THE INFLUENCE OF CROPS UPON THOSE WHICH FOLLOW

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INTRODUCTION

Although it has been known for many centuries that crops have a decided influence on the growth and production of crops which follow, and much work has been done, directly and indirectly, in regard to this problem, there is still a definite need for specific information in regard to the effect of the growth of plants upon the yields of those grown subsequently on the same soil. Much of the investigational work which has been done in this connection has dealt with comparisons of rotations, in which crops have been arranged in varying sequence, and rotations of two, three, four, five or more years duration have been compared.

The investigations presented herewith, are not concerned with length of rotation but have been conducted with the following objects in mind: (1) to determine the relative influence of a number of commonly grown field crops upon those which follow directly in the subsequent cropping season; (2) to determine why, under certain conditions crops, especially legumes, exert a very beneficial influence upon following crops, while under other conditions no such influence is apparent; (3) to discover certain soil or climatic factors which are responsible for the influence which crops exert upon those which follow.

HISTORY OF CROP ROTATION

The literature dealing with crop rotation or crop sequence is somewhat voluminous and shows many conflicting statements. That continuous cropping results sooner or later in decreased yields was observed from the earliest days of agriculture. Virgil in 30 B.C. extolled the value of crop rotation, particularly recommending in series, fallow, grain, and leguminous crops. He said "After the harvest let the fallow fields lie at rest in succeeding years ..... Then when you have reaped the legume with shaking pod, the vetch and the lupine, sow your wheat or spelt." After the decline of Rome the practice of crop rotation, including leguminous crops, was lost for many centuries.

Hales (35) in 1727 was among the first to claim that plants excrete certain substances and implied that these had some affect on soils and crops following. Micaire (70) in 1832 remarked that in the broadest sense the rotation of crops is as old as agriculture itself, having come into practice as a matter of necessity. He further stated that the definite foundation of a theory of crop rotation in the early part of the 19th century marked an important advance in the science of agriculture. The theory to which he refers was that of De Candolle (25) based on the idea of Humboldt and Plenck that the grouping of naturally growing plants into societies might often be due to materials given off by the roots of the plants inhabiting any area, these materials being injurious to other plants and thus keeping them out. De Candolle theorized that all plants give off excretions which may be beneficial to some plants and injurious to others, and that this explained the fact that continuous cropping often results in decreased growth. He distinguished between true exhaustion of the soil in which case the soil is depleted of soluble salts necessary for plant growth and false exhaustion where poor growth is caused by the presence of injurious excretions.

Probably the first extensive field work to be done in regard to rotations was that of Daubeney (24) in England, who grew oats, tobacco, flax, potatoes, beans and clover, continuously and in rotation for a 10-year period. He found that crops grew more satisfactorily in rotation than when continuously cropped, and in his conclusions supported the "plant food theory" of Leibig, according to which soil productivity may be measured primarily in terms of the available supply of plant nutrients. Differences in the effect of crops on other crops is thus explained on the basis of differences in the kinds and quantities of plant nutrients removed from the soil by different preceding crops.

The oldest experiments with crop rotations in the world which are still being conducted were laid down shortly after those of Daubeney at the Agricultural Experiment Station at Rothamstead in England (36). In

1852 a four-year rotation of swedes, barley, clover or fallow and wheat was started and this rotation has continued without change to the present time. In addition to the rotation, barley has been grown continuously on the same land for a similar period, and in another area wheat has been grown continuously since 1843. This experiment has become a classic of agricultural research.

On the North American continent the oldest rotation experiment is that which was laid down at the Agricultural Experiment Station at Urbana, Illinois (26) in 1876. These experiments included corn grown continuously compared with a two-year rotation of corn and oats. In 1888 experiments were started at Columbia, Missouri, (72) in which corn, oats, wheat, clover and timothy have been grown continuously compared with the same five crops grown in rotation. In 1894 rotation experiments were commenced at the Agricultural Experiment Station at Wooster, Ohio, (79). The experiments at this station were the first to provide a plot for each crop in the rotation. All previous experiments had only one plot and required as many years to complete the cycle of the rotation as there were crops in the rotation. This change was an important advance in the technique of field experiments and shortened the length of time necessary to obtain results.

In Canada experiments were started in 1888 at the Central Experimental Farm, Ottawa, Canada (90) in which oats, barley, wheat, mangels, turnips and corn were grown continuously on the same soil. These were discontinued in 1910. In 1912 a four-year rotation consisting of mangels, oats, clover and timothy was laid down and later three and five year rotations were begun. Similar experiments were commenced at various Experimental Farms and Stations throughout Canada and the results were published in the Annual reports of these stations up to the year 1931 and by Hopkins et al (47) (48).

Valuable as these and other similar field experiments have been, they have failed to give specific information in regard to the actual effect of crops upon those which follow and to isolate the factors which are responsible for that influence. Many laboratory experiments and in more recent years greenhouse and crop sequence field tests have been conducted which throw further light upon the factors involved.

REVIEW OF LITERATURE ON LABORATORY AND FIELD STUDIES REGARDING THE EFFECT OF PLANTS UPON OTHER PLANTS

Various crops when grown on soils leave certain after effects which exert a marked influence on the growth of subsequent crops. In some cases the effect is beneficial and in others it may be injurious. It is proposed to review first, some of the investigations which show beneficial influences and later deal with reported injurious effects of different crops upon those which follow.

Beneficial Effects of Legume Crops

Legume crops (Leguminosae) have been looked upon from earliest times as soil building crops or crops which are beneficial to succeeding crops. Fred et al (29) presents a very complete literature review and history of leguminous plants from which a number of the following references have been taken. Theophrastus 370-285 B.C. spoke of leguminous plants "reinvigorating" the soil. He said "Of the other leguminous plants the bean best invigorates the ground" and again "Beans are not a burdensome crop to the ground; they even seem to manure it because the plant is of loose growth and rots easily; wherefore the people of Macedonia and Thessaly turn over the ground when it is in flower".

Cato in De rustica written in the 2nd century B.C. said "Lupins, field beans and vetches manure the land." Varro in Rerum rusticarum 37 B.C. wrote, "Legumes should be planted in light soils not so much for their own crops as for the good they do to subsequent crops." Pliny in 79 A.D. argued that lupines enrich the soil of a field or vineyard as well as any manure. For this purpose the bean ranks first among legumes. In New England Borderly (9) in 1801 suggested "clover plowed in together with the remains of grain stubble year after year will gradually meliorate the soil. .... Wheat on clover hast the best grain and the fullest crop,"

Considerable work has been done in recent years in regard to the beneficial effects of legumes. Headden (42) reported a yield of potatoes after grain of 8250 pounds, while the same crop after alfalfa yielded 15400 pounds. Lyon (66) obtained marked increases in yield of various crops after legumes as compared with non-legumes as shown in table 1.

TABLE 1 - YIELD OF CROPS FOLLOWING LEGUMES AND NON-LEGUMES AT ITHACA, NEW YORK

	Yield of Succeeding Crops of Entire Plant, Pounds per Acre		
1st year crop	2nd year oats	3rd year wheat	4th year corn
Red clover	5246	5940	7354
Timothy	2146	5293	6733
	Second Series		
1st year crop	2nd year corn	3rd year wheat	4th year rye
Alfalfa	9226	8055	3580
Timothy	6413	5409	3087

Red clover and alfalfa were both followed by higher yields of succeeding crops than was timothy, and this influence carried over in decreasing amounts for a period of three years.

Six years later Lyon (67) published the results of a more extensive study on the residual effects of a large number of legume as compared with non-legume crops. Barley and rye were used as indicator crops alternately following a group of preceding crops. The 10-year average yield in pounds per acre of grain and straw from the indicator crops after the various crops is listed in order of yield as follows:

1. Following alfalfa	6068	pounds
2. " red clover and alsike clover	5243	"
3. Following red clover	5144	"
4. Following alsike clover	5126	
5. Following sweet clover	5119	
6. Following sweet clover and vetch	4951	
7. Following soybeans	2953	pounds
8. " peas and oats	2907	"
9. " vetch and wheat	2805	"
10. " field beans	2760	"
11. " cereal crops	2214	"

Perennial legume crops were more beneficial than annuals and all legumes were followed by higher yields than were non-legumes.

The Ohio Agricultural Experimental Station (80) concluded from 11 years' comparisons of the residual effects of legumes and non-legumes in three and four year rotations that alfalfa, and sweet clover had a marked beneficial effect on corn, oats, or wheat following, although red clover and soybeans had no beneficial influence.

Outstanding increases in the yield of wheat and corn following legumes were obtained by the Manitoba Agricultural College (68) on fertile Fort Garry clay containing .35 per cent of nitrogen. The crops were grown after four legume and four non-legume crops and the average yields for four years are shown in table 2.

TABLE 2. THE EFFECT OF LEGUME AND NON-LEGUME CROPS ON THE YIELDS OF WHEAT AND CORN, WINNIPEG, MANITOBA, CANADA.

Preceding Crops	Average Yield per Acre of Succeeding Crops	
	Wheat (bu)	Corn (tons)
Non-legumes		
Meadow fescue	19.2	7.00
Brome grass	14.3	5.58
Western rye	19.9	6.29
Timothy	19.6	6.69
Average of non-legumes	18.2	6.39
Legumes		
Alsike	31.8	10.77
Red clover	31.2	11.02
Sweet clover	32.5	11.05
Alfalfa	31.3	12.15
Average of legumes	31.7	11.24

Many other instances could be cited in which legumes have benefited crops following them in a rotation but those included above will serve to illustrate the beneficial influence of legumes under a wide range of conditions.

Various theories have been advanced regarding the factors involved in the beneficial effects of legumes on other crops.

