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CROP ROTATIONS and SOIL PRODUCTIVITY

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CROP ROTATIONS AND SOIL PRODUCTIVITY

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This bulletin is a report of what were known as the Fry Farm rotations,[3] the Five-year Rotation Corn-Agronomy Experiment No. 1, and Continuous Corn Culture-Agronomy Experiment No. 2, at the Ohio Agricultural Experiment Station.

In the early history of agronomic research much emphasis was placed upon determining the role of the major nutrients in plant nutrition. In the majority of soil fertility experiments the crops used were limited to a few relatively simple crop rotations, the greater number of variables being assigned to the fertility treatments. The role of legumes in nitrogen fixation and the removal of nutrients by different crops were appreciated as factors in soil fertility. However, as time went on, it became evident that crop rotation itself was a factor in soil productivity, through its influence upon soil structure and other physical properties, upon the soil organic matter supply, and upon the activity of soil microorganisms.

The effect of rotations upon soil productivity, therefore, received increasing attention from agronomists during the first half of this century.

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[3] The Fry Farm Crop Rotation Experiments were planned by C. G. Williams, at that time Chief of the Agronomy Department of the Ohio Agricultural Experiment Station at Wooster. The original plans were revised with the 1936 crop year under the direction of R.M. Salter, who had succeeded Director Williams as Chief of the Agronomy Department. Mr. Thatcher had the entire responsibility for these experiments beginning in 1938. He prepared a report of them before his retirement in 1953. For various reasons publication was delayed and it has become necessary to rewrite the comparisons of rotations and the conclusions. This has been the sole connection of the junior author with the experiment. The tables, literature review and general considerations are substantially as Mr. Thatcher prepared them. Important conclusions from these rotations were published in the article "Crop rotations and soil nitrogen", by J. L. Haynes and L. E. Thatcher, in Soil Sci. Soc. Amer. Proceedings, 19:324-327, 1955. Two other Ohio bulletins on rotations, Bulletin 847, "Rotation experiments in Paulding, Henry, and Madison Counties", by C. J. Willard, 1959, and Bulletin 839, "Experiments on the use of sweet clover for green manure", by C. J. Willard and E. E. Barnes, 1959, combine with this bulletin to summarize the older Ohio Experiments on crop rotation.

The Five-year rotation corn and continuous corn culture experiments were started in 1894 by Charles E. Thorne, Director, the Ohio Agricultural Experiment Station.

Investigations bearing on many phases have been carried on. In many of these projects where field experiments were used, treatments with supplementary soil amendments were held at a minimum: the variables consisting largely of different kinds of crops, crop sequences and length of rotation. This has been a basic weakness of many of these tests, since a rotation which drains the soil heavily is necessarily penalized when less nutrients are returned than are obviously needed.

REVIEW OF LITERATURE

Rotations Influence Yields

One of the oldest crop rotation and fertility experiments in the United States is the one on Sanborn Field in Missouri. Smith (49) summarized the 50-year results and among other things pointed out:

Crop rotations have given better returns than continuous cropping.

Short rotations gave larger economic returns but longer rotations were more effective in maintaining soil productivity.

The length of rotation or the sequence of crops in a rotation has a less important effect on crop values or on the return from the land than soil treatments or different systems of soil management.

The greater the length of time a thick-growing crop is on the land and the less frequent the cultivation of the soil the less rapid is the decline in soil nitrogen.

The soil building value of fertilizer treatments or cropping systems is reflected in the changes in soil nitrogen. The most evident phase of soil exhaustion is the decline in soil nitrogen.

Crop rotations alone without the necessary nutrient additions from manure, lime and commercial fertilizers to supply a balanced nutrient medium for plants cannot indefinitely maintain profitable yields of high quality crops.

Page and Willard (39) reported the effects of 10 years of cropping with different rotations upon the physical properties and associated crop yields upon a heavy lacustrine soil, Paulding clay (now Latty clay), in Northwestern Ohio. This soil, originally highly productive, became relatively unproductive due largely to the loss of its granular structure with an accompanying decrease in pore space. Applications of fertilizer were relatively ineffective in increasing crop yields. A restoration of desirable soil structure and physical properties was accomplished by the use of a 4-year rotation of corn, oats, and 2 years of alfalfa or alfalfa-bromegrass mixture harvested for hay. Crop yields increased significantly as the rotation got under way and without the use of commercial fertilizer or manure. Continuous corn resulted in a gradual decline of yields for the period and a further decrease in porosity.

These studies show that poor soil physical conditions may seriously limit plant growth.

Neal (35) reported an experiment at the Marlboro Field Conservation Experiment Station in Monmouth County, New Jersey, in which the effects of land resting on the conservation and productivity of vegetable-growing soils were studied. The plan consisted of following 3 years of intensive cultivation of vegetable crops by a year of "land resting" during which the land was held in a cover crop unharvested and followed by a period of vegetable production as before. The year of land resting increased the production of the following vegetable crops enough to justify the practice. Sweetcorn yields were increased 29 to 66 percent. There was an improvement in the soil physical properties of volume weight, air pore space and aggregation but these disappeared after 3 years of cultivation in vegetable crops.

Nissen, Meyer, and Richer (37) made a statistical analysis of the yields of corn, oats, wheat, and hay on the Jordan fertility plots in Pennsylvania as influenced by different fertility and manure treatments over a 56-year period. It was stated that yield trends over a period of time are as important as the average yields for the period in determining the significance of various treatments. Yield trends were studied by means of linear regression equations. It was shown that manure treatments and also complete fertilizer treatments maintained the yields over a 56-year period and indicated that this level of yield may be maintained indefinitely. Crop yields varied from season to season. The authors found that annual varietion in crop yields attributed to the weather were generally from 20 to 40 percent of the average yield with maximum variations from 40 to 80 percent. Large annual variations in crop yields were not only unpredictable but difficult to explain on the basis of existing weather records. There was no correlation between the annual yields of corn grain, wheat grain and oats grain; a good or poor harvest in one of these crops meant nothing in regard to the yield of the other crops.

Rotations Influence Soil Nitrogen Balance

Many experiments have shown that the addition of manure, crop residues, or nitrogen fertilizers may not result in appreciable storage of nitrogen in the soil as organic matter under some conditions, because such additions may be used up in greater crop production. The term "nitrogen turnover" has long been applied to this process. Volkerding and Stoa (55) reported on a long-time crop rotation and fertility test in North Dakota. There was an average loss of 20 percent in soil nitrogen during the 25-year period 1923-1948. They point out that a considerable portion of the nitrogen supplied by manure and crop residues is readily utilized by the crops grown and is reflected in higher yields rather than in the maintenance of high soil nitrogen levels. Crop yields were increased on the plots treated with manure, crop residues and fertilizer.

Pinck, Allison, and Gaddy (41) (42) reported a pot test with Sassafras sandy loam soil maintained at a reaction of $_{p}H$ 6.5 and treated with 0-15-6 fertilizer at the rate of 2,000 pounds an acre plus 40 pounds of magnesium sulfate. Straw was added at the rates of none, two and four tons an acre and, in the soybean series, each rate was treated with urea at the rates of none, 25, and 100 pounds an acre. In the wheat series and the Sudangrass series urea was applied at the rates of none, 25, 100, and 200 pounds an acre. Wheat and soybeans were grown in the winter months, and Sudangrass and soybeans were grown as summer crops. Each crop was followed by a gleaning crop of Sudangrass, and nitrogen was determined in both crops. Extra nitrogen in the Sudangrass series increased the total nitrogen in the crop; the effect was linear. However, the extra nitrogen increased the yield of dry matter at a decreasing rate with successive increments of nitrogen. It was pointed out that carbonaceous crop residues can be utilized satisfactorily by direct application to the soil without preliminary rotting if adequate nitrogen is added to meet the needs of the microorganisms active in their decomposition. This microbial nitrogen will be released later for crop use. In the soybean series, applications of straw significantly decreased the soybean yields. Adding urea increased the yields but not the total nitrogen content. The addition of urea nitrogen was accompanied by a reduced fixation of nitrogen. A single crop of soybeans fixed up to 165 pounds of nitrogen per acre; less when urea was added and more when straw was added. If the proportion of straw and added urea was such as to produce a favorable carbon:nitrogen ratio there was no marked effect on nitrogen fixation. One hundred pounds of urea more than counteracted the effect of two tons of straw but not of four tons. In general, the data show that nitrogen fixation by soybeans is favored by a low level of soil nitrogen. Even 25 pounds of fertilizer nitrogen per acre apparently lowered the fixation in the absence of straw but not in its presence.

Alderfer (1), reporting on some of the results obtained from the Jordan fertility plots in Pennsylvania, referred to a 4-year rotation of corn, oats, wheat and mixed clover-timothy hay fertilized with phosphate-potash (Plot 29) and carried on for 14 rotation rounds. During this time the average yields were: corn 61.5 bushels, wheat 21.7 bushels and mixed hay 4440 pounds per acre. When 144 pounds of nitrogen per acre were added to PK (Plot 28) the average yields were increased 5.1 bushels of corn, 2.0 bushels of oats, 7.7 bushels of wheat and only 5 pounds of hay. In a "steel rim" experiment the same rotation and treatments were carried on for 8 years. When nitrogen was added to the PK plot the clover fixed less nitrogen than it did with no nitrogen added.

Leguminous and Non-leguminous Green Manure Crops

Green manure crops may play an important role in maintaining soil productivity through their effect on the soil organic matter storage and nutrient supply. Their effectiveness is influenced by their carbon:nitrogen ratios (legumes vs non-legumes, mature vs immature development) since these have an influence on decomposition rates, nitrogen mineralization and contribution to the soil humus supply. Green manure crops are also frequently useful in preventing the loss of soil nitrogen through leaching.

Pieters (40) reviewed the results of green manuring experiments in considerable detail. There are many conflicting results due to the different kinds of crops, soil climatic differences, and cultural practices.

McKaig, Carns, and Bower (32) studied the effect of green manure crops in a 3-year rotation of legumes, corn and cotton on Norfolk coarse sand in South Carolina. It was observed that the maximum benefit of a green manure crop was obtained by storing organic matter with its nutrients during the soil improvement period and then releasing the nutrients by the decomposition of the organic matter at a time they are most beneficial to the following crop. If decomposed during the late fall or in the winter on sandy soils or in southern climates with open winters, the released nutrients are likely to be lost by leaching. The cover crop of rye trapped some nitrogen that would otherwise have been lost.

Odland and Knoblauch (38) reported on results in Rhode Island of using cover crops in continuous corn culture over a 40-year period. The fertilizer applied was at the rate of 1200 pounds of 5-8-7 per acre per year. Winter rye seeded at the last cultivation of the corn increased corn yields 6 bushels an acre over no cover crop during the 34-year period. Doubling the nitrogen in the fertilizer to 120 pounds an acre per year increased the corn yields 12 bushels but the leguminous cover crops were the most effective in maintaining the yields of corn. The total soil nitrogen showed a decline for the period on all sections, but cover crops reduced the loss.

Sprague (51) reported the 5-year results obtained with winter green manure crops in New Jersey. Seven kinds of green manure crops were planted in standing corn in August and plowed under the following spring. Winter wheat and rye made satisfactory stands and growth when seeded in corn on August 1, but according to this report had little value as sources of available nitrogen and even depressed the yields of subsequent crops. The legumes increased corn yields from 13.7 to 27.8 percent. Vetch headed the list.

The stover:grain ratio (pounds of stover per bushel of grain) of the corn following the several green manure crops was calculated from the data reported and show the following:

Cover crop	Corn	Stover	Stover:grain ratio
	Bu/A	Lb/A	Lb/Bu
Vetch	40.9	4100	100
Crimson clover	37.0	3679	99
Red clover	36.7	3594	98
Sweetclover	36.4	3600	88
Alsike (poor)	33.4	3717	111
Wheat	31.9	3585	112
Rye	30.9	3235	106
None	32.0	3442	108

The effect of the nitrogen supplied by the legumes is obvious. The alsike was a near failure.

Waksman and Tenny (56) (New Jersey) reported that young rye used as a green manure was rapidly decomposed with the production of much nitrate nitrogen and little residue. Mature rye under like circumstances was much slower to decay, and in doing so, used up some nitrogen thus temporarily lowering the soil supply of available nitrogen. However, a larger residue was added to the soil supply of organic matter.

McIlvaine and Pohlman (31) reported experiments in West Virginia that showed that wheat yielded higher after potatoes than after corn. Three cultivated crops, corn, soybeans, and potatoes, plus cover crops of rye and vetch after corn and potatoes, resulted in an 11 to 13 percent loss in organic matter over a 10-year period. The green manure crops failed to supply enough organic matter to maintain the original organic matter level in the soil.

Blair and Waksman (9) reported the effect of hairy vetch and rye on corn yields in a cylinder test in New Jersey. On a percentage basis if the corn produced by the hairy vetch cover crop to be taken as 100, no cover crop was 72 and rye cover crop was 68 percent.

Bauer (6) reported on a corn, oats, wheat rotation with and without sweet clover green manure crop and with the return of the straw and stover versus no residues returned. He concludes that non-legume residues alone had either no effect or a slight depressing effect on corn yields. Sweetclover alone gave a substantial yield increase. When sweetclover and non-legume residues were used together greater increases were obtained than with either alone. Reinforcing nitrogen-rich succulent green manure crops with high carbon residues may result (1) in preventing soil nitrogen losses from leaching and (2) in the conservation of soil humus. (It has been noted at Wooster that a sweetclover green manure crop seeded either in wheat or oats made more growth when accompanied by the return of straw and stover residues to the land than without their return.)

Coleman (16) grew corn at three locations in Mississippi following rye, rye plus nitrogen, nitrogen fertilizer alone, and no cover crop. At all three locations the yields of corn were less following rye than where no cover crop was used. When 30 pounds of nitrogen were added to the rye, yields were increased but not as much as where nitrogen was used alone. Rye had a depressing effect upon corn yields even though nitrogen was added. At State College on a sandy loam soil as a 10-year average, corn after rye cover crop yielded 30.0 bushels an acre and corn without rye yielded 30.6 bushels, a small difference, but at least there was no benefit from the rye cover crop. Corn after hairy vetch yielded 38.1 bushels an acre for the same period.

Lipman and Blair (28) reported the results of a cylinder experiment at the New Jersey Agricultural Experiment Station in which nitrogen was supplied to the soil by various legume green manure crops grown between the main crops of rye, corn, potatoes and oats. It was pointed out that it may be possible to maintain crop yields at a rather high level even when the total nitrogen content of the soil is not as high as the original soil. Under such circumstances a constant turnover of readily available nitrogen is necessary.

Pohlman and Henderson (43) reported 13 years' results with cover crops in DeKalb silt loam soil on the Dairy Husbandry farm near Morgantown, West Virginia. A two-year rotation of corn silage and soybean hay was followed with cover crops seeded in the corn at the last cultivation and in the soybean plots immediately after the hay harvest. No fertilizer was used for the first nine years but 300 pounds of superphosphate per acre were applied annually for the last four years. Better growth of cover crops was obtained after soybeans than in corn. They say "It is of interest to note that a rye cover crop gave larger increases in yield than did vetch for soybeans but vetch gave higher yields of corn. This is probably accounted for by the fact that the vetch furnished more available nitrogen for corn than did rye. Since soybeans are able to take nitrogen from the air the amount of nitrogen added was not an important factor." In the Grain vs. Livestock Farming experiment at Wooster, likewise, soybeans following non-leguminous cover crops seeded in corn outyielded soybeans following leguminous cover crops seeded in corn.

The yields were as follows:

	8-year average yield	
	Corn	Soybeans
	Bu/A	Bu/A
After 7 good legume cover crops	86.6	24.6
After 6 good non-legume cover crops	83.3	25.4
L.S.D. 5% point	1.09	0.5

Broadbent (12) and Broadbent and Norman (13) (Iowa) reported experiments in which the decomposition of the biologically resistant soil organic matter was studied by means of the stable isotope of nitrogen, N^{15} and carbon C^{13}. It was shown that the normally resistant soil organic matter was readily attacked by soil microorganisms when a highly active microbial population was stimulated by the addition of considerable amounts of energy material such as straw, and sufficient nitrogen was added to the energy material to meet the requirements of the soil microorganisms. This apparently resulted in an increased oxidation of the soil organic matter and the mobilization of some of its nitrogen. Rapidly decomposing green manure crops may accelerate the decomposition of the soil humus; this may account for the failure of some green manure crops to maintain the soil's organic matter supply.

In general, green manuring experiments show that green manure crops either (1) supply readily available nitrogen for crops immediately following their incorporation into the soil or (2) increase the storage of soil organic matter. It is seldom that both results can be obtained simultaneously to the extent of each alone. The soil humus supply is favored by those crop residues that are somewhat slow to decompose in the soil, whereas immature green crop residues that decompose quickly leave relatively small amounts of residue to be added to the humus supply. Thus in order for the available nutrients liberated by the green manure crop to be used effectively in increasing subsequent crop yields, the following crop must occupy the land soon after the green manure crop has been turned under. Otherwise the mineralized nitrogen may be lost through leaching or volatization. This sometimes happens when a green manure crop is early spring plowed and the planting of the following crop delayed as, for example, corn planting in a wet spring. If the wet weather has been accompanied by much leaching the nitrate nitrogen released from the green manure crop may be lost in the drainage water or carried below the root zone. On the other hand it may be undesirable to delay turning under a green manure crop because of the danger that the rapidly growing green manure crop will lower the soil moisture supply. This often happens when a green manure crop of rye or sweetclover is plowed late for corn.

The Equilibrium Concept

That the soil organic nitrogen and crop yields under a given rotation and cropping system tend to come to equilibrium is evidenced by the reports of many investigations. Jenny (25) in 1930 emphasized the tendency for soils to come to equilibrium in their nitrogen content as a result of the counter-balancing of the gains in nitrogen as a result of nitrogen fixation and additions in rainfall with the losses of nitrogen resulting from crop removal, leaching and volatization.

Bear and Prince (7), reporting on the organic matter in New Jersey soils stated that, "By good management the organic matter of the soil that has a normal value of two percent may be raised fairly rapidly to two and one-half percent but any further rise will be difficult to effect. Under poor management it may fall as low as one and one-half percent but further loss of organic matter will be very slow."

Giddens, Perkins and Collins (21) reported the results of a "land building" project at Whitehall, Georgia. A 4-year period was devoted to the growing of various legumes with lime and fertilizer all turned under and followed the fifth year with a crop of corn. The soil was analyzed for organic matter in 1940 and 1948. The authors conclude that, "Except for the plot with manure applied, there was a tendency for the cultivated soils to approach a constant level, low ones to increase and high ones to decrease."

Chen and Arny (15) in reporting some 30 years results of rotation studies in Minnesota indicated that the yield differences exhibited by the different cropping systems were brought about largely in the first 10 years or less after which the yield differences did not change appreciably.

Dodge and Jones (18) reported the 30-year results of a crop rotation and fertility test at the Kansas Agricultural Experiment Station in which a 16-year rotation of 4 years of alfalfa followed by a sequence of corn, oats and wheat for 12 years was compared with a 3-year rotation of corn, cowpeas and wheat and with continuous wheat. The fertilizer treatments were none, P, PK, and NPK. All grain and hay were removed. Wheat straw and corn stover were returned except that corn stover was removed when it preceded wheat and alfalfa. There was a continual overall loss of nitrogen and carbon over the entire period regardless of the cropping systems or fertility treatments. Plots with the highest initial nitrogen content suffered the greatest loss. The speed with which the nitrogen and carbon content declined and its <u>ultimate level</u> were influenced by the cropping systems and the rotations. The soil nitrogen in the continuous wheat had nearly reached an equilibrium at the end of 20 years.

Salter and Green (45) in 1933, as a result of studies made of the crop yield trends and soil organic matter trends of some long-time fertility and rotation plots at the Ohio Agricultural Experiment Station at Wooster, proposed a formula for evaluating the effect of individual crops on soil productivity. This was further enlarged and methods for calculating the soil productivity balance proposed by Salter, Lewis and Slipher (47). The use of the "soil productivity index" has been a standard procedure in evaluating different cropping systems by the Ohio Agricultural Extension Service and others. The "soil productivity index" of a crop is the percentage by which one year of that crop increases or decreases the productivity of the soil, and is described as "an approximate measure of the balance between the favorable and unfavorable effects of that crop on soil nutrients, tilth, biological activity and organic matter content of the soil." The "soil productivity balance" of a rotation or farming system, in turn, is the algebraic sum of the indexes for the crops grown plus similar indexes for fertilizer, manure, soil erosion, etc.

They also pointed out that "It is recognized that a cropping system which yields a positive soil productivity balance if followed continuously will not continue indefinitely to increase soil productivity. Instead the effect will be to stabilize at a relatively high maximum. Similarly the use of a destructive cropping system will deplete the soil only to a certain low minimum of production where crop yields will remain fairly constant. Practically, most land will lie well within these two extremes. In this immediate region the destructive or constructive effects of different crops and management practices will be roughly proportional to the existing level of soil productivity thus justifying the use of productivity indexes stated as percentages."

Metzger (33) reported the results of crop rotations and cropping systems in the fertility project at the Kansas Agricultural Experiment Station and shows that the soil nitrogen and organic matter content of the soil are influenced by the cropping system and follow the pattern laid down by Salter and Green (45). There was a high positive correlation between total crop production over the 25-year period and the total soil nitrogen. The nitrogen of the soil of the experimental field studied appeared to be approaching an equilibrium characteristic of the cropping system employed.

SOME GENERAL CONSIDERATIONS

Crop Rotation Experiments and The Time Element

Most agronomic research projects fall into one of two classifications with respect to the time element: (1) Those which can be expected to produce a satisfactory answer in a relatively short time and, (2) those which require many years of experimentation in order to develop such an answer. In (1) are found many cultural experiments, such as time, rate and date of seeding crops; the length of time required being one that gives a good sample of the season fluctuations for the locality. Some fertilizer experiments also may be concluded in a few years. In (2) are found those experiments which bring about gradual changes in basic soil productivity. Crop rotation studies, such as those reported in this bulletin, are definitely in the latter category. Some experiments include elements from both categories. For example, the immediate response of alfalfa to different amounts of liming materials on a given soil can be measured in a few seasons. However, the cumulative effects of lime applications upon the reaction of the subsoil and upon changes in the ionic exchange pattern of the soil are evident only after longer periods of time. Too often "quickie" experiments fail to reveal the full potentialities of a treatment.

Choosing The Rotation

The choice of a crop rotation for a given farm enterprise is based largely upon the following factors: (1) Crops required by the farm enterprise for feed, sale, or soil improvement. (2) The adaptation of the crops to the soil type, climate and length of day. (3) The effect of the crop rotation upon soil productivity and (4) The need to control plant diseases, insect pests, and weeds that are favored by some cropping systems.

Economic considerations have a profound influence upon the kind of farm enterprise carried on and hence upon the crop rotation. Different farm enterprises call for different kinds and quantities of crops, but the success and stability of the farm enterprise is governed largely by the adaptation of the cropping system to the soil.

Widely different soil types may call for the use of different crop rotations. A heavy dark-colored clay soil with a soil structure problem requires a different cropping system from that suited to a light sandy or gravelly soil: first bottom soils subject to overflow and with a weed problem need to be cropped differently from shallow, drouthy upland soils.

Length of Rotation

The length of a rotation will be determined by the number of crops required by the farm enterprise and the ease with which they form a workable pattern. Usually it is convenient to include all of the crops in one rotation but there are circumstances under which it may be desirable to divide the crops into two or three separate rotations to fit specific situations. For example, a part of the farm with upland soil and rolling topography may be given over to a rotation with much of the land in meadow and pasture crops and the bottom-land with a deep organic soil given over to the production of grain crops. A long rotation requires more fields than a short one - sometimes a disadvantage.

Crop Sequence

The order in which crops appear in the rotation has been pretty well standardized by farm experience over the years. The sequence is governed largely by the convenience of carrying on the farm operations, the distribution of labor and the relative needs of the crops for the benefit to production that follows the plowing down of a soil building crop such as a good legume or legume-grass sod or a green manure crop. Corn and other row crops usually follow the plowing down of a sod or green manure crop because corn can make efficient use of the large amount of nutrients liberated by decomposition of the residues plowed down. For the most part, the small-grain crops follow the row crops: if they follow the sod crop directly, the abundant supply of nitrogen is likely to result in rank growth and lodging. If corn followed the small-grain crops it would miss direct benefit from the soil building crop unless the small-grain crop has been seeded successfully to a leguminous green manure crop such as sweetclover. Meadow seedings are conveniently made in the small-grain crops thus avoiding the necessity of extra seedbed preparation. In fact many Ohio farmers grow small grains partly because they afford a convenient place in which to make meadow seedings. Sequence will be discussed in more detail in connection with the different rotations.

Crop Variety Adaptation

The success of a cropping system depends upon the use of crop varieties adapted to the local environment. The use of unadapted low-yielding varieties of any crop makes the rotation that much less profitable and more precarious. Unadapted clover and alfalfa may winter kill or suffer from diseases; poor corn hybrids will yield less and suffer more from insects and diseases than good ones; good wheat and oat varieties lodge less, suffer less from diseases and insects and are of better quality as well as yield.

