# CROP ROTATION AND PRODUCTIVITY

Canada Department of Agriculture

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# SUMMARY

Information from rotation experiments conducted at various Research Stations across Canada and an extensive review of literature from countries in similar latitudes are presented.

It is shown that some form of crop rotation is safer and usually more productive than monoculture, or growing a crop on the same soil year after year. Rotation may mean the simple expedient of introducing a summerfallow crop, a legume or grass crop or a green manure crop, at more or less frequent intervals, to control weeds, insects and disease or to add organic matter, or it may mean growing two or more crops that may be desired in a planned rotation. This does not mean that crops cannot be grown continuously on the same soil. Where pests can be controlled and fertility and good physical conditions maintained, crops have been grown successfully in monoculture for many years. Corn was grown at Woodslee, Ontario, for 15 years on the same soil and produced an average yield of 52.1 bushels per acre. In rotation, the yield was 77.1 bushels per acre. At Charlottetown, Prince Edward Island, potatoes grown continuously for 26 years yielded 187.8 bushels per acre, in rotation 235.4 bushels. At Lethbridge, Alberta, wheat grown continuously for 50 years yielded an average of 12.5 bushels per acre and 27.8 bushels when alternated with summerfallow. Wheat grown continuously at Rothamsted in England for 120 years produced an average yield of 34.2 bushels per acre and an average of 44.7 for the last 8 years.

In Eastern Canada mixed farming is the chief type of farming practiced. Grain and forage for feeding livestock is produced. Manure is returned to the soil and with crop residues left from grasses and legumes the productivity of the soil can be well maintained with rotations, simply arranged to produce the required amount of feed. The cash-crop areas create more of a problem. Cropping systems must be planned to cope with depleting organic matter, unfavorable physical conditions, reduced soil fertility and pests.

In Western Canada the Brown and Dark Brown soil zones are in the area of approximately 12 to 16 inches of annual precipitation and 21 to 29 inches of evaporation from a free water surface. Wheat is the main crop grown, and ranches are in the drier sections. Summerfallowing every second or third year has proved to be necessary for wheat. Grass and legume crops are grown with difficulty, and yields of hay are usually less than 1 ton per acre. Irrigation makes the growing of alfalfa, wheat, sugar beets and canning crops economically possible.

In the Black soil zone some of the most fertile soils in the world are found. The annual precipitation is from 14 to 17 inches and evaporation from

a free water surface about 19 inches. It is subhumid country, but farming can be more diversified. Summerfallowing is usually unnecessary. Perennial hay crops can be grown satisfactorily and mixed farming can be carried on successfully.

In the Gray Wooded soil zone the annual precipitation is from 17 to 20 inches and evaporation a low 16 inches. Mixed farming can be carried on successfully. Long hours of daylight and cool temperatures facilitate seed production. All grain crops grow well, and grass, legume and some vegetable crops produce seed abundantly. Summerfallowing is unnecessary. Low fertility is the main problem.

The river valleys in British Columbia, in the main, receive sufficient rainfall for the production of most farm crops. The exception is the dry central region where irrigation is required for the extensive production of fruit crops.

# INTRODUCTION

The study of crop rotations has received more attention from agricultural researchers than, perhaps, any other farm problem because the study is complicated by its relationship to many other factors. Each crop has a considerable effect, beneficial or otherwise, on crops that are grown subsequently. Crops also affect the soil in which they grow and they may have a profound influence on fertility, physical condition and soil development. The effects often do not become apparent for many years. Therefore, field experiments must be continued for long periods before reliable results can be obtained. This introduces the further complication of climate, which must be considered before conclusions can be drawn.

It is often desirable to grow a cash crop such as corn, potatoes or wheat continuously on the same area. These cash crops are usually soil depleting. They may use large amounts of plant nutrients and consequently reduce soil fertility. They return only a small amount of plant residues, and the physical condition of the soil soon becomes impaired. They are susceptible to attacks from disease, insects and weed growth. In recent years chemical fertilizers and chemicals for pest control have made it possible to grow crops continuously for long periods of time. However, an occasional change of crop may be advantageous.

This publication reviews some of the recent literature on crop rotations, and gives the results of experiments that have been conducted by the Canada Department of Agriculture over a long period of years.

# HISTORY OF CROP ROTATIONS

The history of crop rotations was presented in some detail by Ripley (1941). A brief review will suffice at this time. Virgil was among the first to record the value of crop rotation. In 30 B.C. he recognized the importance of leguminous crops and fallow. In 1727, Hales' "Vegetable Staticks" claimed that some plants excreted substances that had some mysterious effect on other plants. Micaire, in 1832, pointed out the importance of a rotation of crops and suggested that the idea was as old as agriculture itself.

In 1845, Daubeney, in England, reported the first extensive field work ever recorded. He grew oats, tobacco, flax, potatoes, beans and clover continuously and in rotation for a 10-year period and reported more satisfactory growth of the crops in rotation. In 1844, Lawes, of England, laid down a series of fertility treatments on wheat grown continuously on the same soil. Later, in 1852, the results were compared with wheat treated similarly in a rotation of swedes, barley, clover or fallow, and wheat. These plots are still in production; they are discussed in more detail later in this publication.

In 1876, rotation experiments were started in North America at the Agricultural Experiment Station, Urbana, Illinois. This was followed by work at Columbia, Missouri, in 1888 and at Wooster, Ohio, in 1894. The first work in Canada was begun at the Central Experimental Farm, Ottawa, in 1888. In 1911 other experiments were started on a number of Branch Stations across Canada. Some of these North American projects have continued to date.

A bibliography, with 111 references, reviewed by Ripley (1941) brought the information on the subject up to date to 1939. An excellent review of the North American and other literature (89 references) that included reports of work up to 1959 was prepared by Siemens (1963). Information from many experiments in Western Canada was included in this publication.

# REVIEW OF RECENT LITERATURE

The author is indebted to Mr. G. V. Jacks, former Director of the Commonwealth Bureau of Soils, for most of the references presented in this publication. Mr. Jacks (1966) provided 440 references on world literature from 1947 to 1965. Since crops grown in tropical countries are not discussed in this publication, and other references were not pertinent, only 140 have been used to illustrate certain points.

## Effect of Crops on Other Crops

### Monoculture

It is often desirable to grow a single crop year after year on the same soil. Much of the wheat, sugarcane, cotton and rice of the world is grown in this way. There is little information in the scientific literature that shows that continuous cropping is more satisfactory than cropping in some form of rotation. Few tests have been carried on for a sufficient length of time to determine this point.

*The Rothamsted experiment*—The oldest experiment in the world dealing with monoculture was started by Lawes and Gilbert (1864) at Rothamsted, England, in 1844 and is still in operation. Wheat has been grown continuously on the same land during the entire period. Based on data from various sources, Garner (1959), Gilbert (1895), Rothamsted reports (1895–1905), (1906–1938), (1939–1947), (1948–1963), this old experiment provides much useful information. Table 1 shows the average yield by 8-year periods from 1844 to 1963, and also average yields for the complete period.

The wheat was grown on single plots, without replication, but the single yields show definite trends. When no manure was added the wheat yields declined steadily from 16.1 bushels per acre in the first 8-year period to 10.5 bushels in the period 1876–1883. There were slight increases in the next two 8-year periods, and a further decline in the period ending in 1906. After this there was a steady increase in each 8-year period until in 1956–1963 there was an average yield of 22.5 bushels per acre. The average yield over the entire 112 years was 14.3 bushels per acre.

Where farmyard manure was applied annually at 14 tons per acre the 8-year average yield trends have been similar but at a much higher level. The higher yields are shown by the 112-year average yield of 35.2 bushels per acre, 124.9 percent more than where no manure was applied. Where 550 pounds of nitrate of soda and 412 pounds of combined phosphate and potash

Table 1. Wheat continuously and in rotation at Rothamsted

| Years | Wheat continuously: 14 Tons farmyard manure | No manure | Complete fertilizer | Fallow wheat |
|---|---|---|---|---|
| 1844–1851 | 28.0 | 17.4 | 29.2 | — |
| 1852–1859 | 34.4 | 16.1 | 35.5 | 30.8 |
| 1860–1867 | 35.7 | 13.5 | 36.2 | 20.2 |
| 1868–1875 | 35.4 | 12.2 | 31.0 | 16.6 |
| 1876–1883 | 28.6 | 10.5 | 28.0 | 13.0 |
| 1884–1891 | 39.2 | 12.7 | 32.0 | 17.3 |
| 1844–1893 | 33.5 | 13.5 | — | — |
| 1892–1899 | 39.8 | 12.1 | 36.3 | 14.5 |
| 1900–1906 | 35.5 | 11.8 | 32.4 | 13.9 |
| 1909–1915 | 28.6 | 8.2 | 27.3 | 10.5 |
| 1916–1923 | 26.9 | 9.3 | 23.2 | 9.6 |
| 1924–1931 | 24.9 | 11.5 | 26.5 | 9.1 |
| 1932–1939 | 28.9 | 14.6 | 28.7 | 21.7 |
| 1852–1928 | 33.2 | 11.8 | 35.3 | 14.2 |
| 1844–1943 | 32.2 | 12.6 | — | — |
| 1940–1947 | 42.7 | 20.8 | 42.7 | 20.6 |
| 1948–1955 | 45.9 | 22.2 | 43.0 | 18.7 |
| 1956–1963 | 44.7 | 22.5 | 42.3 | 19.0 |
| 1844–1963 | 34.2 | 18.8 | — | — |
| 1852–1963 | 35.2 | 14.3 | 36.3 | 15.9 |
| High yield | 59.5(1938) | 32.5(1930) | 54.9(1940) | 57.7(1939) |
| Low yield | 6.5(1926) | 0.9(1926) | 7.5(1926) | 0.5(1927) |

were applied per acre, the yield trend was almost identical with that of the farmyard manure with a 112-year average yield of 36.3 bushels per acre.

In an adjoining field, of comparable soil type, wheat was grown in alternate years with complete summerfallow and no manure. The yield was only slightly higher at 15.9 bushels per acre than continuous wheat with no manure. This is hardly a correct comparison, however, as Garner (1959) points out, "The main agricultural problem in continuous corn growing is weeds. Great efforts were made to keep the field clean by hand weeding but in wet years even this was unsuccessful. When labor became increasingly scarce and expensive the only practicable alternative was to introduce periodical bare fallows. This was started in 1925 and made a definite break with the time-honored system."

After 1925 a definite trend upward was shown on all the continuously cropped areas. This shows that if weeds and disease can be properly controlled, and adequate fertility supplied, wheat can be grown continuously on the same soil for long periods with reasonable success. This may be possible by using modern chemicals for pest control.

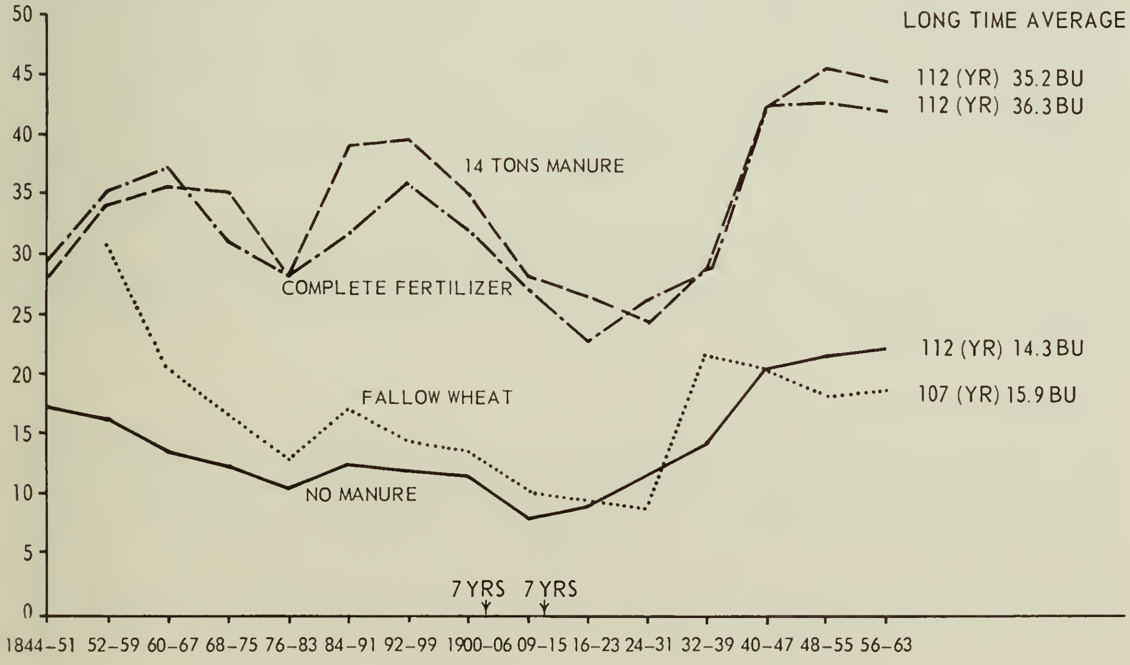
In a third field at Rothamsted, wheat was grown in a 4-year rotation of swedes, barley, legumes or fallow, and wheat. Since the wheat was grown only once every 4 years, the yields are not comparable with the 8-year or longtime averages shown in Table 1 and Figure 1. In the 21 years for which comparisons were available, the unmanured wheat in rotation gave a higher yield than unmanured continuous and unmanured fallow wheat. The yield was higher than where continuous wheat was fertilized with minerals and nitrogen only four times, and higher than where farmyard manure was used only twice. Therefore, although the rotation was effective in itself, it must be associated with adequate fertilization to give maximum yields.

*Other monoculture experiments*—Agerberg and Bjorklund (1963), Sweden, reported that, although most crops produce better yields when grown after another crop in the rotation, some crops may be grown in monoculture until specific diseases or parasites interfere. Sugar beets can sometimes be grown for up to 7 years without any decrease in yields. Mustard is also very tolerant of monoculture. However, growing barley in continuous cropping or after wheat was conducive to fungal diseases and crop failure.

Allaway (1957) reported on the Morrow plots, which have been in continuous operation at Urbana, Illinois, since 1876. Unmanured continuous corn gave a yield of 36 bushels per acre in the 79th year of the experiment. In a 3-year rotation of corn, oats, meadow, the corn yielded 63 bushels per acre. With liberal amounts of fertilizer applied in 1955 continuous corn yielded 86 bushels per acre and corn in rotation 102 bushels. The rotation increased the yield over continuous corn by 27 bushels, but one application of complete fertilizer increased it by 50 bushels. The combination of rotation and fertilizer gave an increase over continuous unfertilized corn of 66 bushels per acre.

Chandnani *et al.* (1960), India, reported satisfactory yields of wheat, cotton and sugarcane grown continuously on the same land for 5 years. Egerov

*Figure 1. Continuous wheat, Rothamsted Experimental Station, England. Average yield per acre 8-year periods, 1844–1963.*



(1958), USSR, concluded that after 46 years of cropping yields of flax and clover were reduced considerably in monoculture, rye and oats to a lesser extent and potatoes least of all. The decrease was caused largely by weed growth. Essafi (1964), France, compared continuous wheat with fallow and wheat alternately and a 4-year rotation of wheat, vetch, legume, wheat for 25 years. Fallow was not necessary to maintain wheat yields when the rainfall was over 17.7 inches annually. It was recommended that the wheat be grown in a rotation with legumes. Margineanu *et al.* (1963), Romania, found that corn grew well in continuous culture, but winter wheat did not. Müller (1962), Germany, reviewed 23 references and concluded that nutrient and pest effects were more important than crop incompatibility. Schmid (1964), Germany, found that yields were higher in a rotation with 25 percent clover–grass than in a predominantly cereal rotation.

## Mixed Grasses and Legumes

Both grasses and legumes provide beneficial effects on soil and, therefore, on the crops that follow them. Heard (1965), United Kingdom, found that wheat yields were higher after white clover and alfalfa than after orchard-grass. Kuksin (1961), USSR, found that 3 to 4 years of ley in a 6- to 8-year rotation increased productivity 40 to 80 percent over long-term seeded meadows and 400 to 500 percent over natural unimproved grassland. Mandal (1955), India, reported that corn yields after grasses and legumes were increased by as much as 26.3 percent over continuous corn. The yield of potatoes was 3 tons per acre higher after grazed ley than after tillage crops in experiments by Mann, Raheja and Dhillon (1963), England.

Odland and Sheehan (1957), Rhode Island, USA, found that sod crops affected the yield of potatoes in decreasing order, redtop, redtop and timothy, redtop and alsike, timothy and alsike, timothy and red clover, timothy. Uhlen (1963), The Netherlands, reported that grain yields were 17 percent higher in a rotation of oats, potatoes, barley and 3 years ley, or potatoes, barley and 4 years ley than where the cereals were grown continuously on the same land. The effect of the leys lasted about 5 years. Agerberg (1962), Sweden, found that a rotation with hay crops fed to livestock and then the manure applied to the soil was more productive than one without a hay crop and with the chopped straw and sugar beet tops plowed in. Zhubritzky (1963), Hungary, suggests that vegetables such as cabbages, cucumbers, carrots, and tomatoes require less fertilizer to maintain soil fertility when grown in rotation, especially where grass–clover meadows are included, than where the crops are grown in monoculture. However, the yields of the crops were higher when grown continuously.

## Legumes Alone

Legumes alone have been effective as preceding crops. Their benefit has been chiefly their ability to fix nitrogen and to produce root and top residue, which adds organic matter to the soil and improves its physical condition. Doll and Link (1957), USA, found that the yield of wheat and corn were increased by legumes in the order: soybean hay, lespedeza hay, soybean grain straw returned, lespedeza plowed down, red clover hay, red clover plowed down, first-cut hay regrowth of sweet clover plowed down. Duley (1960), USA, showed that oats yielded 60 bushels per acre where there was sweet clover in the rotation and only 30 bushels with no sweet clover. The yield of corn was increased also with sweet clover in the rotation.

Friessleben (1964), Germany, found that preceding cereal crops the legumes peas and red clover were beneficial. Sugar beets and potatoes were also beneficial, but to a lesser extent. Kaminska (1965), Poland, showed that sweet clover and alfalfa with tall oatgrass had a beneficial effect on mustard. Birdsfoot trefoil and red clover were slightly less effective. Ruthowski (1962*b*), Poland, showed that legumes increased soil aggregates and made the soil more friable. He showed also (1962*a*) that rye grows better after legumes than after cereals. Sen and Dhillon (1963), India, reported that cereals grown in a rotation with legumes yielded better than in a completely cereal rotation. Sim (1953, 1958), South Africa, found that alfalfa and lupines were excellent preceding crops for oats and wheat. Zecev, Sarkizov and Georgiev (1964), Bulgaria, found that irrigated corn grew well after alfalfa and winter pea.

## Grasses Alone

Grasses do not add nitrogen to the soil, but they produce extensive root growth. Their residues add large amounts of organic matter to the soil, and improve the physical condition. Hammerton and Edwards (1965), England, found that grasses were beneficial preceding barley in the order: ryegrass, cocksfoot, meadow fescue, bentgrass and timothy. Odland and Sheehan (1961), USA, found that potatoes yielded 60 to 80 bushels more per acre in rotation with redtop than in continuous culture.

## Wheat

Wheat and rice are the most universally grown cereal crops. Rice will not be emphasized in this publication, but wheat is of considerable interest in the temperate countries. Arora and Raheja (1963), India, determined that wheat yielded better in a rotation of fallow, wheat, cotton, fallow sugarcane than in continuous culture. Weeds were better controlled in the rotation. Boswinkle (1960), Kenya, East Africa, reported that corn and wheat grew well after potatoes if the potatoes received an application of 210 pounds of double superphosphate per acre or 105 pounds each on the potatoes and other crops.

