, for the period 1915 to 1937, inclusive, calculated by the method, least squares.

Periods of precipitation	Rainfall trends	Equation of line of least squares	Extremitios of trend lines
Annual	+0.09	y= +.09x+ 20.23	20.23 —22.21
Aug., Sept., Oct., and Nov.	—0.02	y= —.02x+ 6.14	6.14 — 5.72
Dec., Jan., Feb., and March	+0.14	y= +.14x+ 8.94	8.94 —12.02
Apr., May, June, and July	—0.04	y= —.04x+ 5.20	5.20 — 4.32

Yield and Trend Relationships

It will be observed from Table 3 that the high yielding plats of winter wheat and oats in the various rotation systems generally also show relatively high upward trends, while the lower yielding plats show either low, or, in instances, definite negative yield trends. A correlation between the average yields of the 14 wheat plats included in the separate cropping systems and their respective trend evaluation show a value of "r" = 0.8025 ± .0666. Figure 4 gives a graphic presentation of the yield and trend relationships in the wheat yields of the various rotation systems. A corresponding calculation of "r" for the average yields and trend evaluations in the case of the eight oat plats included in the test gave a correlation of 0.8779 ± .0584. The higher yields and also the higher upward yield trends in the rotations to which manure is applied, as compared with the lower yields and not infrequently negative trends of the rotations not receiving manure, are especially noteworthy.

Wheat Yields in Rotation Systems

Since wheat is the most important crop of the Palouse area, the yields of this crop in the various systems of rotations will be considered first. The average wheat yields taken from Table 2 are presented graphically in Figures 5 and 6 for the long and for the shorter periods that the rotations have been in progress.

It is interesting to note that the wheat yields of rotations 3, 1, 4, 5, 8, 6, and 2, fall in the same descending order for both the long and the shorter test periods. While the highest wheat yield was

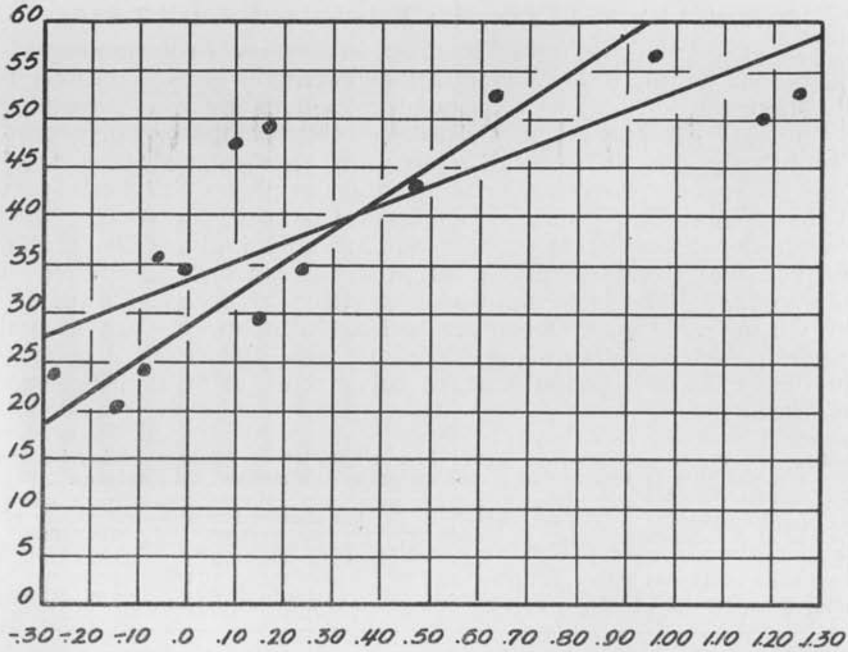

Figure 4.—Correlation diagram showing relationship between the average yields of the wheat plats included in the various rotations and their respective trend evaluation, "r" = 0.8025 ± 0.0666. The regression lines for x on y and y on x are $\bar{x} = 0.03$ y —0.86 and $\bar{y} = 19.52x + 33.31$, respectively.

obtained in rotation 3, wheat, oats and fallow plus manure, it should be noted from Figure 5 that the yields for the long-time rotations are comparatively high up to and including rotation 2. Rotations 7, 11, and 12 show significantly lower yields than the preceding ones.

The results for the shorter period of comparison, Figure 6, giving the wheat yields of all the various rotation systems from 1923 to 1937 show a different yield relationship than brought out in Figure 5, based strictly on the yield data for the 23-year period from 1915 to 1937. The yields drop off more or less in regular sequence from rotation 3 to 12. The yields of rotation 12, continuous wheat, are low for both tabulations of the data. The low yields in rotations 9 and 10 can be accounted for by the fact that the wheat in both instances follows sunflowers, a crop removing more moisture and nitrogen from the soil than any other crop grown in the rotation systems. It is hardly fair to evaluate rotation 16 on the basis of the wheat yields alone. This particular rotation measures up to the standards of a good system of cropping. It should be noted from Table 2 that the oat yields following 2 years of sweet clover are exceeded only by those in rotation 1. The wheat follows the oats. The oats gets the major benefits of the sweet clover, but evidently these effects resulting from the production of sweet clover for hay are not passed on to the wheat. The corn yields following the winter wheat are only fair; on the other hand, very good yields of barley, 57.0 bushels per acre, were obtained after the corn. A word is in order on the wheat yields of rotation 13, peas followed by 3 years of winter wheat. The yield of wheat following the pea crop is 39.4, while that of the 2 successive years is 25.2 and 24.7 respectively. The rotation has 75 per cent of wheat and an average yield of 29.8 bushels per acre. Other factors brought out in the graphical presentation of the

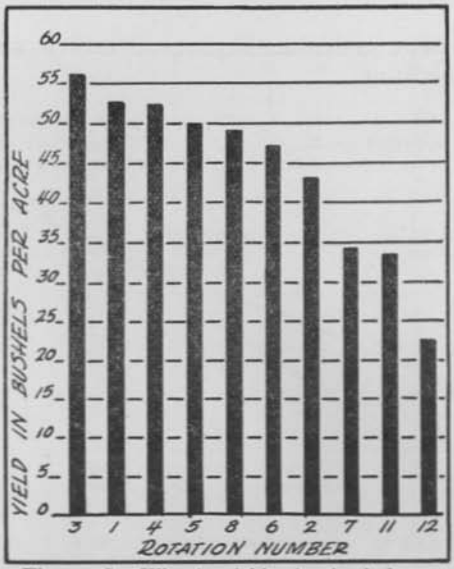

Figure 5.—Wheat yields in bushels per acre in the indicated rotation systems on the University farm at Moscow, Idaho, for the 23-year period from 1915 to 1937, inclusive.