Good Rotations Benefit Soil Physical Properties

Soil structure, aeration, drainage, and moisture holding and delivery capacity are all influenced by crop rotations. As a group the cultivated row crops tend to break down the soil aggregates or "crumb" structure which is responsible for good tilth. On the other hand, sods of the grasses or grass-legume mixtures are somewhat more effective restorers of soil tilth than the legumes alone and their effectiveness is somewhat correlated with the length of time the sod is left unplowed.

Crop Rotations May Control Plant Diseases, Insect Pests, and Weeds

Certain plant disease and insect pests may be encouraged by some crop rotations. Continuous culture and short rotations which include their host plants are frequently responsible for increasing pathogenic organisms and the buildup of insect pests. Takeall disease of wheat increased to an alarming extent in northern Ohio a few years ago as a result of wheat following wheat on many farms. Brown stem rot of soybeans, leaf spot and black root of sugarbeets are other diseases that are favored when crops are grown in short rotations. Corn root aphids are likely to increase to a serious extent with continuous corn culture. In southwestern Ohio where corn is a frequent crop on river bottom soils, the corn root worm is likely to become a serious pest.

Crop Rotations, Soil Erosion and Soil Productivity

No measurements of soil losses due to soil erosion were made in connection with the Fry farm rotation studies. However, observations showed that the row crops--continuous corn, potatoes and soybeans--resulted in appreciable soil losses from erosion.

There is abundant evidence that soil erosion losses and soil productivity losses go hand in hand. Losses in soil productivity from soil erosion are different in character from losses due to the depletion of soil nutrients or the impairment of soil structure caused by undesirable cropping systems. In the latter there is the probability that the depleted soil can be restored to a satisfactory productivity level provided the top soil has remained in place. If, however, erosion has removed all or a part of the top soil, the degree of regeneration is limited by the volume of top soil left or by the nature of the subsoil; the latter may or may not be amenable to improvement. Thus, the control of soil erosion is of prime importance to the success of any rotation.

On sloping land with soil erosion under control or on level land where soil erosion is at a minimum, losses of soil productivity are still certain to occur under undesirable cropping practices. The encouraging thing about this situation is the fact that soils tend to come to equilibrium with respect to soil productivity; yields adjust to a point where the proportion of favorable factors balance the unfavorable ones. Exploitive cropping systems result in lowered soil productivity because of the depletion of available soil nutrients (oftentimes accompanied by an increase in soil acidity), the reduction of soil organic matter, and the loss of a favorable soil structure, limiting soil aeration and drainage. Since the texture of the top soil has not been altered appreciably as regards the proportion of clay, silt, sand and coarser particles, its ionic exchange mechanism is essentially unaltered. The use of the proper crop rotations and management to restore the soil organic matter and soil tilth together with the application of the lime and fertilizer needed to build up the nutrient supply will, in time, restore the soil productivity to a level characteristic of the kind of soil involved. Thus, the exploitation of our soil resources during a period of national emergency need not result in permanent injury to the productive capacity of our soil, provided the volume of top soil is maintained. Unfortunately the intensive cropping practices followed under such circumstances make the control of soil erosion difficult.

THE FRY FARM CROP ROTATION EXPERIMENT

A crop rotation experiment was initiated at the Ohio Agricultural Experiment Station at Wooster in 1915 on a recently acquired addition to the land area of the station known as the Fry Farm. This farm had been operated for many years under a mixed livestock and grain system of farming. The crops grown were largely corn, oats, wheat and mixed clover-timothy hay. The manure, for the most part, was applied to the sod land to be plowed down for corn. No lime and but little commercial fertilizer had been used on this land prior to its acquisition by the Station. The productivity of the land was good on the more level areas: soil erosion damage to a serious degree was evident only on the steeper slopes. Much of the more level land was suitable for the establishment of soils and crops experiments.

Approximately twenty-five acres of fairly uniform soil on the south side of this 200 acre farm were set aside for a crop rotation experiment. The soil in this area is classified as Wooster silt loam. A contour map of this area (Fig. 1) shows the location of the experimental sections and the elevation at 2.5 foot intervals.

A map of the experimental plots (Fig. 2) shows the arrangement of the sections and plots in detail. The land was systematically tile drained; a 4-inch tile line was located in every second aisle between plots 1 and 2, 3 and 4, and so on, so that each plot was bordered on one side by a tile drain.

The plots were grouped in sections of 10 plots each and bordered by permanent roadways on the sides and ends. The plots (with a few exceptions as noted on the map) were one-tenth acre in area, 272 1/4 feet long and 16 feet wide with a 2-foot aisle separating the harvested areas.

Forty crop rotations and ten continuous cultures were established in 1915 and 1916 and continued with a few minor changes until the end of the 1935 season. The changes made are noted in the discussion of the individual rotations. This period is designated as Period I.

At the end of Period I the rotation plan was revised. The period from 1936 to 1950 inclusive is designated as Period II. Only a few rotations were continued on the same plan as before. The new rotations were given the same numbers plus 100. Rotation 123, for example, was conducted on the plots previously occupied by Rotation 23.

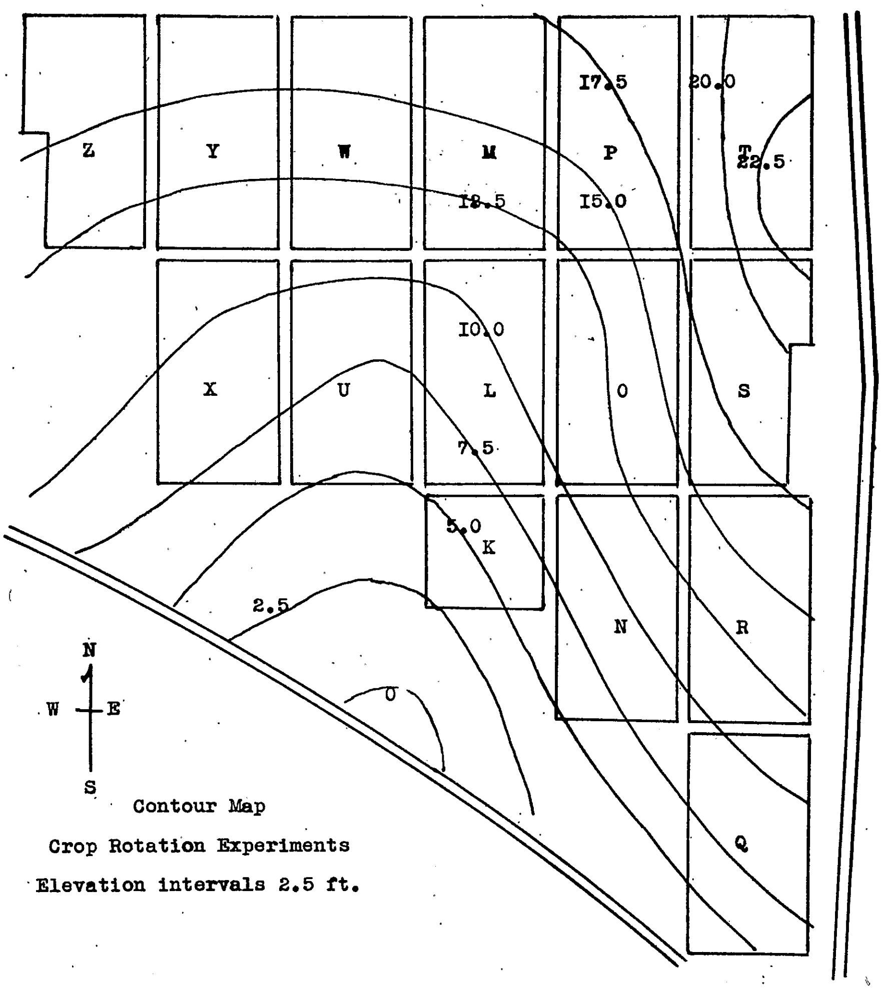


FIGURE 1.

Contour map, Fry farm crop rotation experiments.

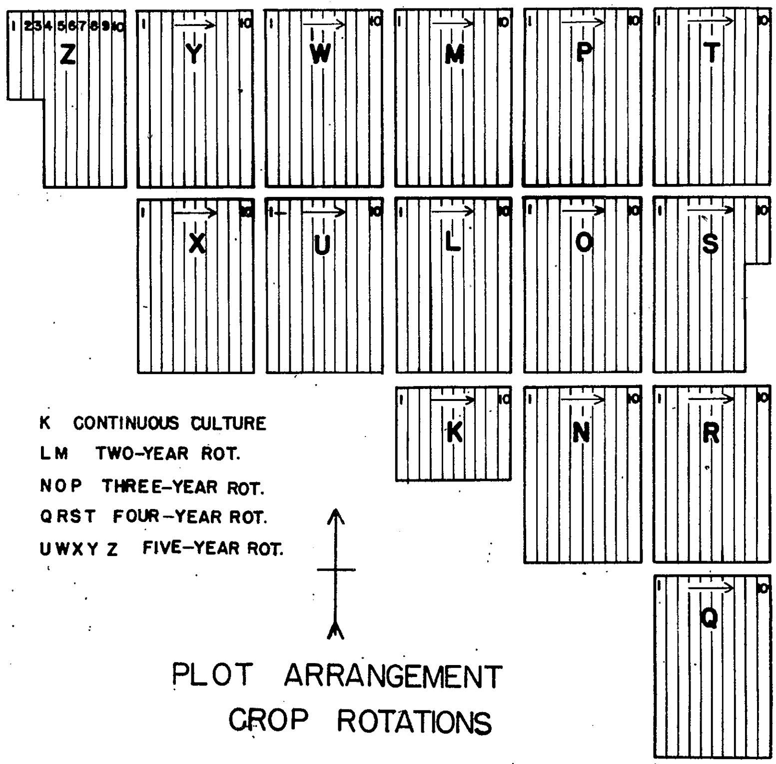


FIGURE 2.

Plot arrangement, Fry Farm crop rotations.

The Fertility Program for Period I

The fertilizer, manure, and lime treatments in the rotation experiment were kept as uniform as consistent with good management. This was essential since the objective of the experiment was to measure the effect of the crops and their culture upon the productivity of the soil. If the applications of fertilizer and manure were too generous, some of the effect of crops on soil productivity would be masked.

The plan followed during Period I was to use a basic treatment of manure and superphosphate fertilizer. No nitrogen fertilizer was used since it would tend to correct deficiencies brought about by a shortage of nitrogen fixation in the rotation. The only source of added nitrogen was that applied in the manure. (It is recognized that some nitrogen is added to the soil in rain and snowfall and that an unknown amount of atmospheric nitrogen may be fixed by non-symbiotic microorganisms.

The annual average application of manure and superphosphate was the same for all rotations; two tons of manure and 200 pounds of 16% superphosphate per acre. However, the manure was all applied to the first crop in the rotation. The continuous cultures got 4 tons of manure per acre every 2 years; the two-year rotations got 4 tons on the first crop, three-year rotations 6 tons, four-year rotations 8 tons, and five-year rotations 10 tons. This method of distributing the manure makes it difficult to compare directly the corn yields from a two-year rotation that got 4 tons of manure per acre with those of a five-year rotation that got 10 tons plowed down with the sod. The most legitimate comparisons are those made between rotations of the same or nearly the same length.

Lime During Period I, agricultural ground limestone was applied to the experimental area at the rate of 2 tons every 4 years until the soil had approached a reaction of pH 6.5 to 7.0: After that lime was applied as needed according to test, to maintain the pH 6.5 to 7.0 reaction.

Crop Management -- Period I

Corn Clarage corn, an open-pollinated variety well adapted to the growing season at Wooster, was grown on the rotation plots throughout Period I. The corn was planted at a rate to obtain approximately 11,000 plants per acre. This rate was a little too low for maximum yields from a few high-yielding rotations, but was satisfactory for most rotations.

The corn was usually check planted in hills 42 by 42 inches; occasionally it was drilled in 42 inch rows. The fertilizer was applied in the hill or row according to the planting method.

Wheat The varieties of wheat used were Ohio 9920, a Poole selection, during the 1915-1925 period and Trumbull for the 1926-1935 period. Wheat was drilled at the rate of two bushels of seed per acre: the fertilizer for wheat was drilled at the same time. The wheat was kept free from stinking smut by treatment as needed in the early years of the period with formaldehyde, and later, with copper carbonate dust. The wheat was binder harvested and shocked. When the grain was dry enough to thresh the shocks were weighed, threshed with a grain separator, and the weight of grain recorded. The difference between the total weight and the threshed grain was recorded as straw weight. Samples of grain were taken for moisture and test weight determinations.

Oats The Miami variety of oats, a medium-late maturing variety developed at the Station, was used throughout Period I. The oats were drilled at the rate of 10 pecks to the acre together with fertilizer when it was called for. The formaldehyde treatment of the seed oats was used as necessary to keep loose smut under control. The methods of harvesting, threshing and yield determinations were the same as for wheat.

Soybeans The varieties of soybeans used were Manchu for the 1915-1922 period and the 1929-1935 period. A selection of Manchu, Ohio 13177, was used during the 1923-1928 period. Soybeans for grain were planted in 28-inch rows, with a grain drill at one bushel of seed per acre. For hay, the soybeans were drilled solid at the rate of 7 to 8 pecks of seed per acre. One or two cultivations were made with a weeder if necessary to control weeds. Inoculated soil was used at first for inoculating the soybean seed, followed in later years by commercial cultures. The grain soybeans were binder-harvested, shocked, and threshed like the small-grain crops. Some loss of seed through shattering resulted from the binder harvesting.

The hay soybeans were mowed, partly cured in the swath, raked and cocked. When dry the cocks were weighed. The hay kept well in the cocks and was, with few exceptions, of excellent quality.

Potatoes Russet Rural, a full season variety of potatoes, was used throughout Period I. Certified seed was used after it became available in 1921. The spray program followed for the control of insects and diseases was kept up-to-date with the findings of the research programs in Entomology and Plant Pathology. The quality of Certified seed improved and the spray treatments became more efficient as time went on. This may account for the gradual increase in the potato yields in all of the potato rotations. Weights were taken in the field at harvest time; the small unmarketable tubers were discarded.

Meadow crops The seeds of red clover and timothy were from commercial lots of domestic origin. The alfalfa was Grimm (bacterial wilt was not a problem at Wooster during Period I). Meadow seedings were made in wheat, oats, and in one rotation, alfalfa in the standing corn. On wheat, timothy was sown in the fall at wheat-seeding time. If the seeding was a mixture of timothy and clover, the clover was broadcast in March or early April, as were all of the straight seedings of clover and alfalfa in wheat. When oats were the companion crop, the seed was sown broadcast following the grain drill. The alfalfa seeding in the standing corn was made with a one-horse drill immediately after the last cultivation in July.

The alfalfa seed was inoculated with commercial cultures but the clover was dependent upon the legume bacteria in the soil. Good inoculation was obtained in both crops.

The rates of seeding per acre were: In wheat; timothy, 5 lb. (fall); timothy 3 lb. (fall), red clover 3 lb. (spring); alfalfa, 10 lb. (spring); In oats: timothy 6 lb., red clover 8 lb.; alfalfa, 10 lb.; In corn: alfalfa, 15 lb.

The meadow crops were cut, partly cured in the swath and windrowed, cocked by hand and let stand until ready for mow storage, when they were weighed. The hay was of good quality from well-made cocks. Alfalfa harvests were made 2 or 3 times a year depending upon the season. Clover and timothy meadows were harvested once and the aftermath undisturbed for the rest of the season.

Sweetclover green manure Scarified biennial white sweetclover seed at 12 lb. per acre was broadcast in wheat in March or early April. In oats it was broadcast immediately after seeding the oats.

It was a practice for the first ten years of Period I to clip the small-grain stubble in August whenever ragweeds were bad; about one season out of two. This practice was discontinued, however, for the last ten years of the period after research had demonstrated the serious reduction of its value for green manure when sweetclover was clipped. Sweetclover used as a green manure crop would have made a better showing during Period I if no summer clipping had been done.

The Potato Rotations

Eleven of the crop rotations in Period I included potatoes. The yields were lower than yields obtained by commercial growers who apply larger quantities of fertilizer than were used in this experiment. The rotations were not planned to find out how to grow maximum crops of potatoes but rather to measure the effects upon the yields of associated crops and upon soil productivity when potatoes were included in the common farm crop rotations either by addition to the rotation or by substitution for some crop in the rotation.

At the end of Period I, the potato crop was dropped because it was realized that if potatoes were included in a rotation, all other crops would and must be less important, and that unless a potato rotation helped to grow more potatoes, it was not helpful.

The potato crop and the soil nitrogen supply. The potato crop had an effect upon the soil nitrogen balance that differed from that of the other crops of the rotations studied at Wooster. The potato crop with yield levels as obtained in these experiments removes somewhat less nitrogen from the soil in the tubers harvested than comparable crops of corn or small grain, and, since the tops are returned to the land in the fall, a considerable quantity of nitrogen-rich residue was returned to the soil. As a result of this return and probably also because the soil has been well aerated by the harvesting operation, relatively large amounts of nitrate nitrogen and the smaller amounts of ammonia nitrogen are made available in the fall and early winter months. This abundant supply of available nitrogen is credited, many times, with causing the rank growth of wheat that follows potatoes in the rotation. Welton and Morris (58) in their studies of lodging in wheat and oats found more nitrate nitrogen in the soil following potatoes than following corn, soybeans, oats, or wheat but a little less than after clover. If the nitrate nitrogen figures for the period September 18 to October 6 (the time of seedbed preparation and wheat seeding) for the four years, as published in their tables 62 and 63, are averaged, the following amounts of nitrate nitrogen (parts per million of soil) are found: Following corn 12.6; soybeans 15.2; oats 17.3; wheat 20.8; potatoes 23.7; and clover 28.0.

Potato tops; yield and nitrogen content. Very few data are available giving the composition of potato tops. Analyses of tops from potatoes grown in a cylinder experiment are reported by Lipman and Blair (27). Hawkins (23) published several analyses of the non-tuber portions of the potato crop sampled at several stages of maturity taken from plots at the Maine Agricultural Experiment Station. At the Ohio Agricultural Experiment Station at Wooster in the fall of 1952 samples of tops were obtained from three experimental plots at harvest time and the dry weight and nitrogen content determined. From these data the following table was prepared.

Source of data	Dry tops/bu. tubers	Based on 300 bushel yield: Dry wt. tops	Percent nitrogen in tops	Nitrogen returned to soil
	Lb.	Lb/A		Lb/A
Ohio (Wooster)	6.5	1950	2.47	48
Maine	4.7	1410	2.65	36
New Jersey	8.5	2550	1.75	45
Average	6.56	1970	2.29	43

These data suggest that potato tops, because of their favorable carbon: nitrogen ratio, would be rapidly decomposed in the soil in the fall and early winter adding considerably to the available soil nitrogen supply. If a winter cover crop does not occupy the land a large percentage of this nitrogen may be lost through leaching.

Tops:tuber ratio Little is known regarding the ratio of potato tops to tubers comparable to the stover:grain or straw:grain ratios of corn and small grains. Also little is known about the variation in the carbon:nitrogen ratio of potato tops when grown under different seasonal and nutritional conditions. These factors would have a bearing on the effect of tops upon soil productivity.

Crop Yield Comparisons, Period I

Tables 1, 2, 3, 4, and 5, have been prepared for convenience in comparing the yields of the several rotations for the last 15 years of the period. This discards the first 5 years of the experiment during which time the long 5-year rotations were becoming established. The average yields are given by 5-year sub-periods and for the 15 years of the test. For purposes of statistical analysis, however, different length periods were used depending upon the length of the rotations being compared. For example in continuous corn culture, the first crop was harvested in 1915. The crop the following year, 1916, begins to register the effect of corn following corn so that a 20-year period of 1916 to 1935 inclusive is available for yield comparisons. A full round of a 5-year rotation would be completed with the harvest of 1919 so that a 15-year period from 1920 to 1935 inclusive would be available for analytical purposes. When rotations of different lengths are compared the period used was that of the longer rotation.

The Method of Statistical Analysis

The plot design as shown on the map (Fig. 2) does not lend itself to the conventional "analysis of variance" method whereby a generalized standard error is obtained with which the significance of average differences can be determined. The treatments lack replication and randomization. This limits the method of analysis to a simple one of unique comparisons of selected rotations for a given period of time using the well-known Student's test for unique samples.

The seasonal differences in yield between two selected rotations as well as the average difference are presumably the result of the different treatments (rotations) plus any residual difference in soil productivity associated with the soil of the plots. This confounding of effects is unavoidable with the plot arrangement here used. However, experience with the method as applied to the yield data of this experiment leads to the belief that the soil differences are small compared with the rotation effects and can be disregarded in most cases. Confidence in the dependability of the results of the analyses is strengthened when similar treatments in different rotations respond alike. For example, the effects upon crop yields of a sweetclover green manure crop in different rotations are similar as are the responses to a full year of clover. The superiority of the full year of clover over the sweetclover green manure crop in storing soil nitrogen has been consistent for the several comparisons.

When a rotation is greatly different from expectancy the influence of some unknown factor is suspected. Such was the case with the corn crop in Rot. 11, corn, wheat, and clover, and Rot. 21, corn, oats, wheat, and clover, Period I. Corn in Rot. 11 yielded significantly less than corn in Rot. 12, corn, oats, and clover, and somewhat less than corn in Rot. 15, corn, wheat, and timothy. Corn in Rot. 21 yielded less than corn yields in Rot. 22, corn, oats, wheat, and timothy occupying adjacent plots. Corn would not be expected to yield higher after timothy than after clover. The depressing effect seems to have been limited to the corn crops. The plots in Rot. 11 and Rot. 21 lie end to end and are bordered on the west side with a grass roadway, so that greater wind and insect exposure may have been factors.

The Check Groups -- Period I

The Check Group yields are composite yields from selected rotations used as "bench marks" or reference measurements.

The objective is to have a standard yield and yield trend performance record with which to compare the performance of selected rotations under test. The Check Group yields for different numbers of years are given in Tables 14 to 19.

The Check Group corn. The corn crops from 10 rotations were selected to make up the Check Group on the basis of their average performance. They maintained a fairly level yield trend for a 21-year period and also the average soil nitrogen content of these rotations was estimated to have changed but little during the period. These were Rotations 1, 13, 15, 16, 28, 31, 33, 34, 36, and 39.

Yield trends. It is desirable to know if the yields of the crops in a rotation are increasing or decreasing with time as a result of the treatments as distinguished from other causes. This is difficult to measure because of the influence of season effects -- weather, disease, insects, etc. -- upon yields. The trend of the yields of a crop over a period can be shown by a regression line fitted to the distribution. A linear regression line was fitted to the Check Group corn (Fig. 3). The 21-year regression line did not differ significantly from a line drawn through the mean*. The level trend of the 21-year regression line is the result of a fortuitous distribution of seasonal influences plus such additional trend influences as may be ascribed to the 10 rotations within the group. It is thought that the latter is relatively small compared with the seasonal influences of the individual rotation effects and for the long period, at least, to represent a yield level that has changed but little. It becomes a convenient "bench mark" with which to compare the corn yields in selected rotations.

There is need for some criterion of soil productivity that is independent of the disturbing influence of season. An approach to such a criterion is that of

*Second and third degree curvilinear regression equations were also calculated for the Check Group corn but were not significantly different from the linear regression line.

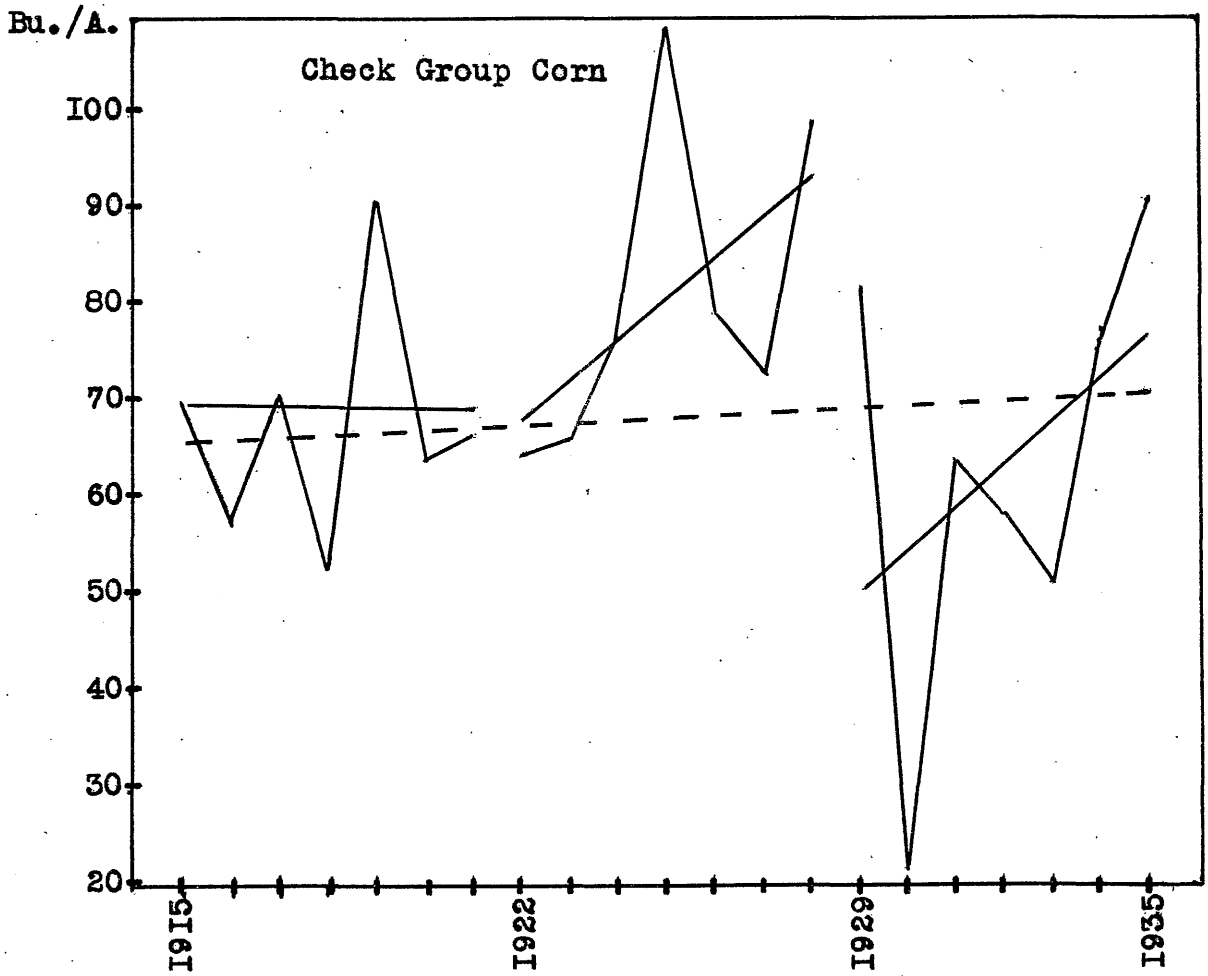


Figure 3. Regression line for Check Group corn.

the soil nitrogen supply as suggested by Salter and Green (45), and Salter, Lewis and Slipher (47). Within a given soil type changes in soil productivity are shown to be correlated with changes in the total soil nitrogen supply: these changes take place within the region that lies between the stabilized upper and lower nitrogen content limits characteristic of the soil type and environment. Charting the trend of soil productivity by means of the status of the soil nitrogen supply would be largely independent of the seasonal fluctuations that are characteristic of crop yield trends.