Dei and Hamasaki (1956), Japan, found that wheat and barley removed nutrients from the soil, and decreased its porosity. Lupines removed some nutrients but returned nitrogen, manganese and some potassium. Harvey (1963), England, found that wheat and barley benefited for 2 or 3 years after a 3-year ley had been plowed. Hedlin and Ridley (1964), Canada, recorded wheat yields after various crops in the order from high to low: fallow, flax, corn, oats, barley, spring rye. Hobbs and Brown (1955), USA, after 41 years, found that wheat and corn did better in a 16-year rotation with legumes prevalent than in a 3-year rotation. Legume yields deteriorated in the 16-year rotation.

Klapp (1961), Germany, in one of the few results of this type, found that winter wheat yielded better after sugar beets than after clover. Lewis, Proctor and Hood (1960), England, found that 2- to 3-year leys were better than 1-year leys for wheat and kale. All arable rotations decreased yields because of poor physical condition. Margineanu *et al.* (1963), Romania, found that wheat grew better in a 2- to 4-year rotation, while corn did well in continuous culture. Mann, Raheja and Dhillon (1963), India, found that fallow was not beneficial for bjara, but that wheat produced more than double after fallow than it did after bjara. Mazurak and Ramig (1963), USA, after 20 years in which a fallow wheat sequence followed 2, 4, 6 and 8 years of ley, found that water entered the soil more readily in longer periods in ley. Wheat yields increased in direct relation to the water penetration.

Ozaki (1964), Japan, found that corn, potatoes and sugar beets were better preceding crops for kidney beans, soybeans, azuki beans, oats and sugar beets than were wheat, barley, oats, flax or beans. Ruther (1961), Germany, found that wheat thrived best after potatoes and peas and poorly after sugar beets and cereals. Wicke (1965), Germany, showed that cereal crops preceding cereals were effective in the following order: winter wheat, winter rye, winter barley, spring barley, spring wheat and spring oats.

## Corn

Since the development of hybrid varieties of corn, the crop has been grown more extensively throughout the world. Bartholomew, Shrader and Engelhorn (1957), India, grew corn under various conditions for 37 years. They were interested particularly in nitrogen maintenance. The decline in nitrogen content from the greatest to the least was in the order: corn continuously, corn followed by oats, a 5-year rotation with 2 years in meadow and a 3-year rotation with 1 year in meadow. Shalaby, Sakr and Moursi (1961), Egypt, found that at several nitrogen levels corn yielded well after beans, but not after wheat, barley or flax.

Urano *et al.* (1960), Japan, reported that the yield of corn was higher after soybeans as compared with continuous cropping. However, soybeans decreased the yield of barley and wheat. As a preceding crop sweet potatoes had no effect on corn, wheat, barley, radishes or potatoes. Under irrigation Zecev, Sarkizov and Georgiev (1964), Bulgaria, found that corn yielded well after alfalfa and winter peas.

## Oats

Harper (1961), USA, reported that oats was a good crop to precede alfalfa. The yield of alfalfa after oats was 4,492 pounds per acre, after barley 4,411, after cotton 4,132 and after sorghum 3,523. Larson *et al.* (1958), also in the USA, showed that alfalfa in the rotation increased considerably the yield of oats and potatoes and to a lesser extent sugar beets.

## Potatoes

Hanley, Ridgman and Jarvis (1964) found that when P and K were applied at high levels on light gravelly soil the sequence of cropping had little effect on the yield of potatoes that received 4 cwt per acre nitrochalk. In the absence of nitrogen a ley containing alfalfa produced higher yields than other sequences did.

Harvey (1963), England, reported that potatoes, if supplied with sufficient nitrogen, were little affected by preceding crops. Yields were somewhat better, however, after grazed leys than when the latter were cut for hay.

### Miscellaneous Crops

It was found by Fajkowska and Skodowski (1962), Poland, that for the best results it was necessary to grow chicory, snap beans and peas in rotations. Other vegetables could be grown satisfactorily in monoculture. Reeve *et al.* (1957), USA, showed that tomato yields were doubled following alfalfa and sweet clover over those of tomatoes grown continuously on the same area. Phillips and Norman (1962), Australia, compared several crops preceding millet and Sudan grass and found that they gave the best yield after peanuts, and the poorest after sorghum. Sorghum, however, grew best after cowpeas, and was poorest after Sudan grass.

## Biological Activities

Many research scientists have been interested in studying the effect of various crops on the biological activity in the soil. Differences in the development of bacterial disease, earthworms, insects and weeds may have an important effect on the production of crops grown later.

### Bacteria and Fungi

Afanas'eva (1953), USSR, found that bacteria were more numerous after crops of alfalfa than after perennial grasses and persisted for 5 to 6 years. Also more nitrates were formed after alfalfa. Hervey (1957), USA, found that bacteria and actinomycetes were higher in cotton soil after oats, sweet clover, or grass than where cotton was grown continuously. In addition, soil organic matter content was greater. Lambina (1957), USSR, found protopectinase higher under clover and timothy than under wheat, oats, flax, potatoes, cabbages, peas or tomatoes.

Latariza (1958), USSR, recorded that the $CO_2$ concentration (milligrams per liter of air) increased under wheat from 12 in May to 34–36 in June and then decreased to 14–17 in October. Under grass the corresponding values were 17, 27 and 16. This is an indication of bacterial activity. The $NO_3$ content of the soil followed parallel curves. Louw (1957), South Africa, found high levels of fungi and bacteria in soil under wheat following alfalfa, not quite so high following lupines and lower still after fallow.

Jedrzejewska-Dobrzanska (1955), Poland, found that clover–grass mixtures increased the total number of bacteria and actinomycetes and anaerobic nitrogen-fixing bacteria, but not that of nitrosomonas or azotobacter. Dobrotverskaya, Belikova, and Gordienko (1956), Ukraine, reported that microbial flora were more abundant in a rotation with lupines and grasses than in a grain-hoed crop rotation. The number of microbial flora was twice as large in winter wheat after ley. Müller (1959), Germany, found a significantly higher number of bacteria where preceding crops were plowed down than where the soil carried no previous crop. Highest numbers occurred after alfalfa and lowest after orchardgrass. Fungal populations were higher after white clover than after grass–clover, alfalfa, orchardgrass and uncropped soil, in decreasing order.

## Disease

Disease has been responsible for the breakdown of growing crops in monoculture. Even with the introduction of chemicals for the control of many diseases, some kind of rotation is usually needed. Egerov (1958), USSR, after 46 years of work found that diseases, weeds, and root secretions greatly decreased the yields of flax and clover in monoculture, those of rye and oats to a lesser extent and those of potatoes least of all. Curl (1963) reviewed 415 references on control of plant diseases by crop rotation.

Many workers have studied the disease take-all, *Ophiobolus graminis* Sacc. of wheat and barley. Most of them have found that a rotation of some sort is helpful in its control. Hood (1961), Britain, found that take-all and weeds were worse in wheat grown continuously than in a rotation with 1 to 3 years in ley. Similar results were obtained by Angell and Mills (1951), Australia. Adams (1951), also Australia, found that take-all in wheat was minimized but not controlled by growing oats for grazing or by bare fallow the year before seeding wheat.

Bjaanes (1956), Norway, showed that take-all in wheat and barley was reduced by preceding crops of roots, peas, clover and oats. Bare fallow was exceptionally effective but redtop and timothy were poor preceding crops. Grossmann (1954), Germany, found that growth of take-all in agar cultures was inhibited by additions of triturated plant material. Red clover and yellow clover suppressed growth completely. Blue lupines, peas and broad beans decreased growth by 10 to 30 percent in the order named. Oats gave complete inhibition, but barley, corn, winter and summer rape and mustard had no effect. Zogg (1957), Germany, reported that take-all was destroyed by soil microorganisms and also by rape and clover.

Eyespot, *Cercosporella herpotrichioides* Fron, is closely related to take-all and responds to similar treatment. Hansen and Aastveit (1959), Norway, found that rape, mustard and oats preceding barley and wheat controlled both diseases quite well. Red clover increased eyespot but decreased take-all. Storey (1947), Britain, found that oats and 2 to 3 years in ley decreased both diseases.

Bockman (1953), Germany, and Glynne and Slope (1959), USA, found that weeds grew more profusely in wheat affected by take-all disease, probably because the weakened wheat plants could not compete with the weeds. Kincaid (1960) reviewed literature on 16 pests and diseases and found that growing grasses and legumes controlled diseases in tobacco but not in potatoes, which are subject to similar diseases.

*Helminthosporium sativum* Pamm., King & Bakke and *Fusarium culmorum* (W. G. Sm.) Sacc. are usually associated with root rot of cereals. As evidence of their importance, considerable study has been given to them and reported in the literature. Paharia (1956) found that root rots of wheat and corn were decreased when these crops followed oats, soybeans or flax. Dilution plate counts demonstrated the increased populations of bacteria and also fungi of the genera *Alternaria, Cephalosporium, Fusarium, Helminthosporium,* *Rhizoctonia* and *Verticillium,* in the rhizosphere of susceptible cereals. However, *Aspergillus, Chaetomium, Mucor, Penicillium, Rhizopus* and *Trichoderma* prevailed in that of resistant crops.

Malloy and Burkholder (1959), USA, found that wheat reduced root rot when grown before beans in the field. Alfalfa reduced root rot in the following crop of beans in the greenhouse. Tyner (1948), Canada, found that root rot diseases were 15 times more abundant in wheat than in oats, barley, or bean roots. Williams and Schmitthenner (1963), USA, reported that corn grown continuously for 7 years yielded two-thirds as much as corn grown for 2 years, and half as much as corn preceded by soybeans. Corn yielded well after wheat, oats or alfalfa if these crops were preceded by soybeans. Root and stalk rots reduced the yield in the 7-year continuous corn. Williams and Schmitthenner (1962) recorded 66 groups of fungi in a soil where a crop rotation was used, but only 32 in monocropped soil.

Weinhold, Oswald, and Bowman (1964) reported that potato scab reached its maximum infection in potatoes grown in pots continuously for 8 years. Barley cover crop plowed down doubled the scab infestation, while soybeans checked but did not control it.

## Earthworms

There are few references to conditions where earthworms develop extensively. The presence of worms, however, is supposed to indicate a friable productive soil. Barley (1959), Australia, found that pastures 6 or more years old carried an average of 80 grams of worms per 1,000 grams of annual production of herbage. An equal amount was found after 2 years in ley in a ley–ley–fallow–wheat rotation but dropped to one-quarter the amount in the fallow–wheat years. Applications of phosphorus on pasture increased the worm population. Fursov (1958), USSR, found that earthworms increased under alfalfa from the first to the third year of its life.

## Insects

Recent literature has few reports on the effect of crop rotations on insect infestation. Bombosch (1960), Germany, reported that *Cetomaria linearis* was restricted in sugar beets grown in continuous culture as compared with the crop grown in rotation. This was probably due to the presence of *Cephalosporium* species. Agricultural practices produced no effect on *Aphis fabae* Scop. and its parasites, which have a different life cycle.

## Toxic Secretions

Only one reference is recorded here that suggests that toxic substances from one crop affect other crops. Patrick (1960) found that substances toxic to tobacco resulted from the decomposition of timothy, corn, rye and potato residues. The toxicity was greater in wet than in dry soils. The toxic substances made tobacco more susceptible to black root rot.

## Weed Infestations

The effect of rotations on weeds has already been discussed briefly in association with disease. Bockman (1953), Egerov (1958), Glynne and Slope (1959), and Forbes (1963), Britain, reported a lower infestation of wild oats where the rotation included long leys. Watanabe and Ozaki (1964), Japan, found that the weed population was lower in a rotation with soybeans, sugar beets and oats, in that order. With potatoes, soybeans or kidney beans in the first and third years of a 4-year rotation the weed population decreased, but with flax, oats, corn or sugar beets it tended to increase.

## Carbon, Nitrogen and Organic Matter

Many investigators have studied the effect of various crops on the carbon, nitrogen and organic matter content of the soil. Legumes and grass crops, especially, are well known for their root growth and crop residues, which add carbon and organic matter. It has been known for many years that legumes, especially, add nitrogen to the soil.

Andharia, Stanford, and Schaller (1953), USA, found that meadows of clover and grass increased both organic matter and nitrogen content of the soil under the succeeding corn crop. Oats preceding the corn did not have this effect. Balev (1950), Romania, analyzed the soil that had been in various crops for 36 years. He found the levels of organic carbon, total nitrogen, exchangeable calcium and aluminum and the aggregate composition to be highest in uncultivated meadow, and then in the order: 9-year rotation, continuous clover, continuous rye and continuous fallow. He concluded that ley farming was the only method of maintaining the fertility level in these soils. Bear and Prince (1951), USA, reported that the residues of soybeans and sweet corn increased soil organic matter levels and yields, whereas shavings, sorrel and sweet clover had the opposite effect.

Birecki and Smierzchalski (1957), Poland, in 37 years of comparisons, found that nitrogen content declined to the greatest extent under continuous corn, followed in order by a 2-year rotation of corn and oats, a 5-year rotation with 2 years in meadow and a 3-year rotation with 1 year meadow. Bishop and Atkinson (1954), Canada, showed, after 40 years, in a 10-year rotation with 6 years in alfalfa that nitrogen content increased 7 percent and organic matter 10.5 percent in the top 6 inches. In the 6- to 12-inch level the increase in nitrogen content was 42.5 percent and in organic matter content 45.2 percent. Börringer (1954), Germany, found that 1 to 3 grass leys improved crumb structure and increased the levels of organic matter, potassium and phosphorus more than did alfalfa or red clover. The legumes, however, increased nitrogen content, soil respiration and pore space more than did the grasses.

Brage, Thompson, and Caldwell (1951), USA, found that a long rotation of root crops, grain and 1 to 3 years in hay increased the amounts of carbon and nitrogen in the soil, but did not increase yields.

Caldwell, Wyatt, and Newton (1939), Brown, Wyatt, and Newton (1942), and Newton, Wyatt, and Brown (1945) did extensive analyses of 1,000 samples of soil from 85 locations on virgin and cultivated soils in Alberta, Saskatchewan and Manitoba. The cultivated fields had been cropped for an average of 22 years. They concluded that the average losses of original organic carbon from surface 6 inches of Brown, Dark Brown and Black soils amounted to 20 percent. The loss of original nitrogen was 18 percent. In Gray soils the loss of organic carbon and nitrogen was greater, amounting to over 30 percent in each case.

The average losses of organic matter, to a depth of 12 inches, were for Brown soils 25,566 pounds; Dark Brown 32,289; Black 62,935; Black transition 92,115; Gray 28,253. The average losses of nitrogen, to a depth of 12 inches, were for Brown soils 889 pounds; Dark Brown 1,208; Black 2,658; Black transition 3,662; and Gray 1,308. The greatest loss was in the surface 6 inches. Approximately one-third to one-half of the average nitrogen loss was due to crop removal.

A grain–fallow system has not maintained the organic matter content or the nitrogen content of cultivated prairie soils of Western Canada. Cultivation has resulted in a narrower C:N ratio in most of the soils analyzed. Rotations that included legumes or grasses and the addition of barnyard manure reduced or prevented losses of organic matter and nitrogen.

Braken (1953), USSR, found that a mixture of alfalfa and *Agropyron* was more effective in increasing humus levels in a Chernozem soil than was alfalfa alone. Chizhevskii and Charuiskaya (1958), USSR, found that more than 6 tons of root and stubble residues were accumulated per hectare in the soil during the first year of utilization of perennial herbage and up to 11.7 tons by the end of the second year. Accumulation under grain and industrial crops was only 2.3 to 4 tons per hectare. Clement (1961), England, found that a grass sward grazed for 3 years increased the organic matter content by 4 tons per acre. The water-holding capacity and the crumb stability were also increased. Cooper and Eslick (1963), USA, found that legumes had more influence than grasses on the yield of barley due to increases in nitrogen content. Drover (1956), Australia, reporting a 24-year experiment, found that a rotation of fallow, wheat, lupines and lupines, or continuous wheat maintained the nitrogen and organic carbon content of the soil at levels approaching that of virgin soil. Fallow–wheat and fallow–wheat–pasture rotations resulted in serious losses in these soil constituents.

Dubetz and Hill (1964), Canada, found the yield of corn lowered by sweet clover because of phytotoxicity. Levels of organic matter and nitrogen were maintained in the soil by a rotation with 3 years of alfalfa or a mixture of alfalfa and bromegrass but not with 1 year of the legume. Egerov (1958), USSR, found that the soil under rye in monoculture or in a 6-year rotation of fallow, rye, potatoes, oats, clover, flax lost humus in the period 1912–1960 unless dung was applied. Eich (1964), Germany, found that crops that produced a large root mass, such as alfalfa and lupines or rye–vetch or rye–rape, increased the soil carbon and nitrogen content and its sorption capacity. Fritschen and Hobbs (1958), USA, reported the most unusual result: a 3-year rotation of corn, soybeans and wheat resulted in a loss of 0.038 percent of nitrogen; a 16-year rotation with 4 years corn, 4 years legume and 8 years wheat caused a loss of 0.031 percent nitrogen; while, with continuous wheat, the nitrogen loss was only 0.021 percent in 43 years.

Gouerre (1956), France, reported an increase in humus content under well-fertilized high residue crops. Gomez Lopez, Ramiro Guerrero, and McClung (1964), Spain, showed that continuous cropping of corn resulted in a decrease in soil nitrogen content and yield. In rotation with soybeans or alfalfa the nitrogen level was restored for 1 year only. Applications of nitrogen were just as effective as alfalfa and the latter depleted the potassium supply in the soil. Haban (1965) showed a relationship between large numbers of organisms, which decomposed organic carbon and nitrogen compounds in preceding crops, and the yield of wheat grown subsequently. Hanley, Ridgman, and Jarvis (1964*b*) showed that alfalfa–grass leys increased the yield of wheat for 6 years after breaking because it improved the physical condition of the clay soil and also increased the nitrogen supply. They also showed (1964*a*) that nitrogen supplied by alfalfa increased the yield of potatoes grown subsequently.

Hass, Evans, and Miles (1957) in the Great Plains region of the USA found that in a cropping period of 30 to 43 years the average loss of nitrogen from the surface soil was 24 percent for continuous small grains, 29 percent for alternate grains and fallow and 43 percent for continuous row crops and alternate row crops and fallow. Organic carbon losses were slightly higher. There was a relationship between total nitrogen content and nitrate production. Hill, Bishop, and Cannon (1953), Canada, compared nine different rotations. They found that a 2-year rotation tomatoes–peas or corn–peas plus 30 tons of farmyard manure per acre every 5 years considerably increased the levels of organic matter, exchangeable potassium and acid-soluble and adsorbed phosphorus in the soil. The yields were greater than where green manure crops were plowed down.

Hobbs and Brown (1957), USA, found a smaller loss of nitrogen and carbon from the soil, after 30 years of cropping, where small grains were grown continuously or in rotation than where row crops were grown continuously. Hood (1961) compared ley-arable farming systems containing 1-, 2- and 3-year grazed leys with those of continuous arable cropping. The soil was depleted of nitrogen in the continuous arable system, but not where leys were included. There was also a breakdown of soil aggregates and greater incidence of weeds and disease in the continuous arable system.