(a) Increase of soil nitrogen

The theory which has received the greatest attention is that of the symbiotic fixation of atmospheric nitrogen which increases the nitrogen content of the soil with subsequent benefit to succeeding crops. There is still a considerable difference of opinion in regard to this theory. Metzger (69) in Kansas studied the nitrogen content of soil which was variously treated and cropped for a period of 25 years. He reported that alfalfa grown continuously increased the soil's supply of nitrogen at the rate of 0.71 per cent per year and that it appeared to continue to add nitrogen to the soil over a period of 19 years. Swanson (106) of the same station on the other hand found no increase in soil nitrogen where alfalfa had been grown 28 to 30 years and in general the nitrogen was no higher under the alfalfa than under native pasture grass. Brown (18) found soybeans grown with corn for four years increased the total nitrogen in the soil 0.0088 per cent. Lyon (67) showed a gain in soil nitrogen under legumes grown in alternate years with barley and rye for a period of 10 years. With alfalfa the gain was 607 pounds per acre, alsike clover 595 pounds, red clover and alsike 577, red clover 532, sweet clover 420, sweet clover and vetch 410 pounds per acre. With soybeans in the rotation there was a loss, however, of 42 pounds per acre and with field beans a loss of 100 pounds. Sears (100) reports that soybeans based on a yield of 20 bushels of seed or 4,500 pounds of hay or green manure per acre will add 88 pounds of nitrogen per acre when used as green manure. When cut for hay and manure returned the addition is 26 pounds per acre. Harvested for seed with a combine and the straw left on the land the addition is only 16 pounds. Harvested for seed with straw removed there is a loss of 3 pounds and harvested as hay no manure returned there is a loss of 30 pounds per acre.

Hopkins (49) of Illinois demonstrated that alfalfa obtains one-third of its nitrogen from the soil and two-thirds from the atmosphere. Greaves and Hirst (34) showed that approximately 40 per cent of the nitrogen in alfalfa is in the roots and concluded that if only two-thirds of the total nitrogen of the plant is obtained from the air it is, therefore, evident that the quantity returned to the soil with the roots and plant residues does not exceed that removed from the soil by the growing plant which leaves the soil neither richer nor poorer from the growth of alfalfa where the entire crop is removed.

Morse (75) found no evidence of an accumulation of nitrogen by the application of nitrogenous fertilizers or by the growth of legume crops. A number of recent investigations indicate that nitrogen may be excreted from the nodules of legumes (64,109,110,111) to benefit other plants growing in association with them. Lyon and Bizzell (65) report increases in the percentage of protein found in timothy grown with alfalfa over timothy grown alone. Similarly, oats grown with peas contained more protein than oats grown alone. They found also that soil on which alfalfa had grown for five years contained more nitrates than did soil which had grown timothy for the same length of time. The rate of nitrification of ammonium sulphate was greater in alfalfa soil than in timothy soil, indicating that the alfalfa has an influence on the conditions favouring nitrification. In a later bulletin Lyon (67) again suggests that the nitrogen content of a soil is not always increased by the growth of a legume nor is this necessary for a legume to be beneficial. "The effect of growing a legume is to make the soil nitrogen more active." This influence will be more pronounced on some soils than others, depending on the supply of other available nitrients; if these are abundant the benefit from the legume will be greater than if fertility of this kind is lacking.

Newton et al (76, 77) found no difference in the total nitrogen in the soil after alfalfa, timothy, brome grass or western rye grass in experiments where each of the crops was grown on the soil for periods of 1 year, 3 years and 5 years respectively. There was, however, a greater accumulation of nitrates in the soil after alfalfa than there was after the grasses. No significant difference in the yield of wheat was noticeable after any of the four crops but the mean annual absorption of nitrogen by the wheat crop was higher after alfalfa than after the grasses. Thus there was a relationship between nitrogen intake by the crop and the nitrate accumulation after the respective crops.

Albrecht (1,2) found that cropping had a marked effect on the removal of nitrates from the soil. Where no crop was grown the nitrate levels fluctuated from 21 pounds to 42 pounds during the growing season. Where grass, corn, or wheat was grown the accumulation of nitrates ranged from 6 to 14 pounds and was very similar under all three crops. Nitrates followed seasonal conditions closely. In the spring the nitrates increased, reached a peak in mid-summer and dropped again in late summer and fall. Comparisons of different rotations in which clover was grown once every three, four or six years indicated that the more frequently the clover was grown the greater the nitrate producing capacity of the soil.

(b) Improved Physical Condition of the Soil by Legumes

A number of investigators have attributed at least part of the benefit of legumes to their effect upon the physical condition of the soil. This view was held by Moore (74) as early as 1801. Headden (42) calculated that a good stand of alfalfa would have on the average, 250,000 plants per acre, having roots ½ inch or more in diameter and penetrating the soil to an average depth of 7½ feet. He suggested "It is evident that it would be presumptious to attempt to give any estimate of the mechanical effects of a crop of alfalfa on any ordinary soil. We have not only the penetration of the soil by the roots but the additional fact that each hole thus made is filled with organic matter very active while living and well distributed when dead and decaying. While we do not know all of the effects produced we are satisfied that they are considerable and beneficial and in no case to be left out of the reckoning. Sears (100) found soybeans showed a marked tendency to improve the tilth of the soil.

(c) Increased Bacterial Activity

An increase in bacterial activity has been reported by many experimenters as a factor producing beneficial effects by legumes. Lohnis (63) attributed the beneficial after effect of legumes harvested for hay to favourable changes in microflora of the soil which are still marked and even increasing a few weeks after the surface growth of legumes has been removed. Sears (100) found the micro-organic population of the soil increased greatly immediately after soybeans. The increase was said to be brought about by improvement in soil tilth and an increase in the available nitrogen in the soil after soybeans. Leclair (56) found strong nitrifying efficiency under cowpeas. He also reported an increase in the total number of soil bacteria and in the production of CO_2 in the soil.

(d) Increase in CO_2 Production in the Soil.

Headden (42) in Colorado attributes the beneficial effects of legumes to the large amount of CO_2 which is produced in the soil by their roots. This CO_2 combines with the soil water to form carbonic acid which increases the availability of the potash in the soil. The experiments on which these conclusions were based were conducted on soil derived from rocks rich in quartz and feldspars, the feldspars containing 2.2 to 2.5 per cent of potash. It was found that the soil air under fallow contained 60 parts of CO_2 per 10,000, while under alfalfa there were 300 parts per 10,000. There was more than twice as much soluble potash under alfalfa as under fallow. The CO_2 also increased the soluble phosphoric acid in the soil. Considerable CO_2 was also developed under red clover and wheat but less than under alfalfa.

Beneficial Effects of Non-legume Crops.

Non-legume crops as well as legumes have been found by some investigators to have a beneficial influence on those which follow or on those with which they are grown in direct association. Dandeno (23) found that Canada thistle stimulated the growth of wheat, oats and barley when grown in association with them. The stimulation was attributed to the fact that the beneficial plants excreted substances from their roots which stimulated growth or released plant food. Haedden (42) suggests beneficial results from wheat due to production of CO_2 by the roots, releasing potash from the soil in a more readily available form. Odland, Smith and Damon (78) refer to squash, red top, onions and potatoes as favourable crops to precede other crops, while carrots, alsike clover and red clover are classified as unfavourable. Comparing potatoes and onions as representing favourable or beneficial preceding crops with carrots as unfavourable the authors suggest several factors which may contribute to the beneficial effects of the former. The potatoes and onions have created less soil acidity and have removed less of the basic elements, dry matter and nitrogen than have carrots.

Injurious Effects of Plants upon One Another.

While a very large number of investigators have attempted to learn what factors in crop sequence are responsible for exerting a beneficial effect, a much larger number have approached the problem from the opposite angle, and have attempted to isolate those factors which produce a detrimental effect on succeeding or associated crops. In reviewing the literature it is quite evident that no one factor can be the cause of the injurious effect of one crop upon another. Apparently an association of factors are involved and these factors differ with different crops or with the same crops under varying environmental conditions.

In a very comprehensive review of the literature Miller (73) groups the probable causes of the deleterious influence of one plant or crop upon another into three general groups.

(a) The depletion of nutrients in the soil so that there is not a sufficient supply for the plants which follow.

(b) The production in the soil of compounds by the decomposition of roots, stems, leaves, and the cells which are lost from the growing root that are deleterious to the roots of the plants with which they come in contact.

(c) The excretion of toxic substances by the roots of the plants which are injurious to the roots of the plants growing near by or which follow in succession.

Bear (6) has enumerated and discussed the following theories which might explain the action of different crops.

(a) The theory of toxic root excretions.

(b) Different kinds and amounts of nutrients required by various plants.

(c) Differences in the feeding power for nutrients.

(d) Differences in the effect of various crop residues on the microbiological population of the soil.

(e) Differences in the effect of various plants on the soil reaction.

(f) Differences in the growth of various crops on the control of insects and fungus diseases.

Odland Smith and Damon (78) conclude that no one factor is the sole cause of the effects of crops on those that follow but that more than one factor is operative. It is suggested that these factors might include:

(a) Effect of different crops on soil acidity.

(b) The relative acid base balance of the minerals removed by certain crops.

(c) Depletion of mineral elements caused by the differences in removal of such elements by various crops.

A number of these theories have been studied extensively by various investigators and the conclusions of some of them are presented in the following review.