Check Group potatoes. The Check Group is the average of Rotations 17, 18, 25,26, and 37. The 21-year average yield for the Group was 177 bushels per acre and the average soil nitrogen content at the end of the period 2600 pounds, a slight gain from the calculated original amount of 2535 pounds in 1915. The trend of the Check Group potato yields is shown in Fig. 4. A significant up-trend in the yields is indicated by the regression line ($Y = 125.3 + 4.7X$). This up-trend is common to potatoes in all rotations except continuous potatoes, C2,

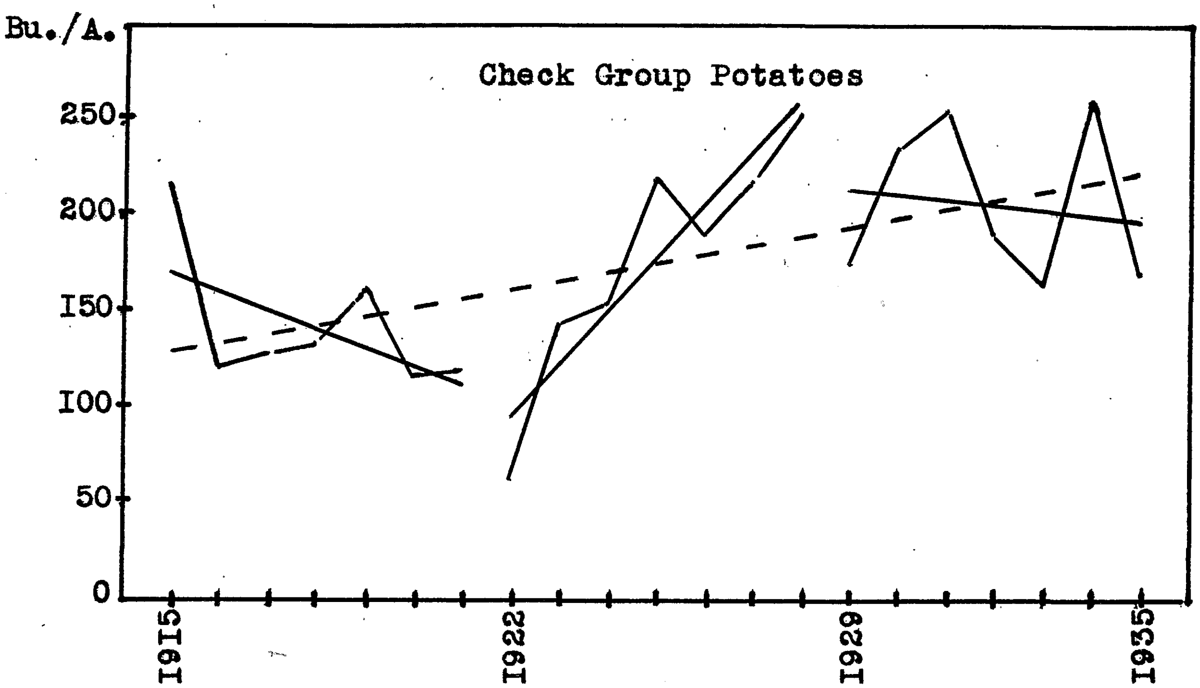


Figure 4 Regression line for Check Group potatoes.

where the yields are essentially level beginning with the 1916 crop (the first crop to follow potatoes in the rotation). This general up-trend is probably partly the result of an improved spray program and to the use of better quality disease-free seed as time went on. It is also possible that the increase was due in part to the influence of a fortuitous distribution of favorable seasons during the period.

Check Group soybeans. The Check Group soybeans was the average of two similar rotations, Rot. 26, potatoes, soybeans, wheat, and clover, and Rot. 27, corn, soybeans, wheat, and clover. The 17-year average soybean yields in these two rotations differed by less than a bushel per acre and the soil nitrogen as determined by the 1936 sampling at the end of Period I differed in the two rotations by only 28 pounds per acre. The Check Group soybeans showed a significant up-trend in yield with time (Fig. 5). This was characteristic of the soybeans in all of the soybean rotations and also of soybean yields in the state. This increase in yield with time is thought to be due in part to improved harvesting methods that reduced shattering losses and to the attainment of a more favorable soil reaction with time. That more favorable seasons may also have been a factor is a probability.

Check Group wheat. The Check Group is composed of the 5 rotations, 28, 31, 33, 34, and 36 (Fig. 6). The 20year regression line is essentially level: it does not differ significantly from a line through the mean at 36.3 bushels.

Check Group oats. Four rotations, 22, 28, 31, and 40 constitute the Check Group oats (Fig. 7). The 21-year regression line shows a downtrend: this down-trend is characteristic of the oats yields in all 10 rotations that contain oats.

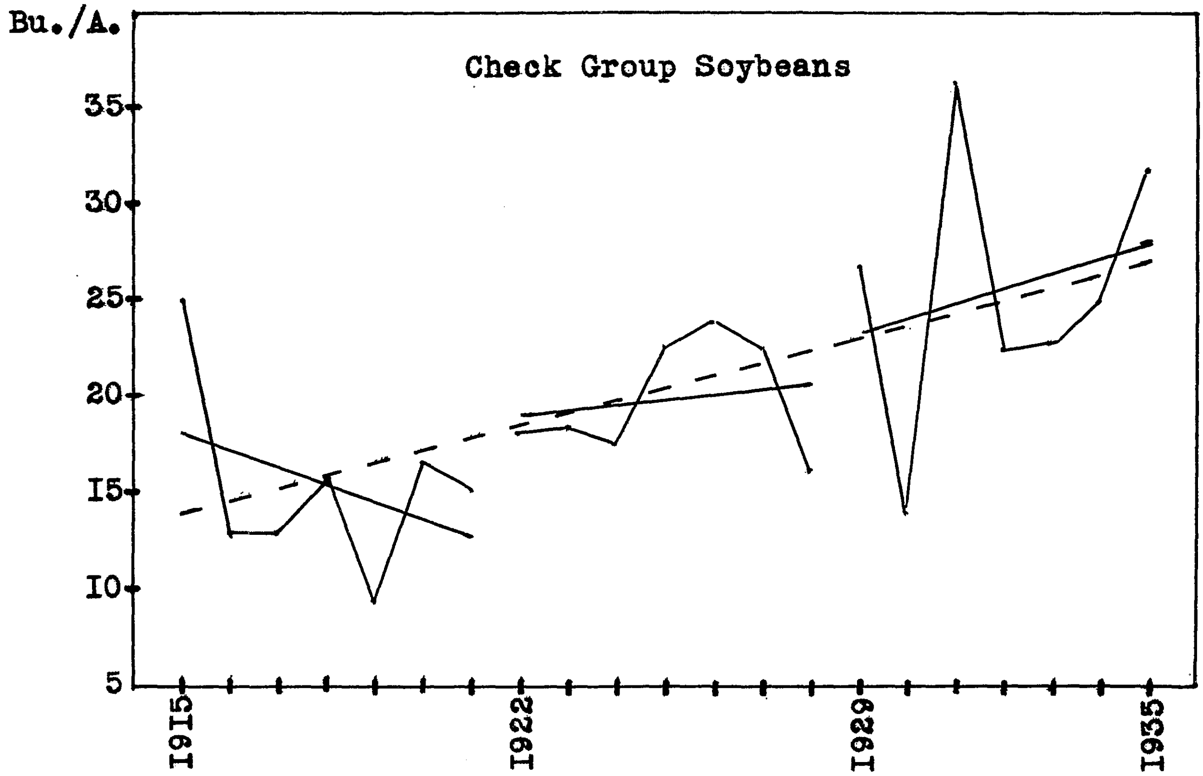


Figure 5 . Regression line for Check Group soybeans.

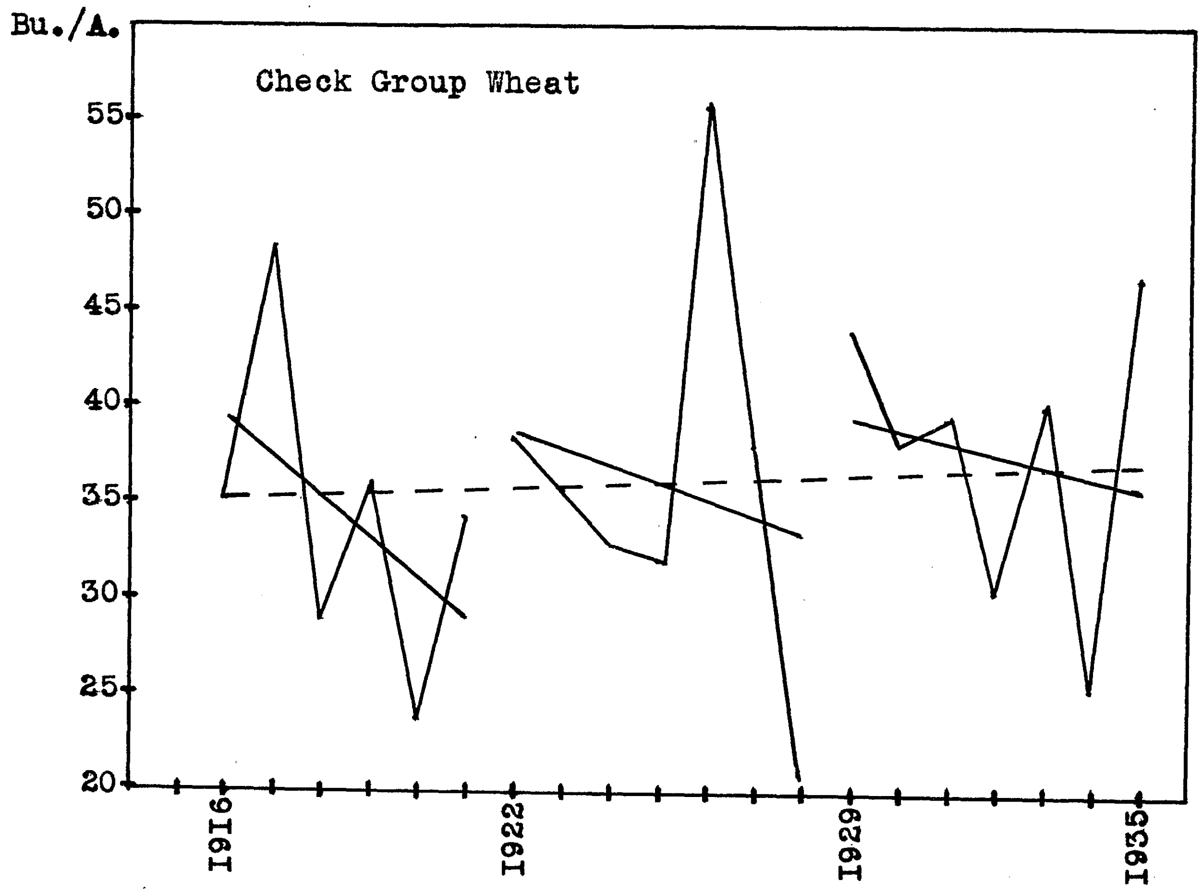


Figure 6. Regression line for Check Group wheat.

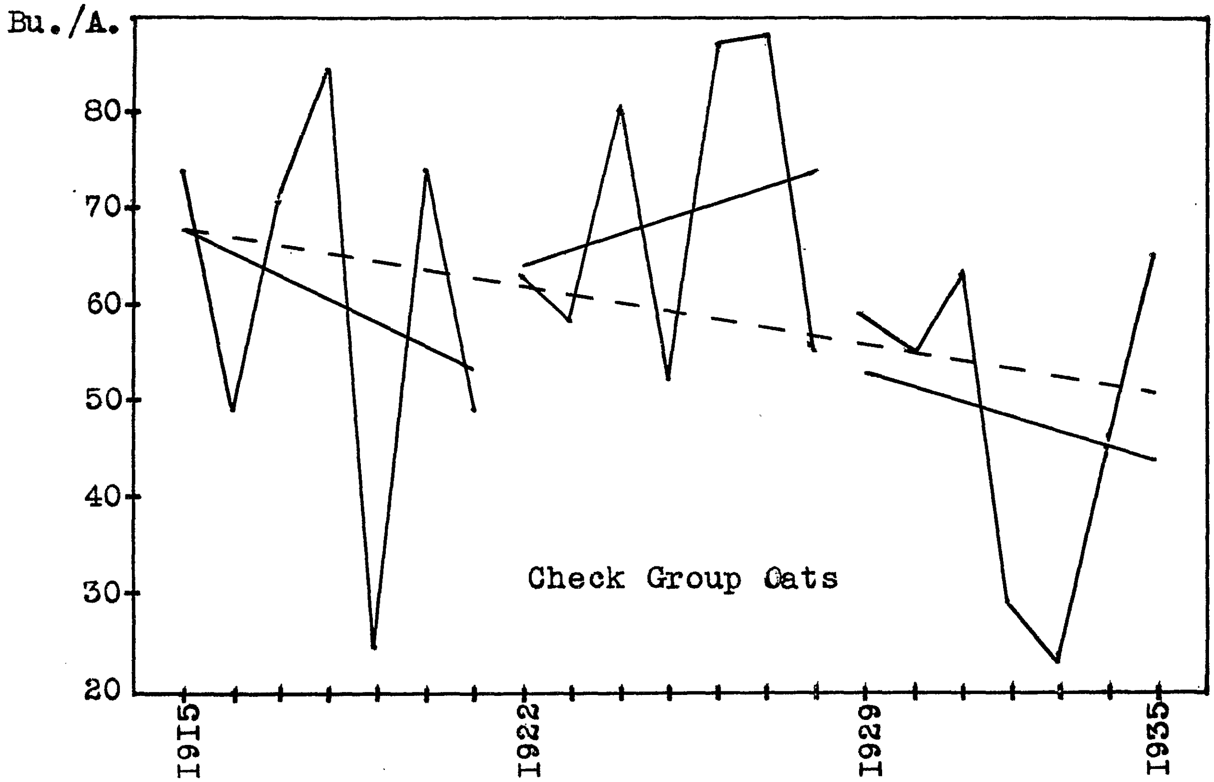


Figure 7. Regression line for Check Group oats.

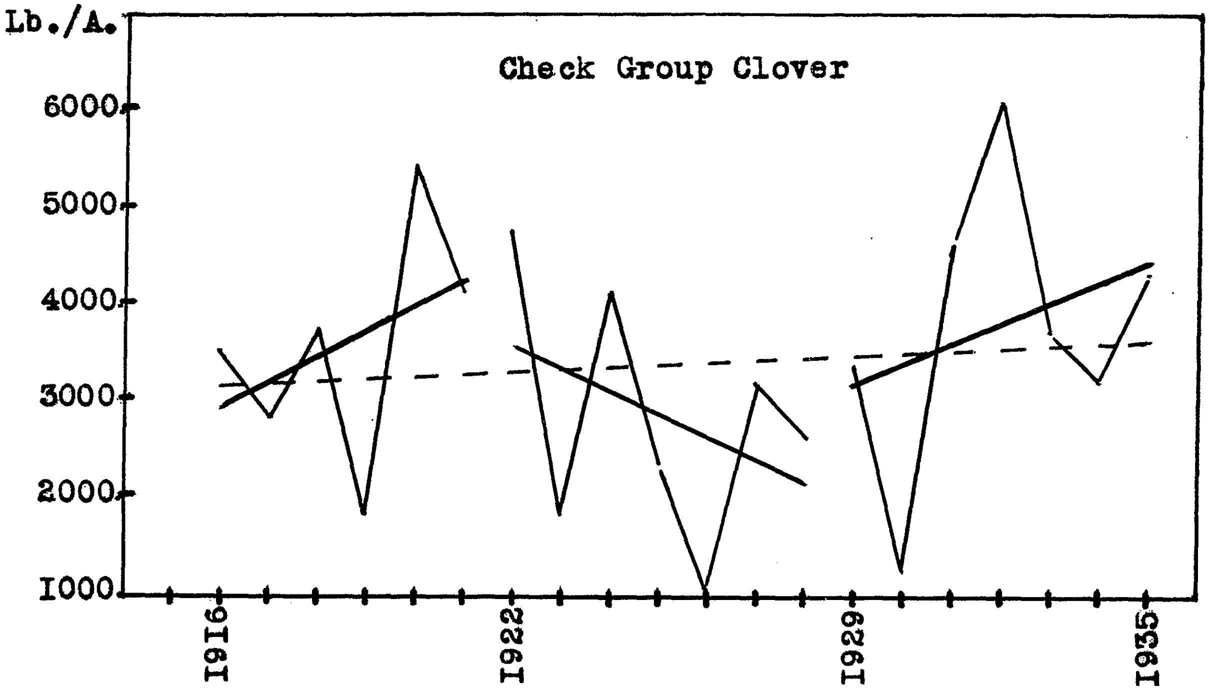


Figure 8 . Regression line for Check Group clover.

Check Group clover. The Check Group clover consists of Rotations 21, 23, 24, 25, 26, 27, and 35 (Fig. 8). The yield trend for the period is essentially level.

Soil Nitrogen Analyses

No systematic sampling of the soil of individual plots was made at the beginning of the experiment in 1915-1916. Indirect evidence from samples obtained from other sources suggest that the average soil nitrogen content at the start of the rotation experiment was in the neighborhood of 2500 pounds per acre. A figure of 2530 pounds was selected since it represents the average nitrogen content of the soil of the plots that were included in the Check Group corn and which had maintained a fairly level yield trend over the period.

Systematic sampling of the soils of the plots in the experiment was done at the close of Period I in 1936 and at the close of Period II in 1950. Eighty borings from each tenth acre plot were taken to a depth of 6 2/3 inches. The borings from each plot were composited, air dried, thoroughly mixed and a sample stored for future analysis. Just prior to analysis the sample was ball-milled, brought to uniform moisture content and analyzed for total nitrogen using the official Kjeldahl method. All analyses given in this report were made by one laboratory technician. The total nitrogen content of the soil of a rotation is the average of the plots of that rotation. The 1950 data are the averages of the sampling dates, October 1948 and February 1950. Since these two dates showed no significant difference in nitrogen contents they were combined in one population and reported as representing the nitrogen content of the soil at the end of Period II. A highly significant correlation of .738 occurred between the two sampling dates (L.S.D. 1% point .215).

Nitrogen in Crops Harvested

The nitrogen content of the crops harvested was calculated and includes all crops grown regardless of any changes that may have been made in the crops of the rotation. Average analyses as published in Morrison's "Feeds and Feeding" 21st ed. and adjusted for moisture content were used in the calculations.

The Stover:Grain and Straw:Grain Ratios

N. Jasny (24), in his book, Competition Among Grains, summarizes the results of a study of the literature on stover:grain and straw:grain ratios. He concludes that the stover:grain ratios of corn show a definite tendency to be high if the yield of corn is small and vice versa. No such tendency is observed with reference to the small grains and even the opposite may be true for them. Insufficient moisture tends to increase the stover:grain ratio and the application of nitrogenous fertilizers in the presence of sufficient moisture tends to lower it materially. In both situations the effect may be opposite on the small grains. The Check Group corn for Period I showed a negative correlation of -.73 between seasonal yields and the stover:grain ratios. The correlation was highly significant.

Stover:grain and straw:grain ratios have been influenced significantly by some of the crop rotations in the Wooster experiment. The response has been similar to that reported by Jasny. These ratios may be indicative of the efficiency with which the crops are responding to the soil productivity level, but the factors resulting in a high or low proportion of straw or stover to grain are sufficiently complex so that it is difficult to isolate them in these rotations.

Limitations on Interpretation of Results

It should be pointed out that the yields obtained in these crop rotation experiments are determined largely by the balance between the soil building and soil depleting crops plus the limited use of fertilizer and other supplementary measures. Larger crop yields can be expected in most instances from these rotations if support measures are increased to bolster the weak points brought out by the rotation experiment. In most rotations, maximum yields would call for increasing the fertilizer application, substituting a complete fertilizer for P or PK goods, taking advantage of green manure crops, plowing down supplementary nitrogen fertilizer, or other similar measures.

It should also be emphasized that the results of these rotation experiments were obtained under a given set of soil, climatic and crop adaptation conditions. Extending the results to cover different conditions should be done with caution.

Crop Management, Period II

Potatoes, spring wheat, and spring barley were omitted from the Period II rotations.

Corn. Hybrid corn W17, a full season hybrid at Wooster, was planted during the 1936-1945 period. An early maturing hybrid, K35, was planted during the 1946-1950 period. The corn was drilled to obtain approximately 12,000 plants per acre. The fertilizer for the corn was drilled in the row. The corn was either binder harvested or cut by hand and shocked except for those rotations in which the corn was picked and the stalks left on the land. The corn was sampled at husking time for moisture and shelling percentage. Yields were based on 56 pounds of shelled corn per bushel at 14½% moisture content. The stover was bundled and reshocked to stand until the moisture content had approached equilibrium when it was weighed.

Wheat. The Trumbull variety of wheat was used throughout Period II. The wheat harvest was the same as during Period I. In the residue rotations the wheat was binder harvested, threshed and the straw spread back on the land (simulating combine harvesting).

Oats. The Miami variety of oats was used throughout Period II as for Period I. The harvesting, threshing and yield determinations were the same as for wheat.

Soybeans. The Manchu variety of soybeans was used during the 1936-1940 period and Mingo for the 1941-1950 period. The cultural practices for soybeans were the same as for Period I. The combine was used for harvesting the soybeans in Rotation 125.

Meadow crops. Adapted red clover (Midland in later years), was used in Period II. The timothy was commercial domestic seed. The alfalfa was Northern-grown Grimm, or Kansas-Oklahoma common until the later years of the period when the wilt-resistant Ranger was used. However, bacterial wilt was not a problem in these rotations. The rates of seeding were the same as for Period I except for the alfalfa, clover, timothy mixture which consisted of 6 pounds alfalfa, 4 pounds red clover and 3 pounds timothy (fall) or 6 pounds (spring) per acre. The hay harvests were the same as those of Period I.

Green manure crops. Biennial white sweetclover was used for green manure in the 2-year rotations and in the continuous culture corn, C110. The small-grain stubble in which sweetclover was seeded was not clipped during Period II. Rye or domestic (Oregon) ryegrass was used on the continuous corn plots C106. Hairy vetch was seeded in addition to the rye or ryegrass on continuous corn plots C107. The cover crops in the corn were seeded at the time of the last cultivation, except that rye in the early years was seeded in August between the corn rows with a one-horse drill. During the 1945-1950 period, the ryegrass was seeded at the time of the last cultivation.

The following rotations were used to form the Check Groups of Period II:

Corn. 107, 111, 114, 125, 127, 131, 134, 138 (1)
Oats. 101, 102, 104, 119, 120, 121, 122, 123, 131, 132
Wheat. 108, 111, 114, 120, 131, 134
Soybeans. 125, 126
Clover. 111, 112, 121, 122, 124, 125, 126

See Check Group, Period I, for a discussion of methods.