Lÿkov (1961), USSR, found after 48 years cropping that soil under continuous fallow lost 50 percent of its humus and under continuous rye only 15 percent. Levels of nitrogen, phosphorus and potassium were reduced also. Shalaby, Sakr, and Moursi (1961), Egypt, found that corn yields were lower after flax and barley than after wheat at low levels of nitrogen in the soil. The corn yields were higher after beans than following the other crops. Stockinger, MacKenzie, and Cary (1963), USA, found that alfalfa and sesbania increased the organic matter content of the soil and the yield of sugar beets that followed. The addition of 420 pounds of nitrogen per acre as ammonium nitrate had the same effect. Strickling (1957), USA, compared 13 cropping systems. He found that continuous wheat, bluegrass and ladino plus orchardgrass increased soil organic matter content and aggregate stability, while continuous soybeans, corn or bare fallow reduced both.

## General Fertility

References to the effect of crops on general fertility or the level of plant nutrients in the soil have been made in other sections. Some workers have referred directly to nutrient levels and a few are presented here. Dubetz (1954), Canada, found that in an irrigated 10-year rotation cropped for 42 years the soil organic matter content increased from 4.17 percent to 4.82 percent and nitrogen levels were well maintained. Alfalfa was grown for 6 years of the 10-year rotation and farm manure and commercial fertilizers were added. The phosphorus and potassium levels were well maintained. Bishop and Atkinson (1954), Canada, did chemical analyses on the soils of the Dubetz experiment and found no change in the amounts of phosphorus or potassium after 40 years of cropping.

Fajkowska and Skodowski (1962), Poland, found that when enough mineral fertilizer was supplied, peas, leeks, tomatoes and cucumbers grew well in monoculture. Chicory and snap beans had to be grown in a rotation. All crops, except peas, produced higher yields with farm manure than with mineral fertilizers.

## Physical Condition

Many researchers have attributed the effect of one crop upon another to the effect of the preceding crop on the physical condition of the soil. This effect has been attributed particularly to perennial grasses and legumes. There are numerous ways of measuring the physical condition of the soil. Not all of these measurements can be directly related to the growth of the crop. They are presented here without dealing with their relationship to crop production in most cases.

### Aggregate Stability

Many workers have used aggregate stability or the number of water-stable soil aggregates to give an indication of the structure or physical condition of the soil. The theory is that the greater the number of water-stable soil aggregates the better the physical condition, and better crop growth should follow. van Bavel and Schaller (1951), USA, found that the degree of soil aggregation under continuous corn was about half as high as that in rotations and a significant correlation existed between degree of aggregation and yield of corn. Bireck and Smierzchalski (1957), Poland, found that grasses improved soil aggregation and increased the carbon content more than did legumes. Brill, Campbell, and Blake (1959), New Jersey, USA, found that aggregate stability was greater under a 3-year rotation of potatoes–wheat–hay than under a monoculture of potatoes. Doyle and Hamlyn (1960), Canada, found that grass increased and potatoes decreased the number of water-stable aggregates, the porosity, organic matter content and cation exchange capacity of the soil. Förgeteg (1957), Hungary, found that grass, cereals and flax with their greater root residues increased the number of water-stable aggregates, while potatoes and fallow decreased them. Greacen (1958), Australia, found the degree of aggregation high under grass and clover and low under cultivation.

Koblet and Wehrli (1959), and Wehrli (1958), Germany, found the aggregate stability to be higher under grass than under clover, but the effect lasted only 1 year. Bolton and Webber (1952), in extensive work in Canada, found the degree of aggregation to be increased by crops in the order: bluegrass, alfalfa and brome second year, alfalfa–brome first year, oats and continuous corn. Organic matter content was an important factor. Jabonski (1957), Poland, reported that grass–legume mixtures had a better effect on soil aggregation than legumes alone. The structure was better, also, after perennial grasses and legumes than after annual legumes. There was no correlation between the number of water-stable aggregates and the yield of crops following. Low, Piper, and Roberts (1963), Scotland, found that a 3-year ley increased the number of soil aggregates and decreased the draw bar pull, which indicated a superior physical condition. The effects were still apparent after 2 years of arable culture. With 1-year ley there were no such results.

Mazurak and Ramig (1963) and Mazurak, Valassis, and Harris (1954), Nebraska, USA, found the number of water-stable aggregates under continuous potatoes to be 1.79; in a 3-year rotation 1.97; and in a 6-year rotation 3.21 (geometric mean diameter). Lungu (1958), Romania, found that mixed grass–legume meadows increased the number of water-stable aggregates $> 0.25$ mm diameter by 161 and 196 percent respectively in the second and third years from sowing. The soil was a Chestnut-brown Chernozem. Sobolev (1956), USSR, found that the percentage of aggregates $< 1$ mm decreased from 34.22 under perennial herbage to 19.18 under potatoes, 18.96 under fallow, 18.71 under winter wheat, and 18.11 under oats. It is quite unusual for the number of aggregates to be higher under fallow and row crops than under cereals. Strickling (1957), USA, studied 13 different cropping systems. He found that cereals, grass and clover improved soil aggregation and increased the organic matter content, whereas soybeans, corn, and fallow had the opposite effect.

Tjaglo (1958), Czechoslovakia, showed that grass and clover increased the number of water-stable soil aggregates; potatoes and sugar beets destroyed them. Uhlen (1963), The Netherlands, reported a greater degree of water-stable aggregation as an indication of improved physical condition under clover and grass compared with cereals, potatoes or sugar beets. Uhreczky (1957), also in Czechoslovakia, found that soil structure, as measured by aggregate analysis, improved under clover and grass. The effect lasted about 3 years. Webber (1965), Canada, reported that grasses and legumes increased the amount of soil polysaccharides and the number of aggregates in crop sequences. Wehrli (1958), Germany, reported better soil aggregation under grass than under clover. Toogood and Lynch (1959), Canada, found that a 5-year rotation with grass and legumes showed double the degree of aggregation and the amount of polysaccharides in the soil than was found in wheat–fallow. He measured aggregation by mean–weight–diameter.

## Structure — General

Several writers referred only to general structure improvement as an indication of physical condition. Börringer (1954), Germany, found that grass leys gave better crumb structure than did legume leys. Dospekhov (1960), USSR, found that leys generally improved the structure, porosity, and water permeability of the soil. Oden and Lundh (1959), Sweden, found that an increase in the intensity of growing sugar beets harmed the soil structure and reduced yields in spite of sufficient fertilizing. Spicka (1956), Germany, in experiments on various soil types and with 20 different crops, established that under dry conditions clay soils had greater cloddiness, specific resistance and density after root crops than after winter crops such as cereals and rape. Thatcher and Willard (1962), Ohio, USA, conclude that with enough fertilizer, 1 year in 4 or 5 years, meadows may maintain even a moderately heavy soil in good physical condition. Continuous cropping with cereals on heavy soils is disastrous without heavy fertilizing. Theron and Haylett (1953) referred to the fact that no legume was available to be grown in the dry farming areas of South Africa. It was found, however, that Rhodes grass grown for several years restored soil structure and humus content. Wagner (1961), Germany, referred to experimental results in which grass and clover improved the structure of Chernozem soils for 2 years after plowing the ley. This was followed by a decline in the third year. The effect was attributed to organic matter in the soil. Williamson, Pringle, and Coutts (1956), Scotland, concluded that grass leys gave good crumb structure.

## Erosion

Much has been written concerning the effect of crops or soil cover on erosion. Grass and legumes are considered to be excellent crops for erosion prevention. Only two references are given. Horner (1960), USA, listed several crops or rotations in order of their capacity to prevent erosion: alfalfa, sweet clover, Hubam clover – wheat, peas (green manure) – wheat, peas (seed) – wheat, summerfallow wheat. The soil nitrogen content was increased by the legumes. Wheat after legumes yielded 50 percent more than wheat after fallow. Ripley (1941), Canada, showed that alfalfa and timothy were superior to oats in controlling runoff of both water and soil. Fallow and row crops did not prevent erosion even when cultivated on the contour.

## Moisture and Crop Cover

Crops differ in their water requirements and, therefore, in their effect on the moisture in the soil. Summerfallow was introduced into Canada and other countries to conserve moisture and to increase the yield of the crop grown subsequently.

Brown (1964) reviewed the literature on the effects of cropping on moisture in the dryland cropping areas of the northern and central great plains area in USA. He listed 86 references. He concluded that in the Chernozem, Chestnut and Brown soil areas legumes and grasses usually depressed the yields of following crops and depleted the soil moisture, sweet clover to 9 feet and grasses to about 6 feet. In the higher rainfall areas legumes increased the yield of corn and small grains. Byalyi (1962), USSR, showed that moisture consumption was high by perennial grasses and clovers and low by sunflowers.

Krutikov (1960), USSR, found moisture in the soil to be highest under bare fallow, lower under rye after fallow and still lower under spring wheat following rye. He maintained that in this area of pale Chestnut Solonetz-like soils, irrigation is essential for high yields. Mazurak, Asper, and Rhoades (1955) found that the water intake after 2 hours of irrigation was 30.6 cm with unmanured alfalfa, 16.2 cm with potatoes after a legume and 0.5 with continuous corn. Where manure was applied to the crops in each case, the intake was considerably higher. This was on a Chestnut soil after 39 years of cropping. Robinson and Jacques (1958), New Zealand, found the moisture reserves under bare fallow higher than under crops. Rodionovskiĭ (1959), USSR, recorded similar results and found that the loss of spring moisture available to plants during their vegetative period was 19.6 to 35 percent in bare fallow, 69.2 to 92 percent under winter wheat and 82.4 to 90.4 under perennial herbage.

## Salinity

Only one reference was found in the recent literature on the effects of cropping on soil salinity. Blizhin (1958), Germany, found that cropping perennial herbage for several years resulted in the desalinization of the soil. Soil under continuous cotton, however, became quite salinized.

# ROTATION RESEARCH BY THE CANADA DEPARTMENT OF AGRICULTURE

## Background Information

Before 1959, the Experimental Farm Service, and after the reorganization in 1959, the Research Branch, of the Canada Department of Agriculture, has been in a unique position to carry on field and laboratory work on crop rotations. Over the years 60 experimental farms and laboratories and 220 illustration stations or special project farms have been located in various regions across Canada where research could be done in various soil and climatic zones and on different soil types.

The first rotation experiments were set up in Canada at the Central Experimental Farm, Ottawa, in 1888. These were revised in 1911 and expanded to other units. This was before experimental design and statistical analyses had been developed extensively. Consequently, the experiments were not replicated, or designed, for extensive analyses of the results. Some of the experiments, in continuous operation for 55 years, have provided information that could not have been obtained in short-term projects, no matter how well they were designed. When the long-term results were confirmed in a considerable number of well-designed short-term experiments, conclusions were drawn with reasonable authority.

In this publication, the great mass of information that has been obtained over the years is brought together. These data give the possible cropping systems for various regions in Canada, which may apply to other arid and semiarid countries of the middle latitudes.

In the early experiments, considerable importance was placed on the length of rotation and the arrangement of crops in the rotation. Continuous cropping was compared with 1, 2, 3 up to 10 years in the rotation. The shorter rotations usually included cash crops such as cereals, forage seed crops and vegetables or canning crops. The longer rotations were for the production of coarse grains and forage for mixed or livestock farming. Considerable attention was given to weed, insect and disease control. The soil fertility level was important, as was crop adaptation, to climatic and soil conditions.

These points are still important, but new technologies have changed the emphasis. Chemical fertilizers, herbicides, insecticides and fungicides have relieved, if not solved, many of the previous problems. Disease-, frost- and drought-resistant varieties have revolutionized crop production. Mechanization has completely changed cultivating, seeding, harvesting and processing operations. Agriculture has a new look. Rotation needs also have changed. Years of research have developed reliable information for setting up cropping systems for any type of farming in northern areas. Discussion is divided into two sections: the more humid five provinces of Eastern Canada, and the semiarid three Prairie Provinces and British Columbia.

## Eastern Canada

The first group of experimental results covers a number of projects on crop-sequence experiments, which give information about the effects of individual crops on those that follow. Most of the experiments are set up in a 3-year rotation or sequence: the first year is preparation or balancing year; the second year, preceding or affecting crops are grown; the third year, the succeeding or affected crops are grown.

### The Effect of Crops on Following Crops

#### *Ottawa, Ontario—Brown Forest Grenville Loam Soil*

A crop-sequence experiment was started in Ottawa, Ontario, in 1934. The early work, 1934–1939, was discussed quite thoroughly by Ripley (1941). The work from 1935 to 1944 was further reviewed by MacLean (1948), whose data have been used in this publication.

*Central Experimental Farm, Ottawa. A crop-sequence experiment is shown at the extreme right and center.*

Table 2. Effect of different preceding crops on the yields of five succeeding crops

| Preceding crops | Average yield of succeeding crops* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No manure | | | | | Manure, 12 tons/acre every 3 years | | | | |
| | Corn, tons | Mangels, tons | Potatoes, bu | Rye, bu | Oats, bu | Corn, tons | Mangels, tons | Potatoes, bu | Rye, bu | Oats, bu |
| Alfalfa | 16.21 | 24.7 | 182.4 | 35.5 | 58.6 | 17.74 | 33.1 | 265.9 | 45.0 | 61.8 |
| Red clover | 16.13 | 24.5 | 174.4 | 32.9 | 53.6 | 18.45 | 31.2 | 255.6 | 40.7 | 62.4 |
| Timothy | 14.43 | 22.1 | 186.4 | 23.7 | 48.5 | 16.37 | 29.2 | 262.2 | 28.9 | 48.3 |
| Rye | 15.22 | 23.4 | 138.9 | 25.1 | 51.0 | 17.24 | 27.5 | 232.6 | 31.1 | 60.5 |
| Summerfallow | 13.99 | 25.4 | 148.0 | 36.7 | 50.5 | 14.94 | 28.0 | 222.1 | 41.5 | 67.1 |
| Oats | 13.55 | 21.2 | 125.6 | 25.8 | 48.7 | 14.78 | 24.7 | 226.7 | 25.2 | 49.2 |
| Corn | 13.74 | 22.6 | 131.3 | 26.1 | 51.7 | 14.37 | 27.5 | 227.3 | 30.7 | 57.6 |
| Potatoes | 13.50 | 24.9 | 135.6 | 38.7 | 56.0 | 13.56 | 26.3 | 160.7 | 31.5 | 50.6 |
| Average | 14.60 | 23.6 | 152.8 | 30.6 | 52.3 | 15.93 | 28.4 | 231.6 | 34.3 | 57.2 |
| Increase low to high preceding crop | 2.71 | 4.2 | 60.8 | 15.0 | 10.1 | 4.89 | 8.4 | 105.2 | 19.8 | 18.8 |

* 10-year average yield per acre for corn, rye, and oats;
9-year average for mangels (crop failure 1937) and for potatoes (crop failure 1943).

The experiment was conducted on a Brown Forest Grenville loam soil. The pH values of 7.38 to 7.66 showed slightly alkaline conditions. The organic matter level at 3.3 to 4.6 percent and total nitrogen content of 0.174 to 0.264 percent were high. However, the level of soluble phosphorus (Truog method) was low at 0.0016 to 0.0066 percent, as was that of potassium (ammonium acetate extraction) at 0.002 to 0.025 percent. The wide range in these results was due to the fact that the areas sampled had been under various crops.

Eight preceding crops were grown and their effects were noted in the yields of five succeeding crops. The treatments were in duplicate; one received no additional fertility and the other an application of 12 tons of well-rotted manure in the preparation year of the 3-year rotation.

The 10-year average yields for the succeeding crops are presented in Table 2.

Manure was not particularly effective on this rather fertile soil. Since the phosphorus level is low, better results might have been obtained if the manure had been supplemented with superphosphate.

There was considerable difference in the response of the various succeding crops to the eight preceding crops. However, all crops were favorably influenced by the legumes alfalfa and red clover, in agreement with the results of Doll and Link (1957), Duley (1960), Friessleben (1964), Kaminska (1965), Ruthowski (1962*b*) and others. Timothy was a poor preceding crop; potato

*Preceding crops of alfalfa at Ottawa. Rye is in the background.*

*Preceding crops of timothy, red clover, oats and rye at Ottawa, from foreground to background.*

*Rye after alfalfa yielded a 10-year average of 35.5 bushels per acre* (see *Table 2).*

*Rye after red clover yielded a 10-year average of 32.9 bushels per acre* (see *Table 2*).

*Rye after timothy yielded a 10-year average of 23.7 bushels per acre* (see *Table 2*).

*Rye after rye yielded a 10-year average of 25.1 bushels per acre* (see *Table 2*).

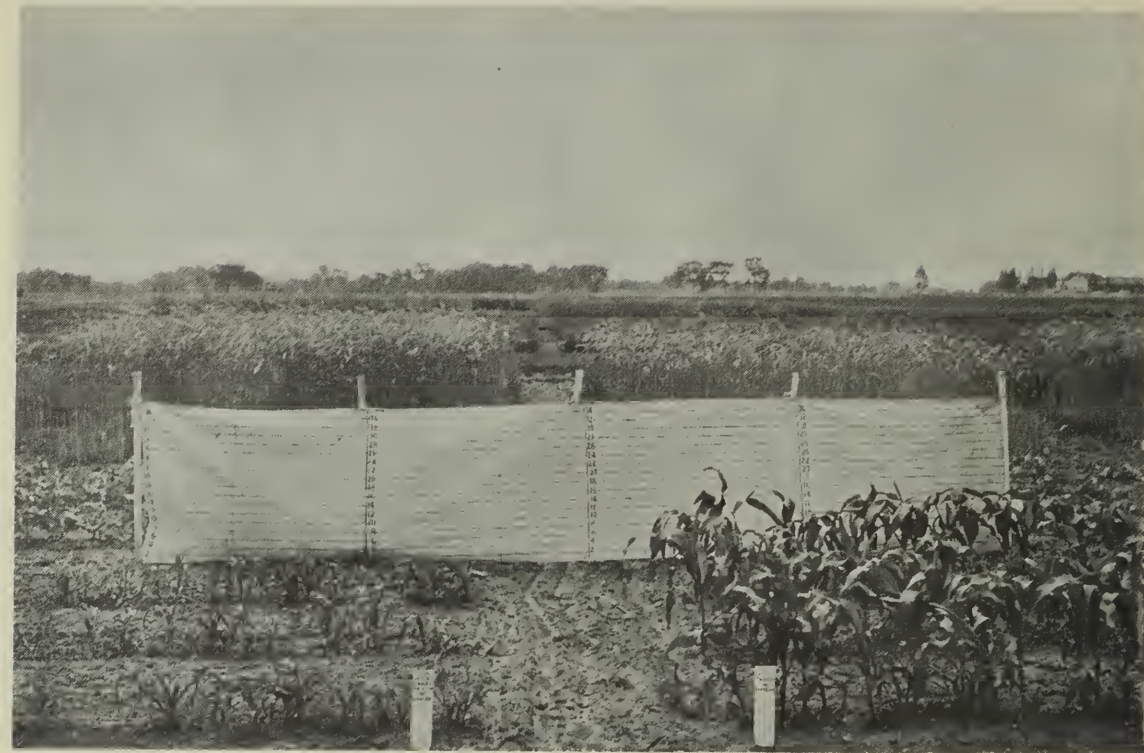
*Rye after summerfallow yielded a 10-year average of 36.7 bushels per acre* (see *Table 2*).

*Rye after oats yielded a 10-year average of 25.8 bushels per acre* (see *Table 2).*

*Rye after corn yielded a 10-year average of 26.1 bushels per acre* (see *Table 2).*

*Rye after potatoes yielded a 10-year average of 38.7 bushels per acre* (see *Table 2*).