The Influence of Depletion of the Nutrients in the Soil on Plant Growth

Liebeg (58) was one of the first investigators to recognize the conception of multiconditioned processes or the interrelation of various factors in plant growth and this was expressed in his law of the minimum dealing with the yield of field crops. This law as commonly stated says: "The yield of any crop always depends on that nutritive constituent which is present in the minimum amount". It is quite conceivable that a crop which requires a large amount of a particular nutrient if grown continuously on the same soil might eventually deplete the soil of the nutrient until its yield was reduced by the lack of the element. This is particularly true if the element was deficient in the soil in the first place. This might easily explain the detrimental effect of continuous cropping. Daubeny (24) grew 16 different crops continuously on the same plots and compared the yields with those of crops shifted so that each crop was followed by one of a different kind. There was a gradual decrease in yield under both systems of cropping but the decrease was greater under continuous cropping than under rotation and this was attributed to the more rapid removal of the needed nutrients in the continuously cropped areas. This was borne out by soil and crop analyses.

Holter and Fields (46) in studies on the greater detrimental effect of kafir than of corn found a higher ash content in the kafir and also that the kafir removes larger amounts of phosphorus and potash from the soil than does corn.

In extensive studies at the Woburn Experimental Fruit Farm near Bedford in England, Pickering and the Duke of Bedford (81, 83, 84) could find no reduction in nutrients in the soil by crops which caused a detrimental effect on following crops. Livingston et al (59,60,61,62) and Schriener et al (91, 92, 93, 94, 95, 96, 97, 98, 99) in the United States Bureau of Soils could find no correlation between the mineral content of the soil and its crop producing power. It was suggested that the beneficial effects of applying mineral salts to the soil was not due to their addition as plant food but to the fact that they absorb or counteract substances in the soil which may be toxic to the plant.

Burgess, Hartwell, Damon, Odland and their associates at Rhode Island (19,39,40,41,78,) in very extensive field, greenhouse and laboratory experiments concluded that the divergent effect of crops on those which follow seems not to be attributed, at least principally, to differences in the amount of nutrients removed by the crops grown previously; that is, the smallest yield may not occur after the crop which removed the largest amount of even the most needed nutrient.

Hall, Brenchley and Underwood (37) state "Within wide limits the rate of growth of a plant varies with the concentration of the nutritive solution irrespective of the total amount of plant food available. When other conditions such as the supply of nitrogen, water and air are equal, the growth of the crop will be determined by the concentration of phosphorus and potash in the soil solution which in its turn is determined by the amount of these substances in the soil, their state of combination and the fertilizer applied". The net result of these investigations is to restore the earlier theory of the direct nutrition of the plant by fertilizers.

Conrad (22) explained that the deleterious effect of sorghums on a following crop of wheat was due to a high sugar content in the roots of sorghums. This supplied extra energy producing materials, thus increasing the number of micro-organisms in the soil which compete more actively with the wheat crop for the available nitrogen.

THE INFLUENCE OF THE SECRETION OF TOXIC SUBSTANCES BY THE ROOTS OF GROWING PLANTS ON PLANT GROWTH

The theory that plant roots excrete certain substances into the soil which have a marked effect upon plants grown in association or following them was one of the earliest theories used to explain how plants influence other plants. Probably more research has been done in regard to this phase of crop sequence than in any other. Clements (21) has presented a very comprehensive review of the literature in connection with "Toxic Exudates and Soil Toxins". Hales (35) was probably the first to mention these root excretions and he assumed that albumen as well as CO_2 was secreted by roots. Duhamel (28) noted the earth about the roots of old elm trees was darker and more greasy than usual and concluded that this was the result of root secretion. Plenck (85) believed that plants excreted refuse more or less after the manner of animals as shown by the drops exuded at night through openings in the roots. He regarded this excrement as partly useful, partly injurious to the plant itself as well as to its neighbors. Micaire (70) assumed that the excretion of gummy substances, $Ca\ CO_3$ etc. free the plants of nutrients which could not be assimilated or were injurious. De Candolle (25) worked in conjunction with Micaire and concluded that all plants give off excretions which have an injurious effect on other plants and used this theory to explain the benefits of crop rotation. Boussingault (10) concluded that roots do not normally excrete substances. Gasparrini (33) made the statement that he had observed that the root hairs had small lids which opened and emitted secretions. Cauvert (20) concluded that roots physiologically sound did not excrete poisons or other substances. He maintained the theories of Macaire were not well founded and that the rotation theory advanced by de Candolle and supported by Macaire and Liebeg was based on error. He declared that the sterility of a field after cultivation was not due to the excretion of injurious substances by plants of the same species. Difference in the amount of nutrients absorbed were attributed to the selective power of the roots.

From the middle of the 19th century to the beginning of the present century the plant food theory more or less dominated the field of experimentation in soil productivity. About 1900 the subject of root excretions was revived by Pickering (81, 83, 84,) in England and the Bureau of Soils (59 to 62 and 91 to 99) in United States. In both these investigations the toxin theory was very emphatically reiterated and the presence of toxic substances in the soil was demonstrated by very extensive experiments. Jones and Morse (53) observed an apparent antagonism between the buttercup and cinquefoil and attributed it to root relations rather than to shade. Breazeale (12, 13) demonstrated that extracts of certain soils were toxic to wheat seedlings in water culture and that this toxicity is removed wholly or in part by carbon black, calcium carbonate, ferric hydrate and other solids.

Russell (89) suggested that in pot experiments at Rothamstead no evidence existed of lasting toxic effect produced by one crop on its successor. Hall et al (37) could find no evidence of toxin in soils which had been growing a particular plant for upwards of 60 years. Howard (50) suggested that CO_2 may be the toxin which inhibits growth. He found that tobacco requires a great deal of air and green manures produce large amounts of CO_2 in the soil which has a deleterious effect on growth. Water logged soils have a similar effect. He suggests that the results of the Woburn experiments may have been due to the inhibiting effect of the CO_2. King (55) objected to the short term, the small amount of solution and the generally abnormal conditions of many of the experiments in regard to toxic substances and concluded that the results published by the United States Bureau of Soils did not provide positive proof that toxic excreta play an important role in rendering soils unproductive. He held more to the opinion that nutrients in the soil tend to become less due to continued cropping and the composition and concentration of the soil solution changes.

Russell (89) sums up the position regarding toxins as in 1932 as follows:

"There is no evidence of the presence of soluble toxins in normally aerated soils sufficiently supplied with plant food and with calcium carbonate.

Toxins including hydrogen ions, soluble aluminum,iron and manganese compounds, and organic substances may occur on sour soils badly aerated and lacking in calcium carbonate, or on other exhausted soils.

There is no evidence of plant excretions conferring toxic properties on the soil, bbut the Woburn fruit tree results show that a growing plant may poison its neighbour. The effect does not appear to be specific; any plant will be injured by any other within its range, but it may suffer more from one of its own kind than from one another".

Clements (21) sums up his review of the literature on the subject as follows: "The early assumption that root secretions were a factor in plant communities and in succession is no longer valid. Many successional stages and climaxes have been under detailed observation in Nebraska and Colorado since 1896 without the slightest evidence that toxins are in any manner concerned in their condition. Some of these are more luxuriant than when first seen. It seems certain that most climaxes have occupied their habitats for thousands of years or even longer, and their present growth and composition make the depressing effect of toxins unthinkable. Soil toxins are probably definitely related to deficient aeration and to anaerobic conditions. This is shown by the fact that they are readily oxidized and soon disappear under proper tillage. The cause of toxicity appears to be a direct lack of oxygen and its indirect effect in permitting the accumulation of CO_2 in harmful amounts and in producing injurious organic acids and other compounds.

THE INFLUENCE OF THE INCREASE IN SOIL ACIDITY BY PLANTS ON ASSOCIATED OR SUBSEQUENT PLANT GROWTH

Closely associated with the secretion of substances which are claimed to be poisonous to other plants is the effect of certain crops upon the reaction of the soil. In the extensive Rhode Island (19, 39, 40, 41, 78) experiments striking results were obtained in this connection. Squash, onions, and potatoes showed the least deleterious effect on succeeding crops over a period of 22 years and were also in a group which had apparently created the least soil acidity within the same period. On the other hand, carrots and red clover created the most acidity in the soil, and were followed by the lowest yield of crops. Little correlation appeared to exist between the acidity produced and the relatively more basic than acidic elements removed by the crops. However, there was a tendency toward larger yields of four succeeding crops where base removals were relatively low. Potatoes, onions and oats form a group low in excess of bases over acids, and these crops were beneficial to corn, rutabagas, mangels and potatoes that followed. Other crops did not appear to fall in line with these observations sufficiently to afford significant correlations. In the Woburn researches (83) no effect of plants on the reaction of the soil was found. Russell (89) suggested that since all plants give off carbon dioxide from their roots it might be expected that all would make the soil acid. This does not necessarily happen, however, because water cultures tend to become alkaline as the plant takes up the acid radicle of the sodium nitrate and leaves behind the base which immediately appears as the carbonate. Hall and Miller (38) obtained similar evidence when the calcium nitrate formed during nitrification was converted into calcium carbonate while the nitrate radicle was taken by the plant. This tends to increase the amount of calcium in the surface soil.

THE INFLUENCE OF THE DECOMPOSITION OF ROOTS IN THE SOIL ON PLANT GROWTH

As early as 1858 Garreaud and Brauwers (32) were of the opinion that the exfoliated matter left in the soil by the growth of roots served to explain the antipathy of certain plants for others. Dandeno (23) grew squash and corn seedlings together in distilled water in vials, and the two plants separately in other vials.