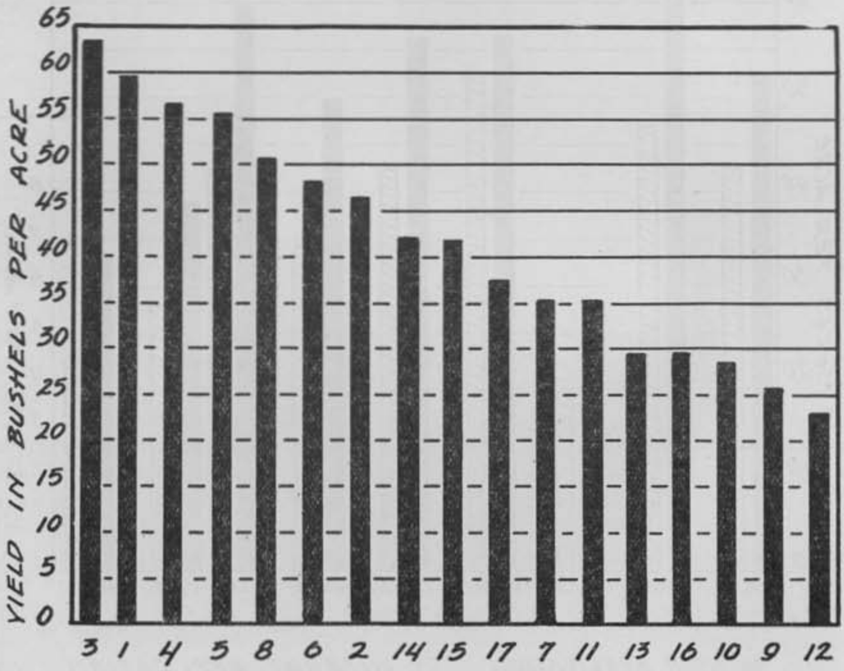

Figure 6.—Wheat yields in bushels per acre in the indicated rotation systems on the University farm, Moscow, Idaho, for the 15-year period from 1923 to 1937, inclusive.

wheat yields in Figures 5 and 6 will be discussed under special headings.

TABLE 5.—Average yields and trends of winter wheat, oats, peas and corn over a period of 23 years, 1915-1937, inclusive, grown on the University farm at Moscow in rotations with and without the application of manure.

Rotation Number	Crops and sequence of crops	Yields in trends in bu. per acre *				Increase from use of manure	
		With manure		Without Manure		In bu. per acre	In per cent
		Yield	Trend	Yield	Trend		
1 and 2	Wheat	52.9	+1.26	43.0	+0.47	+ 9.9	+23.0
	Oats	63.5	+1.26	47.1	+0.20	+16.4	+34.8
	Peas	20.0	—0.51	20.3	—0.42	— 0.3	— 1.5
3 and 4	Wheat	56.4	+0.96	52.5	+0.63	+ 3.9	+ 7.4
	Oats	56.1	+0.46	42.3	—0.52	+13.4	+32.6
	Fallow	......	......	......	......	......	......
5 and 7	Wheat	50.0	+1.18	34.3	+0.24	+15.7	+45.8
	Oats	59.7	+0.62	42.4	—0.24	+17.3	+40.8
	Corn	7.82	—0.11	5.61	—0.12	+ 2.21	+39.4
11 and 12	Continuous wheat	33.4	+0.03	22.6	—0.17	+10.8	+47.8

*Corn yields in tons of silage per acre.

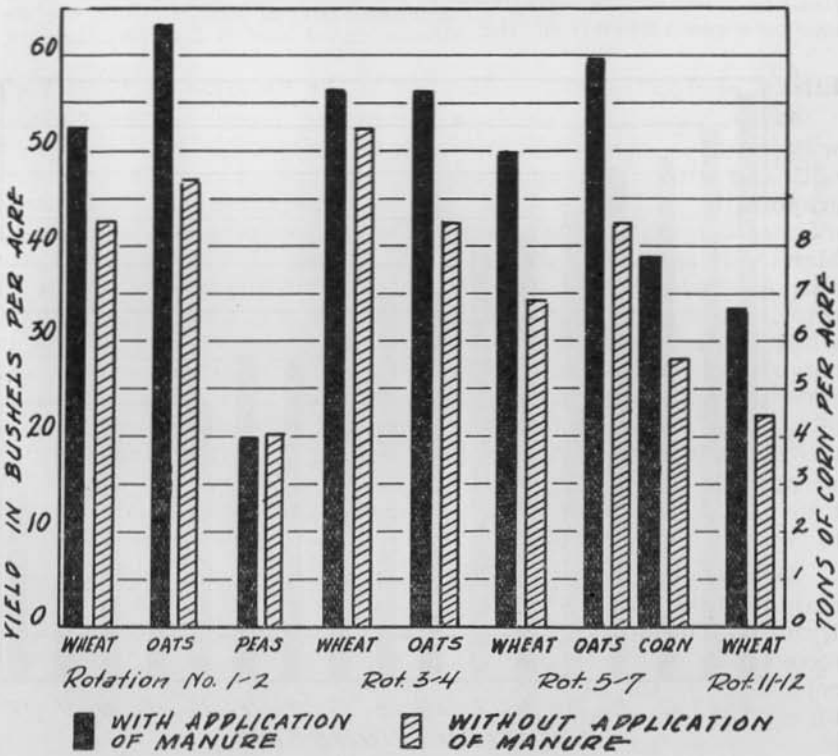

Figure 7.—Yields of crops in rotation on the University farm, Moscow, Idaho, with and without applications of manure.