*Left, corn after alfalfa yielded a 10-year average of 16.21 tons per acre. Right, corn after red clover, 16.13 tons* (see *Table 2*).
*Photo, June 1939.*



*Left, corn after summerfallow yielded a 10-year average of 13.99 tons per acre. Right, corn after timothy, 14.43 tons* (see *Table 2).*
*Photo, June 1939.*

*Left, corn after oats yielded a 10-year average of 13.55 tons per acre. Right, corn after potatoes, 13.50 tons* (see *Table 2).*
*Photo, June 1939.*

was the only crop that did well after timothy, although the other hoed crops corn and mangels produced fairly high yields. Summerfallow rated quite high as a preceding crop for mangels, rye and oats on manured land. When the loss of one crop is considered, summerfallow has no place in the agriculture of Eastern Canada, where the annual precipitation is from 25 to 43 inches.

Oats and corn were rather poor crops preceding all crops on both manured and unmanured land. Potatoes were poor preceding crops on manured land and for corn and potatoes, where no manure was applied, rye was of intermediate value as a preceding crop for all crops but rye. All crops that succeeded themselves, including corn, potatoes, rye and oats, produced low yields.

In general, the preceding crop had a greater influence on succeeding crops than did the application of 12 tons of manure every 3 years.

Chemical analyses of the soil under various crops after 5 years of cropping showed that levels of organic matter and nitrogen were higher under alfalfa, red clover, rye, oats and timothy than under summerfallow, corn, or potatoes. This agrees with Andharia, Stanford, and Schaller (1953), Balev (1950), Birecki and Smierzchalski (1957), Bishop and Atkinson (1954), Brage, Thompson, and Caldwell (1951), Cooper and Eslick (1963), Eich (1964), and others. Drover (1956), in Australia, Fritschen and Hobbs (1958), in USA, and Klapp (1961), in Germany, reported the opposite effect.

Sod crops such as perennial grasses and legumes usually tend to improve the soil. Lewis, Proctor, and Hood (1960), and Chizhevskii and Charuiskaya (1958) claimed that grass and legume crops were more beneficial if left down several years than if grown for only 1 year. To obtain further information, the following experiment was begun in Ottawa in 1946: alfalfa was grown for 1, 2 and 4 years; timothy for 2 years; corn, peas and oats for 1 year; and an area was summerfallowed for 1 year. Then oats and potatoes were grown to measure the effects. The average yields of the succeeding crops supplied by Cabana (1958) are presented in Table 3.

Table 3. Effect of sod crops for 1, 2 and 4 years, 1946–1958

| Preceding crops | Years | Average yield of succeeding crops, bushels per acre | |
|---|---|---|---|
| | | Oats | Potatoes |
| Alfalfa | 4 | 61.5 | 206.7 |
| Alfalfa | 2 | 57.4 | 199.3 |
| Alfalfa | 1 | 58.4 | 160.5 |
| Timothy | 2 | 38.7 | 170.2 |
| Corn | 1 | 46.9 | 130.0 |
| Peas | 1 | 55.4 | — |
| Oats | 1 | 46.6 | 155.3 |
| Summerfallow | 1 | 61.4 | — |
| Continuous oats | – | 45.5 | — |

Table 4. Yield of indicator crops after various other crops at Kapuskasing, Ontario

| Preceding crop | Manure applied, tons/acre | Oats 15 years, bu/acre | Barley 16 years, bu/acre | Oats, peas, vetch 16 years, tons DM | Potatoes 13 years, bu/acre |
|---|---|---|---|---|---|
| Alfalfa | 12 | 71.0 | 55.9 | 2.91 | 222.0 |
| Sweet clover | 12 | 68.8 | 54.1 | 2.84 | 223.1 |
| Red clover | 12 | 77.6 | 55.9 | 2.97 | 239.3 |
| Timothy | 12 | 57.7 | 43.5 | 2.61 | 218.7 |
| Barley | 12 | 49.9 | 34.3 | 2.41 | 185.3 |
| Oats | 12 | 44.4 | 36.7 | 2.27 | 182.4 |
| Oats, peas, vetch | 12 | 54.2 | 41.2 | 2.46 | 185.0 |
| Potatoes | 12 | 60.2 | 45.9 | 2.53 | 157.2 |
| Sunflowers | 12 | 56.1 | 43.8 | 2.45 | 171.2 |
| Summerfallow | 12 | 60.0 | 48.4 | 2.51 | 172.1 |
| Red clover | No manure | 66.0 | 48.3 | 2.67 | 202.1 |
| Timothy | No manure | 49.7 | 38.0 | 2.34 | 196.8 |
| Increase from manure on red clover | | 11.6 | 7.6 | 0.30 | 43.2 |
| Increase from manure on timothy | | 8.0 | 5.5 | 0.27 | 21.9 |
| Increase low to high preceding crop | | 33.2 | 21.6 | 0.70 | 82.1 |

The results obtained during the 12-year period 1946 to 1958 showed that alfalfa is a good preceding crop for potatoes, particularly, and also for oats. The yields were better after 4 years of alfalfa than after 1 or 2 years. Oats produced a good yield after summerfallow, but it took 2 years to produce 61.4 bushels per acre and, therefore, the yield per acre was equivalent to only 30.7 bushels. Corn and oats were poor preceding crops.

## *Kapuskasing, Ontario—Gray Wooded Clay Soil*

In 1941 a crop-sequence experiment similar to the Ottawa project was begun at Kapuskasing on a Gray Wooded clay soil of northern Ontario (*see* Figure 2). The soil was low in organic matter and nitrogen content, although it was overlaid with muck soil of varying depth. The area has an annual precipitation of about 27.5 inches and cool temperatures and low evaporation.

Four succeeding crops were grown following 10 preceding crops manured at 12 tons per acre once in 3 years. Red clover and timothy check plots without manure were included. The average yields of succeeding crops for the 16-year period supplied by Dermine (1956) are presented in Table 4.

All succeeding crops produced well after the legume crops, especially after red clover, which grew better than alfalfa or sweet clover in the Kapuskasing area and was therefore more effective. Even without manure, red clover was a good preceding crop. Timothy, where manure was applied, was a good preceding crop, but without manure it did not produce enough growth to provide sufficient crop residue to improve the physical condition of

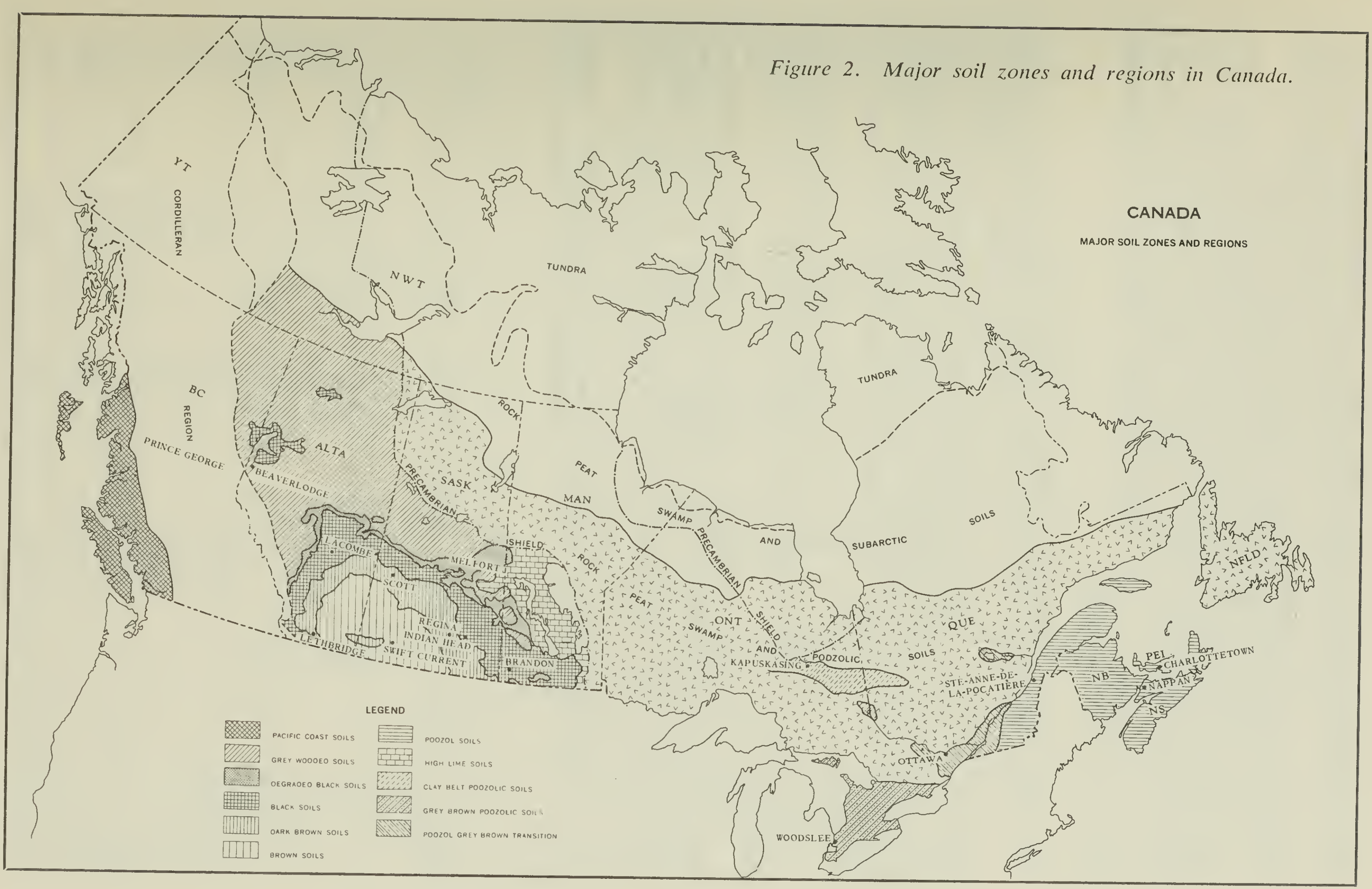



*Figure 2. Major soil zones and regions in Canada.*

this fine-textured clay soil. This improvement in the physical condition of the soil is the beneficial factor attributed to timothy and other grasses by many researchers — Doyle and Hamlyn (1960), Förgeteg (1957), Greacen (1958), Bolton and Webber (1952), Jabonski (1957), and many others.

Oats, barley and sunflowers were poor preceding crops in all cases. Oats, barley and potatoes each produced the lowest yield following itself. Oats, peas and vetch yielded low after oats, barley and oats, and peas and vetch. Increases were greater between high and low effects of crops than between manured and unmanured red clover and timothy, which shows a greater effect due to crop than to manure.

## *Ste. Anne de la Pocatière, Quebec—Podzol Soil*

A crop-sequence experiment similar to those at Ottawa and Kapuskasing was established in 1939 at Ste. Anne de la Pocatière, Quebec, located in the Podzol soil zone (*see* Figure 2). The experiment was conducted on La Pocatière clay Humic Gleysol. This soil is well supplied with organic matter (6.63 to 9.50 percent) and nitrogen (0.23 to 0.31 percent), and is acid in reaction (pH 5.6 to 6.4). The annual precipitation is 35.45 inches. The temperature and evaporation are low.

Four succeeding crops were grown after eight preceding crops. The average yields for the succeeding crops supplied by Godbout (1951) are presented in Table 5.

The yields of the succeeding crops all show a favorable response to alfalfa, although the yield of barley was higher after summerfallow and that of oats higher after potatoes. Summerfallow, generally, was quite favorable before all four crops. Red clover was the third most satisfactory preceding crop. The yields of all succeeding crops were low following timothy. There was a considerable effect of preceding crops on those succeeding. Potatoes yielded 119.6 bushels more following alfalfa than after timothy. Swedes

Table 5. Effect of crops on succeeding crops at Ste. Anne de la Pocatière, Quebec

| Preceding crop | Succeeding crops average yield/acre for 9 years | | | |
|---|---|---|---|---|
| | Potatoes, bu | Swedes, ton | Barley, bu | Oats, bu |
| Alfalfa | 229.7 | 13.68 | 47.6 | 65.4 |
| Red clover | 223.0 | 9.51 | 43.1 | 62.4 |
| Summerfallow | 184.1 | 9.40 | 48.3 | 64.0 |
| Potatoes | 177.1 | 9.09 | 46.3 | 66.5 |
| Peas | 189.0 | 9.26 | 37.0 | 54.4 |
| Oats | 182.2 | 10.97 | 28.4 | 49.0 |
| Swedes | 143.4 | 6.15 | 33.0 | 53.8 |
| Timothy | 110.1 | 6.08 | 22.5 | 40.9 |
| Increase low to high preceding crop | 119.6 | 7.60 | 25.8 | 25.6 |

yielded 7.60 tons more after alfalfa than after timothy. Barley yielded 25 bushels more after summerfallow than after timothy, and oats 25.6 more after potatoes than after timothy.

It is difficult to explain why some of these differences occur. Alfalfa is generally considered a beneficial crop because it adds nitrogen to the soil and its extensive root systems improve the physical condition. The levels of organic matter and nitrogen were originally high in this soil. Both were increased, however, by alfalfa as shown in Tables 6 and 7. Red clover affected both crops and soil in a manner similar to alfalfa.

Table 6. Percentage of organic matter in soil following various crops at Ste. Anne de la Pocatière, Quebec

| Preceding crop | Succeeding crops | | | | |
|---|---|---|---|---|---|
| | Potatoes | Swedes | Barley | Oats | Average four crops |
| Alfalfa | 8.24 | 8.13 | 8.82 | 8.78 | 8.49 |
| Red clover | 7.38 | 7.27 | 7.29 | 8.02 | 7.49 |
| Summerfallow | 7.17 | 7.04 | 7.36 | 7.56 | 7.28 |
| Potatoes | 7.32 | 7.30 | 7.68 | 7.72 | 7.51 |
| Peas | 7.71 | 7.15 | 7.80 | 8.15 | 7.70 |
| Oats | 9.34 | 9.37 | 9.50 | 9.39 | 9.40 |
| Swedes | 7.41 | 7.10 | 7.21 | 6.63 | 7.09 |
| Timothy | 7.02 | 6.78 | 7.23 | 7.40 | 7.17 |

Table 7. Percentage of nitrogen in soil following various crops at Ste. Anne de la Pocatière, Quebec

| Preceding crop | Succeeding crops | | | | |
|---|---|---|---|---|---|
| | Potatoes | Swedes | Barley | Oats | Average four crops |
| Alfalfa | 0.285 | 0.275 | 0.310 | 0.295 | 0.290 |
| Red clover | 0.265 | 0.260 | 0.250 | 0.285 | 0.265 |
| Summerfallow | 0.245 | 0.240 | 0.255 | 0.260 | 0.250 |
| Potatoes | 0.260 | 0.235 | 0.260 | 0.265 | 0.255 |
| Peas | 0.265 | 0.260 | 0.265 | 0.280 | 0.267 |
| Oats | 0.305 | 0.310 | 0.305 | 0.305 | 0.306 |
| Swedes | 0.240 | 0.240 | 0.230 | 0.235 | 0.236 |
| Timothy | 0.245 | 0.230 | 0.245 | 0.240 | 0.240 |

Possibly the legumes activated the large amount of nitrogen already in the soil. The increase in nitrogen would not explain the increase in yields, especially when timothy, which usually produces large amounts of residue, was followed by the lowest yields and the lowest percentage of organic matter and nitrogen. Swedes, as might be expected, were followed by low yields and

Table 8. Soil pH after various crops

| Crop | Potatoes | Swedes | Barley | Oats | Average four crops |
|---|---|---|---|---|---|
| Alfalfa | 5.7 | 5.8 | 5.8 | 5.7 | 5.7 |
| Red clover | 5.8 | 5.9 | 6.0 | 5.9 | 5.9 |
| Summerfallow | 5.8 | 5.8 | 5.7 | 5.6 | 5.7 |
| Potatoes | 5.7 | 5.8 | 5.8 | 5.8 | 5.8 |
| Peas | 5.7 | 5.8 | 5.6 | 5.6 | 5.7 |
| Oats | 5.7 | 5.9 | 5.8 | 5.7 | 5.8 |
| Swedes | 6.2 | 6.2 | 6.3 | 6.4 | 6.3 |
| Timothy | 6.1 | 6.1 | 6.1 | 6.2 | 6.1 |

Table 9. Dry weight of root residues of field crops

| Crop | Pounds of residue per acre |
|---|---|
| Potatoes | 321 |
| Soybeans | 550 |
| Wheat | 767 |
| Corn | 1160 |
| Sweet clover | 2421 |
| Alfalfa (1 year) | 3351 |
| Alfalfa (old sod) | 5108 |
| Bromegrass | 3926 |
| Bluegrass | 4900 |
| Timothy | 5600 |

lower levels of organic matter and nitrogen in the soil than other crops.

Oats was followed by low yields except following swedes, but levels of organic matter and nitrogen were higher after oats than after any other crop.

The soil reaction seemed to have little effect on yield (Table 8).

Higher yields of most crops are usually obtained on less acid soils. Even though only slight differences in pH were recorded, it was unexpected to find that, when swedes and timothy were followed by low yields of succeeding crops (Table 5), the soil pH was higher than after any of the other crops. Yields and pH following oats and peas were rather low.

## Root Residues from Various Crops

Legume and grass crops generally produce beneficial effects on the soil and on the crops that follow them in a rotation. One reason is that both legumes and grasses produce large amounts of root and other residues, which add organic matter to the soil. Researchers working separately at Ottawa, Ontario, and Ohio and Nebraska, USA, determined the amount of roots produced by various crops, as shown in Table 9.

The amount of roots produced by potatoes, soybeans, wheat and corn is much less than that produced by the other grasses and legumes listed. Alfalfa, sweet clover and soybeans produce thick, deeply growing taproots, which affect the soil to considerable depth. The perennial grass roots grow nearer the surface, are very fibrous and spread extensively. These results agree with the findings of other workers, Andharia, Stanford, and Schaller (1953), Chizhevskii and Charuiskaya (1958), and Clement (1961).

## Rotations for Eastern Canada

Rotations do not need to be set up in a regular sequence or number of years in a rotation. An arrangement of crops can be used to suit the system of farming which is practiced.

### *Corn–Grain–Hay Rotation*

In Eastern Canada the greater part of the agricultural area is in mixed farming. The crops are chiefly rough grains, barley and oats, and forage crops for livestock feed. Hay can be seeded with a companion crop of oats or barley. Corn and alfalfa can be grown in the Gray Brown Podzolic and Podzolic Gray Brown transition soil regions (*see* Figure 2). A crop rotation or cropping system can be set up to suit the livestock needs if this is to be the main source of revenue. A possible plan for a 250-acre farm is shown in Table 10.

Table 10 gives the arrangement for 200 acres of good agricultural land and 50 acres of woodlot or rough pasture set up in a 5-year rotation. The yields per acre are from average yields obtained on Grenville loam at the Experimental Farm, Ottawa. This system should produce enough feed for the livestock listed in Table 11.