During the first 12 hours the plants in association grew better than when grown separately. During a later period, from 36 hours to 4 weeks the reverse was true. The deleterious effect in the latter period was ascribed to the bacteria and aquatic fungi preying upon the dead cells of the root caps and dying roots producing an excrementitious substance which was decidedly injurious to the growing plants. The detrimental effect can be removed by oxidation, boiling, shaking up with powdered talcum, or carbon black, or by supplying decomposing vegetable matter. Livingston et al (59,60) found that solutions from unproductive soils which they examined contained rather insoluble organic substances which were toxic to wheat plants. These substances may be produced by the growth of wheat plants in water or sand cultures, from soaking wheat seeds in water or in some cases, may be washed from the bark and leaves of trees. These substances may be absorbed and rendered inactive by the addition of nutrient substances as sodium nitrate, acid phosphate and potassium nitrate, or by non-nutrient materials such as carbon black, ferric hydrate, aluminum hydrate, pyrogallol or hydroquinone. Breazeale (12,13) reported that the deleterious effect on wheat seedlings of toxic substances from soil extracts was counteracted by the addition of calcium carbonate tri-calcium phosphate, carbon black, magnesium carbonate, barium carbonate and quartz flour. Schreiner et al (91 to 99) in very extensive chemical research in the United States Bureau of Soils isolated and identified many organic compounds in the soil, some of which were found to be injurious and some beneficial to plant growth. Some of the substances which were injurious were cumaim, vanillin, dihydroxy stearic acid, alanine, glycocol neurine, aninone, pyridine, compounds and tryosine. Other compounds which have been isolated and identified which may or may not be injurious were pecoline, carboxylic acid, agroceric acid, hydroxy fatty acids, paraffinic acid, lignoceric acid, resin, glycerides of fatty acids, phystosterol, pentosan, pentose, histidine, arginine pyrimidine, oxalic acid, succinic acid, purine nucleic acid, xanthine, choline, adenine, creatine and others. The toxicity of these compounds was greatly reduced by the use of certain fertilizers as absorbing agents. Phosphate fertilizers overcame the harmful effects of cumain, nitrogenous fertilizers were more effective with vanillin while potassium salts were more suitable in overcoming the toxic effect of quinone.

Many of the organic substances listed above are those which commonly result from the decomposition of animal and vegetable matter so it is not improbable that they are present in the soil following many species of crops.

Skinner (103) found that sesame was injurious to a succeeding crop of cabbage, and concluded that the injury was caused by the remains of the vegetation of the sesame crop which results in a lack of oxygen and an abundance of carbon dioxide. Pickering (84) suggested that although toxic excretions from the roots are possible, there is no need for imagining such an occurrence; all growing plants leave much root detritus in the soil and such dijecta may account for toxic properties just as well as ejecta.

Sewell (101) suggested the one possible cause of the harmful effects of kafir on a wheat crop following is that of toxic properties of decay. Breazeale (14) found the stubble of sorghum was injurious to the growth of wheat seedlings but only for a short time. When the stubble was completely decomposed the toxic substance was either volatilized or was itself decomposed into a non-toxic compound. The toxic effect was more pronounced on heavy soils than on light soils. Similar results were reported by Garner, Lunn and Brown (31) and Hawkins (43)

THE INFLUENCE OF CHANGES IN PHYSICAL CONDITIONS OF THE SOIL ON PLANT GROWTH

The injurious influence of certain crops have been attributed by some investigators to the unfavourable physical condition which they produce in the soil. Breazeale (14) found that sorghum rendered the soil impermeable as it tends to deflocculate it. Deflocculation and toxicity seem to be related in some way. Deflocculation takes place in these Arizona soils only when some "black alkali" or sodium carbonate is already present or when soils are near a state of alkalinity. Calcium flocculates the soil. If a soil dries out, the calcium is gradually replaced by sodium in the zeolite, the calcium taking the form of calcium carbonate and the sodium uniting with silica to form a sodium zeolite. Dry soils are likely to be highly dispersed. Calcium carbonate has very low solubility and in dry soils becomes more or less inert. In the presence of carbon dioxide, however, it goes into solution readily and becomes active. It then becomes calcium bicarbonate which is also a good flocculating agent. In productive soil carbon dioxide is usually high, due to the action of microorganisms. Sorghum apparently produces some sort of toxin in the soil, possibly hydrocyanic acid, which destroys the microflora and prevents the formation of carbon dioxide. If this happens on a soil near the alkaline point the production of carbon dioxide may be halted long enough to allow the sodium zeolite to form and cause deflocculation. The soil after a heavy crop of sorghum feels sterile and dead like a soil that has been burned. Thus sorghum indirectly brings about a poor physical condition.

Pickering and Bedford (83) could observe no difference in the effect of different crops on the physical condition of the soil. Hawkins (43)suggested that any amount of mechanical working of a soil which has recently grown a sorghum crop does not entirely rectify its poor physical condition. He attributed the poorer condition of the soil after sorghum than after corn to the fact that sorghum roots are more abundant in the upper 6 to 8 inches of soil, which accounts for the "run together" condition of sorghum soil. Some crops such as field peas do not use this upper stratum of soil and are thus not depressed in growth following sorghum, while vetch with a root system similar to sorghum is deleteriously affected. Haedden (42) suggested that the extensive rooting system of the alfalfa plant has a beneficial influence on the physical condition of the soil.

THE INFLUENCE OF CROPS UPON SOIL AERATION AND THE SUBSEQUENT EFFECT UPON OTHER CROPS

Pickering, (81,82,) reporting on the deleterious effect of grass and weeds growing near apple trees suggested that this might be caused by the fact that the grass and weeds prevented normal aeration of the soil. Clements,(21) in summing up an extensive review of literature on the subject of toxins, made the observation that soil toxins are probably definitely related to deficient aeration and to anaerobic conditions. Hole (45) also pointed out the probable significance of defective aeration in the Woburn (81, 83, 84) experiments. Hedrick (44) reported a yield of 72.9 barrels of apples where grass was grown as a cover crop and cut onee or twice a year. Where the soil was plowed each spring, cultivated four times, and a cover crop planted in July, the yield was 109.2 barrels. He ascribed the increase on the tilled plot to higher water content, more favourable aeration and bacterial activity.

THE INFLUENCE OF THE REMOVAL OF WATER BY PLANTS UPON THE EFFECT ON SUCCEEDING PLANTS

Considerable research work has been done in regard to the removal of moisture from the soil by various crops. Most of this work has been done in regions where water is a limiting factor in crop production. It has been definitely established in these "dry farming" areas that crops grown after summerfallow produce higher yields than after a crop, because of the fact that a crop uses soil moisture in large quantities by transpiration and other physiological action in its growth, while it is conserved by the summerfallow. The water requirements of different plants varies greatly, and where moisture is a limiting factor, the difference in moisture removal from the soil by different crops would be expected to produce a marked effect on crops which follow.

Briggs and Shantz (15, 16, 17,) found in their extensive work in Colorado that the water requirement of some 150 plants studied, ranged from 261 for Kursk millet to 1,076 for western wheat grass. Briggs and Piemeisel, as reported by Miller, (73) summarized the variation in the water requirement in regard to plants studied by them as follows: Considering the water requirement of proso millet as 1.00 the requirement of other crops would be: millets 1.06, sorghum 1.10, corn 1.26, wheat 1.34, barley 1.83, oats 2.04, rye 2.34 legumes 2.81, and grasses 3.10. The millets, sorghums and corn had the lowest water requirements, the small grains twice as much and legumes almost three times as much as the millets, sorghums and corn. These latter crops have been extensively used as summerfallow substitute crops in the drier sections.

Barnes (5) in soil moisture investigations at Swift Current, Canada, obtained similar results to those of Briggs and Shantz and listed the water requirements of crops in pounds of water (transpiration ratio) required to produce one pound of dry matter as follows: wheat, grain and straw 375 pounds; oats, grain and straw 326; barley, grain and straw, 345; Russian thistle 221; stinkweed 529; tumbling mustard 559; corn 240; sunflowers 386; brome grass, 1st season 1,247, second season 374, and sweet clover 1st season 1,018, second season 220 pounds. All of these crops were grown after grain.

The percent of moisture remaining in the surface 12 inches of soil after growing a number of crops at Swift Current was as follows: native prairie grass 8.41; alfalfa 9.47; wheat 7.47. After summerfallow there remained 17.65 per cent. Alfalfa used practically all of the soil moisture to a depth of 9 feet, while the prairie grass which was more shallow rooted used the moisture to a depth of only 7 feet. The moisture following the summerfallow was relatively high to a depth of 9 feet.

At the same station the 7-year average yield of wheat following summerfallow in a three-year rotation of summerfallow, wheat, wheat, was 43.3 bushels with a water requirement of 516 pounds. Wheat after wheat in the same rotation yielded 18.4 bushels and required 652 pounds of water to produce one pound of crop. When plants experience difficulty in securing moisture the yield is reduced, and the amount of water used for the production of each unit of crop is materially increased.

Under the conditions obtaining at Swift Current corn was considered to be economical in the use of water, using only 240 pounds as compared with 386 for sunflowers and 375 for wheat. The yields of wheat following these crops at Swift Current were related to the amount of moisture used by the crops. Wheat after corn yielded in a 5-year period an average of 29.8 bushels, after sunflowers 14.9, and after summerfallow 50.8 bushels.

It is quite evident, therefore, that under dry farming conditions the amount of moisture removed from the soil by various crops may have a decided influence upon succeeding crops.

THE INFLUENCE OF CROP SEQUENCE UPON DISEASES IN SUCCEEDING CROPS

Many investigators have attributed the beneficial or injurious effects of crops upon those which follow, to the fact that some crops may promote disease in the same or different crops following. On the other hand certain crops and crop sequence may eliminate this factor entirely. Bolley(7) reported that the fungus causing flax wilt which can exist for years in the soil may be the cause of unproductiveness. This disease is much more prevalent in flax under continuous culture than when grown in rotation with other crops. Bolley (8) also suggested that constant cropping with wheat tends to introduce with seed, stubble and roots a number of wheat disease-producing fungi. These destroy, blight, or rot off the roots of wheat plants and live internally in straw and seeds.