The Fertility Program for Period II

The fertilizer program for Period II differed from Period I mainly in the substitution of 0-14-7 fertilizer for the manure and superphosphate of Period I. However, manure was used in certain rotations and the residues, stover and straw, were returned to the land in others in addition to the 0-14-7 fertilizer. The average annual application of fertilizer was 150 pounds per acre per year but was applied to selected crops in the rotation as indicated in the tables. The manure and residue applications are also shown. The substitution of 0-14-7 fertilizer for the manure of Period I is thought to have overcome some of the yield differences that were obtained when different amounts of manure were applied to selected crops in the rotation. Nitrogen fertilizer was omitted in order to identify more definitely the effect of nitrogen fixation by the legumes upon crop yields. Consequently the fertilizer program used was not usually the best one from the standpoint of maximum crop production but was designed to emphasize the effect of the crops themselves upon soil productivity. The soil reaction was maintained of pH 6.5-7.0 by applications of agricultural ground limestone as needed.

CORN YIELD TRENDS IN A FORTY-YEAR TEST

Five-year Rotation Corn. Agronomy Experiment No. 1,
and
Continuous Culture Corn. Agronomy Experiment No. 2

The Ohio Agricultural Experiment Station in 1894 established a series of crop rotations and fertility trial plots on land that was in a low state of productivity as a result of many preceding years of cash crop farming.

Agronomy Experiment No. 1 was a five-year rotation of corn-oats-wheat and two years of mixed timothy-clover hay. There were five sections of land thus permitting all crops to be grown each year. Each section contained 30 plots, ten of which were without any fertilizer or manure treatment (the check plots) and 20 which received varying amounts of fertilizer and manure. Agronomy Experiment 2 was a continuous corn culture experiment consisting of 10 plots, four of which were without treatment (check plots 1, 4, 7, and 10) and 6 which received varying amounts of fertilizer or manure. Four groups of these treatments were selected for this study as shown in the following table.

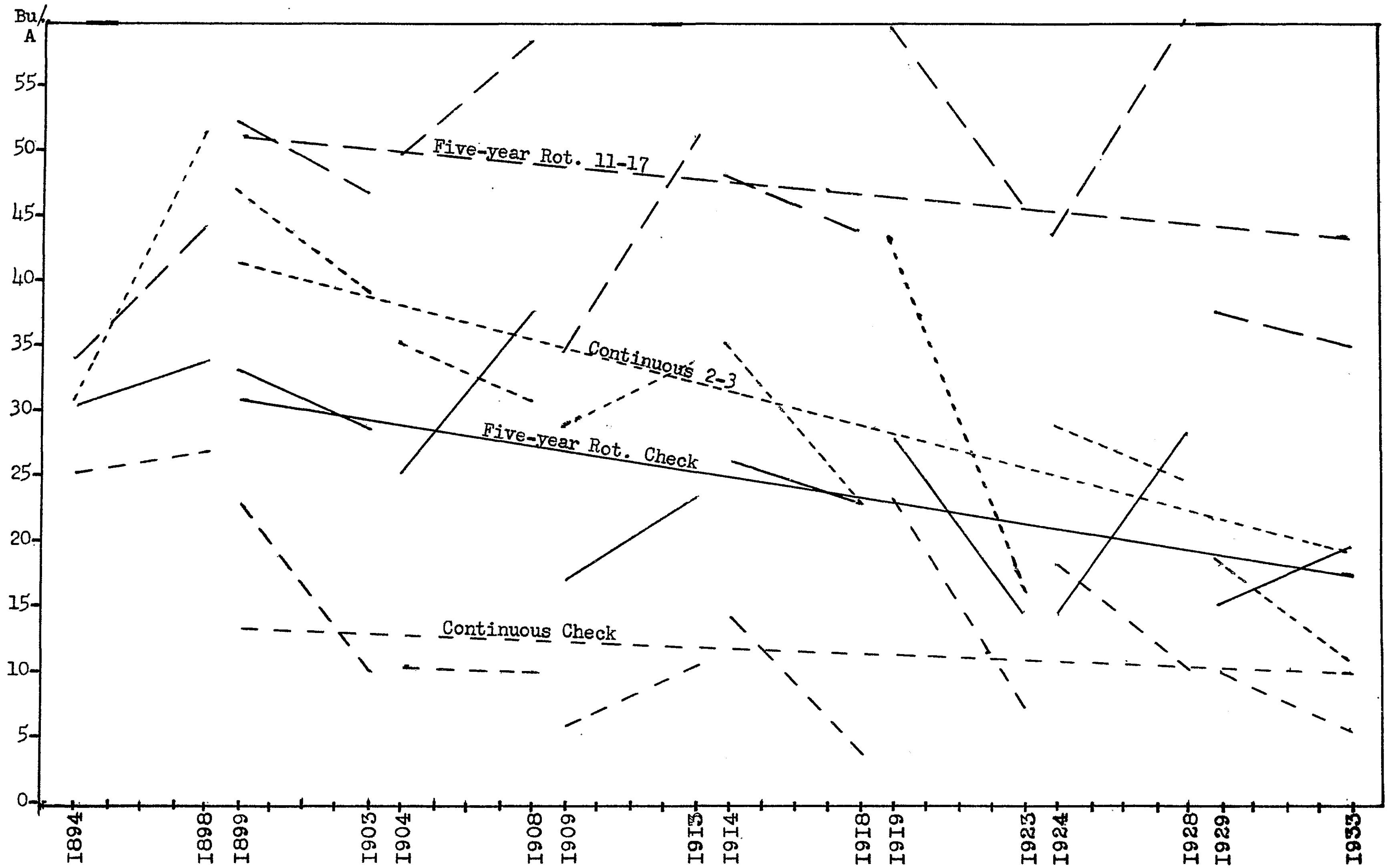
Corn crop		Av. treatment $N-P_2O_5-K_2O$	Plots averaged	35 yr. av. yield		Stover: grain ratio
				Grain	Stover	
		Lb/A	Numbers	Bu/A	Lb/A	Lb/Bu
Group I	Continuous	None	1,4,7,10	13.7	1020	74.4
Group II	Continuous	25-15-30	2 and 3	30.6	1890	61.8
Group III	Five-year rotation	None	1,4, to 28	24.2	1440	59.5
Group IV	Five-year rotation	20-20-40	11 and 17	47.6	2240	47.0

(See Ohio Agricultural Experiment Station Bulletin 381, The Maintenance of Soil Fertility, for the details of the fertilizer treatments.)

Group I consisted of the 4 check plots in the continuous corn culture experiment which received no fertilizer or manure. Group II was the average of plots 2 and 3 which received a complete fertilizer on the corn containing 25 pounds of nitrogen per acre applied as nitrate of soda: plot 2 received a little more phosphorus and potassium than did plot 3, but the average was approximately 25 pounds of N, 15 pounds of P_2O_5, and 30 pounds of K_2O per acre. Group III was the average of the 10 check plots in the five-year rotation. Group IV was the average of plots 11 and 17 in the five-year rotation that received approximately 20 pounds of N, 20 pounds of P_2O_5, and 40 pounds of K_2O per acre on the corn, oats and wheat crops: no fertilizer was applied to the meadow crops.

All of the grain, straw, stover, and hay were harvested and removed from the land.

Fig. 9 shows the yield trends for the last 35 years of the 40-year period. The first 5-year period is not included because the 5-year rotation was not fully established until the beginning of the second 5-year period in 1899. The continuous corn culture yields were treated in the same way in order to be compared with the 5-year rotation yields.



Corn Yield Trends in a Forty-year Test

Figure 9. Regression lines for corn in 5-year rotation experiment and continuous corn experiment.

In the first 5-year period the yields of all groups are closely grouped, indicating that all groups started out under somewhat similar soil productivity conditions. Following this first period the corn yields in Group I dropped sharply with the second period and leveled off at around 12 bushels per acre. The slight drop in the regression line is not significant. The two drouth years of 1930 and 1932 pulled down the yields and influenced the slope of the regression line. The yield level attained by the Group I corn was probably determined by the nitrogen released by the oxidation of the soil organic matter plus that contained in the rainfall. Non-symbiotic nitrogen fixation might have been a factor also but no proof of that is available. The phosphorus and potassium supply from the untreated soil was also very probably limiting corn yields.

In sharp contrast to the yield trends of Group I, is that of Group IV the two plots in the 5-year rotation that received a complete fertilizer. The yields increased sharply with the second rotation and leveled off at around 47 bushels an acre. The slight drop in the regression line is not significant. Note that the regression lines for Group I and Group IV are essentially parallel. The complete fertilizer and the contribution of nitrogen to the soil by the sod crops brought the yields of corn in Group IV to a level about 35 bushels per acre above that of the Group I continuous corn check plots.

The Group III corn consisted of the average of the ten check plots in the 5-year rotation. There is a significant drop in the slope of the regression line. The F value for the reduction in the variance due to fitting the regression line is 4.31: a value of 4.14 represents the 5% point. The corn yields were gradually declining during the period. If the test had been continued, it is probable that the yields would have leveled off eventually at a point somewhat above that of the Group I corn. The contribution of nutrients by the sod crops, especially the nitrogen fixed by the clover was not sufficient to compensate for the removal by the crops harvested and for the loss of nutrients from the store in the soil.

Group II corn yield trends for the two continuous corn plots 2 and 3 that received a complete fertilizer also show a decline in yield with time comparable to that for Group III 5-year rotation check plots. The reduction in the variance from the regression line is highly significant; the F value being 22.3 whereas only F 7.47 is required for significance at the 1% point. For the 35-year period Group II corn (continuous corn plus fertilizer) outyielded the Group III 5-year corn check plots by an average of 6.2 bushels per acre, a highly significant amount. The spread between the two regression lines for Group II and Group III becomes less with time. However, this tendency is not statistically significant. One cannot say with certainty that the two groups are approaching a common level although the tendency is in that direction.

<u>The stover:grain ratio</u>. The pounds of stover per bushel of grain, the stover:grain ratio, increases with a decrease in yield of corn. When Group I continuous corn check plots are paired with Group II continuous corn fertility plots for each year the stover:grain ratio was larger for Group I--33 times in the 40 comparisons. When the Group III check plots in the 5-year rotation are compared with Group IV 5-year rotation fertility plots the Group III plot stover:grain ratio was larger in every comparison. Although Group II corn outyielded Group III corn, the stover:grain ratio for Group III was higher only 21 times in the 39 comparisons (one stover yield was missing in Group III), a little short of significance.

When the effect of season upon the corn yields and the stover:grain ratios are examined for each group there is a highly significant negative correlation between corn yields and stover:grain ratios as follows:

		Correlation coefficient
Group I	Continuous check plots	-.69
Group II	5-year check plots	-.72
Group III	Cont. corn fert. plots	-.72
Group IV	5-year fert. plots	-.68

It thus appears that environmental conditions that depress the yields of corn grain such as seasonal conditions or low soil productivity also increase the pounds of stover per bushel of grain produced within the yield levels of this experiment.

DISCUSSION AND COMPARISONS OF ROTATIONS

Tables 1 through 5, Period I, and 6 through 11, Period II, give the numbers identifying the rotations, the crops, their treatments and yields.

In the tables and discussion, abbreviations for the crops are as follows: C = corn, S = soybeans, P = potatoes, W = wheat, O = oats, B = barley, Cl = clover, A = alfalfa, T = timothy, Swcl = sweetclover, (swcl) = sweetclover green manure. The constituents of the meadow mixtures are shown by combining the abbreviations, as A,Cl,T = alfalfa, clover, timothy mixture, etc.

When a crop appears more than once in a rotation, identification is made by the notations (1), (2) or (3) following the crop name or abbreviation, as corn(1), corn(2), wheat, clover, or C(1),C(2),W,Cl.

Crops Grown Continuously

Continuous corn. Like other experiments in which corn has been grown continuously with little or no fertilization, the yield of corn in Period I first dropped sharply and then continued at a somewhat uniform low level. A regression line calculated for the entire period sloped slightly downward. This was largely the reflection of the sharp early drop. This system illustrates the tendency of any cropping system to vary around a norm which is determined by the original condition of the soil, the climate, the crops, and the treatment. With two tons of manure per acre per year and some superphosphate this normal yield on the Wooster soil seems to have been between 25 and 30 bushels per acre. In Period II when the manure was omitted and only a small amount of 0-14-7 put on, this normal yield dropped to between 10 and 15 bushels with a corresponding reduction in stover.

The tendency to approach equilibrium is particularly well brought out in the second period when five plots of continuous corn were started on land in good condition and Plot C1, which had been in continuous corn since 1915,

Table 1 - Crops Grown in Continuous Culture, Period I

The continuous culture plots of Period I received manure at the rate of 4 tons per acre every odd year (1915, 1917...) and 400 pounds per acre of 0-16-0 every even year (1916, 1918...)

Culture	Crop	Yield, first crop 1915		Acre yields by 5-year periods exclusive of first crop: 1916-1920		1921-1925		1926-1930		1931-1935		Average yield per acre 1916-1935	
		Grain or tubers	Stover or straw	Grain or tubers	Stover or straw	Grain or tubers	Stover or straw	Grain or tubers	Stover or straw	Grain or tubers	Stover or straw	Grain or tubers	Stover or straw
No.		Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.
C1	Corn	78.6	3310	36.0	2100	25.0	1600	26.8	1930	29.2	2030	29.2	1910
C2	Potatoes	215	....	59	....	78	....	98	....	78	....	78	....
C3	Soybeans*	22.3	3220	10.3	1770	13.4	1700	12.3	1630	16.4	1520	13.1	1650
C4	Oats(swcl)	77.0	3030	56.6	2280	49.5	2240	54.9	2890	36.0	2420	49.2	2460
C5	Wheat(swcl)	(1916) 38.2	4240	(1917-1920) 34.5	2600	36.6	3120	38.9	3680	33.9	3460	36.0	3210

*Cultivated rows.

Table 2 - Two-year Rotations, Period I

Four tons of manure applied to the first crop.

Rotation	Crops	Acre yields by 5-year periods 1921-1925 Grain	1921-1925 Stover straw or hay	1926-1930 Grain	1926-1930 Stover straw or hay	1931-1935 Grain	1931-1935 Stover straw or hay	Average yield per acre 1921-1935 Grain or tubers	Average yield per acre 1921-1935 Stover straw or hay
No.		Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.
1	Corn	76.3	2970	74.2	3410	69.3	3730	73.3	3370
	Red clover		Eleven failures in 21 years					....	590
2	Corn	73.1	2800	75.8	3350	77.8	3920	75.6	3360
	Sweetclover hay		Nine failures in 21 years					....	990
3	Corn	53.1	2250	53.2	2420	59.1	2820	55.1	2500
	Soybeans (grain)	17.2	2380	17.8	1700	21.7	1480	18.9	1850
						1931		(1921-1931)	
4	Corn	66.0	2500	69.6	2900	63.4	3120	67.4	2740
	Spring wheat(swcl)	17.4	2160	14.5	2180	12.9	3120	15.5	2260
5	Corn	64.3	2530	65.3	2900	69.7	3510	66.4	2980
	Oats(swcl)	49.9	1940	62.2	2220	38.1	2190	50.1	2120
6	Corn	61.0	2520	64.0	2900	67.0	3400	64.0	2940
	Wheat(swcl)	30.5	2380	37.0	2690	29.6	3300	32.4	2790
7	Potatoes	114	....	170	....	185	....	156	....
	Wheat(swcl)	35.2	3030	41.6	3180	31.9	3470	36.2	3230
8	Soybeans (grain)	17.7	2500	21.7	2070	25.2	1960	21.5	2180
	Wheat(swcl)	24.3	1980	28.3	2290	29.9	2980	27.5	2420
						1931-1932		(1921-1932)	
9	Wheat	37.7	3500	41.7	4660	32.2	4320	39.7	4080
	Red clover + vol. bluegrass	....	3950	....	4350	....	4060	....	4150
						1931-1932		(1921-1932)	
10	Wheat	39.2	3680	43.0	4410	31.4	4090	41.1	4040
	Sweetclover hay	....	4980	....	4830	....	5010	....	4900

Table 3 - Three-year Rotations, Period I

Six tons of manure applied to the first crop

Rotation	Crops	Acre yields by 5-year periods 1921-1925 Grain	1921-1925 Stover straw or hay	1926-1930 Grain	1926-1930 Stover straw or hay	1931-1935 Grain	1931-1935 Stover straw or hay	Average yield per acre 1921-1935 Grain	Average yield per acre 1921-1935 Stover straw or hay
No.		Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.
	Corn	69.1	2880	67.8	3380	62.1	3280	66.3	3180
11	Wheat	36.3	2990	39.8	3250	38.2	4390	38.1	3540
	Red clover	....	3660	....	2970	....	4690	....	3770
	Corn	76.5	2910	71.3	3470	68.4	3460	72.1	3280
12	Oats	59.4	2560	67.7	2870	36.8	1990	54.6	2470
	Red clover	....	4180	....	3340	....	3810	....	3780
	Corn	79.0	3060	71.5	3600	79.0	4050	76.5	3570
13	Wheat	35.3	2680	40.3	3210	36.4	4260	37.3	3380
	Sweetclover hay	....	5180	....	5310	....	5080*	....	5200
	Corn	74.7	3200	75.3	3780	81.5	4050	77.2	3680
14	Wheat	37.6	3160	42.3	3560	35.0	4460	38.3	3730
	Alfalfa	....	4370	....	5150	....	6930	....	5480
	Corn	74.3	3640	63.8	3350	65.1	3270	67.7	3420
15	Wheat	31.7	2480	36.9	3140	33.4	4280	34.0	3300
	Timothy	....	3360	....	3650	....	3850	....	3620
	Corn	68.9	2580	59.3	3080	65.0	3430	64.4	3030
16	Barley	22.7*	1610*	33.9	1770	25.5	2030	27.7	1820
	Red clover	....	4070	....	3500	....	4180	....	3920
	Potatoes	111	....	214	....	210	....	178	....
17	Wheat	38.5	3360	47.3	3840	38.1	4280	41.3	3830
	Red clover	....	3840	....	2960	....	4100	....	3630
	Potatoes	144	....	197	....	219	....	187	....
18	Oats	58.9	2470	68.2	2590	36.6	1950	54.6	2340
	Red clover	....	4250	....	3570	....	3600	....	3810
	Soybeans (grain)	21.0	2250	20.2	2110	27.6	1910	22.9	2090
19	Wheat	35.8	2790	37.5	3140	39.3	4020	37.5	3320
	Red clover	....	3630	....	2970	....	4020	....	3540
	Soybeans (grain)	20.9	2110	21.0	2960	27.0	1780	23.0	1950
20	Potatoes	115	....	152	....	126	....	131	....
	Wheat(swcl)	39.3	2840	33.6	3010	31.8	2960	34.9	2940

*Four years only.

Table 4 - Four-year Rotations, Period I

Eight tons of manure applied to the first crop

Rotation	Crops	Acre yields by 5-year periods 1921-1925 Grain	1921-1925 Stover straw or hay	1926-1930 Grain	1926-1930 Stover straw or hay	1931-1935 Grain	1931-1935 Stover straw or hay	Average yield per acre 1921-1935 Grain	Average yield per acre 1921-1935 Stover straw or hay
No.		Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.
21	Corn	65.1	2700	64.7	3290	56.2	3270	62.0	3090
	Oats	59.4	2360	68.5	2380	45.3	1950	57.7	2230
	Wheat	36.3	3100	41.5	3710	38.3	3970	38.7	3590
	Red clover	....	3500	....	2490	....	4280	....	3420
22	Corn	74.4	2880	72.8	3540	64.5	3520	70.6	3310
	Oats	59.7	2500	72.6	2740	44.5	2000	58.9	2410
	Wheat	38.1	2950	38.3	3970	33.1	3880	36.5	3600
	Timothy	....	3830*	....	4090	....	3870	....	3940
23	Corn	75.3	3070	67.3	3430	56.0	3230	66.2	3240
	Corn	52.1	2140	58.1	2800	57.6	2940	55.9	2630
	Wheat	32.2	2570	33.5	2950	34.7	3880	33.5	3130
	Red clover	....	3530	....	2380	....	4650	....	3520
24	Corn	76.6	2950	73.0	3720	63.5	3330	71.0	3330
	Potatoes	105	....	134	....	180	....	140	....
	Wheat	37.5	3260	45.9	3900	34.9	4280	39.4	3810
	Red clover	....	3700	....	2380	....	4710	....	3600
25	Potatoes	153	....	225	....	223	....	200	....
	Corn	55.0	2430	63.3	2910	68.5	3230	62.3	2860
	Wheat	34.9	2910	38.0	3160	36.0	4100	36.3	3390
	Red clover	....	3540	....	2240	....	4530	....	3440
26	Potatoes	145	....	231	....	211	....	196	....
	Soybeans (grain)	18.9	2690	20.2	2330	28.7	2610	22.6	2540
	Wheat	31.7	2470	33.4	2890	37.2	3680	34.1	3010
	Red clover	....	3480	....	2460	....	4680	....	3540
27	Corn	69.2	2880	70.7	3350	60.8	3160	66.9	3130
	Soybeans (grain)	17.9	2230	21.3	2370	26.9	2160	22.0	2250
	Wheat	29.0	2260	28.4	2310	34.6	3460	30.7	2680
	Red clover	....	3100	....	1960	....	4150	....	3070
28	Corn	72.0	2710	76.8	3430	74.7	3520	74.5	3220
	Oats	57.3	2280	68.9	2510	44.8	2570	57.0	2450
	Red clover	....	3900	....	2780	....	3920	....	3530
	Wheat(swcl)	41.4	4180	44.3	4340	34.7	3980	40.1	4170
29	Corn	69.5	2980	76.8	3060	72.4	3300	72.9	3110
	Oats(swcl)	53.3	2190	73.2	2420	40.9	2200	55.8	2270
	Corn	58.4*	2330*	56.8	2570	58.7	2650	57.9	2530
	Wheat(swcl)	32.2	2830	33.3*	2740*	34.1	3820	33.2	3160
30	Corn	79.6*	3370*	78.9	3510	77.0	3900	78.4	3610
	Alfalfa	....	1710+	....	1330+	....	1480‡	....	1510
	Alfalfa	....	5010	....	4370	....	7290	....	5560
	Alfalfa	....	4460	....	5480	....	7720	....	5890

*Four years only - +Two failures - ‡Three failures

Table 5 - Five-year Rotations, Period I

Ten tons of manure applied to the first crop

Rotation No.	Crops	Acre yields by 5-year periods 1921-1925 Grain	1921-1925 Stover straw or hay	1926-1930 Grain	1926-1930 Stover straw or hay	1931-1935 Grain	1931-1935 Stover straw or hay	Average yield per acre 1921-1935 Grain	Average yield per acre 1921-1935 Stover straw or hay
		Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.
	Corn	75.0	2750	68.3	3350	67.0	3760	70.1	3290
	Oats	62.0	2430	61.1	2210	44.2	2490	55.8	2380
31	Wheat	38.5	3550	41.0	3760	37.3	4220	38.9	3840
	Red clover-timothy	....	3990	....	3820	....	4650	....	4150
	Timothy	....	4030*	....	4030	....	3010	....	3670
	Corn	80.4	3190	74.8	3870	75.1	4100	76.8	3720
	Wheat	34.9	2830	29.0	3330	37.9	4390	37.3	3520
32	Red clover-timothy	....	4090	....	4040	....	4430*	....	4170
	Timothy	....	3860	....	4940	....	4370	....	4390
	Timothy	....	3610*	....	3520	....	2720	....	3260
	Corn	80.5	3180	69.8	3460	66.5	3440	72.3	3360
	Corn	64.1	2510	63.5	2870	61.4	3320	63.0	2900
33	Wheat	29.1	2440	29.8	2550	34.0	3880	31.0	2960
	Red clover-timothy	....	4100	....	3270	....	4360	....	3910
	Timothy	....	4150*	....	4710	....	3890	....	4260
	Corn	81.0	3260	74.3	3770	68.4	3760	74.6	3600
	Potatoes	105	....	161	....	164	....	143	....
34	Wheat	36.6	3300	42.1	3920	36.1	4330	38.3	3850
	Red clover-timothy	....	4050	....	3500	....	5080	....	4210
	Timothy	....	4320*	....	5240	....	4730	....	4790
	Corn	80.0	3180	69.3	3670	62.7	3530	70.7	3460
	Corn	67.4	2470	65.7	2730	69.2	3160	67.4	2790
35	Soybeans (grain or hay)	19.5	(straw) 2340	....	(hay) 4230*	....	(hay) 5280	....	....
	Wheat	27.2	2250	32.9	2900	38.3	4220	32.8	3120
	Red clover	....	3370	....	2300	....	3980	....	3220
	Corn	80.5	3300	76.8	3860	66.5	3690	74.6	3620
	Potatoes	119	....	180	....	173	....	157	....
36	Soybeans (grain or hay)	19.1	(straw) 2520	....	(hay) 4170*	....	(hay) 5220	....	....
	Wheat	28.4	2360	40.2	3070	38.5	4380	35.7	3270
	Red clover	....	3530	....	2820	....	4780	....	3710
	Potatoes	153	....	210	....	188	....	184	....
	Soybeans (grain)	22.0	2260	22.4	1930	29.3	2420	24.6	2200
37	Potatoes	92	....	137	....	142	....	124	....
	Wheat	38.7	3410	44.9	3650	36.8	4070	40.1	3710
	Red clover	....	3790	....	2780	....	4900	....	3820
	Corn	74.1	2980	68.5	3320	60.5	3310	67.7	3200
	Corn	63.3	2360	60.6	2620	56.9	3060	60.3	2680
38	Corn	61.5	2470	58.1	2640	63.6	2930	61.1	2680
	Wheat	31.4	2540	34.3	2620	33.5	3650	33.1	2940
	Red clover	....	3370	....	2380	....	4970	....	3570

Table 5 (continued)

Rotation No.	Crops	Acre yields by 5-year periods 1921-1925 Grain	1921-1925 Stover straw or hay	1926-1930 Grain	1926-1930 Stover straw or hay	1931-1935 Grain	1931-1935 Stover straw or hay	Average yield per acre 1921-1935 Grain	Average yield per acre 1921-1935 Stover straw or hay
		Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.
	Corn	77.5	3140	74.1	3630	64.0	3570	71.9	3450
	Oats(swcl)	63.4	2530	70.2	2920	45.3	2860	59.6	2770
39	Corn	70.8	2790	69.4	3280	73.5	3400	71.2	3160
	Wheat	35.1	3090	37.4	3180	33.3	4090	35.3	3450
	Red clover	....	3410	....	2770	....	5140	....	3770
	Corn	83.7	3240	84.0	3780	78.5	4030	82.1	3680
	Oats	65.0	2620	75.0	2940	48.6	2890	62.9	2820
40	Alfalfa	....	5270	....	4910	....	5590	....	5260
	Alfalfa	....	5640	....	7020	....	8850	....	7170
	Alfalfa	....	6200	....	6490	....	10,830	....	7840

*Four years only.