The feed requirements of a herd of dairy cattle, some hogs and a few hens are amply provided in the list in Table 11. Some protein supplement and some tankage for hogs and laying mash for poultry might have to be bought. Besides the 40 acres of pasture, extra pasture might be provided in hay aftermath, part of the surplus oat crop and some of the 50 acres of improved rough pasture. The feed produced could be switched to support a beef herd. Little fertilizer would be needed, since manure would be returned to the soil. The manure might be supplemented with stable phosphate or

Table 10. Crop production on 200 acres

| Year of rotation | Crops | Acres | Probable yield per acre | Total production |
|---|---|---|---|---|
| 1 | Barley | 40 | 45 bushels | 86,400 pounds |
| 2 | Corn silage | 20 | 14 tons | 280 tons |
| | Oats | 20 | 60 bushels | 40,800 pounds |
| 3 | Oats | 40 | 60 bushels | 81,600 pounds |
| 4 | Alfalfa hay | 40 | 3 tons | 120 tons |
| 5 | Pasture | 40 | 1 animal unit | 40 animals |

Table 11. Feed requirements for livestock

| Livestock | Silage | | Hay | | Oats | | Barley | |
|---|---|---|---|---|---|---|---|---|
| | Per animal per day, pounds | Total per year, tons | Per animal per day, pounds | Total per year, tons | Per animal per day, pounds | Total per year, pounds | Per animal per day, pounds | Total per year, pounds |
| 75 cows (200 days) | 30 | 225 | 12 | 90 | 3 | 45,000 | 2.3 | 34,500 |
| 12 two-year-olds | 20 | 24 | 10 | 12 | — | — | — | — |
| 12 yearlings | 15 | 18 | 7 | 8 | — | — | — | — |
| 12 calves | 5 | 6 | 4 | 5 | 1 | 2,400 | — | — |
| 1 bull | 10 | 2 | 12 | 2 | — | — | — | — |
| 8 sows (365 days) | — | — | — | — | 3.3 | 9,636 | 2.7 | 7,884 |
| 100 hogs | — | — | — | — | — | 32,000 | — | 38,000 |
| 150 hens (365 days) | — | — | — | — | — | 6,000 | — | 6,000 |
| Total | — | 275 | — | 117 | — | 95,036 | — | 86,384 |
| Pasture — for approximately 75 animal units for 165 days | | | | | | | | |

superphosphate applied to the fields directly. If some cash crops were preferred, the livestock could be reduced. This rotation could be used under various circumstances.

## *Grassland Rotations*

In some areas such as in much of the Podzolic soil zone (*see* Figure 2) corn and alfalfa cannot be grown satisfactorily. Podzolic soils are mostly too acid in reaction for alfalfa and the climate is too cool for corn. Oats, Ladino clover and grasses such as timothy, however, can be grown quite satisfactorily and will produce almost as much feed as the 5-year rotation given in Table 10.

Three rotations were compared at the Experimental Farm at Ottawa, Ontario. Ottawa is not in the Podzolic soil zone, but the experiments show the production that might be obtained. From 1953 to 1958 a corn–grain–hay rotation was compared with two grassland rotations in which all crops were harvested as hay, silage or pasture. One rotation included Ladino clover and timothy in the hay seed mixture; the other, alfalfa and timothy. Analyses for protein and total digestible nutrients were made by the Nutrition Section of the Chemistry Division. Production figures are presented in Table 12.

Table 12. Comparisons of corn, grain, hay and grassland rotations

| Crops | Yield per acre, pounds | Dry matter, percent | Protein, percent | TDN, percent | Total dry matter, pounds | Total protein, pounds | Total TDN, pounds |
|---|---|---|---|---|---|---|---|
| Corn, grain, hay rotation: | | | | | | | |
| Corn | 29,179 | 27.4 | 0.82 | 18.1 | 7,995 | 239 | 5,281 |
| Oats, grain | 2,608 | 90.0 | 9.40 | 70.0 | 2,347 | 245 | 1,826 |
| Hay | 5,492 | 90.0 | 7.80 | 51.0 | 4,943 | 428 | 1,800 |
| Pasture | 31,727 | 22.0 | 3.00 | 15.0 | 6,980 | 952 | 4,759 |
| Oats, grain | 2,251 | 90.0 | 9.40 | 70.0 | 2,026 | 212 | 1,576 |
| Total | — | — | — | — | 24,291 | 2,076 | 15,242 |
| Grassland rotation (oats, Ladino clover, timothy): | | | | | | | |
| Oats, silage | 14,688 | 26.6 | 1.9 | 17.0 | 3,907 | 279 | 2,497 |
| Hay, Ladino clover, timothy | 4,026 | 88.0 | 8.5 | 53.0 | 3,543 | 342 | 2,134 |
| Silage, Ladino clover, timothy | 15,472 | 27.3 | 3.8 | 18.9 | 4,224 | 588 | 2,924 |
| Silage, Ladino clover, timothy | 16,760 | 20.0 | 3.8 | 18.9 | 3,352 | 637 | 3,167 |
| Pasture, Ladino clover, timothy | 27,150 | 20.0 | 3.6 | 13.8 | 5,430 | 977 | 3,747 |
| Total | — | — | — | — | 20,456 | 2,823 | 14,469 |
| Grassland rotation (oats, alfalfa, timothy): | | | | | | | |
| Oats, silage | 14,688 | 26.6 | 1.9 | 17.0 | 3,907 | 279 | 2,497 |
| Hay, alfalfa, timothy | 4,685 | 89.0 | 10.5 | 50.0 | 4,170 | 492 | 2,342 |
| Silage, alfalfa, timothy | 25,400 | 20.5 | 2.9 | 19.0 | 5,207 | 737 | 4,816 |
| Silage, alfalfa, timothy | 21,042 | 19.0 | 2.9 | 20.5 | 3,998 | 610 | 4,314 |
| Pasture, alfalfa, timothy | 30,380 | 20.0 | 3.4 | 13.8 | 6,077 | 1,032 | 4,192 |
| Total | — | — | — | — | 23,359 | 3,150 | 18,161 |

The yields of various crops shown in Table 12 are greater than those shown in Table 11, which were the average yields for Eastern Canada. However, they are not exceptionally high yields, but they show the general relationship in production among the three types of rotation. The total production of dry matter was 932 pounds lower in the Ladino clover – grass rotation and 3,835 pounds lower in the alfalfa–grass rotation than in the corn–grain–hay rotation. The total yield of protein was greater, however, in both grassland rotations. Total digestible nutrients were highest in the alfalfa–grass rotation and only 773 pounds lower in the Ladino clover – timothy than in the corn–oats–hay rotation.

The potential for feed production is high in all three rotations and is useful for mixed or livestock farming in Eastern Canada and British Columbia. The three rotations are excellent for soil erosion control and soil conservation. The grassland rotations are good on land with up to 10 or 15 percent slope (*see* Ripley *et al.*, 1961).

## *Cash Crop Rotations*

In many parts of Eastern Canada cash crops are grown extensively. Potatoes are grown especially in New Brunswick and Prince Edward Island, but in other areas as well. Vegetables and small fruits are produced widely near most large cities, and on organic soils in the Holland marsh in Ontario, in the Ste. Clothilde area of Quebec and in Newfoundland. Canning crops, corn, soybeans and winter wheat occupy large areas in southern Ontario.

*Cropping systems for potatoes at Charlottetown*—Considerable research has been done on the production of potatoes. Boswall (1953), at the Research Station at Charlottetown, Prince Edward Island, found that potatoes could be grown continuously on the same soil for a few years if well managed. In a 26-year experiment, however, the average yield of unfertilized potatoes grown continuously was 76.0 bushels per acre. With 1,000 pounds of a 4-8-8 fertilizer the yield was 187.8 bushels. In a 3-year rotation of potatoes, oats, red clover, the yield of potatoes increased to 139.5 bushels without fertilizers, and to 235.4 bushels with fertilizer. A combination of manure and chemical fertilizer raised the yield of potatoes in rotation to 267.9.

Manure and fertilizer were more effective than rotation in increasing the yield. Continuous potatoes should be broken with a crop of clover every 5 or 6 years.

*Cropping systems for corn at Woodslee*—In the cash crop growing area of southern Ontario, grain, corn and soybeans are grown more extensively than in any other area in Canada. They are produced usually on Brookston clay, a Humic Gleysol common to that area. The topography is fairly level and drainage is a problem. Much of the land has been tile-drained. Corn was grown continuously on much of the area for many years. Very little manure was available and grass or legume crops were not grown. Under these conditions, the original organic matter content of 10.8 percent in the virgin soil was reduced to 5.3 percent with a corresponding decrease in nitrogen content. The physical condition of the soil was greatly impaired. Its phosphorus content was naturally low, but it was well supplied with potassium. Corn yields became quite low.

In 1946, the Experimental Substation at Woodslee was set up to study the problem. Since the chief contributing factors seemed to be low levels of organic matter, nitrogen and phosphorus, emphasis was given to grass–legume crops in the rotation and to fertilizer treatments. Some of the results of this work prepared by Aylesworth (1953) are presented in Table 13 and Figure 3. Average yields are shown for the first 8-year period, 1947–1954, the second 8-year period, 1955–1962, the last year, 1962, and the 16-year period, 1947–1962. Alfalfa and soybeans in the rotation had a favorable effect on the yield of corn. The yield of corn in all periods, fertilized and unfertilized, was lowest where corn and oats were grown alternately or where corn was grown continuously.

The fertilizer application for corn was 6 pounds of N per acre, 36 pounds of $P_2O_5$ and 30 pounds of $K_2O$, and a similar application on all other crops in the first 8 years, 1947–1954. In the second period, 1955–1962, the nitrogen application on corn was increased to 100 pounds per acre. The effects of fertilizer and rotations are illustrated in Table 14 and Figure 4, which show the increases due to treatment.

In the first period of low nitrogen application, 1947–1954, fertilizer had very little effect on any cropping combination. Legumes in the rotation had

*Figure 3. Cropping systems for corn in fertilized and unfertilized rotations at Woodslee, Ontario.*

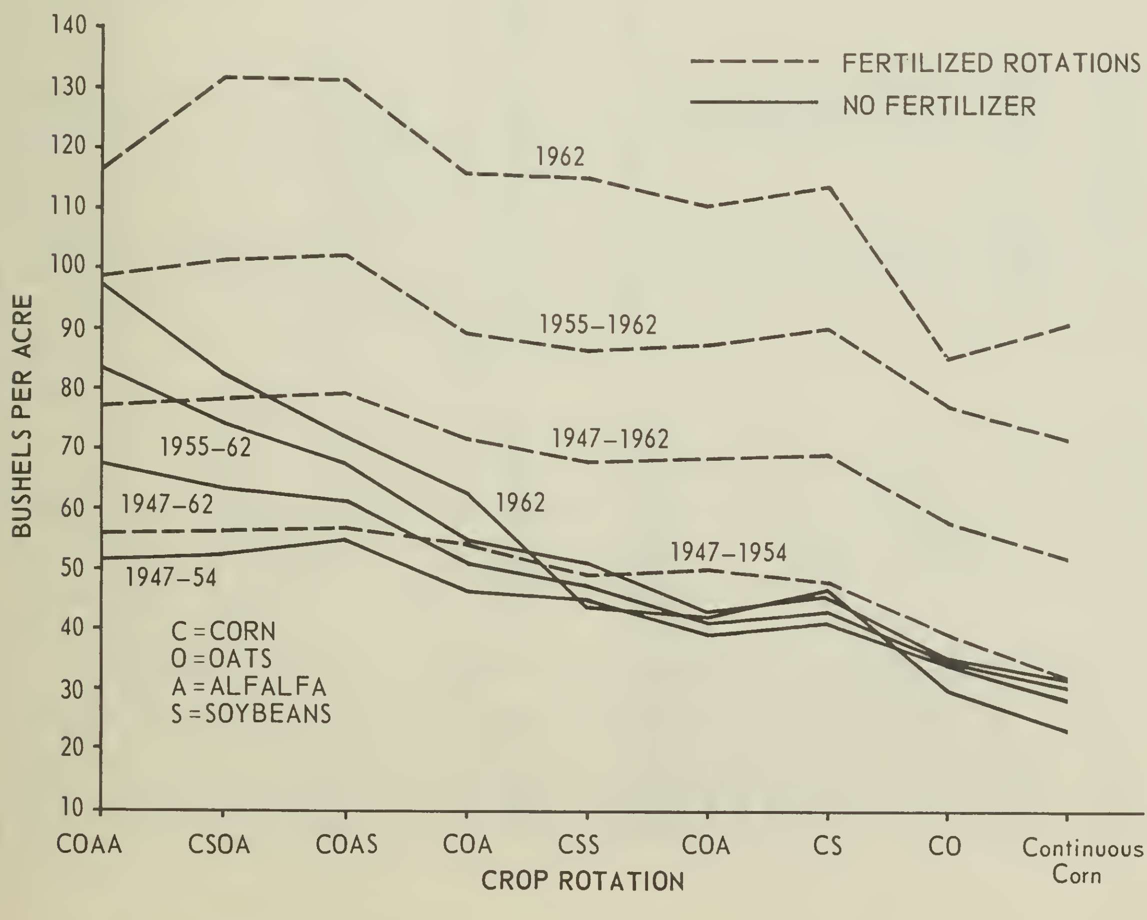


Table 13. Cropping systems for corn at Woodslee, Ontario

| Rotation | 1947–1954 | | 1955–1962 | | 1962 | | 1947–1962 | |
|---|---|---|---|---|---|---|---|---|
| | No fertilizer | Fertilizer | No fertilizer | Fertilizer | No fertilizer | Fertilizer | No fertilizer | Fertilizer |
| Corn, oats, alfalfa, alfalfa | 51.4 | 55.7 | 83.1 | 98.5 | 97.2 | 116.1 | 67.2 | 77.1 |
| Corn, soybeans, oats, alfalfa | 52.3 | 56.0 | 74.3 | 101.2 | 82.6 | 131.7 | 63.3 | 78.6 |
| Corn, oats, alfalfa, soybeans | 55.2 | 56.8 | 67.6 | 102.2 | 72.3 | 131.4 | 61.4 | 79.5 |
| Corn, oats, alfalfa | 46.8 | 54.4 | 55.6 | 90.0 | 63.5 | 116.9 | 51.2 | 72.2 |
| Corn, soybeans, soybeans | 45.2 | 49.9 | 50.4 | 87.1 | 44.4 | 115.9 | 47.8 | 68.5 |
| Corn, oats, alfalfa seed | 39.9 | 50.2 | 43.5 | 88.2 | 42.9 | 111.1 | 41.7 | 69.2 |
| Corn, soybeans | 41.7 | 48.2 | 46.1 | 90.4 | 46.2 | 114.1 | 43.9 | 69.3 |
| Corn, oats | 34.3 | 39.2 | 34.7 | 77.8 | 30.0 | 85.3 | 35.1 | 58.5 |
| Continuous corn | 28.9 | 32.1 | 31.7 | 72.1 | 23.2 | 91.3 | 30.3 | 52.1 |
| Mean all treatments | 44.0 | 49.2 | 54.1 | 89.7 | 55.8 | 112.6 | 49.1 | 69.4 |
| Mean increase from fertilizer | — | 5.2 | — | 35.6 | — | 56.8 | — | 25.3 |

Table 14. Cropping systems for corn at Woodslee, Ontario

| Rotation | Increases due to rotation and fertilizer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1947–1954 | | 1955–1962 | | 1962 | | 1947–1962 | |
| | Rotation | Fertilizer | Rotation | Fertilizer | Rotation | Fertilizer | Rotation | Fertilizer |
| Corn, oats, alfalfa, alfalfa | 22.5 | 4.3 | 51.4 | 15.4 | 75.0 | 48.9 | 36.9 | 9.9 |
| Corn, soybeans, oats, alfalfa | 23.4 | 3.7 | 42.6 | 26.9 | 59.4 | 47.1 | 33.0 | 15.3 |
| Corn, oats, alfalfa, soybeans | 26.3 | 1.6 | 35.9 | 34.6 | 49.1 | 59.1 | 31.1 | 18.1 |
| Corn, oats, alfalfa | 17.9 | 7.6 | 23.9 | 34.4 | 40.3 | 53.4 | 20.9 | 21.0 |
| Corn, soybeans, soybeans | 16.3 | 4.7 | 18.7 | 36.7 | 21.2 | 71.5 | 17.5 | 20.7 |
| Corn, oats, alfalfa seedling | 11.0 | 10.3 | 11.8 | 44.7 | 19.7 | 68.2 | 11.4 | 27.5 |
| Corn, soybeans | 12.8 | 6.5 | 14.4 | 44.3 | 23.0 | 68.0 | 13.6 | 25.4 |
| Corn, oats | 5.4 | 4.9 | 3.0 | 43.1 | 6.8 | 55.3 | 4.8 | 23.4 |
| Continuous corn | — | 3.2 | — | 40.4 | — | 68.1 | — | 21.8 |

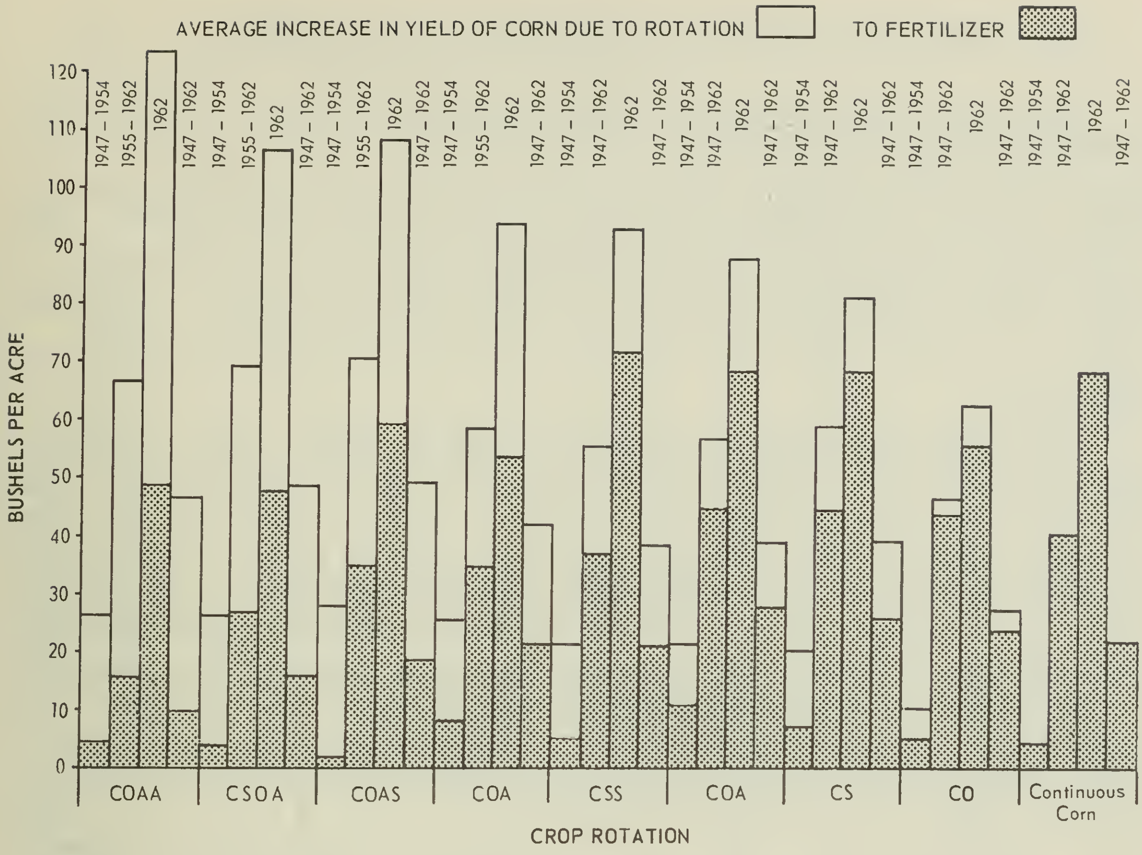



*Figure 4. Average increases in yield of corn due to rotation and to fertilizer at Woodslee, Ontario.*

a much greater effect. In the second period, 1955–1962, with the higher nitrogen application, the fertilizer was more effective than rotation in all but the first three rotations, which included two legume crops. This is demonstrated especially by the increases in 1962 that show an accumulating effect. Nitrogen appears to be the greatest limiting factor, and if more nitrogen had been added to the nonlegume rotations the corn yields might have been equal to those where legumes were used.