Figure 8.—Wheat crops on rotations 1 and 2, wheat, oats, peas, on the University farm in 1938. The plat on the left, rotation 1, received an application of manure every third year; it yielded on the average of 52.9 bushels per acre and showed a positive trend of 1.26 bushels per acre per year. The plat at the right, rotation 2, received no manure; it yielded at the average rate of 43.0 bushels per acre and showed a positive trend of only 0.47 bushels. The yield data are for the 23-year period from 1915 to 1937, inclusive. Numbers on measuring stakes are for purpose of identifying photographs.

Effects of Applications of Manure in the Rotation on Crop Yields

Table 5 gives the average yields and trends in the yields of winter wheat, oats, peas, and corn in comparable rotation systems with and without the application of manure. The yields are shown graphically in Figure 7. In all of these rotations the barnyard manure is applied at the rate of 15 tons per acre every third year. Manure is applied to rotations 1, 3, 5, and 11. In rotation 1, consisting of wheat, oats, and peas, the manure is applied in the fall prior to the plowing of the land for the pea crop. In rotation 3, wheat, oats, fallow, the manure is plowed under in fall with the oats stubble preparatory to the fallow. In rotation 5, wheat, oats, corn, the manure is plowed under with the oats stubble in the fall of the year preceding the corn crop. In the continuous wheat plats, the manure is applied as a top dressing after the seeding of the winter wheat crop. Rotations 2, 4, 7, and 12 are identical to rotations 1, 3, 5, and 11, respectively, except that no manure is applied to them.

Significantly higher yields were obtained with applications of manure in all instances, except in the case of the peas in rotations 1 and 2. The differences in the yields of the manured and unmanured plats of wheat and oats become of special significance when considered in the light of their respective trend relationships. Rotation 1 shows a wheat yield of 52.9 and a positive trend of 1.26 bushels per year, while the wheat yields of the corresponding rotation 2, without applications of manure, show an average yield of only 43.0 with a trend of 0.47 bushels per acre. Figure 8 gives

Figure 9.—Wheat crops on rotations 5 and 7, wheat, oats, corn, on the University farm in 1938. The plat at the left, rotation 5, receiving an application of manure every third year shows an average yield of 50.0 bushels and a positive trend of 1.18 bushels per year. The plat at the right, rotation 7, to which no manure was added shows an average yield of 34.3 bushels and a positive trend of only 0.24 bushels. The yield data are for the 23-year period from 1915 to 1937, inclusive.

a view of the wheat on rotations 1 and 2. The differences in the oat yields and trends in rotations 1 and 2 are even more pronounced than for the wheat. The oats in the rotation receiving applications of manure yielded 63.5 and shows a positive trend of 1.26 bushels as compared to a yield of only 47.1 bushels and a positive trend of 0.20 bushels per acre per year in rotation 2, not receiving applications of manure. The differences in the yields of the wheat and oats in rotations 3 and 4 become especially significant when the trend relationships are taken into consideration. The differences in the yields and trends of the wheat following the fallow are not as outstanding as those of the second crop after the fallow and the manuring, that is, the oats. The beneficial effects of the fallow are apparently taken up completely, or nearly so, by the wheat without any significant carry-over effect to the oat crop. With applications of manure, the oats in rotation 3 yields 56.1 bushels and shows a positive trend of 0.46 as against a yield of only 42.3 and a definite negative trend of —0.52 bushels per acre in rotation 4, in which no manure is used. Negative trends are in evidence for the yields of both peas and corn. Corn definitely responded to applications of manure, peas did not. No attempt is made to explain the negative trends shown by corn yields. In the case of the peas in rotations 1 and 2 the crop was sown in open arrangement, planting two drill rows and skipping two rows from 1915 to 1922. From 1922 up to date, three planted drill rows were alternated with four blank rows. The blank rows were cultivated in both instances. The average pea yields prior to this change in the management of the plats in rotation 1 was 23.4 as compared to 17.9 bushels per acre after the change. In rotation

Figure 10.—Continuous wheat plats on the University farm in 1938. The plat at the left receives 15 tons of manure every third year; the one at the right receives no manure. These plats have been in wheat every year from 1915 to 1938. With applications of manure the yield has averaged 33.4 bushels and shows a positive trend of 0.03 bushels per year as compared to an average yield of 22.6 bushels and a negative trend of —0.17 bushels for the plats not receiving manure. Compare with Figure 7 and note the favorable effect of growing a crop in a rotation system.

2 the average yields of peas were 22.0 and 19.3 bushels per acre for the period prior and after the change in the method of seeding. Due to this shift in the handling of this particular crop, the trend calculations of the pea yields are of no significance.

The most outstanding differences in yields resulting from the application of manure are in evidence in the case of rotations 5 and 7, wheat, oats, and corn with and without applications of manure. The differences in the growth of the wheat crops in these two rotations are shown in Figure 9.

It should be kept in mind, in interpreting the data relating to applications of manure as given in Table 5 that the increases in yields are very significant. Furthermore the results indicate not only increases resulting from the applications of manure, but also bring out the effects of rotation systems on crop yields. This is in evidence by the yields of wheat in the continuous wheat plats as compared with the yields of wheat in the definite rotation systems, even those rotations to which no manure has been added. The wheat in rotation 2, wheat, oats, peas, to which no manure is applied yields 43.0 as compared to a yield of 33.4 and 22.6 bushels per acre for the continuous wheat plats with and without the applications of manure. This is also well brought out by a comparison of Figures 8 and 9 showing the growth of the wheat crops on the plats of rotation 1, 2 and 5 and 7 with Figure 10, showing the growth of the continuous wheat plats with and without the applications of manure.

Manure supplies not only plant nutrients but, due primarily to the organic matter added, brings about definite physical changes in the soil. The soil structure of the plats receiving the manure over the period of years under discussion has been materially altered. The outstanding results are improvements in the ease of handling the soil and decreased erosibility. The improvements in soil structure resulting from the applications of manure favor not only a more rapid rate of water penetration but also increase the water-holding capacity of the soil.

TABLE 6.—Comparative effects of fallow, peas, corn, potatoes and sunflowers on the yields of wheat and oats, and the variable crop indicated. Yields are presented for a 23- and 15-year period with and without applications of manure on the University farm, Moscow, Idaho.