Table 6. Continuous Culture, Period II

(Continued from Period I with some changes in treatment)

Culture No.	Crop	Manure per acre	Fertilizer 0-14-7	Average yields by 3 and 4-year periods								15-year average 1936-1950	
				1936-1938 3-yr.		1939-1942 4-yr.		1943-1946 4-yr.		1947-1950 4-yr.			
				Grain	Stover or straw	Grain	Stover or straw	Grain	Stover or straw	Grain	Stover or straw	Grain	Stover or straw
			Lb/A.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.
C101	Corn	None	150	17.2	1290	6.8	1460	11.2	1310	14.6	1290	12.1	1340
C102	Corn*	2 T.	150	27.4	1450	13.4	1810	24.2	1630	14.6	1290	22.2	1620
C103	Soybeans	None	150	16.5	2490	10.1	1130	10.7	1430	10.9	1500[1]	11.8	1590[2]
C104	Oats	None	150	50.5	2400	44.7	2220	36.5	1800	25.5	1420	38.6	1930
C105	Wheat	None	150	32.1	4020	27.8	2480	26.3	2460	20.7	1840	26.4	2680

*Followed potatoes in Period I.

[1] 2-yr. average

[2] 13-yr. average

Table 7. Continuous Corn, Period II

(Started on productive soil, 1936)

Culture No.	Crop	Cover crop or manure per acre	Fertilizer 9-14-7	Average yield per acre 4-year 1937-1940 Grain	Stover	5-year 1941-1945 Grain	Stover	5-year 1946-1950 Grain	Stover	14-year average 1937-1950 Grain	Stover
			Lb/A	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.
C106	Corn	Rye or ryegrass	150	35.1	2190	25.3	1950	27.0	1840	28.7	1980
C107	Corn	Rye or ryegrass and hairy vetch	150	42.3	2650	37.6	2420	46.4	2420	42.1	2490
C108	Corn	2 tons manure	150	45.9	2750	38.5	2350	39.7	2120	41.0	2380
C109	Corn	None	150	40.4	2440	30.3	2140	29.7	1830	33.0	2120
C110	Corn	Sweetclover	150	44.7	2490	34.2	2130	32.6	1780	36.6	2110

Table 8. Two-year Rotations, Period II

Rotation	Crops	Crop residues or manure per acre	Fertilizer 0-14-7	Acre yields by 4-year periods: 1939-1942 Grain	1939-1942 Stover or straw	1943-1946 Grain	1943-1946 Stover or straw	1947-1950 Grain	1947-1950 Stover or straw	12-year average yields 1939-1950 Grain	12-year average yields 1939-1950 Stover or straw
No.			Lb/A.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.
101	Corn	4 T. manure	150	69.6	3760	57.8	3540	69.7	3200	65.7	3500
	Oats(swcl)	None	150	64.1	2800	55.7	2120	44.1	2140	54.6	2350
102	Corn**	Oats straw	150	69.8	....	59.7	....	73.0	....	67.5	....
	Oats(swcl)#	Corn stover	150	63.2	....	55.1	....	39.2	....	52.5	....
103	Corn∅	None	150	59.2	3310	46.9	2920	59.5	2640	55.2	2950
	Oats(swcl)	None	150	54.4	2500	43.0	1480	38.1	1760	45.2	1920
104	Corn	None	150	64.4	3460	49.7	3040	62.1	2860	58.8	3120
	Oats(swcl)	None	150	59.6	2660	49.7	1680	40.3	1960	49.9	2100
105	Corn	None	150	49.8	2880	36.4	2380	50.2	2450	45.4	2570
	Oats	None	150	44.7	1910	42.3	1370	33.7	1640	40.3	1640
106	Corn	None	150	50.0	2990	33.9	2420	51.7	2330	45.2	2580
	Wheat	None	150	22.7	1720	22.4	1640	23.1	1890	22.7	1750
107	Corn	None	150	59.6	3400	46.3	3000	68.2	3080	58.1	3160
	Wheat(swcl)	None	150	22.9	2420	27.6	2010	28.6	2470	28.7	2300
108	Corn**	Wheat straw	150	64.3	....	48.6	....	74.1	....	62.3	....
	Wheat(swcl)#	Corn stover	150	32.8	....	31.1	....	29.4	....	31.1	....
109	Corn	4 T. manure	150	70.4	3980	53.0	3580	74.5	3450	66.0	3670
	Wheat(swcl)	None	150	31.5	3070	36.2	2820	33.9	3120	33.9	3000
110	Corn∅	None	150	65.7	3600	50.3	3330	73.3	3380	63.1	3440
	Wheat(swcl)	None	150	31.7	2810	29.2	2160	31.4	2760	30.8	2580

∅Influenced by previous rotation of Period I.
**Corn picked.
#Small grain combined.

Table 9. Three-year Rotations, Period II

Ro-tation	Crops	Crop residues or manure per acre	Ferti-izer 0-14-7	Acre yields by 4-year periods: 1939-1942 Grain	1939-1942 Stover straw or hay	1943-1946 Grain	1943-1946 Stover straw or hay	1947-1950 Grain	1947-1950 Stover straw or hay	12-year average yields 1939-1950 Grain	12-year average yields 1939-1950 Stover straw or hay
No.			Lb/A.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.
111	Corn	None	150	68.6	3670	54.4	3630	77.0	3560	66.7	3620
	Wheat	None	300	38.2	3330	37.9	3300	37.9	3460	38.0	3360
	Clover	None	...	.....	5100	....	4160	....	4640	....	4630
112	Corn	6 T. manure	150	74.3	4010	62.7	3990	79.9	3730	72.3	3910
	Wheat	None	300	36.8	3920	46.1	4000	39.9	4380	41.0	4100
	Clover	None	...	....	5890	....	4450	....	5070	....	5140
113	Corn	6 T. manure	150	72.9	4130	59.5	3970	79.7	3670	70.7	3920
	Wheat	None	300	38.3	4000	44.7	3870	40.7	4340	41.2	4070
	Alfalfa	None	...	....	6510	....	5200	....	5780	....	5830
114	Corn	None	150	69.3	3620	56.7	3530	72.2	3470	66.1	3540
	Wheat	None	300	36.0	3520	43.4	3580	37.6	3770	39.0	3620
	Alfalfa	None	...	....	5460	....	5340	....	5260	....	5350
115	Corn	None	150	56.3	3180	49.6	3100	70.3	3220	58.7	3170
	Wheat	None	300	33.6	2760	37.4	3000	32.9	3190	34.6	2990
	Timothy	None	...	....	3840	....	3980	....	2800	....	3540
117	Corn	None	150	62.1	3540	50.7	3480	76.9	3440	63.2	3490
	Wheat	None	300	33.3	2970	42.8	3740	35.3	3520	37.1	3410
	Alf-clo-tim	None	...	....	5380	....	5830	....	6080	....	5760
118	Corn	None	150	70.5	3890	52.3	3430	78.1	3490	67.0	3600
	Wheat	None	300	38.4	3060	40.8	3560	36.8	3570	38.7	3400
	Sweetclover	Not removed pd. for corn	...	....	....	....	....	....	....	....	....
119	Corn#	Oats straw	150	60.2	....	56.5	....	79.9	....	65.6	....
	Oats##	Corn stover	300	64.0	....	60.0	....	44.8	....	56.1	....
	Alfalfa	None	...	....	6640	....	6080	....	6920	....	6540
120	Corn	None	150	62.3	3540	47.7	2850	76.4	3500	62.1	3290
	Oats	None	300	62.6	3150	61.8	2500	47.4	2260	57.3	2640
	Alfalfa	None	...	....	6460	....	5340	....	5760	....	5860

#Corn picked
##Oats combined

Table 10. Four-year Rotations, Period II

Ro-tation	Crops	Crop residues or manure per acre	Fertilizer 0-14-7	Acre yields by 4-year periods: 1939-1942 Grain	1939-1942 Stover straw or hay	1943-1946 Grain	1943-1946 Stover straw or hay	1947-1950 Grain	1947-1950 Stover straw or hay	12-year average yields 1939-1950 Grain	12-year average yields 1939-1950 Stover straw or hay
No.			Lb/A.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.
121	Corn	None	150	57.0	2970	45.4	2840	68.0	3030	56.8	2950
	Oats	None	150	64.1	2800	56.1	2040	48.7	2080	56.3	2300
	Wheat	None	300	38.5	3100	34.9	2720	35.3	3180	36.2	3000
	Clover	None		....	3660	....	4320	....	3860	....	3940
122	Corn	6 tons manure	150	66.3	3580	57.3	3190	76.7	3330	66.8	3360
	Oats	None	150	67.2	3140	58.4	2380	50.2	2340	58.6	2620
	Wheat	(2 tons manure) (top dr. winter)	300	37.2	3240	38.5	3030	35.7	3360	37.1	3210
	Clover	None		....	4400	....	4900	....	5400	....	4900
123	Corn	None	150	64.6	3370	52.8	3090	70.8	3230	62.7	3230
	Oats	None	150	66.3	2900	58.0	2180	49.4	2280	57.9	2450
	Alf,Cl,T.	None		....	5030	....	6220	....	4970	....	5410
	Wheat(swcl)	None	300	39.6	4280	37.8	3900	33.7	3650	37.0	3940
124	Corn	None	150	61.5	3280	54.5	3050	73.3	3150	63.1	3160
	Soybean hay	None	150	....	5660	....	3760	....	4340[1]	....	4610[2]
	Wheat	None	300	36.1	2680	39.5	3120	34.4	3000	36.6	2930
	Clover	None		....	3290	....	3970	....	5110	....	4120
125	Corn	None	150	69.6	3540	54.0	3080	73.3	3250	65.7	3290
	Soybeans, combined	(Combined straw)	150	23.3	....	17.5	....	16.5[1]	....	19.3[2]	....
	Wheat	None	300	34.5	2420	37.2	2820	32.4	2820	37.4	2680
	Clover	None		....	4450	....	4580	....	4960	....	4660
126	Corn	None	150	64.0	3440	55.1	3230	74.2	3310	64.4	3330
	Soybeans, binder hvst.	None	150	20.4	2820	14.6	2200	16.4	1960[1]	17.0	2360[2]
	Wheat	None	300	31.0	2440	33.4	2600	29.2	2620	31.2	2560
	Clover	None		....	3470	....	4260	....	4560	....	4100
128	Corn	Straw	150	77.5	....	55.0	....	79.6	....	70.0	....
	Wheat	Stover	450	38.4	....	42.4	....	43.2	....	41.1	....
	Alfalfa (1)	None		....	6590	....	5760	....	5160	....	5840
	Alfalfa (2)	None		....	9280	....	8300	....	8110	....	8560

Table 10 (continued)

Rotation	Crops	Crop residues or manure per acre	Fertilizer 0-14-7	Acre yields by 4-year periods: 1939-1942 Grain	1939-1942 Stover straw or hay	1943-1946 Grain	1943-1946 Stover straw or hay	1947-1950 Grain	1947-1950 Stover straw or hay	12-year average yields 1939-1950 Grain	12-year average yields 1939-1950 Stover straw or hay
No.			Lb/A.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.
129	Corn	6 tons manure	150	77.9	4280	57.5	3490	78.1	3320	71.1	3700
	Wheat	2 tons manure winter top dr.	450	39.4	3970	44.2	4060	41.4	4590	41.7	4200
	Alfalfa(1)	None		....	7420	....	5830	....	4260	....	5840
	Alfalfa(2)	None		....	9940	....	8400	....	7440	....	8590
130	Corn	None	150	72.7	3910	51.3	3230	74.4	3020	66.1	3380
	Wheat	None	450	37.1	3700	44.5	3860	40.1	4440	40.6	4000
	Alfalfa(1)	None		....	4200	....	4390	....	3520	....	4040
	Alfalfa(2)	None		....	7040	....	6860	....	5880	....	6590

1/ 3-yr. average

2/ 11-yr. average

Table 11. Five-year Rotations, Period II

Rotation	Crops	Crop residues or manure per acre	Fertilizer 0-14-7	Acre yields by 4-year periods: 1939-1942 Grain	1939-1942 Stover straw or hay	1943-1946 Grain	1943-1946 Stover straw or hay	1947-1950 Grain	1947-1950 Stover straw or hay	12-year average yields 1939-1950 Grain	12-year average yields 1939-1950 Stover straw or hay
No.			Lb/A.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.
131	Corn	None	150	59.4	3160	52.3	3200	74.1	3340	61.9	3230
	Oats	None	150	61.3	3020	57.7	2400	49.4	2220	56.1	2540
	Wheat	None	450	37.6	3530	31.1	3640	29.2	3190	32.6	3150
	Clover, timothy	None		....	4220	....	3860	....	4950	....	4340
	Timothy	None		....	5590	....	4680	....	3200	....	4490
132	Corn	6 tons manure	150	74.9	4360	61.0	3600	79.2	3640	71.7	3860
	Oats	None	150	61.5	3180	56.2	2700	53.5	2620	57.1	2840
	Wheat	4 tons manure winter top dr.	450	39.1	4140	35.8	3240	31.1	3720	35.3	3700
	Clover, timothy	None		....	4840	....	4290	....	6000	....	5040
	Timothy	None		....	6540	....	5620	....	3980	....	5380
133	Corn	None	150	74.0	4240	60.3	3910	76.5	3670	70.3	3940
	Wheat	None	450	39.7	3530	40.6	3980	41.3	4340	40.5	3950
	Alf,Clo,T	None		....	5650	....	4800	....	5390	....	5280
	Alf,T	None		....	5960	....	6330	....	4030	....	5440
	Alfalfa, timothy	None	150	....	8450	....	7880	....	5570	....	7300
134	Corn	None	150	66.3	3870	56.3	3600	76.5	3370	66.4	3610
	Wheat	None	450	36.1	3280	40.3	3780	40.4	4150	38.9	3740
	Clover, timothy	None		....	4730	....	4360	....	4840	....	4640
	Timothy	None		....	4400	....	5460	....	3920	....	4590
	Timothy	None	150	....	4610	....	4880	....	3100	....	4200
136	Corn	6 tons manure	150	75.5	4530	61.8	4070	79.4	3810	72.3	4140
	Wheat	4 tons manure winter top dr.	450	39.4	4540	44.2	4600	37.8	4480	40.5	4540
	Alfalfa(1)	None		....	7420	....	5870	....	7490[1]	....	6870[2]
	Alfalfa(2)	None		....	9600	....	8220	....	8260[1]	....	8730[2]
	Alfalfa(3)	None	150	....	9710	....	8480	....	9440[1]	....	9190[2]

Table 11 (continued)

Ro-tation	Crops	Crop residues or manure per acre	Fertilizer 0-14-7	Acre yields by 4-year periods 1939-1942 Grain	1939-1942 Stover straw or hay	1943-1946 Grain	1943-1946 Stover straw or hay	1947-1950 Grain	1947-1950 Stover straw or hay	12-year average yields 1939-1950 Grain	1939-1950 Stover straw or hay
No.			Lb/A.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.	Bu.	Lb.
137	Corn(1)	None	150	71.2	4020	56.6	3360	77.7	3590	68.5	3660
	Corn(2)	None	150	67.9	3460	55.4	3210	69.7	3020	64.3	3230
	Wheat	None	450	32.3	2380	35.8	2820	26.0	2620	31.4	2610
	Alfalfa(1)	None		....	6950	....	5000	....	4050	....	5340
	Alfalfa(2)	None		....	9490	....	6990	....	7210	....	7900
138	Corn(1)	None	150	68.8	3670	45.5	2880	73.2	3450	62.5	3330
	Corn(2)	None	150	63.1	3200	52.3	2710	60.6	2710	58.7	2880
	Corn(3)	None	150	50.7	2910	42.1	2680	46.2	2360	46.3	2650
	Wheat	None	300	20.4	1560	26.5	1720	26.5	1880	24.5	1720
	Alfalfa	None		....	9340	....	3820	....	5000	....	6520
139	Corn	Straw	150	79.3	....	62.1	....	80.3	....	73.9	....
	Wheat	Stover	450	42.6	....	44.4	....	38.9	....	42.0	....
	Alfalfa(1)	None		....	6600	....	5670	....	5960 1/	....	6080 2/
	Alfalfa(2)	None		....	9190	....	6980	....	7670	....	7970
	Alfalfa(3)	None	150	....	9540	....	8710	....	9330 1/	....	9180 2/
140	Corn	None	150	76.9	4130	60.6	3720	80.5	3660	72.7	3840
	Wheat	None	450	42.6	4070	43.7	4280	41.4	4220	42.6	4190
	Alfalfa(1)	None		....	4250	....	3470	....	5030 1/	....	4180 2/
	Alfalfa(2)	None		....	6840	....	5960	....	7350 1/	....	6660 2/
	Alfalfa(3)	None	150	....	7700	....	6990	....	7910 1/	....	7500 2/

1/ 3-yr. average

2/ 11-yr. average

was continued as Plot C101. In Period I, despite the manure that was added, Plot C1 lost more nitrogen from the soil than any other by a wide margin. In the Period II, this was true of plots C106 to C110 but Plot C101, already at a low level, lost comparatively little. On the depleted soil, two tons of manure per acre per year (Plot C102) gave an average of 10 bushels per acre more corn than unfertilized with nitrogen.

On productive soil, two tons per acre of manure (Plot C108) gave an average increase of 8 bushels of corn. The only green manure crop to produce more corn than this was ryegrass and hairy vetch and this difference, 1.1 bushels, was not significant. Corn after ryegrass yielded less than corn with no cover crop by over 4 bushels per acre, a result which is quite general with either rye or ryegrass not supplemented with liberal amounts of nitrogen. The low value of sweetclover, especially white sweet clover, sown in the summer in corn by ordinary methods is indicated by the less than 4-bushel increase obtained as a 14-year average.

Continuous potatoes. The plot (C2) in continuous potatoes merely demonstrated that one cultivated crop is much like another in its effects on soil nitrogen. Its yield was almost level after the first crop, and its similarity to continuous corn was much more noticeable than the differences. The failure of continuous potatoes on these slightly fertilized plots does not mean that continuous or nearly continuous potatoes are necessarily a failure when well fertilized and cared for.

Continuous soybeans. During Period I we were learning better how to grow soybeans in Ohio. This, or unknown factors, resulted in increasing yields of the Check Group soybeans and of soybeans on farms in the state. A slight upward tendency of the regression line for continuous soybean yields probably reflects the same factors. In Period II the yield of continuous soybeans slowly declined. Presumably because of the small root system of the soybean, soybeans in rows were not appreciably different from the corn or other cultivated crops in building up nitrogen in the soil. During Period I, only three plots lost more nitrogen than the continuous soybean plot and one of those was the corn-soybean rotation. Nitrogen in the soil in Plot C103 was in equilibrium during Period II (Table 13). It is not clear why continuous soybeans should yield less than soybeans in rotation with the same fertility treatment, but they have done so in all experiments in Ohio. The possibility that soil-borne diseases are a factor is worth studying here.

Continuous oats. Continuous oats with a sweetclover green manure crop yielded 9.9 bushels per acre less than the check group but the same amount of straw. In Period II there was no sweetclover catch crop and the continuous oats not only yielded 18.3 bushels less grain than the Check Group but also 700 pounds per acre less straw. The soil of the plots, which gained in nitrogen in Period I, lost in nitrogen in Period II. These changes reflect the loss of the nitrogen in the sweetclover and the manure. As with soybeans, the reason for the much lower yields of continuous oats than the oats in rotation in Period I is not clear. The difference may be associated with diseases, although there was no evidence of it. It hardly seems possible that the difference lay in soil fertility effects. The variety Miami, used here, dropped in yield in a good rotation in the variety test over the same period, at the annual rate of 1.6 bushels per acre.

Continuous wheat. In all studies of continuous cropping, wheat has shown smaller proportionate reductions in yield than most crops. This was especially notable in Period I when a catch crop of sweetclover sown with the wheat very nearly maintained the wheat yield at the same point as the Check Group wheat. The sweetclover catch crop furnished almost, if not actually, enough nitrogen for maximum wheat yields. When no legume was sown, in Period II, continuous wheat averaged 10.5 bushels per acre less than the Check Group wheat. The loss would have been even greater, except that volunteer black medic* made considerable growth on the plot, covering the ground and producing the indicated small gain in soil nitrogen. During both periods, continuous wheat yielded from 1/4 to 1/3 more pounds per acre of grain than continuous oats.

Two-year Rotations

In Period I there were ten two-year rotations (Table 2). Not more than half of these can be considered feasible in Ohio farming. In Period II this was recognized and all ten rotations consisted of variants of two that were in the original series.

Rot. 1, C-Cl, and 2, C-Swcl, involved attempting to obtain a red clover or sweetclover stand for hay in the corn. With four tons of manure, the corn yields were fully equal or slightly superior to the Check Group yield, but corn was grown in only one year out of two, and a quarter to a third of a ton of low grade hay was only return in the other year.

Rot. 9, W-Cl, and 10, W-Swcl, paired wheat with the same two legumes. These rotations produced excellent yields of both wheat and hay but they would not ordinarily be profitable.

Rot. 8, S-W(swcl) demonstrated early what the Madison County experiments (Bul. 847**) later showed in detail, that soybeans were not increased in yield being preceded by a sweetclover catch crop. At the same time the wheat yields were not equal to those following corn in Rot. 6, C-W(swcl). In the Madison County experiments, wheat in S-W(swcl) outyielded wheat in C-W(swcl) by a considerable margin, as one would anticipate.

Rot. 7, P-W(swcl), when compared to Rot. 6, confirmed the general opinion that wheat yields more following potatoes than following corn, but the rotation, though possible, is not adapted to present-day conditions.

In Rot. 4, C-SpW(swcl), spring wheat is an excellent companion crop for sweetclover but, as always in Ohio, yielded rather less than half as much as winter wheat, so that by no stretch of the imagination could it be called a profitable crop. Corn was barely significantly better than in Rot. 6, C-W(swcl). This presumably reflects the better sweetclover usually obtained in spring grain.

Rot. 3, C-S, is the familiar "succotash rotation" of Northwestern Ohio. Here as in other experiments (Bul. 847) it is a poor rotation, with yields of both corn and soybeans significantly under the Check Group yields. However, both yields are significantly higher than continuous corn or continuous soybeans.

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*Medicago lupulina

**Throughout the remaining discussion there will be occasional references in this form to "Rotation Experiments in Paulding, Henry, and Madison Counties", Ohio Agr. Expt. Sta. Bul. 847, (1959) and "Experiments on the Use of Sweetclover for Green Manure", Ohio Agr. Expt. Sta. Bul. 839, 1959.

This leaves Rot. 5 and 6, the two rotations including corn followed by a small grain with a sweetclover catch crop, as the two most satisfactory and (except for Rotation 3) widely used two-year rotations and the only ones studied in Period II. The yields of corn and stover are significantly lower than the Check Group yields in both rotations as are the yields of wheat and oats straw. The fact that the stubble was clipped in August for over half of the 20-year period was a factor in this showing. The yield of corn in Rot. 5 is significantly greater than that in Rot. 6, although the difference is only 2.3 bushels. This reflects, in turn, the fact that the sweetclover stands were consistently better in oats than in wheat.

The two-year rotations in Period II were all studies of the corn, small grain rotation with or without a sweetclover catch crop (Bul. 839). Five were corn, wheat, and five were corn, oats. In each group there was one rotation in which there was no sweetclover, one in which the sweetclover catch crop was supplemented with four tons of manure per acre, and one in which the residues were returned. Corn yields equal to or above the Check Group yields were obtained when the sweetclover was supplemented with manure or residues. Manure gave the highest yields in the corn, wheat rotation, but residues outyielded manure (non-sig.) in the rotation. There is no significant difference between the yields of corn in the oats rotations and the wheat rotations as a group. The sweetclover green manure catch crop added twelve or thirteen bushels to the corn yield over corn, oats, or corn, wheat, alone.

The Three-year Rotations

The yields of ten 3-year rotations in Period I are reported in Table 3. Rot. 11, C-W-Cl, consistently gave significantly lower yields of corn than 12, C-O-Cl, 13, C-W-Swcl, or 14, C-W-A. Since the yields of clover were almost identical in 11 and 12, something other than the nitrogen supply from the legume crop must have affected the corn crop (Page 33).