Where possible, however, it is desirable to grow a legume crop occasionally with most nonlegume cash crops. Legumes add nitrogen and organic matter and they improve soil aggregation, as reported by Bolton and Webber (1952). Similar results were reported by Doyle and Hamlyn (1960), Förgeteg (1957), Greacen (1958), Low, Piper, and Roberts (1963), Mazurak, Valassis, and Harris (1954), and others.

While it is possible to grow corn satisfactorily in continuous culture for several years, it is advisable if other crops such as soybeans, winter wheat or field beans are grown to grow them in rotation. This applies also to vegetable and canning crops, as shown by Hill, Bishop, and Cannon (1953). As much crop residue as possible should be returned to the soil.

## Prairie Provinces and British Columbia

The three Prairie Provinces, Manitoba, Saskatchewan and Alberta, and British Columbia, in a semiarid to subhumid region, present an entirely different situation from the rest of Canada. The mean annual precipitation ranges from 12 inches in the south to 20 inches in the north (McKay, 1965). The mean daily temperature for the year ranges from 40° F in the south to 26° F in the north. Evaporation is less in the north than in the south. Geology, climate and vegetation produce variable soil conditions in different areas.

### Soil Zones

Five distinct soil zones are shown in Figure 2. These zones respond to different methods of cropping and farming. The Brown, Dark Brown and Black soil zones have developed under grass or prairie vegetation. Wheat is the main crop grown in the area. Ranching is carried on in the foothills of the Rocky Mountains and in the drier areas. Beef cattle and sheep are produced chiefly. Some mixed farming is done in the Black soil zone. In the Degraded Black and Gray Wooded soil zones, mixed farming is practiced. Some dairying is done. Grass and legume seed crops grow well. Oats, barley and wheat are the chief grain crops. Alfalfa, sweet clover and bromegrass are the main hay crops. Crops are grown under irrigation in the drier areas of these provinces. Cropping systems for each soil zone follow.

#### *Brown Soil Zone—Swift Current, Saskatchewan*

The Research Station at Swift Current, Saskatchewan, is the only Canada Department of Agriculture Research Station located in the Brown soil zone. The Station operates 15 special project farms, which provide research information for the whole area. The mean annual precipitation at the Station is 13.90 inches. Evaporation from a free water surface from May to September is 28.89 inches and the mean annual temperature is 38.1° F. A variety of soil types are found on the Station.

Several projects on rotations have been carried out at Swift Current. A crop-sequence study was conducted during the drought years of 1931–1936. The yields were low accordingly. Wheat and oats were grown after summer-fallow and five preceding crops. The 6-year average yields recorded by Janzen (1936) are presented in Table 15.

In these dry years oats produced more pounds per acre than did wheat. Both wheat and oats gave higher yields after fallow and corn, which conserved more moisture, than after the other crops. The yield after fallow was almost three times that after wheat and oats. Wheat and oats after fallow yielded about double that after millet and peas. Therefore, in this area cereals grow best after fallow, at least in dry years.

Wheat grown continuously was compared with wheat after fallow and fallow wheat at Swift Current from 1923 to 1958. The average yields supplied by Janzen (1961) are presented in Table 16.

During the 36-year period there were seven crop failures in the continuous wheat area, three in the wheat after fallow alternately, two in the wheat after fallow and seven in wheat after wheat in the 3-year rotation. The years of

Table 15. Yields of wheat and oats per acre following various crops, Swift Current, Saskatchewan, 1931–1936

| Previous crop | Yield, bushels per acre | |
|---|---|---|
| | Wheat | Oats |
| Fallow | 10.9 | 27.2 |
| Corn | 9.7 | 21.2 |
| Wheat | 3.2 | 9.4 |
| Oats | 4.0 | 10.5 |
| Millet | 4.7 | 13.8 |
| Peas | 5.5 | 11.2 |

Table 16. Comparison of wheat rotations on sandy loam to clay loam, Swift Current, Saskatchewan, 1923–1958

| | Continuous wheat | 2-year rotation | | 3-year rotation | | |
|---|---|---|---|---|---|---|
| | | Fallow | Wheat | Fallow | Wheat | Wheat |
| Plot yield per acre | 11.6 | — | 19.4 | — | 20.0 | 12.9 |
| Rotation yield per acre | 11.6 | — | 9.7 | — | 10.9 | — |
| Number of crop failures | 7 | — | 3 | — | 2 | 7 |

crop failure have been omitted from the mean yields, which are prepared to make a 28-year average of all crops. The average yields have been higher on the wheat after fallow plots. Where the loss of crop in the fallow area is considered, the yield per acre was 9.7 bushels in the 2-year rotation, 10.9 in the 3-year rotation and 11.6 where wheat was grown continuously. In neither of the rotations did the extra yield after fallow compensate for the loss of crop.

### *Rotations on Special Project Farms*

Wheat growing after fallow and after wheat has been compared on 14 Special Project Farms in the Brown soil area of Swift Current. Comparative figures for both crops from seven farms can be shown for a significant number of years. This information supplied by Janzen (1961) is presented in Table 17.

During the period of these experiments at each Special Project Farm there was a crop failure on fallow only twice, at the Kincaid farm: Crop failures occurred on stubble 13 times: four times at Fox Valley, once at Carmichael, four times at Kincaid, twice at Shackleton and twice at Tugaske. Crop failure years were left out of the average figures. The yields after fallow were double the yields after wheat only at Fox Valley. The yield on stubble equaled the yield after fallow only at Tugaske.

In the 1948–1954 progress report of the Research Station at Swift Current it is stated, "The fallow–crop rotation system provides greater assur-

Table 17. Rotations on Project Farms, Brown soil zone, South Saskatchewan

| Farm | Mean annual precipitation, inches | Soil type | Years, average | Years of experiment | Wheat yields, bushels per acre: On fallow | Wheat yields, bushels per acre: On stubble |
|---|---|---|---|---|---|---|
| Fox Valley | 10.11 | Fox Valley L and SL | 21 | 1938–59 | 18.5 | 9.0 (4)* |
| Gravelbourg | 13.88 | Sceptre C | 9 | 1951–59 | 25.5 | 13.4 |
| Carmichael | 15.98 | Wood Mountain CL<br>Cypress CL | 18 | 1936–59 | 20.0 | 11.6 (1) |
| Kincaid | 14.20 | Haverhill CL<br>Fox Valley SiCL | 23 | 1936–59 | 20.7 (2) | 11.0 (4) |
| Shackleton | 13.38 | Fox Valley SiC–SiCL | 15 | 1940–58 | 22.6 | 12.3 (2) |
| Tugaske | 15.14 | Weyburn L | 17 | 1937–59 | 14.5 | 16.5 (2) |
| Valjean | 13.35 | Hatton FSL<br>Chaplin SL | 17 | 1940–57 | 16.6 | 11.4 |
| Average farms | 13.72 | — | — | — | 19.6 | 12.2 |

*The number of crop failures are in parentheses.

Table 18. Crop yields in rotation at Regina, Saskatchewan

| | Continuous wheat | Wheat on fallow | 3-year rotation: Wheat on fallow | 3-year rotation: Wheat on stubble | 3-year rotation, fertilized: Wheat on fallow | 3-year rotation, fertilized: Wheat on stubble | 6-year rotation | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 years 1936–60 | — | — | 23.3 | 18.3 | — | — | Wheat on fallow 26.6 | Hay 1.14 | Hay 1.08 | Wheat 19.3 | Oats 41.7 |
| 6 years 1956–61 | 8.6 | 23.6 | 24.3 | 11.4 | 24.4 | 12.9 | Wheat on fallow 22.0 | Wheat 13.6 | Hay 0.29 | Hay 0.72 | Hay 0.90 |

ance against crop failure than any other method tested." The next paragraph suggests, however, "Although summerfallowing half of the land each year is common in this area, any practice that keeps half of the land out of production and at the same time tends to expose it to erosion is open to question."

Later the conclusion is drawn: "Records of crop production at this Farm, as well as at the Substation in southwestern Saskatchewan, during the past fifteen years show that crop failures have occurred only when there is little or no moisture in the soil at seeding time. On the other hand, when there was a good reserve of moisture in stubble land, yields have compared favorably with crops on fallow."

Janzen *et al.* (1960) suggested a simple method of determining the depth of soil moisture, based on yield records from 1938 to 1959, related to soil moisture and seasonal rainfall records. They suggest that "in areas of low precipitation, do not seed stubble land unless the depth of moist soil is at least 18 inches in clay soils, 24 inches in loams, and 30 inches in sandy soils at the time of seeding." In this area of low precipitation, 12 to 15 inches per year, these conclusions seem sound (McKay, 1965). Wheat should be grown on summerfallow land except when the soil moisture at seeding time is deep enough for safe seeding on stubble land. Under these conditions wheat can be grown for many years without other crops in the rotation. Perennial grasses and legumes do not grow well in the area and are not recommended except in special circumstances. Oat hay may be grown for forage where necessary.

### *Dark Brown Soil Zone—Regina, Saskatchewan*

A special station was set up at Regina in the early thirties to study soil drifting and weed control. It is located in the Dark Brown soil zone on Regina clay. The mean annual precipitation is 14.66 inches. The mean annual temperature is 36.0° F. The average total hours of bright sunshine for the year is 2,254. Evaporation from a free water surface is 19.51 inches.

From 1936 to 1960 a 3-year rotation of summerfallow, wheat, wheat was compared with a 6-year rotation of summerfallow, wheat, hay, hay, wheat, oats. A second experiment, 1956–1961, compared continuous wheat with a 2-year rotation of summerfallow, wheat; two 3-year rotations of summerfallow, wheat, wheat, one with no fertilizer, one fertilized with 40 pounds of 11-48-0 for wheat on fallow, and 100 pounds of 16-20-0 for wheat on stubble; and a 6-year rotation of fallow, wheat, wheat, hay, hay, hay. The average yields supplied by Molberg (1961) are presented in Table 18.

In the first comparison in Table 18, wheat on fallow yielded well in the 3- and 6-year rotations; there were no crop failures in the 25 years. Wheat on stubble in the 3-year rotation had three crop failures. The 3 years were not included in the average yield, but the average yield on stubble was 5 bushels per acre less than that for wheat on fallow. In the 6-year rotation there were eight crop failures in third-year hay, three in fourth-year hay, three in wheat after hay and four in oats after wheat. The yield of wheat after hay was 7.3 bushels less than for wheat after fallow. Average hay yields with crop failure years removed were 1.14 and 1.08 tons per acre respectively in the third and fourth years.

Table 19. Crop yields in rotations on Special Project Farms, Indian Head, Saskatchewan, 7-year average, 1955–1961

| Farm | Soil type | Years | Soil zone | 2-year rot. fallow, wheat | 3-year rot. fallow, wheat | 3-year rot. stubble, wheat | 6-year rot. fallow, wheat | 6-year rot. Hay | 6-year rot. Wheat after hay |
|---|---|---|---|---|---|---|---|---|---|
| Wawota .......... | Ryerson loam | 25 | Black | — | — | — | 21.1 | 1.59 | 19.3 |
| | Canora SiCL | | | | | | | | |
| Yorkton .......... | Yorkton CL | 7 | Black | 22.2 | 19.4 | 11.1 | 22.6 | 1.75 | 16.8 |
| Kelliher .......... | Oxbow loam | 7 | Black | 26.3 | 24.5 | 16.5 | 22.8 | 0.99 | 20.5 |
| Radville .......... | Trossachs CL | 7 | Dark Brown | 22.7 | 21.8 | 9.7 | — | — | — |
| Almeda .......... | Estevan CL | 6 | Dark Brown | 25.3 | 21.1 | 14.5 | 20.2 | 0.94 | 19.6 |
| Arcola .......... | Alluvial CL | 6 | Dark Brown | 27.1 | 22.4 | 13.6 | 18.1 | 1.03 | 15.6 |
| Aylesbury ....... | Elstow CL | 8 | Dark Brown | 28.5 | 28.3 | 22.2 | — | — | — |
| Lisieux .......... | Alluvial CL | 12 | Dark Brown | 24.0 | 24.1 | 16.6 | — | — | — |
| Strasbourg ....... | Weyburn L | 14 | Dark Brown | 27.1 | 25.1 | 12.2 | — | — | — |
| Viceroy .......... | Haverhill CL | 10 | Brown | 25.2 | 24.1 | 12.9 | — | — | — |
| | | | | 25.9 | 23.8 | 16.8 | — | — | — |

Table 20. Crop yields in rotations, Scott area, Saskatchewan, Dark Brown soil zone

| Station | Soil type | Years | 2-year rot. Fallow, wheat, bushels | 3-year rot. Fallow, wheat, bushels | 3-year rot. Stubble, wheat, bushels | 6-year rotation Fallow, wheat, bushels | 6-year rotation Hay, ton | 6-year rotation Wheat after wheat, bushels | 6-year rotation Oats, bushels |
|---|---|---|---|---|---|---|---|---|---|
| Scott .................... | Scott L | 1921–64 | 18.7 | 16.8 | 14.5 | — | — | — | — |
| Scott .................... | Scott L | 1912–48 | — | 15.6 | 14.1 | 17.7 | 0.77 | 15.1 | 35.8 |
| Rosetown ................ | Elstow SC | 1946–58 | 26.5 | 24.9 | 16.4 | — | — | — | — |
| Conquest ................ | Asquith FSL | 1946–61 | 27.0 | 26.4 | 18.1 | — | — | — | — |
| *Brown soil zone* | | | | | | | | | |
| Kindersley .............. | Sceptre HC | 1931–39 | 17.7 | 15.7 | 9.9 | 15.7 | 1.04 | 6.8 | 43.4 |
| Kindersley .............. | Sceptre HC | 1927–41<br>1946–56 | 21.5 | 21.5 | 12.0 | — | — | — | — |
| Loverna ................. | — | 1946–60 | 12.2 | 18.0 | 12.9 | — | — | — | — |
| Scott .................... | Scott (fertilized) | 1930–64 | — | 20.4 | 13.7 | — | — | — | — |

In the second comparison in Table 18, continuous wheat yielded only 8.6 bushels per acre and wheat on fallow averaged almost three times as much, 23.6 in the 2-year rotation, 24.3 in the 3-year rotation, and 22.0 in the 6-year rotation. Wheat on stubble yielded about one-half that on fallow. Chemical fertilizer gave no significant increase in the yield of wheat. Hay yields were low and the crop was difficult to establish. The third year, however, the yield averaged 0.90 tons per acre, which is almost 1 ton per acre and is considered to be economical.

### *Indian Head, Saskatchewan, and Special Project Farms*

Although the Experimental Farm at Indian Head, Saskatchewan, is located in the Black soil zone, it is near the Dark Brown zone. The Experimental Farm is one of the oldest in the system. A rotation experiment that was conducted there for 54 years is reported in the Black soil zone section. From 1955 to 1961 similar work was done with 2-, 3- and 6-year rotations on Special Project Farms, most of which are located in the Dark Brown zone. McIver (1961) supplied the results that are presented in Table 19.

Six of the farms are located in the Dark Brown soil zone, three in the Black and one in the Brown soil zone. The soil type is shown in each case. Wheat yields at the Dark Brown soil zone project farm are about the same as at the main farm and are higher than in the Brown zone at Swift Current. Crop yields in the 6-year rotation have been lower than at the main farm, but the hay yields have been maintained at close to 1 ton per acre.

### *Scott, Saskatchewan*

The Experimental Farm at Scott, Saskatchewan, is located in the northern section of the Dark Brown soil zone (Figure 2). The mean annual precipitation is 13.80 inches. The mean annual temperature is 33.5° F. The hours of bright sunshine per year are 2,142. Evaporation from a free water surface is low at 18.75 inches.

Two-, 3- and 6-year rotations have been compared at the main farm and at a few special project farms. Information from these experiments has been supplied by Keys (1964) and is presented in Table 20.

Wheat yields on both fallow and stubble land at Rosetown and Conquest, in the Dark Brown soil zone, were considerably better than at Kindersley and Loverna, in the Brown soil zone. At Kindersley and Loverna and at the main farm wheat yields were somewhat lower than at either Regina or Indian Head, because of a slightly less favorable climate. Hay yields were low and this seems to be a borderline area for most hay crops. Fertilizer had no significant effect.

### *Lethbridge, Alberta*

The Research Station at Lethbridge, Alberta, is located on Lethbridge loam in the southwestern section of the Dark Brown soil zone and close to the Brown and Black soil zones. The mean annual precipitation is 16.00 inches. The mean temperature for the year is 41.2° F. The hours of bright sunshine are 2,346.5. Summer evaporation from a free water surface is 23.43 inches, slightly less than at Swift Current in the Brown soil zone. The Station is in the heart of the first irrigation development in Canada. Emphasis is given

Table 21. Rotations at Lethbridge, Alberta

| | Irrigated 10-year rotation | | Dryland rotations | | | | |
|---|---|---|---|---|---|---|---|
| Rotation crops | Fertilized, 33 years | Unfertilized, 55 years | Continuous wheat, 50 years | Wheat on fallow, 50 years | Wheat on fallow, 38 years | Wheat on stubble, 38 years | 6-year rotation crop yield |
| Barley | 81.00 bu | 71.20 bu | — | — | — | — | — |
| Oats | 111.60 bu | 101.80 bu | — | — | — | — | — |
| Alfalfa | 2.82* tons | 2.16* tons | — | — | — | — | — |
| Alfalfa | 2.51* tons | 1.37* tons | — | — | — | — | — |
| Alfalfa | 1.89* tons | 1.16* tons | — | — | — | — | Summerfallow |
| Sugar beets | 19.20† tons | 16.30† tons | — | — | — | — | Wheat 28.9 bu |
| Wheat | 59.20 bu | 54.70 bu | 12.5 bu | 27.8 bu | 27.5 bu | 15.2 bu | Wheat 21.4 bu |
| Alfalfa | 3.06 tons | 2.47 tons | — | — | — | — | Crested wheatgrass 1.20 tons |
| Alfalfa | 3.61 tons | 2.79 tons | — | — | — | — | +alfalfa 1.10 tons |
| Alfalfa | 3.32 tons | 2.94 tons | — | — | — | — | — |

*Rotation change 1951.

†43-year average.

NOTE: Manure, 15 tons on 5th- and 9th-year alfalfa. Fertilizer, 100 pounds of 11-48-0 on 3rd- and 8th-year alfalfa and 6th-year sugar beets.

therefore to research on dryland and irrigation farming. The soil is a silt loam.

On dry land, continuous wheat has been compared with a 2-year rotation of summerfallow, wheat; a 3-year rotation of summerfallow, wheat, wheat; and a 6-year rotation of summerfallow, wheat, wheat, hay, hay, hay (crested wheatgrass – alfalfa) and these compared with a 10-year irrigated rotation. The information for the irrigated area has been supplied by Dubetz (1954), Dubetz and Hill (1964), and Hill (1951) and for the dryland farming area by Pittman (1961) and Hill (1954). The longtime average yields for all rotations are presented in Table 21.

The 50-year average yield of continuous wheat was 12.5 bushels. This did not include 5 years of crop failure due to drought. The yield of wheat on fallow, in the alternate wheat and fallow rotation, was 27.8 bushels per acre, slightly more than double that of continuous wheat. The yield of fallow–wheat in the 3-year rotation was only slightly lower at 27.5 and in the 6-year rotation slightly higher at 28.9 bushels. Stubble–wheat in both rotations yielded less than fallow–wheat, but more than continuous wheat. The yield of hay averaged well over 1 ton per acre. It was profitable to grow wheat continuously for 50 years. Fallowing may be necessary occasionally in this area. Perennial hay can be grown reasonably well. The regression of annual yields with advancing years was calculated and, although positive, was nonsignificant in all cases. The yields have been maintained over the years.