Rotation number	Variable crop or practice	Yields and trends in bushels per acre, tons per acre for corn and sunflower						Yields of wheat and oats on a percentage basis of the yields in wheat, oats, pea rotations under each sub-heading		Yield of wheat on percentage basis of the continuous wheat plats under each sub-heading
		Variable crop		Wheat		Oats				
		Yield	Trend	Yield	Trend	Yield	Trend	Wheat	Oats	
For the 23 year period from 1915 to 1937, inclusive.										
	With applications of manure to rotation									
3	Fallow	....	....	56.4	+0.96	56.1	+0.46	106.6	88.3	168.9
1	Peas	20.00	—0.51	52.9	+1.26	63.5	+1.26	100.0	100.0	158.4
5	Corn	7.82	—0.11	50.0	+1.18	59.7	+0.62	94.5	94.0	149.7
11	Cont. wheat	....	....	33.4	+0.03	....	....	63.1	....	100.0
	Without applications of manure to rotation									
4	Fallow	....	....	52.5	+0.63	42.3	—0.52	122.1	89.8	232.3
2	Peas	20.30	—0.42	43.0	+0.47	47.1	+0.20	100.0	100.0	190.3
7	Corn	5.61	—0.12	34.3	+0.24	42.4	—0.24	79.8	90.0	151.8
8	Potatoes	84.50	—3.36	49.2	+0.17	47.1	—0.51	114.4	100.0	217.7
12	Cont. wheat	....	....	22.6	—0.17	....	....	52.6	....	100.0
For the 15 year period from 1923 to 1937, inclusive.										
	With applications of manure to rotation									
3	Fallow	....		63.5		61.5		106.5	85.3	178.9
1	Peas	17.90		59.6		72.1		100.0	100.0	167.9
5	Corn	7.70		55.6		64.9		93.3	90.0	156.6
11	Cont. wheat	....		35.5		....		60.0	....	100.0
	Without applications of manure to rotation									
4	Fallow	....		56.7		42.0		121.9	84.0	246.5
2	Peas	19.20		46.5		50.0		100.0	100.0	202.2
7	Corn	5.35		35.5		43.0		76.3	86.0	154.3
6	Corn+$NaNo_3$ (1)	5.51		48.2		47.9		103.7	95.8	209.6
8	Potatoes	68.50		50.7		46.0		109.0	92.0	220.4
9	Sunflowers	13.31		25.9		45.5		55.7	91.0	112.6
12	Cont. wheat	....		23.0		....		49.5	....	100.0

(1) 200 pounds per acre of sodium nitrate applied to the winter wheat as a top dressing in early spring.

The Influence of Fallow in the Rotation on Yields

Table 6 gives yield and trend data relative to the effects of including fallow, peas, corn, potatoes, and sunflowers in rotation systems on the yields of wheat and oats in such rotations. The highest wheat yields recorded for both the 15- and 23-year periods of comparison, with as well as without the application of manure, are found in rotations 3 and 4, the two rotations having a fallow every third year. It must be kept in mind, however, in comparing average yields of the fallow systems with those of continuous cropping that one-third of the land is idle every year.

The wheat yields in the fallow systems are high. Wheat is the first crop following the fallow. The beneficial effects of the fallow are taken up completely by the wheat without any carry-over effect on the oat crop following the wheat; as a matter of fact, the oat yields in the rotations where peas are substituted for fallow are uniformly higher than in the wheat, oats, fallow rotations.

One factor worth noting is that the differences in wheat yields between the wheat, oats, fallow and the wheat, oats, pea rotations are materially less in those cases where manure is added to the rotations. This is brought out especially when the yields of wheat and oats are placed on a percentage basis of the yields in the wheat, oats, pea rotations under each of the sub-headings in Table 6. The wheat in rotation 1, wheat, oats, peas plus manure, yields only 6.6 per cent less than in rotation 3, wheat, oats, fallow plus manure. The oat yields in rotation 1 are 11.7 per cent higher than for rotation 3. However, when no manure is applied to these rotations then the wheat in the fallow system, rotation 4, yields 22.1 per cent more than in the continuous cropping system, rotation 2, where peas replace the fallow. But even under these conditions it will be noted that the oat yields in rotation 2 exceed those of rotation 4 by 10.2 per cent. A good comparison of the wheat yields in the separate rotations is also given by stating the yield of wheat for each rotation on a percentage basis of the yield of wheat of the continuous wheat plats under each sub-heading in Table 6. The yields of wheat in the rotation systems range 49.7 to 117.7 per cent higher than for the continuous wheat plats in the case of the long time and from 12.6 to 146.5 per cent higher in the case of the short time rotation systems.

The Influence of Peas in the Rotation on Yields

The production of dry peas has become of great importance in the Palouse area within the past 15 years. The reason for the importance of this crop in this area is quite evident from a study of the comparative yield data presented in Table 6. The comparative yields of wheat in the wheat, oats, pea and the wheat, oats, fallow rotations bring out the economy of the practice of substituting the production of peas, at least in part, for fallow. The pea crop is removed early enough in the season so that a good seedbed can be prepared for winter wheat. Since the peas leave the soil in a loose condition a good seedbed can be prepared by discing and harrowing. Unfortunately the modifications of the structure of the surface soil by the pea crop makes the soil more subject to erosion.

Rotation 1, wheat, oats, peas, plus manure, shows high wheat and oat yields as well as high upward trends in the yields of these crops. The yields of rotation 2, identical to 1 except that no manure is applied, are lower for the wheat and oats than in rotation 1, but are nevertheless high and continue to show upward yield trends. Rotation 1 meets the requirements of a good rotation system. It provides an economical method of cropping and since 15 tons of manure are applied every third year, the soil conditions on these plats have improved over the period of the experiment, consequently the high yields and decidedly upward trends for the cereal crops. Rotation 2, wheat, oats, peas, cannot by the criteria presented early in this publication be classed as a good rotation. Everything except the stubble of the crops grown is removed from the soil, nothing is added, yet the yields are fairly high and the trend of the yields of the cereals in this rotation remain positive. In this connection it is interesting to compare the wheat yields of rotation 2 with those obtained in rotation 12, continuous wheat. The wheat in rotation 2 yields 90.3 per cent more than the plats cropped continuously to wheat. Again the wheat yields of rotation 2 are 9.9 bushels per acre higher than the yields in rotation 11, continuous wheat plus manure. While rotation 2 does not measure up to the standards of a really good rotation, it nevertheless is conducive to the production of high yields; as a matter of fact, the comparative wheat yields of rotations 2 and 11 indicate that the growing of wheat in a rotation system is more effective in increasing yields than a continuous one-crop system even with systematic applications of manure.