The corn yields in Rot. 12, 13, and 14 are not significantly different. Sweetclover has long since been given up as a second year hay crop. Corn, small grain, alfalfa, almost an unknown rotation in Ohio when these rotations were begun, is now very important, a close second to C-W-Cl. It is probable that corn after one year of alfalfa usually slightly outyields corn after one year of red clover under Ohio conditions, but the difference is less than is often thought.

Corn after timothy yields less than corn following the legumes but again the differences are smaller than might be expected. Six tons of manure per acre on the timothy sod helped to erase the differences as did volunteer clover in the timothy. However, all rotation experiments in Ohio emphasize the high value of timothy as a crop to precede corn if the corn can obtain sufficient nitrogen from soil, manure, or fertilizer. Unless treated with herbicides there will almost always be volunteer legumes in timothy to fix considerable nitrogen.

In view of the fact that the red clover in Rot. 16, C-B-Cl, yielded as much as that in Rot. 12, it is hard to see why the yield of corn should be nearly 8 bushels less. The yields of barley are poor, as they frequently are following corn because of scab. Scab (Gibberella zeae (Schw.) Pitch) affects corn and corn is the most important source of infection in barley. A reciprocal effect, with a clover crop between, does not seem likely.

Three rotations including potatoes, 17, P-W-Cl, 18, P-O-Cl, and 20, S-P-W, are as non-realistic in practice as the other potato rotations. Naturally the yield of potatoes is least following soybeans. Manure was not applied to the potatoes in this rotation, as it was in Rot. 17 and 18. Potatoes, small grain, clover, is an excellent potato rotation but more fertilizer than was applied here is required to get good potatoes from this soil. However, we might remind ourselves that the average yield of potatoes in Ohio in the decade 1909-1918 was 81 bushels per acre, against 233 bushels for the period 1949-1956.

Rot. 19, S-W-Cl, is a satisfactory rotation so far as the yield of the crops involved is concerned, but there are few Ohio farms that can get along without corn,and soybeans following a legume is wasteful of the nitrogen accumulated. Comparing Rot. 19 with 8, S-W(swcl), the yield of wheat is nearly 10 bushels greater in the former - apparently, since the soybean yields are almost identical, a carry-over of more nitrogen from the clover sod than from the sweetclover green manure.

In Period II, the study was concentrated on alfalfa in the rotation. Rot. 14 was continued as were 11 and 15. A rotation devoting a year to unharvested sweet-clover for green manure, 118, C-W-Swcl, produced no more corn or wheat than 114, C-W-A, which furnished nearly 3 tons of alfalfa hay. This result agrees with all other experiments on this system.

Corn in Rot. 112, C-W-Cl, and 113, C-W-A, plus 6 tons of manure on corn in each, outyielded 111, C-W-Cl, and 114, C-W-A, with no manure, by about 5 bu./A. The corn yields following alfalfa and clover were the same and those following the A,Cl,T mixture (Rot. 117) now generally recommended, were not significantly different.

Returning straw and stover for corn in a C-O-A rotation (Rot. 119) increased the yield somewhat over taking them off (Rot. 120), but Rot. 119 was not thought of as or intended to be a practical farm rotation. There was no advantage in corn yields for C-O-A over C-W-A, but the former produced, non-significantly, more alfalfa. On other soil types, alfalfa following oats is much surer and higher-yielding than alfalfa after wheat (Bul. 847 and 588) - so much so that the A,Cl,T mixture is generally recommended when sowing hay in wheat.

Rot. 115, C-W-T, with no manure added in Period II, continued to give good yields of corn although they were lower than those following legumes.

The Four- and Five-year Rotations

The yields of ten 4-year rotations in Period I are given in Table 4 and of ten 5-year rotations in Table 5. Many of these rotations are most conveniently discussed together.

Rot. 21, C-O-W-Cl, has already been discussed (Page 19). This is a long-time standard rotation in the Wooster area, frequently lengthened to 5 or 6 years by leaving the meadow down for 2 (Rot. 31) or 3 years. There is no reason to believe that the corn yields in this rotation should be less than those in Rot. 23, C-C-W-Cl, as they are by 4 bu/A (just on the line of significance), so one suspects some unknown factors reducing the yields. C-O-W-Cl is not a very profitable rotation, but gives time to prepare for and harvest each crop, an important point on heavy soils in wet seasons. The data for Rot. 31, C-O-W-Cl,T-T, are similar. There is nothing wrong with these rotations except that there are too many low-profit crops in them.

Rot. 22, C-O-W-T, and 32, C-W-Cl,T-T-T, are very similar, and the corn yields, as in Rot. 15, C-W-T, are excellent - considerably the product of the 8 and 10 tons of manure applied, to be sure, but still emphasizing the value of grass sods on heavy soils. Rot. 33, C-C-W-Cl, T-T, and 34, C-P-W-Cl,T-T, also have good yields of first-year corn after timothy - there are no exceptions.

The four- and five-year potato rotations are subject to the same limitations as the shorter ones. Rot. 24, C-P-W-Cl, and 25, P-C-W-Cl, are identical except for order. By putting corn first we obtained 9 bushels more corn; by putting potatoes first, 60 bushels more potatoes; if one must choose between these rotations, it is obvious that potatoes should come first - an illustration of the general principle that the crop which produced the most economic return from the good tilth developed and nitrogen accumulated by the sod crop should follow it.

Potatoes came first in Rot. 25, in 26, P-S-W-Cl, and 37, P-S-P-W-Cl, and after corn or soybeans in 24, 34, C-P-W-Cl,T-T, 36, C-P-S-W-Cl, and 37. The average potato yield of the first group was 193 bu/A; of the second, 141 bu/A; a further example of the principle above.

Wheat yields after potatoes were consistently higher than after corn; 37.9 bu/A in six rotations following potatoes and 33.2 bu/A in 11 rotations following corn. The higher or lower wheat yields after corn are largely traceable to the nitrogen available to the wheat, and could be considerably modified in practice by nitrogen applications, though infection with scab often reduces the yield and quality of wheat in C-W rotations.

Looking back from 1960, it seems extraordinary that only four of these rotations included corn after corn. Rot. 32, C-W-Cl,T-T-T, 33, C-C-W-Cl,T-T, and 38, C-C-C-W-Cl, studied 1/5 to 3/5 corn with 3/5 to 1/5 meadow. Second and third-year corn did not equal first year corn + 10 tons of manure, of course; The remarkable feature is that the yields held up as well as they did. In Rot. 23, C-C-W-Cl, second-year corn yielded less than third-year corn in Rot. 38; another example of plot variation. The low yields of first-year corn in Rot. 23 and 38 testify to exhaustion of nitrogen under heavy use and low supply.

Rot. 27, C-S-W-Cl, is a rotation that has stood the test of time. Here, because of insufficient fertility for so intensive a rotation, the average corn yields are low.

Rot. 28, C-O-Cl-W(swcl), is the rotation originally suggested by C. G. Hopkins*. It gave good yields, but not enough higher than simpler 4-year rotations to justify the extra labor.

In Rot. 29, C-O(swcl)-C-W(swcl), two good short rotations are combined into a four-year rotation. The same is done in Rot. 39, C-O(swcl)-C-W-Cl, to make a five-year rotation. One wonders why the second corn yielded so poorly in Rot. 29, and so well in Rot. 39. There seems to be more difference than the presence of one sod crop in five years would account for, but perhaps not. Certainly Rot. 29 makes one of the poorest showings for sweetclover of any Station experiment (Bul. 839).

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*Soil Fertility and Permanent Agriculture, P. 228. Ginn and Co. 1910. 653 pages.

Rot. 30, C-A-A-A, is a rotation tried before its time, but its failure did much to stimulate studies of sowing alfalfa in corn. In 7 years out of the 15, alfalfa stands were failures and the first season after corn had to be used in establishing the crop. Even so, the nitrogen accumulated resulted in higher corn yields than any other rotation except Rot. 40, C-O-A-A-A. This last rotation points the way to successful alfalfa and corn production in Ohio. As it stands here, this rotation produced more total digestible nutrients for livestock than any other rotation studied. It would have done still better as a 7-year rotation with 3 years of corn and more fertilizer.

Rot. 35, C-C-S-W-Cl, is the only rotation in Period I with any application to soybean culture today, and here the soybeans were harvested as hay for the last ten years. When these rotations were planned, soybeans were thought of as a soil-building legume. Its deficiencies in that regard, and its use as a cash grain crop, were both to appear 20 years later.

In Period II, the emphasis was shifted, as in the 3-year rotations, to working alfalfa into the rotation. Also, management and manure variables were introduced, but no commercial fertilizer variables were included.

Three four-year rotations studied soybeans in the rotation, but studied only method of harvesting. All were C-S-W-Cl, but in Rot. 124 the soybeans were harvested for hay, in 125 with a combine and 126 with a binder. The significance of the latter today is to study the value of the straw for crop production, since it was removed by the binder harvest. The corn yields varied little, but the wheat yield was larger following combine harvest by 6.2 bu/A, a highly significant difference. The wheat following soybean hay was essentially equal to that following the combined soybeans.

The rotation selected in the late '30's as the best soil-conserving rotation in Ohio, C-W-A-A, was not studied in Period I, but three treatments of it were included in Period II: Rot. 128, with corn stover and wheat straw returned; 129, with 6 tons manure plowed down for corn and 2 tons topdressed on the wheat during the winter; and 130, with no special treatment. Corn with 6 tons manure made 5 bu/A more than without, a significant difference. Returning the straw and stover was essentially equal to the manure, but the straw application for corn is not feasible in farm practice, and with large corn crops the mechanical difficulty of seeding wheat in corn stalks often results in losses instead of gains. Here the wheat yields were not different. The alfalfa yields were about $1\frac{1}{2}$ tons higher in Rot. 128 and 129 than in 130, presumably because of the potash returned by the manure and residues.

Rot. 121, C-O-W-Cl, continued Rot. 21, and like it had lower corn yields than seem normal. Rot. 122 was the same with 6 tons manure on corn and 2 tons winter top-dressed on wheat. The corn indicated a gain of 10 bu/A for 6 tons of manure, a larger gain than is usual, which again indicates that Rot. 121 was basically inferior in some factor or factors. The mulch on the wheat produced a highly significant increase in clover hay - 960 lb/A.

When these two rotations are compared with the corresponding 3-year rotations, 111 and 112, the 3-year rotations produced significantly more corn and stover, both with and without manure. This reflects the greater nitrogen supply with a legume one year in three. In fact the 3-year rotation without manure (111) produced as much corn as the manured corn in the 4-year rotation (122).

Rot. 123, C-O-A,Cl,T-W(swcl), is the Hopkins rotation improved by using the alfalfa mixture instead of clover. The mixture produced a highly significant 3/4 ton more hay than clover in Rot. 121, and corn was a significant 5.9 bushels higher, but wheat and oats yields were not different. Again, and as in the test in Henry County (Bul. 847), the rotation has failed to justify itself.

In the 5-year rotations, there was the same comparison of treatments on the C-W-A-A-A rotation that there was with C-W-A-A in the 4-year rotation. Rot. 140 had no manure or residue, 139 had the straw and stover returned for the corn crop, and 136 received manure - 4 tons winter top-dressing on the wheat here, and 6 on corn. The wheat yields were similar in the three rotations and similar to those of the 4-year rotations. The winter-topdressing, as in the 4-year rotations, produced large increases in alfalfa - almost a ton per acre per year more than Rot. 140, but the potash furnished by the manure and residues may also be a factor here. The manure produced more alfalfa than the straw and stover. The corn yields were alike; for the only time in this series, manure plowed down has not given an increase in the corn crop. Was nitrogen, then, not the limiting factor?

If we compare Rot. 113, 129, and 136 as a group (C-W-A for 1, 2, or 3 years, manured) with Rot. 114, 130, and 140 (same, not manured) the corn yields are the same for the manured set, 71-72 bushels, but reach that figure only after three years of alfalfa in the unmanured set. It seems that for the combination of soil, climate, and cultural practices used here, some factor other than nitrogen was holding corn yields to a 71-73 bushels per acre maximum. Dr. Haynes* feels that too low a rate of planting was a major factor; potash deficiency may also be a factor.

Rot. 131 and 132, C-O-W-Cl,T-T, differ in having 6 tons manure on corn and 4 on wheat in 132, and none on 131. Here the manure produced about 10 bu/A more corn than no manure, and the same yield as Rot. 136, C-W-A-A-A plus manure. The oats yields in Rot. 131 and 132 were not different; the wheat yields in 132 were slightly higher; again the winter mulch in wheat added appreciably to the hay crop.

Rot. 133 is C-W-A,Cl,T-A,T-A,T. It produced essentially (diff. non-sig.) as much corn, wheat, and hay as the alfalfa rotation, 140. Compared to Rot. 134, C-W-Cl,T-T-T, Rot. 133 produced a trifle (non-sig.) more corn and wheat and considerably more hay (sig. 3rd year).

The Period I study of 1/5, 2/5 and 3/5 of the land in corn was repeated with alfalfa as the sod crop in Period II. Rot. 140 had 1/5 the land in corn, 3/5 in alfalfa; Rot. 137 had 2/5 of the land in alfalfa and in corn; Rot. 138 had 3/5 of the land in corn, 1/5 in alfalfa. Wheat was the small grain, and showed extraordinary differences in yield. Wheat in Rot. 140 yielded 11.3 bu/A (highly sig.) more than 137, and in Rot. 137, 6.9 bu. (sig.) more than 138. The first-year hay yields are highest in Rot. 138, next in 137, and poorest in 140, reflecting the wheat in which they were sown - the poorer the wheat, the better the hay. First year corn yielded 10.2 bu/A (highly sig.) more in Rot. 140 than in 138; 137 was intermediate. The third-year corn in 138 yielded a fourth less than the first year, and only 64% of the first year yield in Rot. 140. Considering that no nitrogen was applied anywhere in any form these decreases seem moderate.

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*Personal communication.

NITROGEN CONTENT OF THE SOILS

Table 12, Period I, and Table 13, Period II, give data on the gains and losses of nitrogen from the soil for each of these rotations. By pointing off two places, the figures for pounds of nitrogen per acre can be read as pounds of organic matter per acre 6 2/3 inches. E.g., 1530 pounds nitrogen per acre equals 15.3 tons organic matter per acre in the top soil.

The L.S.D. at 5% between nitrogen contents of the 2-year rotations was 320 pounds; of the 3-year rotations, 260 pounds; of the 4-year rotations, 220 pounds; and of the 5-year rotations, 220 pounds. The figures in general are extremely consistent and logical, as the following summary suggests:

Biennial or perennial legumes or grasses in the rotation	1936 Number rotations averaged	1936 Pounds nitrogen per acre in top soil	1950 Number rotations averaged	1950 Pounds nitrogen per acre in top soil
None; continuous row crops	3	1640	3	1560
Sweetclover catch crop only	9	2360	8	2290
1 year sod in 5 years	4	2370	1	2310
1 year sod in 4 years	6	2500	6	2410
1 year sod in 2 and 3 years	7	2740	9	2620
2 years sod in 4 or 5 years	4	2600	9	2590
3 years sod in 4 or 5 years	3	2760	2	2740

Likewise, the percent of intertilled crops in the rotation affects the nitrogen content of the soil:

Percent of intertilled crops	Number rotations avgd.	Pounds nitrogen per acre in soil 1936	Number rotations avgd.	Pounds nitrogen per acre in soil 1950
100	4	1680	3	1570
67	1	2290	0	-
60	3	2390	1	2310
50	13	2410	10	2330
50,no legume	-	-	2	2030
40	4	2510	1	2420
33	9	2790	9	2630
25	4	2510	7	2470
20	3	2690	7	2660
0	4	2670	2	2570

Systems C106 to C110 were not included in the above tables. The two rotations in 1950 with half intertilled crops but no legume (C-O and C-W) had conspicuously heavy losses of nitrogen - significantly different from the same rotations with legumes.

These nitrogen studies combine with the yields to support the principle of equilibrium. The cropping systems, whatever variants are introduced, rapidly reach or move toward a level of yield and nitrogen content of the soil, and then tend to remain there.* The period 1936 to 1950 was too short for equilibrium to be reached in many rotations.

COMPARISONS OF CROP YIELDS IN VARIOUS ROTATIONS

Tables 14 to 20 (in the Appendix) compare the yields of different crops in the different rotations in which they were grown in Period I, giving the yields, the difference in yields, and the least significant difference at the 5% or 1% point for both grain and straw or stover. The comparisons are arranged by the number of the rotation, but in such a way that the differences in grain yields are always positive. The only negative differences occur in the straw or stover yields or in comparisons with Check Group yields which are placed second in every instance, and hence lead to some negative differences. These tables are for quick reference if one wishes to know how the yield of a crop in one rotation compares with that of another. Of course, despite the number of comparisons, it does not represent all possible comparisons, which would not be feasible. The comparisons are those which are most likely to be of agro-economic interest. Tables 21 to 25 give similar data for Period II. When more years are available for comparison than those given in Tables 1 through 11, they have been used in these tables.

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*This is discussed in detail, from these rotations, with several tables, by Haynes, J. L., and Thatcher, L. E., Crop Rotation and Soil Nitrogen, Soil Sci. Soc. of Amer. Proc. 19: 324-327. 1955.

Table 12. Nitrogen Relations of Rotations, Period I, 1915-1935

Estimated soil nitrogen at start of Period I, 2530 pounds per acre

Rotation		Est. N per acre per year in crops harvested*	Nitrogen per acre 1936 sample	Gain or loss(-) nitrogen for the period	Rank in gain of N
No.	Crops				
		Lb.	Lb.	Lb.	
C1	Cont. C	40	1530	-1000	45
C2	Cont. P	16	1590	-940	44
C3	Cont. S	52	1800	-730	42
C4	Cont. O(swcl)	44	2750	220	7
C5	Cont. W(swcl)	50	2420	-110	29
1	C-Cl	48	2560	30	18
2	C-Swcl	51	2420	-110	28
3	C-S	55	1780	-750	43
4	C-Sp. W(swcl)	--	2260	-270	40
5	C-O(swcl)	60	2210	-320	41
6	C-W(swcl)	60	2320	-210	36
7	P-W(swcl)	42	2360	-170	33
8	S-W(swcl)	59	2380	-150	31
9	W-Cl	57	2760	230	4
10	W-Swcl	--	2760	230	5
11	C-W-Cl	76	2890	360	1
12	C-O-Cl	63	2650	120	11
13	C-W-Swcl	74	2620	90	13
14	C-W-A	32	2620	90	14
15	C-W-T	55	2540	10	21
16	C-B-Cl	57	2600	70	16
17	P-W-Cl	52	2810	280	3
18	P-O-Cl	48	2750	220	6
19	S-W-Cl	63	2740	210	8
20	S-P-W(swcl)	48	2290	-240	39
21	C-O-W-Cl	67	2460	-70	26
22	C-O-W-T	55	2330	-200	35
23	C(1)-C(2)-W-Cl	63	2440	-90	27
24	C-P-W-Cl	56	2520	-10	24
25	P-C-W-Cl	55	2520	-10	23
26	P-S-W-Cl	56	2550	20	20
27	C-S-W-Cl	66	2520	-10	22
28	C-O-Cl-W(swcl)	62	2390	-140	30
29	C(1)-O(swcl)-C(2)-W(swcl)	60	2300	-230	38
30	C-A(1)-A(2)-A(3)	84	2850	320	2

Table 12, continued

Rotation No.	Rotation Crops	Est. N per acre per year in crops harvested*	Nitrogen per acre 1936 sample	Gain or loss(-) nitrogen for the period	Rank in gain of N
		Lb.	Lb.	Lb.	
31	C-O-W-Cl,T-T	55	2630	100	12
32	C-W-Cl,T-T-T	53	2730	200	9
33	C(1)-C(2)-W-Cl,T-T	58	2600	70	17
34	C-P-W-Cl,T-T	54	2610	80	15
35	C(1)-C(2)-S-W-Cl	68	2470	-60	25
36	C-P-S-W-Cl	60	2340	-190	34
37	P(1)-S-P(2)-W-Cl	52	2370	-160	32
38	C(1)-C(2)-C(3)-W-Cl	64	2300	-230	37
39	C(1)-O(swcl)-C(2)-W-Cl	63	2550	20	19
40	C-O-A(1)-A(2)-A(3)	102	2710	180	10

*Based on standard analyses, not those of the crops removed.

Table 13. Nitrogen Relations of Rotations, Period II, 1936-1950

Rotation No.	Rotation Crops	Est. N per acre per year in crops harvested	Nitrogen per acre 1936 sample	Nitrogen per acre 1950 sample	Gain or loss(-) for the period N per acre	Gain or loss(-) for the period Rank in gain of N
		Lb.	Lb.	Lb.	Lb.	
C101	Cont. C	28	1530	1400	-130	29
C102	Cont. C, manure	28	1590	1530	-60	25
C103	Cont. S	46	1800	1760	-40	21
C104	Cont. O	35	2750	2620	-130	30
C105	Cont. W(vol. black medic)	42	2420	2530	110	7
C106	Cont. C(rye or ryegrass)	41	2510	1940	-570	47
C107	Cont. C(ditto + vetch)	56	2340	2130	-210	36
C108	Cont. C, manure	54	2340	2030	-310	43
C109	Cont. C	45	2430	1900	-530	46
C110	Cont. C(swcl)	48	2470	2120	-350	45
101	C-O(swcl), manure	67	2560	2320	-240	40
102	C-O(swcl), residues	42	2420	2250	-170	33
103	C-O(swcl)	56	1780	2170	390	1
104	C-O(swcl)	60	2260	2040	-220	39
105	C-O	51	2210	1940	-270	41
106	C-W	49	2320	2110	-210	37
107	C-W(swcl)	59	2360	2190	-170	34
108	C-W(swcl), residues	40	2380	2350	-30	18
109	C-W(swcl), manure	72	2760	2540	-220	38
110	C-W(swcl)	64	2760	2450	-310	44
111	C-W-Cl	70	2890	2610	-280	42
112	C-W-Cl, manure	77	2650	2690	40	13
113	C-W-A, manure	91	2620	2700	80	10
114	C-W-A	83	2620	2560	-60	24
115	C-W-T	52	2540	2480	-60	26
116						
117	C-W-A,Cl,T	76	2810	2650	-160	32
118	C-W-Swcl	47	2750	2720	-30	20
119	C-O-A, residues	73	2740	2720	-20	15
120	C-O-A	83	2290	2410	120	6
121	C-O-W-Cl	59	2460	2320	-140	31
122	C-O-W-Cl, manure	65	2330	2460	130	4
123	C-O-A,Cl,T-W(swcl)	67	2440	2390	-50	23
124	C-S(hay)-W-Cl	72	2520	2340	-180	35
125	C-S(combined)-W-Cl	67	2520	2500	-20	16

Table 13, continued

Rotation No.	Rotation Crops	Est. N per acre per year in crops harvested	Nitrogen per acre 1936 sample Lb.	Nitrogen per acre 1950 sample Lb.	Gain or loss(-) for the period N per acre Lb.	Gain or loss(-) for the period Rank in gain of N
126	C-S(binder)-W-Cl	65	2550	2450	-100	28
127						
128	C-W-A(1)-A(2), residues	92	2390	2490	100	8
129	C-W-A(1)-A(2), manure	109	2300	2470	170	3
130	C-W-A(1)-A(2)	91	2850	2820	-30	19
131	C-O-W-Cl,T-T	54	2630	2590	-40	22
132	C-O-W-Cl,T-T,manure	62	2730	2710	-20	17
133	C-W-A,Cl,T-A,T-A,T	86	2600	2660	60	11
134	C-W-Cl,T-T-T	65	2610	2510	-100	27
135						
136	C-W-A(1)-A(2),A(3), manure	123	2340	2640	300	2
137	C(1)-C(2)-W-A(1)-A(2)	94	2370	2420	50	12
138	C(1)-C(2)-C(3)-W-A	77	2300	2310	10	14
139	C-W-A(1)-A(2)-A(3), residues	100	2550	2670	120	5
140	C-W-A(1)-A(2)-A(3)	98	2710	2810	100	9

SUMMARY: PRINCIPLES OF CROP ROTATION IN OHIO

Summarizing the preceding discussion and combining with conclusions from Ohio Agr. Expt. Station Bulletins 839 and 847, some principles of crop rotation on silt loam, silty clay loam and clay soils in Ohio may be stated.

In this discussion we have used "H" or "hay" rather than any specific legume or mixture. This hay in practice should be the most desirable mixture for the particular soil and the use for which planned. In Ohio it should include at least one legume, partly alfalfa if the soil permits, and necessarily alfalfa if profitable hay is to be had for more than one year, and one grass, timothy, smooth bromegrass, or orchardgrass, again depending on the situation. Because the Ohio soil-climate combination is not always favorable to alfalfa and because such a large percent of our meadows are sown in wheat, we favor the alfalfa, clover, grass mixture rather than alfalfa, grass in most Ohio situations.*

Is rotation necessary? Recently, strident voices have been raised declaring that rotations are out-of-date, unnecessary. The alternative, of course, is continuous cropping to a high value crop or crops, using heavy fertilizer applications. How feasible is this?