Experiments to determine the effect of various crop sequences upon the development of brown root rot have been conducted by the United States Department of Agriculture, in cooperation with the Wisconsin, Massachusetts and Connecticut Agricultural Experiment Stations (52),Laboratory, pot and field experiments were conducted and the results point to important relationships existing between the brown root rot of tobacco and certain crop sequences. The disease also attacks other plants such as tomatoes, and to a lesser degree clover. The disease is known to be retained by the soil for some time, it also varies in virulence with the amount of organic matter in the soil, and may be transmitted to new areas by affected soil or diseased vegetation. It seems to be more prevalent where tobacco is grown in rotation with other crops, particularly hay crops, than where it is grown continuously or in rotation with fallow. This may be due to the drying and aerating effects of the cultivation involved in continuous culture, and in fallow which seems to cause a reduction in the disease. The yields of tobacco where brown root rot was present were much lower after timothy, corn and clover than after tobacco, beans, potatoes, tomatoes, onions and fallow. The relationship is largely attributed to the prevalence of the brown root rot disease.

The beneficial effect of rotation on cotton at Temple, Texas (86) seems to be closely related to its effect on the root rot of cotton. During the 8-year period 1916 to 1924, exclusive of 1923 the percentage of cotton plants killed by root rot was 33.7 in continuous cropping, 5.7 in a four-year rotation of cotton, cow peas, corn, wheat or Sudan grass, 6.7 in a three-year cotton, corn, oats rotation and 12.8 in a cotton, corn, sorghum rotation. Sorghum seemed to increase the percentage of root rot in the latter rotation.

Leighty (57) writing in "Soils and Men" suggested that, in some instances, the most effective control of some plant diseases is crop rotation combined with seed treatment and general sanitary measures, but these methods are of little or no avail in the case of other diseases. Certain parasites remain from season to season in the soil living on plant refuse from the previous crop or from other sources, and when susceptible crops are grown every year the parasites tend to accumulate to a point which makes production unprofitable. It is for this group of parasites that crop rotation has made the best showing as a control measure. A table is presented by Leighty showing the outstanding examples of diseases which can be so controlled, together with a list of crops affected and crops which are immune.

On the other hand some soil-inhabiting parasites are exceedingly refractory to rotation and sanitary measures. Some of these are: Fusarium of sweet potatoes, peas and beans; white rot of onion; club root of cabbage, turnips and related plants; flax wilt; and root and stem parasites which attack a wide range of plants.

THE INFLUENCE OF CROPS UPON THE SOIL MICRO-ORGANISMS

Russell (88) showed how greatly the disturbance of the normal equilibrium of the soil flora and fauna may affect fertility. Crop production may be improved, if an undesirable condition exists in this regard, by sterilization by heat, by exposure to vapor of toluene or by drying the soil. Russell and Petherbridge (87) concluded that sickness in glass house soils is conditioned by an accumulation of insect and fungoid pests, and by lowered bacterial efficiency. The latter was due to an accumulation of factors detrimental to bacteria. The sickness in tomato and cucumber houses were effectively treated by sterilization.

Starkey (105) has shown that in cropped land the numbers of certain bacteria were increased in the neighbourhood of plant roots. Kellerman and Robinson (54) demonstrated that soil bacteria are markedly affected by soil conditions in the same manner as wheat seedlings. Sterile, aqueous extracts of a soil which did not respond to inoculation with Pseudomonas radicicola proved to be a very poor medium for the development of the bacteria. Treating the extracts with lime removed the deleterious condition, and thereafter the bacteria developed normally.

THE INFLUENCE OF CO_2 PRODUCTION ON CROPS

Howard (50) suggested that carbon dioxide produced by green manure in its decomposition may be toxic to succeeding crops. Clements (21) concluded that the cause of toxicity appears to be a direct lack of oxygen, with its indirect effect in permitting the accumulation of carbon dioxide in harmful amounts, and in producing injurious organic acids and other compounds. Haedden (42) attributed the beneficial effects of alfalfa to the production of CO_2 which formed carbonic acid in combination with the soil water to release the potassium in the soil and render it available for assimilation by the plant.

GENERAL CLASSIFICATION OF THE FACTORS PRODUCING THE EFFECTS OF PLANTS ON THOSE WHICH FOLLOW FOUND IN THE LITERATURE REVIEWED ABOVE

A. Beneficial affects

1. Beneficial affects of legume crops produced by

   (a) Increase in soil nitrogen or soil-nitrifying power.

   (b) Improved physical condition.

   (c) Increased bacterial activity.

   (d) Increase in carbon dioxide.

2. Benefits of non-legumes.

   (a) Excretion of beneficial substances.

   (b) Control of weeds, insects, disease, etc.

B. Injurious affects

   (a) Depletion of soil nutrients.

   (b) Secretion of toxic substances.

   (c) Increase in acidity.

(d) Production of injurious substances resulting from the decomposition of plant residue.

(e) Unfavourable physical condition.

(f) Lack of proper soil aeration.

(g) Removal of moisture.

(h) Diseases of certain plants.

(i) Influence of crops upon the soil flora and fauna.

PLAN OF INVESTIGATION

The field investigations reported below have been conducted on stations of the Dominion Experimental Farms of Canada. Located as these Experimental Farms are at representative points throughout the agricultural area of Canada, they offer ideal facilities for the study of crop rotation and sequence problems under a wide range of climatic and soil conditions.

OUTLINE OF ROTATION AND SEQUENCE EXPERIMENTS ON THE DOMINION EXPERIMENTAL FARMS

In 1911 extensive series of rotation experiments were initiated on a number of Experimental Farms throughout Canada. These consisted of comparisons of rotations of two, three, four, and as high as sixteen years duration. In general, however, the order of crops in these rotations followed approved sequences. The main object was to determine for each district the relative value of the various rotations for different systems of farming. Reports on these experiments, some of which are still in progress, have been issued periodically, and information based thereon has been published by Hopkins et al (47,48).

The technique of rotation experiments was revised in 1925 with the object of determining the specific effect of one crop upon the succeeding crop for as many crops as possible, without primary regard to the relationship of rotations to farm management problems. In the first crop sequence experiment of this type, laid down at Swift Current, Saskatchewan, in 1924, each of six different crops grown in one year were followed by each of the six crops in the succeeding year.

In 1929 a similar experiment was laid down at Ottawa, Ontario, in which five individual crops have followed, each year, eight preceding crops or treatments grown on the same soil the previous year. Since 1929 experiments of a corresponding nature have been commenced at Lacombe and Beaverlodge in Alberta, Regina, and Scott in Saskatchewan, Kapuskasing, Ontario, Ste. Anne de la Pocatiere, Quebec, and Nappan, Nova Scotia.

From the foregoing field experiments the following have been selected for study in this presentation.

1. Lacombe, Alberta.
2. Swift Current, Saskatchewan.
3. Kapuskasing, Ontario.
4. Ottawa, Ontario.

Associated with the field experiments at Ottawa, a certain amount of laboratory and greenhouse work has been conducted. Some laboratory work was also carried on in the Soils Department, Michigan State College of Agriculture, East Lansing, Michigan. Details of this work will be outlined after a discussion of the field work.

RESULTS OF EXPERIMENTS

The Effect of Eleven Preceding Crops on the Yield of Wheat at Lacombe, Alberta.

In 1937 a crop sequence experiment was started at the Dominion Experimental Station at Lacombe, Alberta, This Station is located at latitude 52° 28' longitude 113° 44' at an elevation of 2783 feet above sea level. The climate of Lacombe is continental in character with a mean annual temperature of 36.0°F. and a mean annual precipitation of 17.18 inches. The soil is fine sandy loam to loam and is located in the black soil region of western Canada. The Lacombe experiment compares the effect of eleven different crops on the yield of wheat in a four-year rotation, in which the first year is summerfallow, except where seeding down with grasses and clovers is necessary. In the second year one of the eleven crops, as listed in table 4, is grown in each of the rotations and these are called "preceding" crops. In the third year each of the eleven "preceding" crops is followed by a "succeeding" crop of wheat, the yields of which indicate the effect which the eleven preceding crops have on the crop following. In the fourth year of the rotation wheat is grown again. Facilities are provided for growing all crops each year. The plots are 1/100 acre in size and are laid down in triplicate.

Only three years' results are available for this experiment but these results already show certain definite effects of the various preceding cropping treatments. The three-year average yields of both preceding and succeeding crops are presented in table 3.

Table 3 - AVERAGE YIELD PER ACRE OF WHEAT FOLLOWING ELEVEN CROPS
LACOMBE, ALBERTA

Preceding crop	Yield of preceding crop	Yield of succeeding crop of wheat bu.
Summerfallow	-	38.2
Corn	8.75 tons	34.6
Potatoes	224.8 bu.	29.8
Sunflowers	9.05 tons	29.2
Sweet clover	0.88 tons	25.5
Oats	72.2 bu.	25.2
Alfalfa	1.43 tons	23.6
Wheat	33.7 bu.	22.7
Crested wheat	2.01 tons	22.5
Timothy	1.72 tons	21.8
Brome grass	2.24 tons	21.1

Under the relatively dry conditions which exist at Lacombe, moisture is the most important single factor effecting crop growth. The highest yields of wheat have been obtained, therefore, following summerfallow which conserves moisture which would otherwise be used by the growing crop. The hoed crops - corn, sunflowers and potatoes also conserve moisture to a greater extent than the cereals, forage grasses and legumes. Barnes (5) reports the water requirements of plants in the order from low requirements to high as follows: corn, cereals, legumes and forage grasses, and the yield of any succeeding crop under dry land conditions might be expected to be in reverse ratio. At Lacombe the yield of wheat has been in reverse ratio to the moisture consuming requirements of the preceding crops, except that due to the relatively low yield of the alfalfa and sweet clover the yield of wheat has been higher after legumes than after the cereal crops.