The economy of including peas in a rotation system is dependent in part on price relationships. Peas can be used to advantage in replacing, if not all, then at least a portion of, the area ordinarily devoted to fallow. It is interesting to note from Table 6 that the highest oat yields were in all instances obtained on the wheat, oats, pea rotations. It is interesting to note the performance of the winter wheat crops in rotation 13, peas followed by three successive wheat crops. The yield of the wheat following the peas is 39.4 bushels as compared to 25.2 and 24.7 bushels per acre for the second and third year after the peas respectively. Figure 11 shows the wheat crop of this rotation for the first and second year after the production of peas.

The Influence of Corn in the Rotation on Yields

Corn is not an important crop in the Palouse area. Lack of sufficient summer rainfall and low temperatures are responsible for the comparatively low yields reported. Corn can be grown to maturity only in places favored with proper air drainage. The corn on the rotation plats is harvested for silage, all yields are reported as silage weights of the total crop in tons per acre.

The inclusion of corn in the rotations resulted in reduced wheat yields in all cases except in rotation 6, winter wheat plus 200 pounds of sodium nitrate, oats, corn. The performance record of the wheat in rotation 6 offers an explanation for the depressing effects of corn on wheat yields following this crop. Corn is a coarse feeder, it draws especially heavy on the available nitrate in the soil.

Figure 11.—Wheat in rotation 13 on the University farm, Moscow, Idaho, in 1938, peas followed by three successive crops of winter wheat. The plat to the left shows the growth of the wheat the first year after peas; it yielded an average of 39.4 bushels as compared to a yield of only 25.2 bushels per acre for the plat to the right showing the growth of the wheat for the second year after the production of the pea crop. The yield of wheat for the third year out of peas averaged 24.7 bushels per acre. Yield data for the 15-year period from 1923 to 1937, inclusive.

When, as was the case in rotation 6, this deficiency of available nitrates is corrected by an application of sodium nitrate to the wheat in early spring the wheat yields are materially increased. Rotations 5, 6, and 7 are comparable insofar as they include the identical crops, wheat, oats, corn. Manure is added to rotation 5; the wheat and the oat yields are 55.6 and 64.9 bushels per acre respectively. The yields of these same crops in rotation 6, to which a top dressing of 200 pounds per acre of sodium nitrate is added to the winter wheat crop are 48.2 and 47.9 bushels. To these above yields must be compared those of rotation 7, to which nothing is added, the wheat and oat yields are 35.5 and 43.0 bushels per acre, respectively.

The Influence of Potatoes in the Rotation on Yields

Due to scarcity of summer precipitation, potatoes are not an important crop in the Palouse area. As may be observed from Table 6, the yields of this crop are low. Potatoes are found only in rotation 8, wheat, oats, potatoes. The winter wheat yields following potatoes are higher than those following any other crops grown during both the long and shorter periods of comparison. This is, no doubt, due in part to the low potato yields obtained and to the cultural practices incident to potato production.

The Influence of Sunflowers in the Rotation on Yields

Sunflowers have a place in the Palouse area as a silage crop. They are grown in rotation 9, winter wheat, oats, sunflowers, and in rotation 10, winter wheat, peas, sunflowers. The sunflower yields are reported on the basis of silage weight of the total crop.

It will be observed, Table 2, that the sunflower yields in rotation 10, following peas are 16.77 tons as compared to 13.31 tons per acre in rotation 9, following oats. In both instances, the wheat yields following sunflowers crops are low; as a matter of fact they are lower following sunflowers than any other crop grown in the rotation systems. Sunflowers are coarse feeders, removing not only large amounts of plant food elements but also greater quantities of moisture from the soil than any other crop commercially grown in the Palouse area. Cereal yields in this area are largely determined by the availability of nitrates and moisture in the soil. This accounts for the low wheat yields following sunflowers.

Crop Rotations at the Sandpoint Substation

A rotation consisting of 2 years of sweet clover, winter wheat, potatoes, and oats was established at the Sandpoint substation in 1920 and continued up to and including 1932. No other rotations that could be used for purposes of comparison were laid out until the spring of 1937.

TABLE 7.—Average yields for the rotation at the Sandpoint substation for the 9-year period from 1924 to 1932 inclusive.

Crops in rotation and sequence of cropping	Average yields per acre
Sweet clover first year—hay	0.83 tons (1)
Sweet clover second year—hay	2.70 tons
Winter wheat	35.9 bu. (2)
Potatoes	2348.0 lbs.
Peas (as a nurse crop for sweet clover)	7.1 bu.

(1) Average for 1923 to 1925, inclusive.
(2) Winter wheat winterkilled in 1925 and 1930 and spring wheat was substituted.

Table 7 gives the average yields of the rotation established in 1920. Since the cropping practices were variable for the first years of the test comparable yield data are available only for the 9-year period from 1924 to 1932, inclusive. For the first years of the test, the sweet clover in this rotation was seeded without a nurse crop, averaging for the first year of its establishment a hay yield of 0.83 tons per acre. From 1926 to 1932, inclusive, the sweet clover was established with the use of peas as a nurse crop. The pea yields on the new seeding of sweet clover averaged only 7.1 bushels per acre as compared to an average yield of 20.0 bushels per acre when this crop was seeded alone. This reduction in yield was evidently due to the heavy demands for moisture on the part of the young sweet clover plants.

Table 1 gives a brief summary of the outstanding features of the climate at the Sandpoint substation for the period from 1924 to 1932, inclusive.

Crop Rotations at the Aberdeen Substation

Preliminary rotation studies were started at the Aberdeen substation in 1925. The rotation systems presented in Table 8, showing the sequence of cropping and practices for each of the separate rotations, were established in 1929 and continued up to date.

TABLE 8.—List of rotations and average yields of separate crops grown in rotation systems at the Aberdeen substation for a 9-year period from 1929 to 1937, inclusive.