Chemical analyses (Hill, 1954) were made in 1910, 1922, 1940 and 1953. The pH of the soil tended to increase over the years by approximately 1 unit, from an average of 7.0 to 7.9. This was due probably to erosion and salt movement. The nitrogen content was reduced during 1910–1953 from 0.178 percent to 0.135 on alternate wheat and fallow and to a lesser extent in the 6-year rotation, from 0.168 to 0.140 percent. The alfalfa probably accounted for the reduced loss in the latter rotation. The organic matter level was reduced also. The reduction in the wheat–fallow rotation was from 2.63 percent to 2.35 and in the 6-year rotation from 2.70 to 2.42. These losses had no apparent effect on yield.

The 10-year irrigated rotation has been in operation for 55 years and is believed to be the oldest in North America. The rotation is located on a silty clay loam with a medium-textured subsoil to a depth of 36 inches. The original rotation in 1911 was oats, barley, potatoes, wheat, and 6 years of alfalfa. Manure was applied once in the rotation at 12 tons per acre. In 1942 the manure application was changed to 30 tons per acre, 15 tons applied to barley stubble in the fall and 15 tons to the second-year alfalfa.

Potatoes were replaced by sugar beets in 1923. In 1933 fertilizer was applied at 100 pounds of 11-48-0 per acre to half the rotation, third-year sugar beets, fifth-year alfalfa and eighth-year alfalfa. By 1950 the yield of alfalfa in the eighth, ninth and tenth years of the rotation was greatly reduced by bacterial wilt and crown rot diseases.

The rotation was changed in 1951 so that alfalfa was grown only 3 years in succession. The sequence became barley, oats, alfalfa, alfalfa, alfalfa, sugar beets, wheat, alfalfa, alfalfa, alfalfa. Manure was applied at 15 tons per acre on fifth- and ninth-year alfalfa. Fertilizer was applied at 100 pounds of 11-48-0 per acre to third- and eighth-year alfalfa and to sugar beets.

The longtime average yields and similar average yields for the dryland rotations are shown in Table 23. The yields show the level of production that can be obtained on this fertile soil if adequate moisture is provided. The yield of alfalfa was disappointing, especially in the third, fourth and fifth years of the rotation, which included the eighth, ninth and tenth years before 1951. Under the conditions of this experiment, alfalfa could be grown only 3 years in succession before bacterial wilt and crown rots became prevalent. The yields have not improved greatly since the change of rotation in 1951. It may be difficult to control these diseases when they have become established in the rotation.

Further information for the irrigation rotation is supplied in Tables 22 and 23, and in Figure 5.

Average yields for 10-year intervals and for the entire period are shown in Table 22. Alfalfa yields are shown for only one of the six crop years, but the figures are fairly representative of the alfalfa yields generally. The yields in bushels and tons from Table 22 are expressed in pounds per acre in Table 23 so that they can be shown in the same unit of measurement in Figure 5.

Over the 55 years there has been a general upward trend in the yields of all crops except alfalfa. This corresponds to regression coefficients for yearly yields in advancing years presented by Hill (1951). Hill suggested that alfalfa yields were low partly because of disease and partly owing to a deficiency of

*Figure 5. Irrigated rotation at Lethbridge, Alberta, 1911–1916, 10-year intervals.*

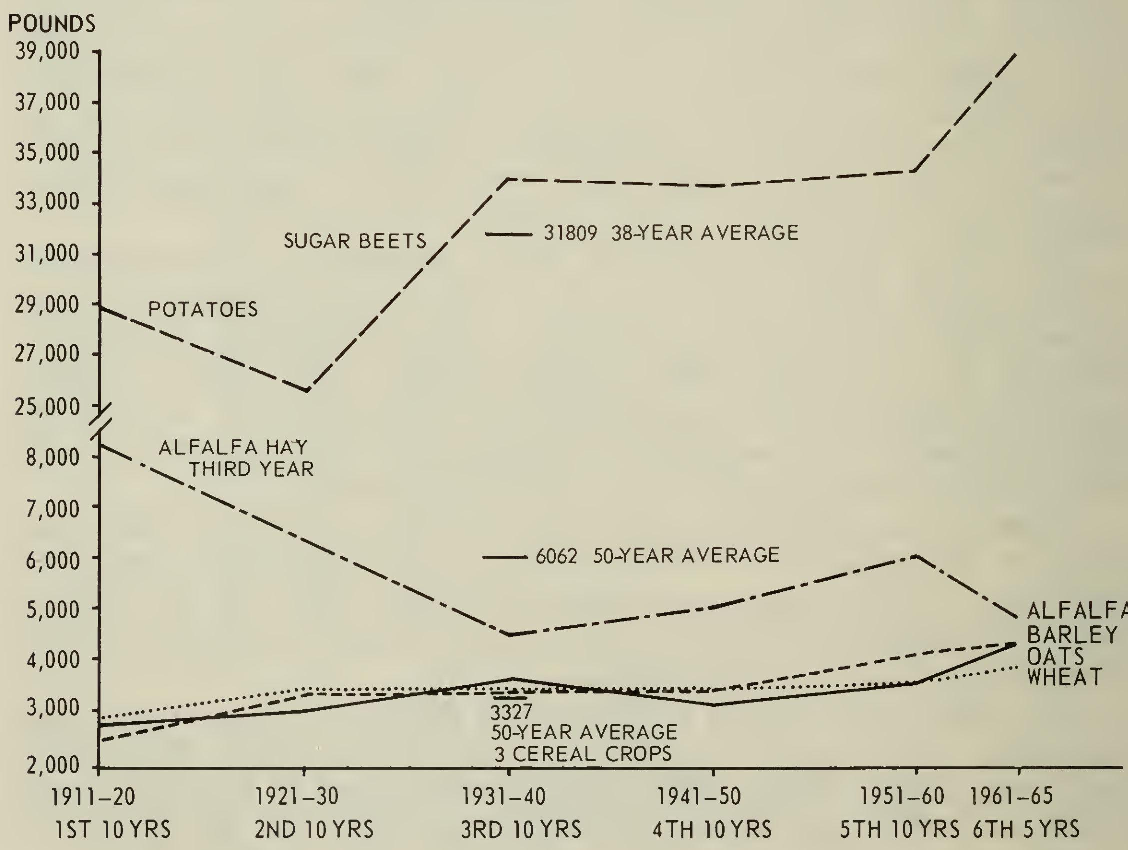


Table 22. Yield per acre of crops in a 10-year irrigated rotation at Lethbridge, Alberta (average for 10-year intervals)

| Years | Barley, bushels | Oats, bushels | Alfalfa, tons | Sugar beets, tons | Wheat, bushels |
|---|---|---|---|---|---|
| 1911–1920 | 51.4 | 84.0 | 4.10 | 14.33 | 46.0 |
| 1921–1930 | 69.1 | 100.9 | 3.21 | 12.78 | 50.1 |
| 1931–1940 | 72.4 | 103.5 | 2.25 | 16.94 | 61.2 |
| 1941–1950 | 71.4 | 102.7 | 2.55 | 16.86 | 52.4 |
| 1951–1960 | 86.4 | 105.9 | 3.04 | 17.15 | 60.0 |
| 1961–1965 (5 years) | 90.9 | 127.9 | 2.43 | 19.50 | 65.4 |
| Mean 55 years | 71.2 | 101.8 | 2.47 | 16.30 | 54.7 |
| Average 33 years with fertilizer | 81.0 | 111.6 | 3.06 | 19.20 | 59.2 |

Table 23. Yield per acre of crops in a 10-year irrigated rotation at Lethbridge, Alberta (average for 10-year intervals, pounds per acre)

| Years | Barley | Oats | Alfalfa | Sugar beets | Wheat |
|---|---|---|---|---|---|
| 1911–1920 | 2,467 | 2,855 | 8,208 | 28,652 (Potatoes) | 2,749 |
| 1921–1930 | 3,315 | 3,431 | 6,426 | 25,464 | 3,007 |
| 1931–1940 | 3,476 | 3,520 | 4,502 | 33,872 | 3,670 |
| 1941–1950 | 3,426 | 3,494 | 5,096 | 33,722 | 3,148 |
| 1951–1960 | 4,147 | 3,599 | 6,078 | 34,308 | 3,598 |
| 1961–1965 (5 years) | 4,856 | 4,349 | 4,362 | 39,020 | 3,925 |
| Average 55 years | 3,417 | 3,461 | 4,940 | 32,600 | 3,282 |
| Average 33 years with fertilizer | 3,888 | 3,794 | 6,120 | 3,840 | 3,552 |

phosphorus in the soil. The regression coefficients showed an upward trend of alfalfa yields in 1933 after the application of chemical fertilizer containing 48 percent $P_2O_5$. However, disease caused a further decline from 1961 to 1965.

The maximum yields in the 55 years are of interest. In 1961 a high yield of 157.9 bushels per acre was recorded for fertilized oats and 155.0 bushels for unfertilized oats. These results were obtained in a drought year when yields were extremely low on dryland rotations. The highest yields were: wheat, fertilized, 71.4 bushels per acre in 1937, unfertilized, 70.6 in 1931; barley, fertilized, 128.8 bushels per acre in 1951, unfertilized, 122.5 in 1960; sugar beets, fertilized, 28.11 tons per acre in 1958, unfertilized, 24.41 in 1958; alfalfa, fertilized, 5.48 tons per acre in 1943, unfertilized, 5.54 in 1913. These figures show the production potential under irrigation.

Fertilizer has increased the average yields of barley by 9.8 bushels per acre, oats by 9.8 bushels, wheat by 4.5 bushels, alfalfa by 0.59 ton and sugar beets by 2.90 tons per acre. Bishop and Atkinson (1954) reported that the nitrogen content at 0.186 percent in 1910 was slightly increased to 0.209 percent in 1950, while the organic matter level had increased also from 2.95 to 3.26 percent. Several researchers, Andharia, Stanford, and Schaller (1953), Clement (1961), Drover (1956), Stockinger, MacKenzie, and Cary (1963) and others, have shown similar increases in soil organic matter levels by growing legumes in the rotation.

### *Summary of Dark Brown Soil Zone Rotations*

The general precipitation of 14 to 15 inches is slightly higher and more favorable than in the Brown soil zone. In the drier, southern parts of the zone, a rotation of summerfallow, wheat, wheat is fairly safe. In the areas close to the Black soil zone, wheat may be grown economically in continuous culture for long periods. Before seeding wheat on stubble in this area, the depth of moist soil should be checked, as in the Brown soil zone, by the method of Janzen *et al.* (1960). In the more favorable sections of this zone, perennial hay may be grown in the rotation. The Brown and Dark Brown soil zones are the most likely areas to respond economically to irrigation, and many different species of crops can be grown if adequate water is supplied.

### *Black Soil Zone*

The climate of the Black soil zone is subhumid with annual precipitation usually over 16 inches. The native vegetation consists of tall grasses with occasional to numerous clumps of shrubs and trees, and is often referred to as the Parkbelt. Black soil is better suited than other prairie soils to diversfied farming. The typical surface soil is very dark brown to black in color. It is very rich in nitrogen and organic matter. The depth of the surface layer may vary from 4 inches to 2 feet. These soils are among the most fertile in the world.

### *Indian Head, Saskatchewan*

The Experimental Farm at Indian Head, Saskatchewan, is located in the Black soil zone. The mean annual precipitation is 17.60 inches. The mean annual temperature is 35.1° F. The hours of bright sunshine are 1,858.0 for the year. Evaporation from a free water surface is 20.27 inches.

Since this is one of the oldest Experimental Farms in the system, rotation records have been taken for a period of 54 years, 1912–1965, on Indian Head clay. Two rotations have been compared: a 3-year rotation of summerfallow, wheat, wheat and a 9-year rotation of summerfallow, wheat, oats, 3 years hay, corn, wheat, oats. No fertilizer was applied during the entire period. The experiments were conducted for a considerable part of the period and the results supplied by McCurdy (1965) and presented in Table 24 and Figure 6.

Mean yields are shown by 10-year intervals and for the entire period. The hay yields for the 3 years of the rotation have been averaged into one record in Figure 6. The yields were higher at Indian Head than at Regina owing to more favorable climatic and soil conditions. There were no crop failures of wheat during the entire period in the 3-year rotation, either on fallow or stubble land, and none on fallow in the 9-year rotation. Yields generally

Table 24. Crop yields in cereal and mixed rotations for 54 years, Indian Head, Saskatchewan

| | 3-year rotation summerfallow–wheat–wheat | | 9-year rotation beginning with summerfallow | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Wheat on fallow, bushels | Wheat on stubble, bushels | Wheat on summer-fallow, bushels | Oats seeded, bushels | Hay, tons | Hay, tons | Hay, tons | Corn, tons | Wheat, bushels | Oats, bushels |
| 1912–21 | 28.7 | 16.8 | 36.0 | 45.1 | 1.16 | 1.79 | 1.79 | 6.50 | 33.5 | 52.6 |
| 1922–31 | 24.3 | 16.6 | 34.0 | 54.5 | 1.58 | 1.68 | 1.35 | 8.00 | 29.8 | 60.0 |
| 1932–41 | 22.6 | 14.7 | 27.2 | 34.7 | 1.12 | 1.12 | 0.80 | 5.32 | 22.3 | 42.5 |
| 1942–51 | 30.3 | 12.8 | 40.5 | 54.9 | 1.06 | 1.13 | 1.03 | 7.96 | 29.7 | 58.0 |
| 1952–61 | 24.3 | 15.2 | 40.1 | 56.4 | 1.11 | 1.30 | 1.09 | 7.22 | 35.4 | 60.5 |
| 1962–65 | 29.9 | 18.4 | 36.8 | 70.6 | 1.02 | 1.67 | 1.32 | 13.73 | 36.7 | 70.5 |
| Mean | 26.2 | 15.2 | 35.7 | 47.1 | 1.05 | 1.28 | 1.09 | 7.22 | 29.0 | 50.4 |
| Number of years | 54 | 53 | 54 | 50 | 48 | 43 | 45 | 52 | 51 | 49 |
| Failures | 0 | 0 | 0 | 4 | 5 | 3 | 1 | 2 | 3 | 5 |

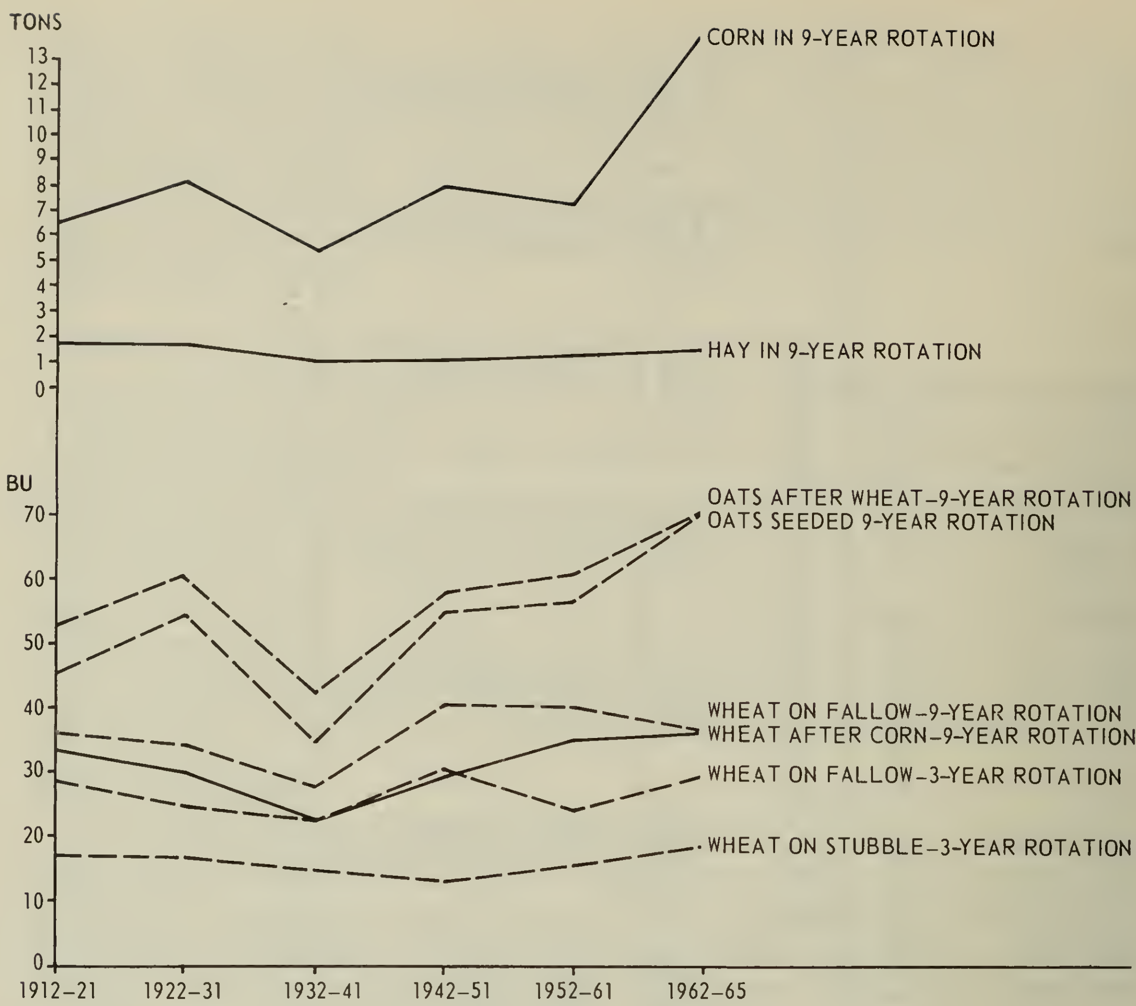



*Figure 6. Crop yields in cereal and mixed rotations at Indian Head, Saskatchewan.*

were higher in the mixed rotation than in the cereal rotation.

Oats after wheat yielded well, except in four crop-failure years. The average yield was 47.1 bushels per acre and the highest in the 50-year period was 114.4. There were five crop failures in fourth-year hay, three in fifth-year hay and one in sixth-year hay in the 54 years. Only 65 times in 146 crop years did the hay yield drop below 1 ton per acre. The average yield in each of the 3 hay years was about the same and for all hay crops was 1.14 tons per acre. The highest yield during the period was 3.17 tons per acre. Corn yielded quite well with an average of 7.22 tons per acre and a high of 17.00. In this area corn would seem to be more economical than sumerfallow. Wheat after corn yielded only 6.7 bushels lower than after summerfallow. Oats after wheat in the ninth year yielded slightly more than in the third year. Most of the crop failures occurred in the very dry years 1929–1939 and in 1961.

Figure 6 shows the higher yields of wheat in the mixed rotation. It also shows that yields were well maintained through the 54 years except in the dry years 1932–1941. From then on there was a general increase in the yield of all crops.

*Wheat on summerfallow at Indian Head, Saskatchewan. Black soil zone in the extremely dry season of 1949.*

*Wheat on stubble at Indian Head, Saskatchewan. Black soil zone in the extremely dry season of 1949.*

*Brandon, Manitoba*

The Experimental Farm at Brandon, Manitoba, is located in the Black soil zone. The mean annual precipitation is 18.16 inches. The mean annual temperature is 34.6° F and evaporation from a free water surface, 18.55 inches.

To obtain information on growing cereal crops over a long period two 4-year rotations of summerfallow, wheat, wheat, oats were compared at Brandon for 48 years, 1911–1958. One rotation received manure at 10 tons per acre in the fall of the fallow year, the other received no added fertility. These rotations have been compared in recent years, 1936–1960, with a 6-year mixed farming rotation of wheat, oats, fallow, wheat, hay, hay, with manure applied. The crops were grown on Assiniboine clay loam. The records for this work, supplied by Ferguson (1960) and Gorby (1962) are presented in Table 25.