The experiment at Lacombe provides fairly conclusive evidence that, under conditions of limited precipitation, the effect of crops upon those which follow is largely dominated by the moisture consumption of the preceding crop.

THE EFFECT OF CROPS ON THE YIELD OF SUCCEEDING CROPS AT SWIFT CURRENT, SASKATCHEWAN

For the twelve-year period, 1925 to 1936, a crop sequence experiment was conducted at the Dominion Experimental Station, Swift Current, Saskatchewan. This station is located at latitude 50°20' longitude 107°45' at an elevation of 2440 feet above sea level. The mean annual temperature is 38.1°F. and the annual precipitation 14.66 inches. The soil is a Haverhill brown loam to clay loam. The Haverhill series is derived from glacial till. It is located in the brown soil zone of Saskatchewan.

This crop sequence experiment was conducted on duplicate, 1/50 acre plots, in a three-year rotation, in which the first year crop was corn from 1925 to 1929 but, due to wire worm damage, the corn was replaced by potatoes for the period 1930 to 1936. In the second year six crops or treatments - oats, peas (sweet clover 1925 and 1926) corn, millet, summerfallow and wheat were each grown on their respective plots. These crops (summerfallow in the following discussion will be considered as synonymous to a crop) were followed in the third year of the rotation by the same six crops. In this way there were 36 three-year rotations in duplicate, in which it was possible to compare the relative influence of six crops grown in the second year of the rotation on five "succeeding" crops grown in the third year. A further study of crop influence was also possible by using potatoes as a "succeeding" crop following the five crops and a summerfallow in the third year of the rotation.

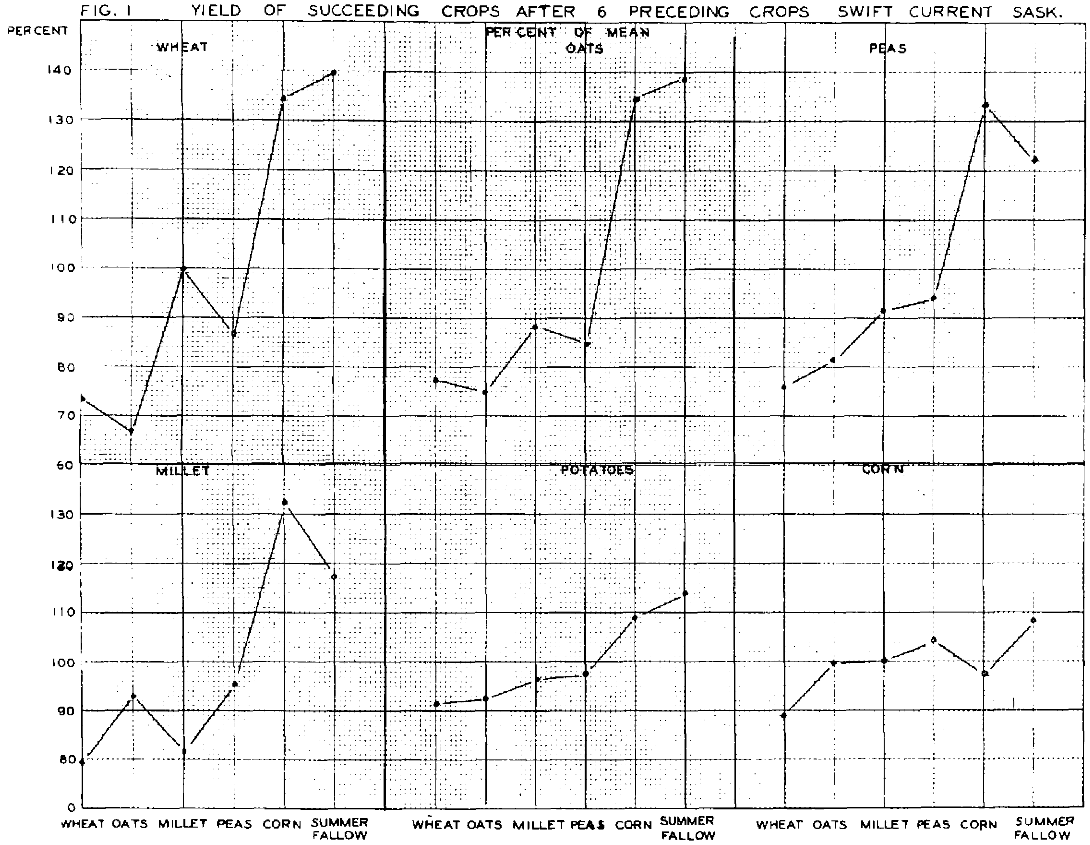
The yields of all "preceding" crops in the second year of the rotation were very uniform, the 12-year average yield of oats ranging from 33.7 to 39.9 bushels per acre, with an average of 36.3. The average yield of the "preceding" peas cut for hay ranged from 1.20 tons per acre to 1.46 tons, with an average of 1.33 tons of field-cured hay per acre. Corn for silage ranged from 3.86 tons to 4.52 tons, with an average of 4.11 tons, millet from 1.54 tons to 1.69 tons, with an average of 1.60, and wheat from 15.1 bushels per acre to 19.3 bushels, with an average of 17.2 bushels.

The 12-year average yields of each of the six "succeeding"crops which followed the six "preceding" crops are presented on the basis of bushels or tons per acre, and also as the per cent of the mean yield, in table 4. The yield on the basis of per cent of mean allows for a standard unit of comparison and shows the relative effect of the various "preceding" crops on "succeeding" crops, and is illustrated graphically in figure 1.

Table 4 – TWELVE-YEAR AVERAGE YIELDS OF "SUCCEEDING" CROPS IN SEQUENCE EXPERIMENT SWIFT CURRENT, SASKATCHEWAN

Preceding Crops	Succeeding Crops 3rd Year of Rotation										First Year	
Second Year	Wheat		Oats		Pea Hay		Millet Hay		Corn Silage		Potatoes	
	Bushels	Percent of mean	Bushels	Percent of mean	Tons	Percent of mean	Tons	Percent of mean	Tons	Percent of mean	Bushels	Percent of mean
Summerfallow	18.2	139.46	39.4	138.98	1.44	122.55	1.71	117.81	3.44	108.97	227.0	113.74
Corn	17.5	134.10	38.2	134.74	1.57	133.62	1.92	132.28	3.08	97.56	218.0	109.23
Peas	11.3	86.59	24.1	85.01	1.11	94.47	1.39	95.76	3.29	104.21	193.8	97.10
Millet	13.0	99.62	25.1	88.54	1.08	91.91	1.19	81.98	3.16	100.10	192.0	96.20
Oats	8.7	66.67	21.3	75.13	0.96	81.70	1.35	93.01	3.15	99.78	184.0	92.19
Wheat	9.6	73.56	22.0	77.60	0.89	75.74	1.15	79.23	2.82	89.33	182.7	91.54
Mean	13.05	100.00	28.35	100.00	1.175	100.00	1.452	100.00	3.157	100.00	199.583	100.00

FIG. I YIELD OF SUCCEEDING CROPS AFTER 6 PRECEDING CROPS SWIFT CURRENT SASK.



As the mean precipitation at Swift Current is lower, even, than at Lacombe, soil moisture was again the controlling factor in the yield of crops. With the exception of peas and millet for hay, all crops showed a considerably higher yield after summer-fallow than after any of the five crops. Peas and millet were higher after corn than after summer-fallow. All "succeeding" crops were higher after corn than after any other crop, except where corn followed corn. This was due to greater conservation of moisture by the corn partly because it is a cultivated crop, and similates summer-fallow, and partly due to the low yields of corn. The average yield of corn preceding wheat was only 4.01 tons per acre, before oats 4.03 tons before peas 3.86 tons, before millet 4.52 tons and before corn 4.12 tons per acre. With such low yields the crop would remove only a relatively small amount of moisture and thus, succeeding crops would be affected in a similar way to those following summer-fallow.

While the yields were considerably higher after summer-fallow and corn than after any of the other crops, indicating the importance of the moisture factor in crop growth at Swift Current, there were also several marked differences in the effect of the other preceding crops. The yields of all succeeding crops were higher after the legume crop, peas, than after wheat or oats. Wheat and oats produced higher yields after millet than after peas. In general, however, the relative production of "succeeding" crops following the six "preceding" crops followed the order from high to low production of summer-fallow, corn, peas, millet, oats and wheat.

There was considerable difference in the range of influence of the preceding crops upon those which followed. Wheat as a succeeding crop was affected to a greater extent than the other crops, the lowest yield of wheat being produced after oats, which yield was 66.67 per cent of the mean, while the highest yield was after summerfallow and was 139.46 per cent of the mean. The range in this case was 72.79 per cent The range for oats as a "succeeding" crop was 63.85 per cent, with the lowest yield after oats and the highest after summer-fallow. The range for peas was 57.88 per cent, for millet, 53.05 per cent, for potatoes 22.20 per cent, and for corn only 19.64 per cent.

It is significant that although the yields were lower under the drier conditions at Swift Current, Saskatchewan, than at Lacombe, Alberta, the relative yields following various preceding crops were affected similarly at both stations. This comparison is shown in table 5.