Rotation Number	Crop and sequence	Average yields
1	Alfalfa and wheat (nurse crop)	55.70 bu.
	Alfalfa hay (1)	2.35 tons
	Alfalfa hay (1)	2.96 tons
	Potatoes	202.30 cwts.
2	Alfalfa and wheat (nurse crop)	64.30 bu.
	Alfalfa hay (1)	2.55 tons
	Alfalfa hay (1)	3.19 tons
	Potatoes plus manure	241.90 cwts.
3	Wheat	50.00 bu.
	Peas	21.40 bu.
	Peas	21.10 bu.
	Potatoes	171.00 cwts.
4	Wheat	57.90 bu.
	Peas	22.60 bu.
	Peas	22.00 bu.
	Potatoes plus manure	202.30 cwts.
5	Red clover and wheat (nurse crop)	47.00 bu.
	Red clover seed	5.37 bu.
	Red clover seed	5.01 bu.
	Potatoes	186.70 cwts.
6	Red clover and wheat (nurse crop)	63.30 bu.
	Red clover seed	5.92 bu.
	Red clover seed	6.31 bu.
	Potatoes plus manure	230.40 cwts.
7	Alfalfa and barley (nurse crop) (2)	67.90 bu.
	Alfalfa hay (1)	2.89 tons
	Alfalfa hay (1)	3.35 tons
	Alfalfa hay (1)	3.06 tons
	Alfalfa hay (1)	2.81 tons
	Potatoes	249.80 cwts.
	Potatoes	210.50 cwts.
	Wheat	64.50 bu.

(1) The hay yields indicated are for the period of 1932 to 1937, inclusive. Alfalfa seed was produced from 1929 to 1931.

(2) The yield data for two years, 1933 and 1935, were lost, as a result the yield indicated is the average of seven years only.

The red clover and alfalfa in the rotation systems during the early years of the experiment made rather limited growth. The cause was attributed to phosphate deficiency. In view of the fact that the true value of the various legumes in the different rotations could not be ascertained as long as this condition existed it was decided that more reliable data could be obtained by applying phosphate to all plats. Applications of 125 pounds per acre of treble superphosphate were given to all plats in 1933, 1935 and 1937.

It will be observed that rotations 1 and 2, 3 and 4, as well as 5 and 6 are directly comparable insofar as each group has the same sequence of cropping but differs in that the even numbered rotation of each group receives an application of 10 tons of sheep manure during the course of the rotation or every fourth year. The manure is applied in the spring prior to plowing the plats for potatoes. Spring wheat and potatoes are found in each of the above three groups of rotations. The variable crops are alfalfa in rotations 1 and 2, peas in 3 and 4, and red clover seed in rotations 5 and 6. Table 9 gives a systematic presentation of the yields and increases in the yields of each of the separate crops in these rotations traceable to the influences of the variable crop grown as well as increases due to the applications of manure for each of the crops in the three groups of rotations indicated. The highest yields both with and without applications of manure were obtained in rotations 1 and 2. It is interesting to note that without applications of manure to the rotation that the wheat yields are higher in the rotation with peas as the variable crop than where red clover seed is produced in the course of the rotation. This condition is altered by the application of manure to these rotations, in which case the clover seed rotation gives yields practically as high as are obtained in the alfalfa rotation. The application of manure results in a greater increase in the yields of wheat and potatoes as well as of the red clover seed in the rotation where the latter is the variable crop than where either alfalfa or peas make up the variable crop in the rotation. This indicates that red clover seed production removes more nutrients from the soil than the production of either alfalfa or peas, or in common terminology red clover seed production is harder on the land than the production of peas or alfalfa. It will be observed from Table 9 that this far-reaching statement does not hold true altogether from the standpoint of the potato yields in this set of rotation experiments under discussion. The potato yields in these rotation systems are not correlated with the wheat yields. As in the case of the wheat the highest

TABLE 9.—The comparative effects of variable crops and applications of manure on the yields of separate crops in rotations 1 to 6 at the Aberdeen substation for the years from 1929 to 1937, inclusive. Wheat and potatoes are crops common in these six rotations.

Variable crop in rotations	Variable crops			Wheat yields			Potato yields		
	Without manure	With manure	Percentage increase due to manure	Without manure in bu. per acre	With manure in bu. per acre	Percentage increase due to manure	Without manure	With manure	Percentage increase due to manure
Alfalfa	Rot. 1	Rot. 2		Rot. 1	Rot. 2		Rot. 1	Rot. 2	
1st year	2.35 tons	2.55 tons	8.5						
2nd year	2.96 tons	3.19 tons	7.8	55.7	64.3	15.4	202	242	19.8
Peas	Rot. 3	Rot. 4		Rot. 3	Rot. 4		Rot. 3	Rot. 4	
1st year	21.4 bu.	22.6 bu.	5.6						
2nd year	21.1 bu.	22.0 bu.	4.8	50.0	57.9	15.8	171	202	18.1
Red clover seed	Rot. 5	Rot. 6		Rot. 5	Rot. 6		Rot. 5	Rot. 6	
1st year	5.37 bu.	5.92 bu.	10.2						
2nd year	5.01 bu.	6.31 bu.	25.9	47.0	63.3	34.7	187	230	23.0

yields of potatoes were obtained in the alfalfa rotations, both with and without applications of manure, but the potato yields are lower in the pea than in the red clover seed rotation. Again, the response of potatoes to applications of manure was somewhat greater in the red clover seed than in the alfalfa or the pea rotations.

High yields of all crops included are in evidence for rotation 7. The outstanding feature of this rotation is that it includes 4 years of alfalfa. Both the potatoes and the cereal crops show high yields; as a matter of fact these yields compare favorably with those of the shorter rotations receiving applications of manure. Allowing alfalfa to remain on the soil for a relatively long period of years has on the basis of the yield data here presented much the same influence on the yields of potatoes and cereal crops in the rotation as the application of manure to rotation systems of shorter duration. It must be kept in mind, however, that if a long time rotation is adopted, it will take a considerable number of years for the rotation to run its course and to cover the acreage of any given farm. The prevalence of the bacterial wilt disease of alfalfa favors the establishment of short-time rotations. In areas where this disease is severe, stands of alfalfa are greatly reduced after the second year of cropping.