These experiments, unfortunately, do not throw much direct light on this problem. In company with practically all other rotation experiments of this period in the United States, they were planned on the tacit assumption that nitrogen could not profitably be purchased for field crops. Some belated attempts (Bul. 847) were made to apply enough fertilizer for continuous corn, but ordinary farm practice has already gone ahead of them.

Rotation is usually desirable when both grain and roughage for livestock are to be produced on one farm. Rotation permits one not to "put all his eggs in one basket". Insects, plant diseases, and weeds may compel rotation and have often done so, but chemical methods of controlling these pests are steadily reducing that compulsion.

For soil conservation the first situation in which rotation is essential is on sloping lands. Any overcropped soil can be reclaimed, if the soil is still there; but with our rainfall pattern, continuous cultivated crops on sloping soils are an invitation to land ruin. On considerably sloping lands, 6 to 8 percent slopes and above, the continuous cropping should be of sod crops. If these can, like some English pastures, be fertilized so as to remain unplowed for 400 years, so much the better.

For strip cropping on steep slopes in Ohio it is hard to find a rotation better than C-W-H-H. By proper selection of the stripped areas, half the land can be pastured after the wheat is harvested without fencing the separate strips, which avoids one of the serious objections to strip cropping. Certainly, one year in four is as often as one can permit intertilled crops on 5 to 6 percent slopes.

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*See Handbook of Experiments in Agronomy, Ohio Agr. Exp. Sta. Special Cir. 53, 1938, Table 52, page 44.

On the broad, nearly level areas which in Ohio and the Midwest produce most of the grain, continuous corn or grain is feasible for a long time - indefinitely on some soils. The unanswered question concerning rotation versus continuous cropping is the effect of continuous cropping on the physical structure of heavy soils. Without heavy fertilization, we have abundant evidence of the disastrous effects of continuous cropping on heavy soils. It is claimed that by returning with abundant nitrogen the grain crop residues from heavy fertilization this physical deterioration can be prevented. We do not, today, have evidence sufficient to prove or disprove this claim.

Experimentally, so far in Ohio, we have not produced in continuous cropping as large corn yields as in a rotation with alfalfa, red clover, or sweetclover, but long-time heavy fertilization tests are lacking. The present tentative answer would be that the more clay there is in the soil, the less feasible is continuous corn over a 10- to 100-year period. On some fine sands, silts, and silt loams with a low proportion of clay it seems that continuous corn is entirely feasible. In the thought of the present writers, it is not feasible on clays or heavy silty clay loams.

However, continuous corn can be produced on these soils as long as it is economically profitable without permanent injury, provided the soil itself stays in place. The physical condition of soils injured by over-cropping to row crops can be brought back by greater use of the same grass-legume mixtures which would have prevented their breakdown.

Rotations for Ohio farms. All successful rotations in these experiments follow the general order cultivated crop--small grain-hay or forage. Any one of these components may continue from part of a year to several years, but always in that order. Attempts to go direct from cultivated crop to forage crop have been unsuccessful except for cover and green manure use, where frequent mediocre results can be tolerated. New methods and equipment may yet solve this problem.

The most common rotation in Ohio a few years ago was C-W-H, and it is still a good one. There is no evidence in Ohio experiments that there is any advantage in soil conservation or crop production on level land for C-W-H-H over C-W-H. C-O-H will give better alfalfa than C-W-H, and for a dairy-hog farm using considerable hay, the rotation C-C-C-O-H-H will give as much hay (or more, since second-year alfalfa usually outyields first-year) as two rounds of C-O-H. In effect, C-C-C-O-H-H substitutes a corn crop for an cats crop. It also saves the expense of one forage seeding.

Soybeans are now generally included in grain rotations in Ohio, though their cash return per acre is practically always less than that of corn. Corn yields per acre are generally about three times those of soybeans, so that an equal acre gross return would require a soybean price per bushel nearly three times that of corn, which has not been true recently. However, soys can be planted later and harvested earlier than corn. Wheat follows soys better than corn (Bul. 847). The labor distribution with some land in soybeans is better than with all corn. Soybeans should always follow corn in the rotation, at least they should not follow sod crops, since corn is more profitable there. Corn does well after soybeans, as do soybeans again - the objection is too many depleting crops. Soybeans are not a soil-building crop.

If we assume that some forage sod crops are necessary in the rotation, we do not know how often they must appear. Tentatively, it seems that with sufficient fertilizer, sod crops one year in four or perhaps five may maintain even a moderately heavy soil in good condition. This would include such rotations as C-S-W-H, C-C-S-W-H, C-C-W-H, etc. This was not a sufficiently high percentage of sod crop for highest corn yields in these Ohio experiments, but they received only small amounts of fertilizer.

The "Hopkins rotation", C-O-A(swcl), did not give sufficiently better results in corn and small grain yields than simpler rotations to justify it.

If wheat and oats are in the same rotation, oats should precede wheat, as dictated by every consideration of seed-time and harvest.

The use of 2 to 4 tons per acre of manure, the strawiest available, on wheat any time before sowing legumes is one of the best ways to improve legume stands and yields after wheat.

Sweetclover is unexcelled as a catch crop to accumulate nitrogen after a small grain crop. Sweetclover, in the C-W(swcl) or C-O(swcl) rotation, will produce as much corn as 6 tons of manure per acre or commercial nitrogen up to 100 pounds per acre.

At present prices of nitrogen, we cannot afford to use an entire crop year just to fix nitrogen from the air, but the livestock producer, by growing large crops of legume hay, feeding it profitably and hauling out the manure, can increase his grain yields more economically than anyone who depends entirely on the fertilizer sack.

Table 14. Comparative Yields of Corn

Period I, Fry Farm rotations

Rotations compared		Period	Grain Bushels per acre			L.S.D.		Stover Pounds per acre			L.S.D.	
(a)	(b)	years	(a)	(b)	(a-b)	5%	1%	(a)	(b)	(a-b)	5%	1%
2	1	20	74.0	71.9	2.1	4.2	-	3240	3250	-10	160	-
3	C1	16	55.7	27.0	28.7	-	6.6	2540	1880	660	-	345
4	5	13	67.8	65.8	2.0	3.5	-	2760	2740	20	340	-
5	6	19	66.4	64.1	2.3	1.8	-	2940	2910	30	155	-
12	5	18	71.9	66.1	5.8	7.9	-	3220	2920	300	300	-
12	15	18	71.9	67.2	4.7	3.8	-	3220	3100	120	235	-
12	16	15	72.1	64.4	7.7	6.7	-	3280	3100	180	230	-
12	23C(1)	17	73.0	68.3	4.7	6.7	-	3270	3260	10	240	-
12	38C(1)	17	73.0	69.1	3.9	5.0	-	3270	3220	50	235	-
13	6	18	75.9	64.1	11.8	-	9.5	3480	2900	580	-	335
13	12	18	75.9	71.9	4.0	5.6	-	3480	3220	260	335	-
13	15	18	75.9	67.2	8.7	-	4.7	3480	3100	380	-	340
14	12	18	77.0	71.9	5.1	5.9	-	3610	3220	390	345	-
14	13	18	77.0	75.9	1.1	3.6	-	3610	3480	130	190	-
14	15	18	77.0	67.2	9.8	-	7.1	3610	3100	510	-	340
14	30	17	78.6	78.3	0.3	6.1	-	3670	3490	180	320	-
22	15	17	72.0	68.8	3.2	7.5	-	3320	3160	160	300	-
23C(2)	38C(2)	16	59.8	56.5	3.3	8.6	-	2670	2680	-10	280	-
24	23C(1)	17	72.6	68.3	4.3	-	4.1	3330	3260	70	165	-
24	27	17	72.6	68.4	4.2	4.2	-	3340	3110	230	235	-
24	25	16	71.2	62.2	9.0	9.0	-	3330	2880	450	370	-
25	23C(2)	16	62.2	56.5	5.7	4.0	-	2880	2680	200	-	185
27	23C(1)	17	68.4	68.3	0.1	4.1	-	3110	3260	-150	155	-
28	12	17	75.3	73.0	2.3	9.9	-	3220	3270	-50	395	-
29C(1)	39C(1)	16	72.1	71.4	0.7	7.4	-	2430	3470	-1040	-	835
32	31	16	75.7	69.3	6.4	-	5.0	3720	3280	440	-	290
32	33C(1)	16	75.7	71.6	4.1	3.4	-	3720	3370	350	275	-
32	38C(1)	16	75.7	67.7	8.0	7.0	-	3720	3250	470	380	-
33C(1)	31	16	71.6	69.3	2.3	3.0	-	3370	3280	90	270	-
33C(1)	38C(1)	16	71.6	67.7	3.9	6.7	-	3370	3250	120	315	-
33C(2)	38C(2)	15	63.0	60.2	2.8	3.5	-	2900	3200	220	245	-
34	31	16	73.5	69.3	4.2	-	3.5	3570	3280	290	255	-
34	33C(1)	16	73.5	71.6	1.9	3.3	-	3570	3370	200	245	-
36	35C(1)	16	74.3	70.2	4.1	3.6	-	3620	3460	160	155	-
38C(1)	23C(1)	17	69.1	68.3	0.8	4.8	-	3220	3260	-40	165	-
38C(1)	38C(2)	15	67.7	60.2	7.5	10.5	-	3200	2680	520	-	400
38C(1)	38C(3)	14	67.7	61.1	6.6	10.0	-	3240	2710	530	-	500
38C(3)	38C(2)	14	61.1	59.5	1.6	7.6	-	2710	2700	10	370	-
39C(2)	29C(2)	14	71.7	57.9	13.8	-	7.4	3200	2560	640	-	310
40	14	16	81.4	77.9	3.5	7.2	-	3700	3720	-20	425	-

Table 14, continued

Rotations compared		Period	Grain Bushels per acre			L.S.D.		Stover Pounds per acre			L.S.D.	
(a)	(b)	years	(a)	(b)	(a-b)	5%	1%	(a)	(b)	(a-b)	5%	1%
40	30	16	81.4	77.4	4.0	5.5	-	3700	3520	180	335	-
40	32	16	81.4	75.7	5.7	4.9	-	3700	3720	-20	300	-
C1	Check	20	29.2	70.8	-41.6	-	11.7	1910	3230	-1320	-	395
1	Check	20	71.9	70.8	1.1	2.3	-	3250	3230	20	125	-
2	Check	20	74.0	70.8	3.2	3.8	-	3240	3230	10	160	-
3	Check	16	55.7	71.5	-15.8	-	10.3	2540	3340	-800	-	255
5	Check	20	66.0	70.8	-4.8	4.5	-	2960	3230	-270	-	250
6	Check	19	64.1	71.5	-7.4	-	7.4	2910	3260	-350	-	320
12	Check	18	71.9	71.5	0.4	4.8	-	3220	3260	-40	220	-
13	Check	18	75.9	71.5	4.4	4.7	-	3480	3260	230	280	-
14	Check	18	77.0	71.5	5.5	4.5	-	3610	3260	350	275	-
15	Check	18	67.2	71.5	-4.3	4.8	-	3100	3260	-160	330	-
16	Check	15	64.4	72.0	-7.6	5.9	-	3330	3100	230	175	-
22	Check	17	72.0	72.6	-0.6	3.8	-	3320	3300	20	210	-
23C(1)	Check	17	68.3	72.6	-4.3	4.2	-	3260	3300	-40	360	-
24	Check	17	72.6	72.6	0.0	3.6	-	3340	3300	40	215	-
27	Check	17	68.4	72.6	-4.2	3.9	-	3110	3300	-190	230	-
28	Check	17	75.3	72.6	2.7	6.1	-	3220	3300	-80	250	-
30	Check	17	78.3	72.6	5.7	5.5	-	3490	3300	190	275	-
31	Check	16	69.3	71.5	-2.2	4.3	-	3280	3340	-60	195	-
33C(1)	Check	16	71.6	71.5	0.1	4.4	-	3370	3340	30	210	-
34	Check	16	73.5	71.5	2.0	3.5	-	3570	3340	230	170	-
40	Check	16	81.4	71.5	9.9	-	6.7	3700	3340	360	-	275

Table 15. Comparative Yields of Wheat

Period I, Fry Farm rotations

Rotations compared		Period	Grain Bushels per acre			L.S.D.		Straw Pounds per acre			L.S.D.	
(a)	(b)	years	(a)	(b)	(a-b)	5%	1%	(a)	(b)	(a-b)	5%	1%
C5	6	18	35.6	30.7	4.9	3.9	-	3240	2720	520	515	-
C5	7	18	35.6	35.1	0.5	3.0	-	3240	3110	130	415	-
C5	8	18	35.6	27.4	8.2	-	4.9	3240	2360	880	-	570
6	8	18	30.7	27.4	3.3	3.1	-	2720	2360	360	-	335
7	6	18	35.1	30.7	4.4	-	3.4	3110	2720	390	315	-
7	8	18	35.1	27.4	7.7	-	5.5	3110	2360	750	-	455
7	20	16	35.3	34.1	1.2	5.6	-	3140	2860	280	375	-
10	9	12	39.5	38.5	1.0	1.8	-	4050	4130	-80	245	-
13	6	17	37.0	31.0	6.0	-	4.8	3380	2940	440	645	-
13	15	17	37.0	33.7	3.3	-	2.2	3380	3250	130	215	-
14	13	17	37.7	37.0	0.7	1.8	-	3680	3380	300	235	-
14	15	17	37.7	33.7	4.0	-	2.5	3680	3250	425	-	220
17	7	17	40.0	35.4	4.6	3.4	-	3760	3170	590	-	485
17	19	17	40.0	37.4	2.6	4.2	-	3760	3330	430	370	-
17	25	15	41.3	36.3	5.0	3.8	-	3830	3390	440	365	-
17	26	15	41.3	34.0	7.3	-	5.5	3830	3010	820	-	400
17	37	13	41.8	40.9	0.9	3.0	-	3850	3770	80	405	-
19	8	17	37.4	27.6	9.8	-	3.8	3330	2410	920	-	355
19	20	15	37.5	34.9	2.6	5.8	-	3320	2940	380	570	-
22	15	15	36.5	34.0	2.5	4.0	-	3600	3300	300	590	-
23	27	15	33.5	30.7	2.8	3.3	-	3600	2680	920	550	-
23	38	14	34.2	33.9	0.3	1.8	-	3610	3020	590	570	-
24	23	15	39.4	33.5	5.9	4.7	-	3820	3600	220	415	-
24	25	15	39.4	36.3	3.1	4.7	-	3820	3390	430	405	-
24	27	15	39.4	30.7	8.7	-	8.2	3820	2680	1140	-	560
25	23	15	36.3	33.5	2.8	-	2.2	3390	3600	-210	535	-
25	26	15	36.3	34.0	2.3	3.3	-	3390	3010	380	365	-
26	23	15	34.0	33.5	0.5	3.2	-	3010	3600	-590	515	-
26	27	15	34.0	30.7	3.3	-	2.2	3010	2680	330	-	255
31	32	14	38.9	37.3	1.6	3.9	-	3820	3600	220	370	-
31	33	14	38.9	31.8	7.1	-	5.0	3820	3040	780	-	540
31	34	14	38.9	38.6	0.3	5.6	-	3820	3890	-70	565	-
32	33	14	37.3	31.8	5.5	-	5.4	3600	3040	560	-	330
32	38	14	37.3	33.9	3.4	3.7	-	3600	3020	580	-	565
34	33	14	38.6	31.8	6.8	-	6.1	3890	3040	850	-	620
36	35	13	35.8	32.7	3.1	2.9	-	3280	3030	150	270	-
37	26	13	40.9	33.8	7.1	5.2	-	3770	3000	770	-	675
38	33	14	33.9	31.8	2.1	3.1	-	3020	3040	-20	-	360
39	29	13	35.6	31.9	3.7	4.7	-	3540	3000	540	-	435

Table 15, continued

Rotations compared		Period	Grain Bushels per acre			L.S.D.		Straw Pounds per acre			L.S.D.	
(a)	(b)	years	(a)	(b)	(a-b)	5%	1%	(a)	(b)	(a-b)	5%	1%
C5	Check	19	36.0	36.4	-0.4	2.7	-	3250	3480	-230	300	-
6	Check	18	30.7	35.7	-5.0	-	4.2	2720	3460	-740	-	470
9	Check	15	35.6	35.3	0.3	3.3	-	3840	3420	420	-	
10	Check	12	39.5	36.8	2.7	3.6	-	4050	3600	450	520	-
17	Check	17	40.0	36.1	3.9	3.4	-	3760	3540	220	220	-
22	Check	15	36.5	36.9	-0.4	2.8	-	3600	3620	-20	180	-
23	Check	15	33.5	36.9	-3.4	3.3	-	3600	3620	-20	360	-
24	Check	15	39.4	36.9	2.5	3.5	-	3820	3620	200	190	-
25	Check	15	36.3	36.9	-0.6	3.8	-	3390	3620	-230	330	-
27	Check	15	30.7	36.9	-6.2	-	5.0	2680	3620	-940	-	395
28	Check	14	39.9	37.1	2.8	3.8	-	4150	3640	510	470	-

Table 16. Comparative Yields of Oats

Period I, Fry Farm Rotations

Rotations Compared (a)	(b)	Period years	Grain Bushels per acre (a)	(b)	(a-b)	L.S.D. 5%	1%	Straw Pounds per acre (a)	(b)	(a-b)	L.S.D. 5%	1%
5	C4	19	51.4	49.5	1.9	4.3	-	2100	2470	-370	-	288
12	5	17	54.3	49.4	4.9	4.9	-	2525	2100	430	420	-
18	12	17	54.6	54.3	0.3	3.6	-	2420	2520	-100	245	-
28	12	16	57.9	56.1	1.8	5.1	-	2450	2560	-110	550	-
39	29	15	59.6	55.8	3.8	6.3	-	2770	2270	500	-	260
C4	Check	20	49.3	59.2	-9.9	-	5.5	2460	2450	10	220	-
5	Check	19	51.4	59.7	-8.3	-	6.5	2100	2460	-360	-	220
12	Check	17	54.3	57.6	-3.3	3.7	-	2520	2470	50	350	-
18	Check	17	54.6	57.6	-3.0	3.9	-	2420	2470	-50	345	-
28	Check	16	57.9	59.6	-1.7	2.3	-	2450	2520	-70	275	-

Table 17. Comparative Yields of Potatoes

Period I, Fry Farm Rotations

Rotations compared (a)	(b)	Period years	Potatoes Bushels per acre (a)	(b)	(a-b)	L.S.D. 5%	1%
7	20	17	152	129	23	18	-
17	7	18	173	149	24	17	-
18	17	18	180	173	7	16	-
25	17	17	197	174	23	18	-
25	24	16	198	137	61	-	33
25	26	17	197	189	8	12	-
26	17	17	189	174	15	21	-
26	37P(1)	16	191	178	13	18	-
37P(1)	17	16	178	174	4	25	-
37P(1)	37P(2)	14	188	126	62	-	34
C2	Check	20	78	175	-97	-	28
17	Check	18	173	180	-7	17	-
18	Check	18	180	180	0	10	-
25	Check	17	197	183	14	-	9
26	Check	17	189	183	6	10	-

Table 18. Comparative Yields of Soybeans

Period I, Fry Farm rotations

Rotations compared (a)	(b)	Period years	Grain Bushels per acre (a)	(b)	(a-b)	L.S.D. 5%	1%	Straw Pounds per acre (a)	(b)	(a-b)	L.S.D. 5%	1%
3	C3	16	18.5	13.4	5.1	-	3.3	1830	1600	230	350	-
19	8	18	21.6	19.8	1.8	2.4	-	2080	2110	-30	250	-
19	20	15	23.0	23.0	0.0	1.5	-	2090	1950	140	135	-
26	27	16	22.4	21.5	0.9	1.9	-	2580	2340	240	265	-
37	26	15	24.6	22.6	2.0	2.3	-	2200	2540	-340	375	-
C3	Check	20	13.1	20.1	-7.0	-	4.5	1660	2430	-770	-	470
3	Check	16	18.5	22.0	-3.5	2.9	-	1830	2460	-630	-	385
20	Check	18	21.6	20.9	0.7	2.7	-	2000	2440	-440	-	365

Table 19. Comparative Yields of Clover Hay

Period I, Fry Farm rotations

Rotations compared (a)	(b)	Period years	Hay Pounds per acre (a)	(b)	(a-b)	L.S.D. 5%	1%
12	23	17	3780	3570	210	750	-
12	28	15	3780	3530	250	480	-
12	38	17	3780	3640	140	885	-
16	12	13	3770	3630	140	815	-
17	19	16	3830	3690	140	265	-
17	25	14	3510	3400	110	425	-
17	26	14	3510	3480	30	495	-
18	12	16	3990	3900	90	550	-
18	17	16	3990	3830	160	515	-
23	25	14	3460	3400	60	235	-
23	27	14	3460	3000	460	-	355
24	23	14	3540	3460	80	230	-
24	25	14	3540	3400	140	260	-
24	27	14	3540	3000	540	-	370
26	23	14	3480	3460	20	205	-
26	25	14	3480	3400	80	240	-
26	27	14	3480	3000	480	-	270
36	35	12	3680	3060	620	-	340
37	17	12	3840	3550	290	550	-
37	26	12	3840	3500	340	435	-
38	23	17	3640	3570	70	350	-
9	Check	14	3350	3840	-490	1015	-
12	Check	16	3900	3530	370	765	-
17	Check	16	3830	3530	300	390	-
23	Check	14	3460	3340	120	180	-
24	Check	14	3540	3340	200	220	-
25	Check	14	3400	3340	60	225	-
26	Check	14	3480	3340	140	160	-
27	Check	14	3000	3340	-340	-	215
28	Check	15	3530	3400	130	585	-

Table 20. Comparative Yields of Mixed Hay

Period I, Fry Farm rotations

Rotations compared (a)	(b)	Period years	Pounds per acre (a)	(b)	(a-b)	L.S.D. 5%	1%
			Clover-timothy 1st. yr. meadow				
31	33	13	3970	3740	230	580	-
34	31	13	4100	3970	130	590	-
34	33	13	4100	3740	360	370	-
			Timothy 2nd. yr. meadow				
33	31	12	4180	3600	580	670	-
34	31	12	4930	3600	1330	-	1170
34	33	12	4930	4180	750	890	-

Table 21. Comparative Yields of Corn

Period II, Fry Farm rotations

Rotations compared (a)	(b)	Period years	Grain Bushels per acre (a)	(b)	(a-b)	L.S.D. 5%	1%	Stover Pounds per acre (a)	(b)	(a-b)	L.S.D. 5%	1%
C102	C101	15	22.2	12.1	10.1	-	4.4	1620	1340	280	-	120
C107	C106	14	42.1	28.7	13.4	-	9.6	2490	1980	510	-	295
C107	C108	14	42.1	41.1	1.1	5.0	-	2490	2380	110	240	-
C107	C109	14	42.1	33.0	9.1	-	8.8	2490	2110	380	-	340
C107	C110	14	42.1	36.6	5.5	4.7	-	2490	2120	370	280	-
C108	C106	14	41.0	28.7	12.3	-	7.5	2380	1980	400	-	200
C108	C109	14	41.0	33.0	8.0	-	4.2	2380	2110	270	-	230
C108	C110	14	41.0	36.6	4.4	4.3	-	2380	2120	260	-	255
C109	C106	14	33.0	28.7	4.3	3.5	-	2110	1980	130	160	-
C110	C106	14	36.6	28.7	7.9	-	7.2	2120	1980	140	180	-
C110	C109	14	36.6	33.0	3.6	3.3	-	2120	2110	10	130	-
101	103	14	67.0	56.7	10.3	-	5.6	3560	2940	620	-	390
101	104	14	67.0	59.6	7.4	-	3.2	3560	3090	470	-	275
101	105	14	67.0	47.5	19.5	-	3.7	3560	2540	1020	-	310
102	101	14	68.3	67.0	1.3	-	2.1	-	-	-	-	-
102	103	14	68.3	56.7	11.6	-	4.8	-	-	-	-	-
102	104	14	68.3	59.6	8.7	-	3.6	-	-	-	-	-
102	105	14	68.3	47.5	20.8	-	4.8	-	-	-	-	-
103	105	14	56.7	47.5	9.2	-	7.4	2940	2540	400	-	320
104	103	14	59.6	56.7	2.9	2.7	-	3090	2940	150	145	-
104	105	14	59.6	47.5	12.1	-	5.2	3090	2540	550	-	220
107	106	14	60.4	47.0	13.4	-	6.7	3190	2580	610	-	335
108	106	14	64.5	47.0	17.5	-	8.7	-	-	-	-	-
108	107	14	64.5	60.4	4.1	-	3.9	-	-	-	-	-
109	106	14	67.7	47.0	20.7	-	7.0	3660	2580	1080	-	415
109	107	14	67.7	60.4	7.3	-	4.0	3660	3190	470	-	305
109	108	14	67.7	64.5	3.2	3.1	-	-	-	-	-	-
109	110	14	67.7	64.9	2.8	2.9	-	3660	3410	250	-	210
110	106	14	64.9	47.0	17.9	-	7.1	3410	2570	840	-	395
110	107	14	64.9	60.4	4.5	-	4.5	3410	3190	220	-	215
110	108	14	64.9	64.5	0.4	2.8	-	-	-	-	-	-
111	114	13	67.8	66.8	1.0	3.6	-	3620	3520	100	275	-
111	115	13	67.8	59.9	7.9	7.0	-	3620	3175	445	360	-
111	117	13	67.8	65.0	2.8	4.7	-	3620	3510	110	255	-
111	120	13	67.8	63.7	4.1	6.7	-	3620	3320	300	335	-
111	121	12	66.7	56.8	9.9	-	7.9	3620	2940	680	-	420
111	123	12	66.7	62.7	4.0	5.0	-	3620	3230	390	300	-
111	131	12	66.7	61.6	5.1	6.7	-	3620	3240	380	375	-
112	111	13	73.2	67.8	5.4	-	3.2	3900	3620	280	-	240
112	113	13	73.2	71.7	1.5	3.0	-	3900	3900	0	135	-
112	122	12	72.4	66.8	5.6	4.7	-	3910	3360	550	-	420