Table 5 - AVERAGE YIELDS OF WHEAT FOLLOWING VARIOUS "PRECEDING" CROPS
SWIFT CURRENT, SASKATCHEWAN AND LACOMBE, ALBERTA

Preceding Crop	Bushels per Acre of "Succeeding" Crop of Wheat	
	Swift Current	Lacombe
	Average 12 years	Average 3 years
Summer-fallow	18.2	38.2
Corn	17.5	34.6
Legume x	11.3	25.5
Oats	8.7	25.2
Wheat	9.6	22.7

x Peas at Swift Current Sweet clover at Lacombe

The yield at both stations was higher following the summer-fallow and the hoed crop. The comparative yields after oats and wheat were reversed at the two stations, but the difference at Swift Current was small, and these two crops are similar in their moisture requirements. The evidence is conclusive that under conditions of low precipitation in which moisture is the major growth factor, summer-fallow and hoed crops, from which there is a relatively small amount of loss of soil moisture, are the most beneficial "preceding" cropping treatments.

THE EFFECT OF CROPS ON THE YIELD OF SUCCEEDING CROPS AT KAPUSKASING, ONTARIO

An experiment was begun at Kapuskasing, Ontario, in 1937 and although only two years' results are available, the growth of preceding crops already show certain definite effects. Kapuskasing is located in the "clay belt" of Northern Ontario at latitude 49° 25' longitude 82° 25' and at an elevation 1053 feet above lea level. The annual mean temperature is 32.5° F. and the annual precipitation 27.63 inches. The virgin soil is a heavy clay overlaid in some locations by a deposit of muck. The land was broken from virgin forest in 1918 and is located in the podsol zone of Northern Ontario.

The experiment at Kapuskasing was laid down in small quadruplicate plots of 1/750 of an acre, of suitable dimensions to accommodate the use of field machinery. Crops are grown in a three-year rotation in which ten "preceding" crops are grown side by side in four ranges in the first year.

These crops are followed by four "succeeding" crops in the second year. In the third year a uniform crop of oats is grown on the entire area with grass and clover sown where necessary to establish these crops for the first year in the next cycle of the rotation.

Each crop is grown each year and a general plan of one of the four replications as conducted each year is shown in Figure 2.

Figure 2 - LAYOUT OF SEQUENCE EXPERIMENT AT KAPUSKASING, ONTARIO

One Replication of Quadruplicate Plots

First Year of Rotation

Alfalfa	Sweet clover	Red clover	Timothy	Barley	Oats	Oats and peas	Potatoes	Sunflowers	Summerfallow
Alfalfa	Sweet clover	Red clover	Timothy	Barley	Oats	Oats and peas	Potatoes	Sunflowers	Summerfallow
Alfalfa	Sweet clover	Red clover	Timothy	Barley	Oats	Oats and peas	Potatoes	Sunflowers	Summerfallow
Alfalfa	Sweet clover	Red clover	Timothy	Barley	Oats	Oats and peas	Potatoes	Sunflowers	Summerfallow

Second Year of Rotation

Potatoes	Potatoes	Potatoes	Potatoes	Potatoes	Pota-toes	Pota-toes	Potatoes	Potatoes	Potatoes
Oats	Oats	Oats	Oats	Oats	Oats	Oats	Oats	Oats	Oats
Barley	Barley	Barley	Barley	Barley	Barley	Barley	Barley	Barley	Barley
O.P.V. x	O.P.V.	O.P.V.	O.P.V.	O.P.V.	O.P.V.	O.P.V.	O.P.V.	O.P.V.	O.P.V.

x Oats, peas and vetch.

MANURED 12 TONS PER ACRE FALL OF SECOND YEAR

Third Year of Rotation

Oats seed alfalfa	Oats seed sweet clover	Oats seed red clover	Oats seed timothy	Oats	Oats	Oats	Oats	Oats	Oats
Oats seed alfalfa	Oats seed sweet clover	Oats seed red clover	Oats seed timothy	Oats	Oats	Oats	Oats	Oats	Oats
Oats seed alfalfa	Oats seed sweet clover	Oats seed red clover	Oats seed timothy						
Oats seed alfalfa	Oats seed sweet clover	Oats seed red clover	Oats seed timothy	Oats	Oats	Oats	oats	oats	oats

The two-year average yields of the four "succeeding" crops, from quadruplicate plots following the ten "preceding" crops are shown in bushels or tons per acre, and per cent of mean, in table 6 and graphically, based on per cent of mean in figure 3.

FIG. 3 YIELD OF 4 SUCCEEDING CROPS AFTER 10 PRECEDING CROPS KAPUSKASING ONTARIO

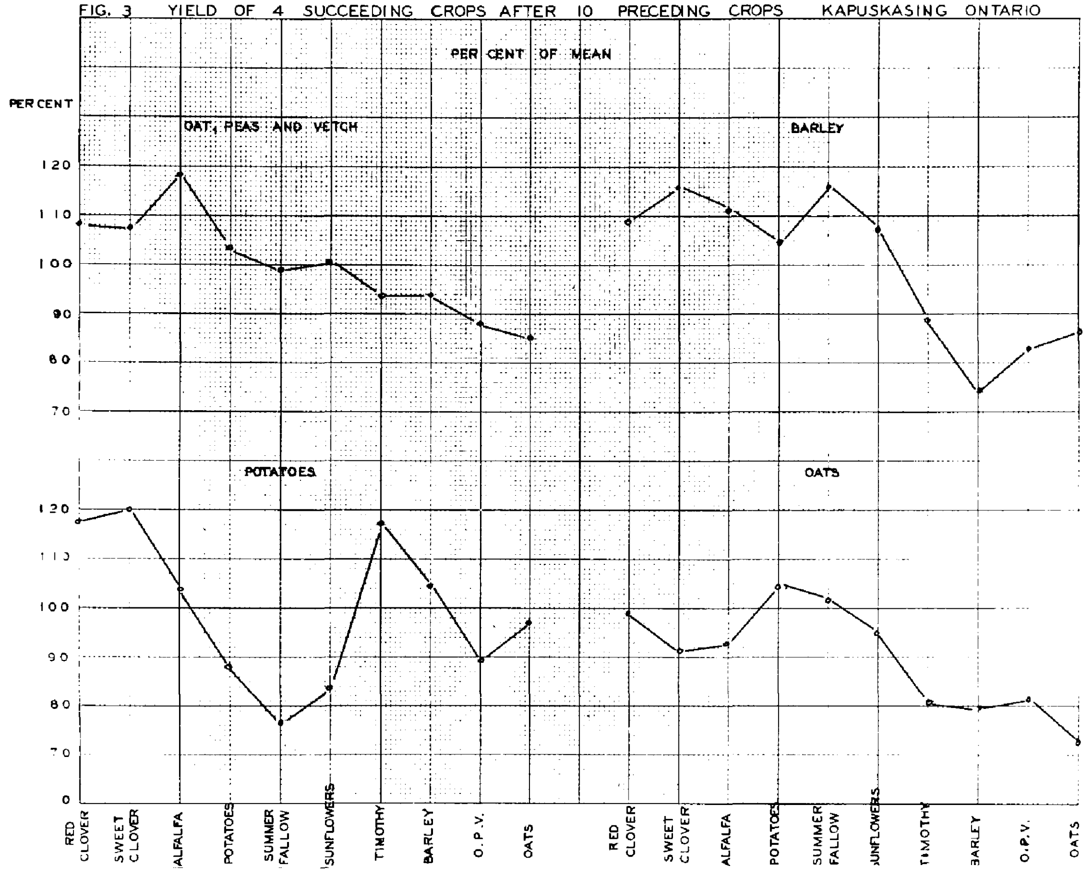


TABLE 6 - AVERAGE YIELD OF SUCCEEDING CROPS IN SEQUENCE EXPERIMENT KAPUSKASING, ONTARIO

Preceding Crop	Potatoes		Oats		Barley		Oats, peas and vetches	
	bushels	percent of mean	bushels	percent of mean	bushels	percent of mean	tons dry matter	percent of mean
Red clover	191.3	117.3	65.5	109.4	62.9	109.5	2.83	108.7
Sweet clover	196.7	120.6	61.0	101.9	66.7	116.2	2.81	107.9
Alfalfa	169.9	104.0	61.5	102.7	64.1	111.6	3.08	118.3
Potatoes	143.9	88.2	68.7	114.7	60.1	104.7	2.70	103.7
Summer-fallow	125.3	76.8	66.9	111.7	66.9	116.5	2.58	99.1
Sunflowers	136.7	83.8	62.9	105.0	61.7	107.5	2.62	100.6
Timothy	192.2	117.8	54.3	90.7	51.1	89.0	2.44	93.7
Barley	170.3	104.4	53.8	89.8	42.9	74.7	2.44	93.7
Oats, peas and vetches	146.3	89.7	54.7	91.3	47.9	83.4	2.31	88.7
Oats	159.1	97.5	49.5	82.7	49.9	86.9	2.23	85.6
Mean	163.15	100.0	59.88	100.0	57.42	100.0	2.604	100.0

While a two-year average may not be sufficient data to provide conclusive information, the yields shown in table 6 are from quadruplicate plots and are included here to show that crops, although only grown for one year on an area, have a definite influence on crops which follow.

(1) The cereal crops, barley and oats for grain, and oats, peas and vetches for silage, all show definitely higher yields following the legumes, red clover, sweet clover and alfalfa, than following the gramineae timothy, barley and oats.

(2) Barley and oats for grain do well following a complete summer-fallow and also following the hoed crops, potatoes and sunflowers.

(3) Potatoes on the other hand yielded decidedly lower, following summer-fallow and the hoed crops, and were beneficially affected by timothy and barley preceding. In common with the cereal crops, however, potatoes yielded well after red clover and sweet clover but fell off slightly after alfalfa.

(4) Barley and potatoes are usually considered to respond more to variations in soil conditions, especially soil fertility, than are oats, or oats, peas and vetches. Both of the first mentioned crops were apparently affected to a greater extent by the various preceding crops than were the oats or oats, peas and vetches. The range from lowest to highest yield in per cent of mean following the different preceding crops varied from 43.4 in the case of potatoes to 41.2 for barley, 32.7 for oats, peas and vetches and 32.0 for oats.