The outstanding features of the climate at Aberdeen are presented in Table 1.

The crop rotations at Aberdeen have up to date yielded valuable and practical information relative to the comparative response of crops in varying sequences and soil management practices. Since, however, they have been in progress, on the present basis, for a period of only 9 years, they should be continued for a longer period before definite conclusions can be drawn. Nine years is a comparatively short period in the cropping history of any given area of land especially when one of the rotations considered, rotation 7, required 8 years to run its course.

The varieties of crops grown in these rotation systems were as follows: alfalfa, Grimm; potatoes, netted Gem; wheat, Federation; barley, Trebi; peas, Austrian winter; and red clover, medium red.

Results of Rotation Experiments at the High Altitude Substation, Tetonia

Rotation experiments have been in progress at the high altitude substation since 1925. Table 10 gives a list of the rotations and the average yields of the separate crops grown in the various rotation systems. All plats are grown in duplicate every year. The results presented are for the 13-year period from 1925 to 1937, inclusive, with the exception of rotation 6, which was established in 1930. The yields given for rotation 6, since the averages are based only on 8 years, are not directly comparable with those of the 13-year rotations.

Table 11 gives the distribution of the wheat yields in frequency classes of five bushel intervals for each of the duplicated

TABLE 10.—List of rotations and average yields of separate crops grown in rotation systems at the High Altitude substation, Tetonia, Idaho for the 13-year period from 1925 to 1937, inclusive.

Rotation Number	Crops and sequence	Average yields
1	Spring wheat	12.7 bu.
	Peas	7.2 bu.
2	Winter wheat	14.2 bu.
	Fallow	......
3	Peas	9.0 bu.
	Spring wheat	12.8 bu.
	Fallow	......
4	Sweet clover	......
	Sweet clover	1.20 tons
	Potatoes	41.2 cwts.
	Spring wheat	17.5 bu.
5	Sweet clover	......
	Sweet clover	0.98 tons
	Spring wheat	11.6 bu.
	Fallow	......
	Winter wheat	15.8 bu.
6[1]	Sweet clover and spring wheat (nurse crop)	7.9 bu.
	Sweet clover, plowed under and fallowed	......
	Winter wheat	15.2 bu.
	Fallow	......
	Winter wheat	13.5 bu.
7	Sweet clover	......
	Sweet clover	1.15 tons
	Fallow	......
	Winter wheat	15.2 bu.
	Fallow	......
	Winter wheat	14.6 bu.

(1) Average of 8 years' results, 1930 to 1937, inclusive.

wheat plats in separate rotation systems. In view of the great variability of these wheat yields, the frequency distributions and the locations of the modal classes of the yields in the separate rotations provides a better index of performance and crop expectancy than the mere presentation of average yields. The yields of both winter and spring wheats at the high altitude substation show a high degree of correlation with total seasonal, growing season and especially with June and July rainfalls. High yields of winter wheat were obtained in 1925, 1928, and 1937; in addition to these years, high yields were also recorded for the spring wheat plats in 1932.

The yields of the crops in the different rotation systems at Tetonia indicate that, up to the present, availability of moisture is more of a limiting factor than soil fertility. Under continued cropping fertility and physical condition of the soil may be expected to become of increasing importance in the future. There is definite danger of wind and under certain conditions, water erosion in part of the area represented by the high altitude substation. It will be observed from Table 10, that the winter wheat yields in the rotation systems including sweet clover, that is rotations 5, 6 and 7,

TABLE 11.—Distribution of the wheat yields of duplicate plats in the various rotation systems at the High Altitude substation, Tetonia, Idaho, into frequency yield classes of 5 bushel intervals. The yield data are for the 13-year period from 1925 to 1937, inclusive.

Limits of yield classes in bushels	Rotation number, crop (spring or winter wheat), and position in rotation										
	1 (1) Spr.	2 (2) W.W.	3 Spr.	4 Spr.	5 Spr.	5 W.W.	6 Spr.	6 1st W.W.	6 2nd W.W.	7 1st W.W.	7 2nd W.W.
0—4.9	3	1	3	2	5	—	8	—	1	1	2
5.0— 9.9	12	8	13	4	11	5	2	3	1	4	4
10.0—14.9	4	10	4	8	2	9	1	6	8	11	12
15.0—19.9	—	2	1	3	—	5	5	4	4	3	2
20.0—24.9	3	1	1	4	5	3	—	2	2	4	4
25.0—29.9	1	3	1	2	2	4	—	1	—	2	2
30.0—34.9	3	—	3	1	1	—	—	—	—	—	—
35.0—39.9	—	1	—	—	—	—	—	—	—	1	—
40.0—44.9	—	—	—	1	—	—	—	—	—	—	—
45.0—49.9	—	—	—	1	—	—	—	—	—	—	—
Modal class	7.5	12.5	7.5	12.5	7.5	12.5	2.5	12.5	12.5	12.5	12.5

(1) Spr.—Spring wheat.
(2) W.W.—Winter wheat.

did not on the average give significantly higher yields than were obtained in the straight winter wheat, fallow system, rotation 2. From Table 11, it becomes evident, however, that even though the modal classes are identical for the yields of the winter wheat in the different rotation systems the distribution of the yields in the fallow rotation show nevertheless a higher percentage of the yields in the frequency class immediately below the modal class than in the case of those rotations containing sweet clover. This indicates a higher yield expectancy in the case of the sweet clover rotations than in the fallow rotation.

The spring wheat yields in the various rotation systems are low except in the case of rotation 4, where spring wheat follows potatoes. The relative performance of the spring wheat following potatoes is especially well brought out in the tabulation of the yield frequencies in Table 11. The yields of the spring wheat in the case of the potato rotation are the only ones falling into the modal class of 10.0—14.9 or 12.5, taking the center value of the class. The yields in the case of the other rotations fall either into the modal class of 7.5 or lower. The low yields of the spring wheat in rotation 6, where spring wheat is used as a nurse crop for sweet clover, indicates that it is best to establish sweet clover alone. While the average yield of the spring wheat is 7.9 bushels per acre, the modal class of the yield frequencies is only 2.5 bushels.