The data for the two 4-year rotations are presented by 10-year intervals and show a good maintenance of yields of all cereals for the entire period. Manure did not increase yields significantly in the first three 10-year periods. The increase was greater in the last 18 years. Yields of wheat were higher after fallow than after stubble in all cases, but not high enough to make up for the loss of crop in the fallow year. The yields in the 10-year interval, 1931–1940, are all low because these years were extremely dry. Yields of cereals were higher in the mixed rotation than in the cereal rotation, except for wheat after fallow, which shows the benefits from perennial grass crops. The hay yielded well and can be grown satisfactorily in this soil zone.

A second group of rotation comparisons were started in Brandon in 1951 on well-replicated 1/50 acre plots. Five rotations were compared with continuous wheat. The 7-year average results are presented in Table 26.

There was no significant difference in the average yield of wheat in the 6-, 3- and 2-year rotations and continuous wheat when the loss of crop in the

Table 25. Crop yields in 4-year rotations in manured and unmanured Assiniboine clay loam at Brandon, Manitoba (mean yields, 10-year intervals and long time, bushels per acre)

| Period | Manured, 10 tons on fallow year | | | Unmanured | | |
|---|---|---|---|---|---|---|
| | Wheat on fallow | Wheat on stubble | Oats on stubble | Wheat on fallow | Wheat on stubble | Oats on stubble |
| 1911–1920 | 26.0 | 18.7 | 25.9 | 25.3 | 15.5 | 25.0 |
| 1921–1930 | 31.1 | 21.6 | 30.0 | 28.9 | 22.9 | 23.6 |
| 1931–1940 | 24.8 | 14.4 | 15.6 | 23.7 | 13.8 | 15.7 |
| 1941–1950 | 37.1 | 18.8 | 22.5 | 30.4 | 13.7 | 19.9 |
| 1951–1958 (8 years) | 30.7 | 23.2 | 40.0 | 26.9 | 16.8 | 27.3 |
| 1911–1958 | 29.9 (48 years) | 19.2 (47 years) | 26.2 (42 years) | 27.1 (48 years) | 16.3 (47 years) | 21.8 (43 years) |
| 1926–1956 | Fallow | Wheat | Hay | Hay | Wheat | Oats |
| 31-year mean | — | 29.7 | 1.81 | 1.45 | 24.7 | 47.0 |

Table 26. Crop yields in various types of rotations at Brandon, Manitoba (7-year average yields, 1951–1957)

| Rotation | Fallow | Wheat | Wheat | Hay | Hay | Hay break | Wheat | Wheat |
|---|---|---|---|---|---|---|---|---|
| 8-year | (23.4) | (23.4) | (23.4) | | | | | |
| | — | 37.0 | 33.1 | 1.27 | 1.44 | — | 30.9 | 31.6 |
| 6-year | (17.8) | (17.8) | | | | | | |
| | — | 35.6 | — | 1.23 | — | 1.31 | 26.7 | 27.2 |
| 3-year | (22.2) | (22.2) | (22.2) | | | | | |
| | — | 35.7 | 30.5 | — | — | — | — | — |
| 3-year | Corn | (30.1) | (30.1) | | | | | |
| | 12.1 tons | 31.6 | 28.6 | — | — | — | — | — |
| 2-year | Fallow | (18.4) | | | | | | |
| | — | 36.9 | — | — | — | — | — | — |
| Continuous wheat | — | 19.6 | — | — | — | — | — | — |

fallow year was considered (figures in parentheses). Continuous wheat yielded 19.6 bushels per acre, wheat on fallow in the 2-year rotation 18.4 bushels, in the 3-year rotation 22.2 bushels and in the 6-year rotation 17.8 bushels. With corn in the 3-year rotation the average yield of the two wheat crops was 30.1 bushels per acre and wheat in the 8-year rotation averaged 23.4 bushels. The hay crops yielded over a ton per acre and seemed to have a beneficial effect on the cereals, and were helpful in the control of weeds and erosion. Summer-fallowing may not be necessary in this area.

Similar results were obtained at substations at Melita by Dryden (1959), and on special project farms by Gerby (1962), associated with the Research Station at Brandon.

### *Melfort, Saskatchewan*

The Experimental Farm at Melfort, Saskatchewan, is located in the northern arc of the Black soil zone. The mean annual precipitation is 14.76 inches. The mean annual temperature is 33.9° F and evaporation from a free water surface, 17.79 inches. As at other stations, 2-, 3- and 6-year rotations have been compared. Information supplied by Bowren (1962) is presented in Table 27.

The information has been recorded for the main farm at Melfort and for 11 special project farms in the area. The yield of fallow–wheat has usually been higher than wheat after crop. In most cases the increase has not been enough to make up for the loss of crop in the fallow year. In two instances, the 3-year rotation at Lens and the 6-year rotation at Star City, the yield was higher on the stubble crop. The yield of hay has been quite satisfactory. Only one of the 2 years in hay is presented in the table.

Chemical analyses were done on the soils at the White Fox Station in 1950, 1953 and 1956 and reported by Bowren and Wilson (1957). The

Table 27. Crop yields in rotations in Black soil zone, Melfort area, Saskatchewan

| Station | Soil type | Years average | 2-year rotation: Fallow wheat, bushels | 3-year rotation: Fallow wheat, bushels | 3-year rotation: Stubble wheat, bushels | 6-year rotation: Fallow wheat, bushels | 6-year rotation: Hay, tons | 6-year rotation: Wheat after hay, bushels | 6-year rotation: Oats, bushels |
|---|---|---|---|---|---|---|---|---|---|
| Melfort | Melfort SCL | 1945–48 | 31.0 | 28.7 | 17.4 | — | — | — | — |
| Melfort | Melfort SCL | 1941–49 | — | 33.9 | 31.2 | 30.6 | 1.12 | 26.9 | 57.1 |
| Archerwill | Waitville L* | 1951–61 | 29.1 | 28.4 | 21.3† | 27.5 | 1.29 | 25.4 | 37.9 |
| Guernsey | Meota FSL | 1936–60 | — | — | — | 26.9 | 1.31 | 23.1 | 33.4 |
| Henribourg | Glenbush FSL | 1952–61 | 33.5 | 32.1 | 20.3† | 28.4 | 1.28 | 25.9 | 36.9 |
| Lens | FSL | 1933–39 | — | 25.9 | 26.5† | 31.1 | 1.55 | 27.4 | 56.2 |
| Paddockwood | Paddockwood L | 1948–52 | — | 21.5 | 15.9‡ | 24.1 | 1.17 | 19.6 | 29.7 |
| Smoky Burn | Tisdale C | 1951–57 | 27.5 | 35.0 | 19.1 | 28.7 | 1.14 | 24.9 | 20.7 |
| Somme | Tisdale C | 1955–61 | — | 40.6 | 18.6 | 47.4 | 1.44 | 35.7 | 35.5 |
| Star City | Waitville L* | 1949–57 | — | 23.8 | 18.2 | 28.4 | 1.30 | 31.1 | 27.2 |
| White Fox | Whitefox FSL | 1936–61 | — | 21.5 | 16.1 | 34.0 | 1.46 | 27.4 | 43.8 |
| Wierdale | Waitville L* | 1943–48 | — | — | — | 29.3 | 1.46 | 25.9 | 49.0§ |

*Waitville L Gray Wooded soil.
†Oats equivalent pounds wheat.
‡Barley equivalent pounds wheat.
§Oats equivalent pounds barley.

average percentage of nitrogen in the 3-year cereal rotation was 0.123 in 1950, 0.102 in 1953 and 0.105 in 1956. Percentage of nitrogen in the 6-year mixed rotation was 0.153, 0.164 and 0.143 in the 3 years, respectively. In the 3-year rotation the percentage of organic matter was 2.97, 2.39 and 2.40 in the 3 years. In the mixed rotation it was 3.45, 3.70 and 3.02, respectively. The hay crop again increased the levels of nitrogen and organic matter.

### *Lacombe, Alberta*

The Research Station at Lacombe, Alberta, is located in the westerly arc of the Black soil zone. The mean annual precipitation is 17.81 inches. The mean annual temperature is 36.1° F and seasonal evaporation from a free water surface, 15.04 inches. A 3-year cereal rotation has been compared with a 6- and 7-year mixed rotation. The yield data prepared by Walker (1964) are presented in Table 28.

The 50-year average yields are similar to those obtained up to 1952 and reported by Leggett and Walker (1952). At that time it was reported, "Mixed farming rotations that include a grass and legume mixture have proved better than straight grain rotations in the Black soil zone. The long time wheat yield after fallow in a 3-year grain rotation is 23.8 bushels per acre (23.0 in 1964), while the yield in a 7-year mixed rotation is 34.7 bushels per acre (33.5 in 1964).

"Another important point that has been brought out by the long term experiments is that summerfallowing is not necessary for profitable grain production in the Black soil zone. A 6-year rotation that has not had a complete

Table 28. Yield per acre at Lacombe, Alberta, 50 years 1915–1965 for cereal and mixed rotations

| Cereal rotation crop | Number of years grown | Yield per acre |
|---|---|---|
| Fallow | — | — |
| Wheat | 50 | 23.0 bushels |
| Wheat | 50 | 13.8 bushels |
| 7-year mixed rotation, 1 year fallow | | |
| Potatoes | 45 | 260.0 bushels |
| Wheat | 50 | 38.2 bushels |
| Oats | 50 | 62.6 bushels |
| Fallow | — | — |
| Wheat | 42 | 33.5 bushels |
| Hay | 49 | 1.62 tons |
| Hay and break | 43 | 1.21 tons |
| 6-year mixed rotation, no fallow | | |
| Corn | 41 | 10.24 tons |
| Wheat | 50 | 39.0 bushels |
| Barley | 50 | 42.7 bushels |
| Hay | 50 | 1.15 tons |
| Hay | 43 | 1.76 tons |
| Hay and break | 43 | 1.33 tons |

*Wheat yielded well in Black soil at Lacombe, Alberta, in 1949, the fifth driest season in 69 years. Summerfallow is not necessary in the Black soil zone.*

year of summerfallow since its inception consistently outyields the 3-year straight grain rotation. The production record of potatoes and corn is impressive. The hay yields on these rotations are somewhat disappointing."

These statements apply also in 1966. In spite of the low yields of hay the crop has had beneficial effects on other crops and has kept weeds under control. Wild oats have been a problem in the cereal rotation, but in recent years the herbicide Avadex has improved this situation. Chemical fertilizer has been beneficial, also, and has increased the yield of wheat on fallow in the 3-year rotation by 5 bushels per acre and in the 7-year rotation by 9.2 bushels.

Analyses were made for organic matter and water-stable aggregates on the three rotations during a 6-year period. There was no significant difference between the 3- and 7-year rotations. The average percentage of organic matter in the 3-year rotation was 10.00 and in the 7-year, 9.50. The mean weight diameter of water-stable aggregates was 0.42 for the 3-year rotation and 0.46 for the 7-year. The 6-year rotation was in a different field with an average organic matter content of 6.87 and a mean weight diameter of water-stable aggregates of 0.61. It could hardly be expected that hay crops would change the organic matter level or physical condition of this fertile prairie soil with its naturally high organic matter content.

Table 29. Crop yields (bushels) in rotations in Gray Wooded soils, Beaverlodge area, Alberta

| | | Gray Wooded soils | | | |
|---|---|---|---|---|---|
| Crop | Treatment | 1946–51 Baldonnel on Codesa SL | 1944–51 Debolt on Donnelly SL | 1947–51 McLennan on Nampa CL | 1946–51 Progress on Humic Gleysol |
| Wheat after oats | Check | 20.8 | 34.3 | 19.5 | 10.5 |
| | Fertilized | 27.2 | 40.2 | 19.1 | 14.5 |
| | Manure | 46.0 | 45.9 | 49.0 | 22.3 |
| Wheat after legume | Check | 23.4 | 36.3 | 16.0 | 13.4 |
| | Fertilized | 25.1 | 38.6 | 14.6 | 15.3 |
| | Manure | 46.9 | 46.3 | 36.7 | 25.4 |
| Oats after wheat | Check | 58.4 | 34.6 | 57.7 | 24.4 |
| | Fertilized | 64.2 | 41.4 | 67.5 | 25.8 |
| | Manure | 84.1 | 43.7 | 90.2 | 44.6 |
| Legume hay | Check | 0.76 | 2.00 | 1.33 | 1.12 |
| | Fertilized | 1.06 | 2.11 | 1.44 | 1.55 |
| | Manure | 1.43 | 2.10 | 1.42 | 1.14 |

Fertilizer: 11-48-0 at 45 pounds per acre + ammonium nitrate at 36 pounds per acre.

Manure: 15 tons per acre.

Legume: red clover at Baldonnel, alfalfa at Debolt, sweet clover at McLennan and Progress.

## *Summary of Black Soil Zone Rotations*

Summerfallowing is unnecessary and wasteful in the Black soil zone, which has over 16 inches of precipitation. This agrees with the conclusion of Essafi (1964). A determination of the depth of soil moisture at seeding time will suggest the doubtful years. Mr. U. J. Pittman of the Research Station, Lethbridge, Alberta, states that if there are 27 inches of moist soil at seeding time, there is a 50 percent chance of obtaining at least 13.5 bushels of wheat per acre.

## *Gray Wooded Soil Zone*

Stobbe and Leahey (1948) report, "The natural vegetation in this zone is woodland. These soils are less productive than the Black soils and present different problems. The Gray Wooded soils will not stand up under continued grain growing and the production of legumes and grasses in conjunction with mixed farming and the use of sulphur and other fertilizers is often essential for the improvement and maintenance of soil fertility. The typical soils have a gray, leached, ash-like layer near the surface immediately below a thin dark leaf mould."

## *Beaverlodge, Alberta*

The Research Station at Beaverlodge, Alberta, is located in northwestern Alberta. The mean annual precipitation is 17.37 inches, the mean annual

Table 30. Crop-sequence effects, 1944–49, Prince George, British Columbia

| Preceding crop | | Yield of succeeding crops, bushels | | |
| --- | --- | --- | --- | --- |
| Crop | Yield | Oats | Barley | Peas |
| Alsike | 1.60 tons | 46.6 High | 31.2 | 14.3 |
| Timothy–alsike | 1.84 tons | 40.5 | 33.2 | 14.9 High |
| Alfalfa | 1.09 tons | 42.2 | 30.7 | 13.2 |
| Alsike after barley | 1.27 tons | 38.3 | 34.1 High | 13.1 |
| Peas after fallow | 12.2 bushels | 39.9 | 28.9 | 13.5 |
| Timothy | 1.75 tons | 36.8 | 30.8 | 13.0 |
| Flax after fallow | 6.6 bushels | 36.3 | 27.0 | 12.7 |
| Potatoes after fallow | 84.1 bushels | 36.0 | 25.4 | 12.2 |
| Oats after turnip | 30.2 bushels | 30.5 | 21.6 Low | 11.8 |
| Wheat after fallow | 17.0 bushels | 27.5 Low | 22.7 | 11.4 |
| Barley after fallow | 23.1 bushels | 27.8 | 23.1 | 11.3 |
| Oats after fallow | 29.6 bushels | 29.9 | 22.4 | 11.0 Low |
| Increase from low to high preceding crop | | 19.1 | 12.5 | 3.9 |

temperature is 35.8° F and evaporation from a free water surface, 16.66 inches. There are more hours of daylight in the summer here than at the other stations and the growing season is shorter.

Crop-rotation experiments have been performed at four special project farms operated by the main farm at Beaverlodge. Wheat has been grown after oats and legume hay. Oats were grown after wheat and legume hay for several years in succession. All crops have been grown with no fertilizer treatments, with farm manure and with chemical fertilizer. The yield data supplied by Hoyt (1951) are given in Table 29.

In other experiments it has been shown that summerfallowing is not necessary to conserve moisture. Low fertility is a greater limiting factor than low moisture content. Therefore, yields after fallow are not included in these data. Yields generally have been fairly high. There have been consistent and, in the case of oats and legumes, significant increases due to chemical fertilizer. Greater increases have been obtained from manure on wheat and oats but not on legume hay. These soils are low in organic matter and fertilizer nutrients, which are supplied by manure. In this area long periods of daylight and cool temperatures encourage seed setting, and cereal, forage and vegetable crops produce seed satisfactorily. Mixed farming is quite economical.

## *Prince George, British Columbia*

Some of the soils in the interior valleys of British Columbia are located in the Gray Wooded soil zone. The Experimental Farm at Prince George in the north central area is on Pineview clay. The mean annual precipitation is 21.97 inches, the mean annual temperature is 38.6° F and the seasonal evaporation from a free water surface, a low 11.14 inches. The main problems on this fine-textured soil are poor drainage, poor physical condition and low

Table 31. Crop yields in rotations in the Prince George area, British Columbia

| Years average | Year of rotation | Crop | No fertilizer | Fertilized | Manure |
|---|---|---|---|---|---|
| 1949–60 (12) | 3 years 1 | Continuous wheat | 19.0 bushels | 23.3 bushels | 30.7 bushels |
| 1949–60 (12) | 2 | Fallow wheat | 24.5 bushels | 32.6 bushels | 38.0 bushels |
| 1950–60 (11) | 3 | Stubble wheat | 21.5 bushels | 23.9 bushels | 29.3 bushels |
| 1950–60 (11) | 3 years 1 | Sweet clover | 0.50 ton | 0.48 ton | 0.54 ton |
| 1951–60 (10) | 2 | Wheat | 23.8 bushels | 30.1 bushels | 35.8 bushels |
| 1949–60 (12) | 3 | Wheat | 20.2 bushels | 24.0 bushels | 26.7 bushels |
| | 6 years 1 | Fallow | — | — | — |
| (12) | 2 | Wheat | 23.5 bushels | — | — |
| (11) | 3 | Hay | 0.62 ton | — | — |
| (10) | 4 | Hay | 0.78 ton | — | — |
| (10) | 5 | Oats | 47.0 bushels | — | — |
| (11) | 6 | Oats | 41.8 bushels | — | — |
| | 6 years 1 | Fallow | — | — | — |
| (12) | 2 | Wheat | 25.0 bushels | — | — |
| (10) | 3 | Alfalfa | 0.43 ton | — | — |
| (11) | 4 | Alfalfa | 0.57 ton | — | — |
| (9) | 5 | Alfalfa | 0.54 ton | — | — |
| (10) | 6 | Oats | 42.1 bushels | — | — |

fertility levels. In 1944 a crop-sequence experiment was laid down at this farm. The 6-year average yield data for three succeeding crops after 12 preceding crops, supplied by McDonald (1956), are presented in Table 30.

The results in Table 30 are similar to the results of other crop-sequence projects referred to in this publication: grass and legume crops are favorable preceding crops; cereal and hoed crops are less favorable; oats yielded 19.1 bushels more after alsike than after wheat; barley yielded 12.5 bushels more after alsike seeded with barley than after oats after turnips; peas were slightly affected by the previous crop.

In another part of the farm at Prince George two 3-year rotations were compared with and without applications of barnyard manure or chemical fertilizers. These were compared with two 6-year rotations with no manure or fertilizer added. The yield data are presented in Table 31.

Wheat on fallow yielded only slightly higher than wheat on stubble in the 3-year rotation and only 5.5 bushels more than continuous wheat. The yield was about the same in the mixed farm rotation as in straight cereals. The hay crops have been difficult to establish and yields were disappointingly low. Such poor crops of hay cannot exert a great effect on crops grown subsequently. The main type of farming in the area should remain mixed.

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