Table 21, continued

Rotations compared		Period	Grain Bushels per acre			L.S.D.		Stover Pounds per acre			L.S.D.	
(a)	(b)	years	(a)	(b)	(a-b)	5%	1%	(a)	(b)	(a-b)	5%	1%
112	132	12	72.4	71.7	0.7	4.0	-	3910	3860	50	410	-
113	109	13	71.7	67.8	3.9	3.0	-	3900	3700	200	285	-
113	111	13	71.7	67.8	3.9	3.2	-	3900	3620	280	265	-
113	114	13	71.7	66.8	4.9	4.7	-	3900	3520	380	-	360
113	129	12	71.2	70.7	0.5	4.7	-	3700	3920	-220	500	-
114	107	13	66.8	59.6	7.2	5.5	-	3520	3150	370	375	-
114	115	13	66.8	59.9	6.9	6.3	-	3520	3180	340	260	-
114	117	13	66.8	65.0	1.8	4.9	-	3520	3510	5	260	-
114	120	13	66.8	63.7	3.1	8.0	-	3520	3320	200	440	-
114	130	12	66.1	66.1	0	6.7	-	3540	3380	160	530	-
114	135	12	66.1	63.8	2.3	7.3	-	3540	3430	110	280	-
117	115	13	65.0	59.9	5.1	5.6	-	3510	3180	330	370	-
118	107	13	67.9	59.6	8.3	-	6.1	3590	3150	440	-	350
118	111	13	67.9	67.8	0.1	3.3	-	3590	3620	-30	235	-
118	114	13	67.9	66.8	1.1	3.8	-	3590	3520	70	265	-
119	102	13	69.4	68.8	0.6	5.6	-	-	-	-	-	-
119	111	13	69.4	67.8	1.6	6.0	-	-	-	-	-	-
119	120	13	69.4	63.7	5.7	5.2	-	-	-	-	-	-
120	104	13	63.7	60.0	3.7	8.2	-	3320	3120	200	410	-
122	121	12	66.8	56.8	10.0	-	4.1	3360	2940	420	-	195
123	121	12	62.7	56.8	5.9	4.5	-	3230	2940	290	-	175
124	121	12	63.1	56.8	6.3	-	4.1	3160	2940	220	180	-
125	121	12	65.7	56.8	8.9	-	5.6	3290	2940	350	-	225
125	124	12	65.7	63.1	2.6	4.6	-	3290	3160	130	155	-
125	126	12	65.7	64.4	1.3	4.2	-	3290	3320	-30	130	-
126	121	12	64.4	56.8	7.6	-	4.2	3320	2940	380	-	365
126	124	12	64.4	63.1	1.3	2.4	-	3320	3160	160	180	-
128	119	12	70.0	67.8	2.2	5.1	-	-	-	-	-	-
128	121	12	70.0	56.8	13.2	-	9.7	-	-	-	-	-
128	127	12	70.0	67.5	2.5	3.9	-	-	-	-	-	-
128	130	12	70.0	66.1	3.9	3.7	-	-	-	-	-	-
129	121	12	71.2	56.8	14.4	-	12.3	3700	2940	760	560	-
129	122	12	71.2	66.8	4.4	6.9	-	3700	3360	340	555	-
129	128	12	71.2	70.0	1.2	3.7	-	-	-	-	-	-
129	130	12	71.2	66.1	5.1	-	4.0	3700	3380	320	-	235
130	121	12	66.1	56.8	9.3	8.2	-	3380	2940	440	515	-
131	121	12	61.6	56.8	4.8	4.7	-	3240	2940	300	235	-
131	138(2)	11	61.5	58.6	2.9	10.0	-	3190	2840	250	445	-
131	138(3)	10	62.1	46.0	16.1	-	14.6	3180	2610	570	480	-
132	131	12	71.7	61.6	10.1	-	7.4	3860	3240	620	-	455
132	122	12	71.7	66.8	4.9	4.5	-	3860	3360	500	-	390
133	117	12	70.3	63.3	7.0	-	6.6	3840	3480	460	-	310
133	131	12	70.3	61.6	8.7	6.6	-	3940	3240	700	-	605
133	134	12	70.3	66.4	3.9	5.0	-	3940	3610	330	-	290
134	115	12	66.4	58.7	7.7	5.4	-	3610	3170	440	-	430

Table 21, continued

Rotations compared		Period	Grain Bushels per acre			L.S.D.		Stover Pounds per acre			L.S.D.	
(a)	(b)	years	(a)	(b)	(a-b)	5%	1%	(a)	(b)	(a-b)	5%	1%
134	131	12	66.4	61.6	4.8	4.0	-	3430	3240	190	315	-
135	116	12	63.8	61.1	2.7	6.2	-	3270	3250	20	260	-
135	131	12	63.8	61.6	2.2	4.2	-	3430	3240	190	315	-
136	113	12	72.3	70.7	1.6	3.0	-	4140	3920	210	300	-
136	129	12	72.3	71.2	1.1	5.4	-	4140	3700	440	430	-
136	131	12	72.3	61.6	10.7	-	9.6	4140	3240	900	-	710
136	132	12	72.3	71.7	0.6	3.9	-	4140	3860	280	430	-
137(1)	131	12	68.5	61.6	6.9	6.9	-	3660	3240	420	425	-
137(2)	131	11	64.2	61.5	2.7	10.3	-	3210	3190	20	525	-
127(1)	137(2)	11	68.5	64.2	4.3	5.5	-	3590	3210	380	325	-
137(1)	138(1)	12	68.5	62.5	6.0	-	5.5	3660	3340	320	255	-
137(2)	138(2)	11	64.2	58.6	7.6	-	3.8	3210	2840	370	-	235
138(1)	131	12	62.5	61.6	0.9	6.7	-	3340	3240	100	320	-
138(1)	138(2)	11	62.3	58.6	3.7	8.0	-	3280	2840	440	-	435
138(1)	138(3)	10	61.8	46.0	15.8	11.7	-	3180	2610	570	465	-
138(2)	138(3)	10	57.9	46.0	11.9	-	9.5	2740	2610	130	265	-
139	119	12	73.9	67.8	6.1	5.3	-	-	-	-	-	-
139	128	12	73.9	70.0	3.9	4.9	-	-	-	-	-	-
139	131	12	73.9	61.6	12.3	-	12.0	-	-	-	-	-
139	136	12	73.9	72.3	1.6	2.9	-	-	-	-	-	-
139	140	12	73.9	72.7	1.2	2.0	-	-	-	-	-	-
140	114	12	72.7	66.1	6.6	4.9	-	3840	3540	300	200	-
140	116	12	72.7	61.1	11.6	-	5.9	3840	3250	590	-	295
140	130	12	72.7	66.1	6.6	-	4.9	3840	3380	460	445	-
140	131	12	72.7	61.6	11.1	-	8.4	3840	3240	605	-	540
140	133	12	72.7	70.3	2.4	3.8	-	3840	3940	-100	105	-
140	134	12	72.7	66.4	6.3	6.9	-	3840	3610	230	210	-
140	136	12	72.7	72.3	0.4	3.2	-	3840	4140	-300	-	245
140	137(1)	12	72.7	68.5	4.2	4.4	-	3840	3660	180	145	-
140	138(1)	12	72.7	62.5	10.2	-	7.4	3840	3340	505	-	330
101	Check	14	67.0	65.7	1.3	5.1	-	3560	3390	170	345	-
102	Check	14	68.3	65.7	2.6	4.6	-	-	-	-	-	-
104	Check	14	59.6	65.7	-6.1	4.6	-	3090	3390	-300	315	-
106	Check	14	47.0	65.7	-18.7	-	5.8	2580	3390	-810	-	340
108	Check	14	64.5	65.7	-1.2	4.6	-	-	-	-	-	-
109	Check	14	67.7	65.7	2.0	3.9	-	3660	3390	270	270	-
111	Check	13	67.8	65.4	2.4	2.6	-	3620	3410	210	180	-
114	Check	13	66.8	65.4	1.4	3.1	-	3520	3410	110	185	-
115	Check	13	59.9	65.4	-5.5	5.5	-	3180	3410	-230	260	-
117	Check	13	65.0	65.4	-0.5	3.7	-	3510	3410	100	225	-

Table 22. Comparative Yields of Wheat

Period II, Fry-Farm rotations

Rotations compared (a)	(b)	Period years	Grain Bushels per acre (a)	(b)	(a-b)	L.S.D. 5%	1%	Straw Pounds per acre (a)	(b)	(a-b)	L.S.D. 5%	1%
107	106	14	29.0	24.2	4.8	-	4.3	2390	1820	570	-	430
108	106	14	31.0	24.2	6.8	-	4.7	-	-	-	-	-
108	107	14	31.0	29.0	2.0	2.8	-	-	-	-	-	-
109	106	14	34.3	24.2	10.1	-	4.9	3140	1820	1320	-	575
109	107	14	34.3	29.0	5.3	-	3.1	3140	2390	750	-	350
109	108	14	34.3	31.0	3.3	2.4	-	-	-	-	-	-
109	110	14	34.3	31.6	2.7	2.2	-	3140	2740	400	-	385
110	106	14	31.6	24.2	7.4	-	4.3	2740	1820	920	-	620
110	107	14	31.6	29.0	2.6	2.0	-	2740	2390	350	-	325
110	108	14	31.6	31.0	0.6	2.8	-	-	-	-	-	-
111	115	11	37.6	34.6	3.0	3.1	-	3270	2940	330	330	-
111	117	11	37.6	36.9	0.7	4.1	-	3270	3400	-130	440	-
111	121	10	37.0	35.8	1.2	4.5	-	3250	3020	230	550	-
111	121	10	37.0	35.8	1.2	4.3	-	3250	3020	230	550	-
111	131	10	37.0	31.8	5.2	6.6	-	3250	3080	170	640	-
112	111	11	40.8	37.6	3.2	3.4	-	4050	3270	780	-	505
112	122	10	41.1	37.3	3.8	4.5	-	4020	3240	780	-	615
112	132	10	41.1	34.7	6.4	7.2	-	4020	3600	420	555	-
113	109	11	41.6	33.4	8.2	-	7.7	4000	2960	1040	-	580
113	111	11	41.6	37.6	4.0	3.9	-	4000	3270	730	565	-
113	112	11	41.6	40.8	0.8	2.8	-	4000	4060	-60	300	-
113	114	11	41.6	39.1	2.5	-	2.4	4000	3560	440	-	350
113	136	11	41.6	40.6	1.0	4.5	-	4000	4540	-540	590	-
114	107	11	39.1	27.9	11.2	-	7.1	3560	2180	1380	-	600
114	111	11	39.1	37.6	1.5	4.0	-	3560	3270	290	470	-
114	115	11	39.1	34.6	4.5	3.3	-	3560	2940	620	440	-
114	117	11	39.1	36.9	2.2	2.5	-	3560	3400	160	310	-
114	118	11	39.1	38.4	0.7	2.2	-	3560	3380	180	235	-
114	135	11	39.1	37.9	1.2	3.2	-	3560	3390	170	630	-
116	135	11	40.3	37.9	2.4	3.9	-	3780	3390	390	685	-
118	107	11	38.4	27.9	10.5	-	6.6	3380	2180	1200	-	555
118	107	11	38.4	27.9	10.5	-	7.9	3380	2180	1200	-	560
118	111	11	38.4	37.6	0.8	3.4	-	3380	3270	110	400	-
121	125	10	35.8	34.2	1.6	4.1	-	3020	2720	300	390	-
121	126	10	35.8	30.4	5.4	4.3	-	3020	2520	500	390	-
121	131	10	35.8	31.8	4.0	4.6	-	3020	3080	-60	325	-
122	121	10	37.3	35.8	1.5	1.8	-	3240	3020	220	-	195
122	132	10	37.3	34.7	2.6	4.2	-	3240	3600	-60	315	-
123	121	10	36.6	35.8	0.8	4.3	-	3840	3020	820	-	610
124	121	10	36.2	35.8	0.4	4.1	-	2950	3020	-70	425	-
124	125	10	36.2	34.2	2.0	2.1	-	2950	2720	230	-	200
124	126	10	36.2	30.4	5.8	-	3.0	2950	2520	430	320	-
125	126	10	34.2	30.4	3.8	-	2.1	2720	2520	200	-	180
128	121	10	40.6	35.8	4.8	-	4.5	4000	3020	980	-	900
129	113	11	41.7	41.6	0.1	2.5	-	4120	4000	120	445	-

Table 22, continued

Rotations compared		Period	Grain Bushels per acre			L.S.D.		Straw Pounds per acre			L.S.D.	
(a)	(b)	years	(a)	(b)	(a-b)	5%	1%	(a)	(b)	(a-b)	5%	1%
129	121	10	42.1	35.8	6.3	-	5.1	4140	3020	1120	-	780
129	128	11	41.7	40.1	1.6	2.2	-	-	-	-	-	-
129	130	11	41.7	41.1	0.6	1.8	-	4160	3930	230	235	-
129	136	11	41.7	40.6	1.1	3.7	-	4160	4540	-380	400	-
130	114	11	41.2	39.1	2.1	1.9	-	3930	3560	370	510	-
130	121	10	41.3	35.8	5.5	4.4	-	3920	3020	900	650	-
130	128	11	41.1	40.1	1.0	2.2	-	-	-	-	-	-
131	137	10	31.8	31.1	0.7	4.5	-	3080	2640	440	530	-
131	138	9	29.5	25.3	4.2	6.2	-	3000	1760	1240	-	690
132	131	10	34.7	31.8	2.9	2.8	-	3610	3070	540	-	335
133	117	11	40.6	36.9	3.7	6.5	-	3900	3400	500	465	-
133	131	10	40.9	31.8	9.1	6.5	-	3980	3080	900	670	-
133	134	11	40.6	38.5	2.1	3.6	-	3900	2630	270	290	-
134	131	10	38.6	31.8	6.8	7.3	-	3700	3080	620	810	-
135	131	10	37.8	31.8	6.0	6.8	-	3350	3080	270	780	-
136	131	10	41.4	31.8	9.6	-	9.5	4520	3080	1440	-	750
136	132	10	41.4	34.7	6.7	-	6.4	4520	3610	910	-	565
137	138	11	31.1	24.8	6.3	5.3	-	2600	1700	900	-	360
139	128	11	41.9	40.2	1.7	3.0	-	4170	4060	110	320	-
139	131	10	41.5	31.8	9.7	-	6.5	-	-	-	-	-
139	136	11	41.9	40.6	1.3	4.2	-	-	-	-	-	-
140	114	11	42.7	39.1	3.6	3.3	-	4100	3560	540	540	-
140	130	11	42.7	41.2	1.5	3.3	-	4100	3930	170	475	-
140	131	10	42.2	31.8	10.4	-	7.5	4080	3080	1000	-	915
140	133	11	42.7	40.6	2.1	3.2	-	4100	3900	200	445	-
140	134	11	42.7	38.5	4.3	3.6	-	4100	3630	470	400	-
140	136	11	42.7	40.6	2.1	4.0	-	4100	4540	-440	-	335
140	137	11	42.7	31.1	11.6	-	4.7	4100	2600	1500	-	420
140	138	11	42.7	24.8	17.9	-	6.6	4100	1700	2400	-	555
140	139	11	42.7	41.9	0.8	2.5	-	-	-	-	-	-
Check	C105	15	36.9	26.4	10.5	-	4.7	3400	2680	720	-	690
Check	106	14	37.2	24.2	13.0	-	4.2	3440	1810	1630	-	515
Check	107	14	37.2	29.0	8.2	-	3.9	3440	2390	1050	-	390
Check	108	14	37.2	31.0	6.2	-	-	-	-	-	-	-
Check	109	14	37.2	34.3	2.9	2.9	-	3440	3140	300	-	245
Check	111	11	36.4	37.6	-1.2	2.5	-	3110	3270	-160	260	-
Check	114	11	36.4	39.1	-2.7	2.4	-	3110	3560	-250	320	-
Check	115	11	36.4	34.6	1.8	2.4	-	3310	2940	370	270	-
Check	117	11	36.4	36.9	-0.5	3.2	-	3310	3400	-90	300	-

Table 23. Comparative Yields of Oats

Period II, Fry Farm rotations

Rotations compared (a)	(b)	Period years	Grain Bushels per acre (a)	(b)	(a-b)	L.S.D. 5%	1%	Straw Pounds per acre (a)	(b)	(a-b)	L.S.D. 5%	1%
101	102	14	55.8	53.7	2.1	3.4	-	-	-	-	-	-
101	103	14	55.8	45.9	9.9	-	4.3	2520	2060	460	-	320
101	104	14	55.8	50.3	5.5	-	4.3	2520	2250	270	-	215
101	105	14	55.8	40.5	15.3	-	6.3	2520	1660	860	-	430
102	103	14	53.7	45.9	7.8	-	6.2	-	-	-	-	-
102	104	14	53.7	50.3	3.4	3.4	-	-	-	-	-	-
102	105	14	53.7	40.5	13.2	-	6.7	-	-	-	-	-
103	105	14	45.9	40.5	5.4	-	4.9	2060	1660	400	-	375
104	103	14	50.3	45.9	4.4	-	3.8	2250	2060	190	-	180
104	105	14	50.3	40.5	9.8	-	3.8	2250	1660	590	-	360
119	102	11	55.6	50.9	4.7	7.2	-	-	-	-	-	-
120	104	11	56.8	48.6	8.2	8.3	-	2620	2070	550	405	-
120	119	11	56.8	55.6	1.2	2.3	-	-	-	-	-	-
121	131	11	55.7	54.7	1.0	5.0	-	2510	2280	230	620	-
122	121	11	57.5	55.7	1.8	2.8	-	2600	2280	320	-	300
122	132	11	57.5	55.9	1.6	6.5	-	2600	2840	-240	1195	-
123	121	11	56.6	55.7	0.9	1.5	-	2400	2280	120	245	-
132	131	11	55.9	54.9	1.0	3.8	-	2840	2510	330	310	-
Check	C104	14	55.6	37.3	18.3	-	3.0	2580	1880	700	-	320
Check	101	14	55.6	55.8	-0.2	4.2	-	2580	2520	60	235	-
Check	102	14	55.6	53.7	1.9	3.7	-	-	-	-	-	-
Check	104	14	55.6	50.3	5.3	4.0	-	2580	2250	330	-	280
Check	105	14	55.6	40.5	15.1	-	5.8	2580	1660	920	-	295

Table 24. Comparative Yields of First-year Meadows

Period II, Fry Farm rotations

Rotations compared (a)	(b)	Crop (a)	(b)	Period years	Hay Pounds per acre (a)	(b)	(a-b)	L.S.D. 5%	1%
111	115	Cl	T	13	4960	3620	1340	-	1295
111	121	Cl	Cl	12	4630	3940	690	555	-
111	131	Cl	Cl,T	11	4640	4560	80	620	-
112	111	Cl	Cl	13	5440	4960	480	425	-
112	122	Cl	Cl	12	5140	4900	240	680	-
113	111	A	Cl	13	6020	4960	1060	1020	-
113	112	A	Cl	13	6020	5440	580	1060	-
113	114	A	A	13	6020	5480	540	610	-
113	129	A	A(1)	12	5840	5840	0	1200	-
114	111	A	Cl	13	5480	4960	520	970	-
114	115	A	T	13	5480	3620	1860	1540	-
114	130	A	A(1)	10	5580	4300	1280	930	-
114	140	A	A(1)	10	5580	4300	1280	-	1220
116	111	A	Cl	13	5820	4960	860	-	715
116	114	A	A	13	5820	5480	340	850	-
116	130	A	A(1)	12	5430	4040	1390	-	1055
116	140	A	A(1)	10	5450	4300	1150	820	-
117	111	A,Cl,T	Cl	13	6040	4960	1080	-	1080
117	114	A,Cl,T	A	13	6040	5480	560	910	-
117	133	A,Cl,T	A,Cl,T	11	5780	5280	500	925	-
119	111	A	Cl	13	6680	4960	1720	-	1250
119	120	A	A	13	6680	6110	570	445	-
119	128	A	A(1)	12	6540	5840	700	635	-
119	139	A	A(1)	10	6220	5850	370	770	-
120	111	A	Cl	13	6110	4960	1150	-	970
120	114	A	A	13	6110	5480	630	940	-
122	121	Cl	Cl	12	4900	3940	960	-	590
123	121	A,Cl,T	Cl	12	5410	3940	1470	-	1390
124	121	Cl	Cl	12	4120	3940	180	570	-
124	126	Cl	Cl	12	4120	4100	20	425	-
125	121	Cl	Cl	12	4660	3940	720	-	615
125	124	Cl	Cl	12	4660	4120	540	550	-
125	126	Cl	Cl	12	4660	4100	560	410	-
126	121	Cl	Cl	12	4100	3940	160	400	-
128	129	A(1)	A(1)	12	5840	5840	0	1010	-
128	130	A(1)	A(1)	12	5840	4040	1800	-	1045
129	113	A(1)	A(1)	10	5840	5820	20	1460	-
129	130	A(1)	A(1)	12	5840	4040	1800	-	1385
131	121	Cl,T	Cl	11	4560	4020	540	910	-
132	112	Cl,T	Cl	11	5260	5120	140	750	-

Table 24, continued

Rotations compared (a)	(b)	Crop (a)	(b)	Period years	Hay Pounds per acre (a)	(b)	(a-b)	L.S.D. 5%	1%
132	122	Cl,T	Cl	11	5260	4980	280	855	-
132	131	Cl,T	Cl,T	11	5260	4560	700	-	620
133	131	A,Cl,T	Cl,T	11	5280	4560	720	1065	-
133	134	A,Cl,T	Cl,T	11	5280	4760	520	-	855
133	140	A,Cl,T	A(1)	10	5270	4300	970	990	-
134	115	Cl,T	T	11	4760	3480	1280	-	1245
134	131	Cl,T	Cl,T	11	4760	4560	200	565	-
134	140	Cl,T	A(1)	10	4700	4300	400	1190	-
136	113	A(1)	A	10	6640	5820	820	700	-
136	129	A(1)	A(1)	10	6640	5840	800	1140	-
136	131	A(1)	Cl,T	10	6640	4550	2090	-	1155
136	139	A(1)	A(1)	10	6640	5850	790	735	-
136	140	A(1)	A(1)	10	6640	4300	2340	-	910
137	131	A(1)	Cl,T	11	4910	4560	345	1140	-
137	140	A(1)	A(1)	10	5180	4300	880	1110	-
138	131	A(1)	Cl,T	11	5180	4560	620	1130	-
138	137	A(1)	A(1)	10	5220	5180	40	1050	-
138	140	A(1)	A(1)	10	5220	4300	920	790	-
139	128	A(1)	A(1)	10	5850	5680	170	610	-
139	140	A(1)	A(1)	10	5850	4300	1550	-	1080
140	130	A(1)	A(1)	10	4300	4300	0	900	-

Table 25. Comparative Yields of Second-year and Third-year Meadows

Period II, Fry Farm rotations

Rotations compared		Crop		Period	Hay Pounds per acre			L.S.D.	
(a)	(b)	(a)	(b)	years	(a)	(b)	(a-b)	5%	1%
				Second Year					
128	130	A(2)	A(2)	12	8560	6590	1970	-	940
129	128	A(2)	A(2)	12	8590	8560	30	975	-
129	130	A(2)	A(2)	12	8590	6590	2000	-	1035
129	136	A(2)	A(2)	10	8330	8260	70	950	-
130	140	A(2)	A(2)	10	6600	6300	300	830	-
132	131	T	T	11	5260	4360	900	-	725
133	131	A,T	T	11	5500	4360	1140	1050	-
133	134	A,T	T	11	5500	4510	990	1295	-
134	131	T	T	11	4510	4360	150	1060	-
136	131	A(2)	T	10	8260	4580	3680	-	1755
136	139	A(2)	A(2)	10	8260	7420	840	630	-
136	140	A(2)	A(2)	10	8260	6300	1960	-	1190
137	131	A(2)	T,Cl	11	7360	4360	3000	-	1735
137	140	A(2)	A(2)	10	7580	6300	1280	-	500
139	140	A(2)	A(2)	10	7420	6300	1120	-	915
140	133	A(2)	A,T	10	6300	5790	510	1575	-
140	134	A(2)	T,Cl	10	6300	4670	1630	1310	-
				Third Year					
133	134	A,T	T	11	6940	4040	2900	-	1795
133	140	A,T	A(3)	10	7260	7080	170	1430	-
136	139	A(3)	A(3)	10	8830	8660	170	1610	-
136	140	A(3)	A(3)	10	8830	7080	1750	-	930
139	140	A(3)	A(3)	10	8660	7080	1580	-	470
140	134	A(3)	T	10	7080	4130	2950	-	2160

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