In addition to the yield data from the regular rotation systems there are available from the high altitude substation the results of an extensive test laid out for the purpose of evaluating the relative immediate effects of preceding crops on the yields of current crops. The results of this experiment for the 7-year period from 1931 to 1937, inclusive, are presented in Table 12. The crops enumerated were grown in a 3-year rotation consisting of summer fallow, fol-

TABLE 12.—Yields of current crops following the preceding crops designated in a three-year rotation system consisting of fallow, the preceding, and the current crops at the High Altitude substation, Tetonia, Idaho, for the 7-year period from 1931 to 1937, inclusive.

Preceding Crop	Yield following summer fallow (1)	Yields of current crops (2)					
		Wheat	Oats	Barley	Potatoes	Rye	Peas
Wheat	13.8	13.1	25.8	18.1	48.1	12.8	5.6
Oats	37.2	13.3	28.2	18.3	49.9	13.5	6.2
Barley	23.9 (3)	14.7	24.9	19.7	48.8	12.8	6.3
Potatoes	70.3	17.5	32.0	21.2	60.6	16.7	7.2
Rye	15.5	12.4	23.7	20.4	45.2	13.2	5.9
Peas	8.5	14.7	29.4	19.9	54.3	15.3	5.8

(1) Since these crops were grown following the summer fallow, the year prior to the production of the current crops, the yields of these crops are not directly comparable with those given for the current crops.
(2) Yields are given in bushels per acre except for the potatoes which are given in cwts.
(3) Yields of 5 years only, yields for 1931 and 1933 are missing.

lowed by the crops designated as preceding, and in the third year by the current crops, the yields of which are reported. The yields following the summer fallow are also presented, since, however, these crops were grown the year prior to the production of the current crops, the yields of these crops are not directly comparable with those given for the current crops. The differences in the yields of the current crops following the various preceding crops are small, again bringing out the fact that soil moisture, rather than fertility constitutes for the time being, the main limiting factor to crop production. The yields of the current crops following potatoes are uniformly high. This checks with the results obtained at Moscow. The crops following peas gave fair yields. The yields of the peas in this test as also in the regular rotation systems are low, as a matter of fact, so low that this crop is of doubtful value in the area represented by the high altitude substation.

Summary

The yield data of crop rotation experiments from the University farm at Moscow, the Sandpoint, Aberdeen, and the High Altitude substations are presented and discussed.

Due to the great diversity of climatic and soil conditions, the results reported from each of the stations are applicable only to the sections represented by the several stations. The results from the University farm are applicable to the Palouse and adjacent areas of northern Idaho, those from Sandpoint to the northern cut-over sections, while those reported from the Aberdeen substation apply to the irrigated areas of southern, particularly southeastern Idaho. The results from the High Altitude substation at Tetonia apply to the dry-land areas of eastern, particularly northeastern Idaho.

The outstanding characteristics of a good rotation system are listed and discussed in relation to their application to the various conditions met with in the different parts of the state.

The yield data of the separate crops in 10 rotation systems are available from the University farm for the 23-year period from 1915 to 1937, inclusive. The yield performances of these crops were analyzed on the basis of averages and by the yield trends shown. The trend evaluations presented give indications of the yield expectations with the inauguration of similar sequences of cropping under comparable environmental conditions. The high yielding plats in the various rotation systems generally also show relatively high upward yield trends, while the lower yielding plats show either low, or in instances, definite negative trends. In all 17 rotation systems were compared at Moscow; seven of these, however, date back to 1923 only.

Wheat is the one crop common to all the rotations on the University farm. The relative performance of this crop is discussed for each of the rotations of the long and shorter periods.

Applications of manure in the course of the rotations on the University farm led to significant increases in the yields of all crops with the exception of peas. The differences in the yields of manured and unmanured plats become of special interest when considered in the light of their respective trend relationships.

The direct effects of variable crops and fallow preceding the wheat in 3-year rotation systems containing wheat and oats as common crops is well illustrated by placing the relative performances of wheat in each of the rotations on a percentage basis of the yields obtained on the continuous wheat plats. With continuous wheat placed at 100, the variable practices and crops can then be evaluated in their relative effects on the wheat yields in the various rotations as: fallow 246, potatoes 220, peas 202, corn 154, and sunflower 113. This comparison is for the 15-year period from 1923 to 1937, inclusive, for the rotations not receiving applications of manure. While the exact evaluations of the variable crops in their respective effects on the yields of wheat in the different rotations differ somewhat, their relative effects remain the same regardless of the lengths of the periods of comparison and whether or not manure was used in the course of the rotation.

While the highest yields of wheat were obtained in the case of the fallow rotations, it must be kept in mind in comparing the average yields of the fallow systems with those of continuous cropping that one-third of the land is idle every year. Furthermore, the beneficial effects of the fallow are taken up completely by the crop following the fallow. The comparative yields of wheat in the wheat, oats, pea, and the wheat, oats, fallow rotations bring out the economy of the practice of substituting the production of peas, at least in part, for the fallow. The highest yields of oats were in all instances obtained in the wheat, oats, pea, rather than in the wheat, oats, fallow rotations.

With the exception of certain limited bean producing areas, no cultivated crop is grown to any appreciable extent in the northern portions of Idaho. Scarcity of summer precipitation results in relatively low potato yields, while low summer rainfall as well as lower than optimum temperatures account for the moderate corn yields obtained. While sunflowers may be grown as a silage crop, it must be recognized that the production of this crop has a depressing effect on the yields of wheat, and no doubt other cereals, following its in the rotation.

The results of one rotation are available from the Sandpoint substation.

A set of six 4-year rotations at the Aberdeen substation provided yield data showing the influences of the inclusion of such leguminous crops as alfalfa, red clover, and peas in the rotation on the yields of potatoes and wheat with and without applications of manure. The use of alfalfa in the course of the rotation systems resulted in higher average yields of both potatoes and wheat than the inclusion of either red clover or peas. Results are also presented from an 8-year alfalfa rotation including wheat, potatoes, and barley.

The yield data of 7 rotation systems are presented from the High Altitude substation at Tetonia. The yields of the crops included in the different rotation systems indicate that, up to the present, availability of moisture rather than soil fertility constitutes the main limiting factor to profitable crop production in the area represented by this station.