THE EFFECT OF CROPS UPON THE YIELD OF SUCCEEDING CROPS AT OTTAWA, ONTARIO

The greater part of the investigations presented herewith, concerning the effects of crops upon those which follow have been conducted at the Central Experimental Farm, Ottawa, Ontario. This farm is located at latitude 45° 24' longitude 75° 43' at an elevation 260 feet above sea level. The mean annual temperature is 41.7 degrees F. and the annual precipitation is 34.43 inches. The soil where these experiments were conducted is a sandy clay loam.

Mechanical analyses were made on the soil from plots in one complete replication of this experiment in the winter of 1938-39 using the hydrometer method of Bouyoucos (11). The variation in the texture of the soil in various parts of the field was found to be relatively small. Of the 48 determinations made the variation in the sand of the surface soil ranged from 50.40 per cent to 57.58 per cent. The silt portion (0.05 to 0.002 m.m.) ranged from 25.86 to 32.30 per cent and the clay portion (0.002 to 0.00 m.m.), from 14.58 to 21.70 per cent. The average per cent of the different portions in the surface six inches of soil was 52.82 of sand, 29.19 of silt and 17.98 of clay. In the 6 to 12 inch depth the average per cent sand was 56.29, of silt 26.90, and of clay 16.87. The subsoil below 12 inches contained 57.78 per cent sand, 26.46 of silt and 15.76 per cent of clay.

The field experiment at Ottawa in its present form was laid down in 1934. It consists of two three-year rotations, one of which has received an application of 12 tons of well rotted barnyard manure in the fall of the second year of the rotation, while the other has not been manured. The plots are .003 of an acre in size in duplicate, and of such dimensions as to permit the use of field machinery. In the first year of the rotation 8 "preceding" crops are grown,- alfalfa, red clover, timothy, summer-fallow, silage corn, fall rye, oats, and potatoes. These are each followed in the second year by corn, mangels, fall rye, oats and potatoes. In the third year all plots are seeded to oats with grass and clover seeded where required to again start the rotation. Figure 4 shows the general plan of the Ottawa field experiment.

FIGURE 4 - FIELD PLAN OF CROP SEQUENCE EXPERIMENT AT OTTAWA, ONTARIO

1st year Preceding crops		2nd year Succeeding crops		3rd year
Potatoes	No manure	Corn, Mangels, Rye, Oats, Potatoes	No manure	Oats
Oats				Oats
Rye				Oats
Corn				Oats
Summerfallow				Oats
Timothy				Oats and timothy
Red clover				Oats and red clover
Alfalfa				Oats and alfalfa
Potatoes		Corn, Mangels, Rye, Oats, Potatoes	Manure 12 tons per acre fall of 2nd year	Oats
Oats				Oats
Rye				Oats
Corn				Oats
Summerfallow				Oats
Timothy				Oats and timothy
Red clover				Oats and red clover
Alfalfa				Oats and alfalfa

In 1939 the experiment had been in operation for 5 years. In order to show the production of preceding crops the 5-year average, 1934 to 1938, yields of each of the seven crops are shown in table 7, as they precede each of the five succeeding crops.

Table 7 - AVERAGE YIELD OF SEVEN "PRECEDING" CROPS AT OTTAWA

	Yield (5-Year average) of Crops Preceding				
Preceding Crop	Corn	Mangels	Rye	Oats	Potatoes
		Manured			
Alfalfa, x tons	3.23	3.50	3.23	3.37	3.33
Red clover, x tons	1.91	2.03	1.79	1.81	1.59
Rye x bushels	34.9	41.7	41.6	37.9	37.7
Timothy xl tons	2.80	3.26	2.77	2.56	2.40
Corn silage, tons	15.81	21.03	20.63	20.94	20.43
Oats, bushels	61.9	69.9	66.5	61.1	63.7
Potatoes, bu.	176.1	217.8	195.5	202.8	163.5
		Unmanured			
Alfalfa x tons	3.07	3.04	2.75	2.42	2.55
Red clover x tons	1.56	1.58	1.29	1.20	1.29
Rye x bu.	33.7	38.1	35.7	32.7	35.9
Timothy xl tons	1.92	2.34	2.04	1.98	2.10
Corn silage, tons	14.43	18.54	19.18	18.35	17.57
Oats, bu.	65.8	66.2	69.9	60.6	66.1
Potatoes, bu.	140.8	171.9	193.0	188.3	138.6

x Alfalfa, red clover and rye 4-year average.

xl Timothy 3-year average.

The average yields of preceding crops as shown in table 7 have been normal yields in most cases. Only four years' results are presented for alfalfa and red clover. The crops seeded in 1934 only occupied the land for one season and there was not enough crop produced to record a yield as hay. Similarly timothy only grew during the year in which it was sown, in 1934, and in addition this crop was completely winter killed in 1937. The yield of alfalfa and red clover was also reduced following the severe winter injury in that year but some crop was harvested. The rye was also completely killed in the same year thus allowing for only a 4-year average. The yield of all crops was considerably lower on the unmanured land than on manured land.

To determine the influence of these eight "preceding" crops upon those which follow, five "succeeding" crops have been grown every year following each of the "preceding" crops. The yields of the "succeeding" crops are presented in table 8.

TABLE 8 FIVE-YEAR AVERAGE YIELD OF "SUCCEEDING" CROPS AT OTTAWA, ONTARIO

"Succeeding" Crops 1935 to 1939

Preceding Crops	Corn	Mangels	Rye		Oats		Potatoes
			grain	straw	grain	straw	
	tons	tons 4 yrs.	bu.	tons	bu.	tons	bu.
			Manured				
Alfalfa	19.87	42.4	48.6	2.31	66.8	1.88	344.7
Red clover	20.88	39.3	42.3	2.20	67.7	1.97	337.5
Rye	19.46	34.2	36.7	1.68	65.3	1.70	313.3
Timothy	18.02	36.8	35.7	2.17	58.3	1.87	334.7
Summer-fallow	17.16	35.9	48.6	2.34	73.9	2.01	296.7
Corn silage	16.03	35.7	38.2	1.91	61.1	1.71	300.8
Oats	17.31	33.7	28.8	1.55	60.5	1.59	306.7
Potatoes	16.24	35.1	35.0	1.77	56.5	1.51	219.9
			Not Manured				
Alfalfa	18.23	32.2	40.3	2.07	65.8	1.59	220.8
Red clover	18.08	31.3	39.8	1.93	58.9	1.43	212.2
Rye	17.23	29.1	31.8	1.61	57.1	1.53	176.1
Timothy	15.40	29.4	30.6	1.80	55.5	1.54	235.5
Summer-fallow	15.61	32.8	44.8	2.39	56.3	1.31	194.5
Corn silage	14.84	28.1	34.0	1.59	59.8	1.52	162.2
Oats	15.29	27.0	29.1	1.33	52.7	1.48	160.0
Potatoes	15.25	31.9	45.4	2.17	61.6	1.68	177.4

In order to compare the relative yields of the various crops on the basis of a uniform unit of measurement they are presented in table 9 in pounds per acre and also in percent of the mean. The yields are also shown graphically on the basis of pounds per acre in figure 5 and in per cent of the mean in figure 6.

TABLE 9 - AVERAGE YIELD OF SUCCEEDING CROPS IN FIELD EXPERIMENT AT OTTAWA, ONTARIO

Preceding Crop	Corn		Mangels		Rye		Oats		Potatoes	
	lb.per acre	% of mean	lb.per acre	% of mean	lb.per acre	% of mean	lb.per acre	% of mean	lb.per acre	% of mean
				Manured						
Alfalfa	39740	109.6	84800	115.7	7342	118.8	6031	105.3	20682	112.3
Red clover	41760	115.2	78600	107.3	6769	109.5	6241	108.9	20250	110.0
Rye	38920	107.4	68400	93.3	5415	87.6	5620	98.1	18798	102.1
Timothy	36040	99.4	73600	100.4	6339	102.6	5722	99.9	20082	109.1
Summerfallow	34320	94.7	71800	98.0	7402	119.8	6533	114.1	17802	96.7
Corn	32060	88.5	71400	97.4	5959	96.4	5497	96.0	18048	98.0
Oats	34620	95.5	67400	92.0	4713	76.3	5237	91.4	18402	100.0
Potatoes	32480	89.6	70200	95.8	5500	89.0	4941	86.3	13194	71.7
Mean	36243	100.0	73275	100.0	6180	100.0	5728	100.0	18407	100.0
Range	26.7		23.7		42.5		27.8		40.6	

Table 9 (Cont'd.)

	Unmanured									
Alfalfa	36460	112.2	64400	106.5	6397	110.4	5417	107.1	13248	114.8
Red clover	36160	111.3	62600	103.5	6089	105.1	5263	104.1	12732	110.3
Rye	34460	106.1	58200	96.3	5001	86.3	5001	98.9	10566	91.6
Timothy	30800	94.8	58800	97.3	5314	91.7	4967	98.2	14130	122.4
Summerfallow	31220	96.1	65600	108.5	7289	125.8	4534	89.6	11670	101.1
Corn	29680	91.4	56200	93.0	5084	87.7	5073	100.3	9732	84.3
Oats	30580	94.1	54000	89.3	4290	74.1	4752	93.9	9600	83.2
Potatoes	30500	93.9	63800	105.5	6882	118.8	5454	107.8	10644	92.2
Mean	32483	100.0	60450	100.0	5793	100.0	5058	100.0	11540	100.0
Range		20.8		19.2		51.7		18.2		39.2

FIG. 5

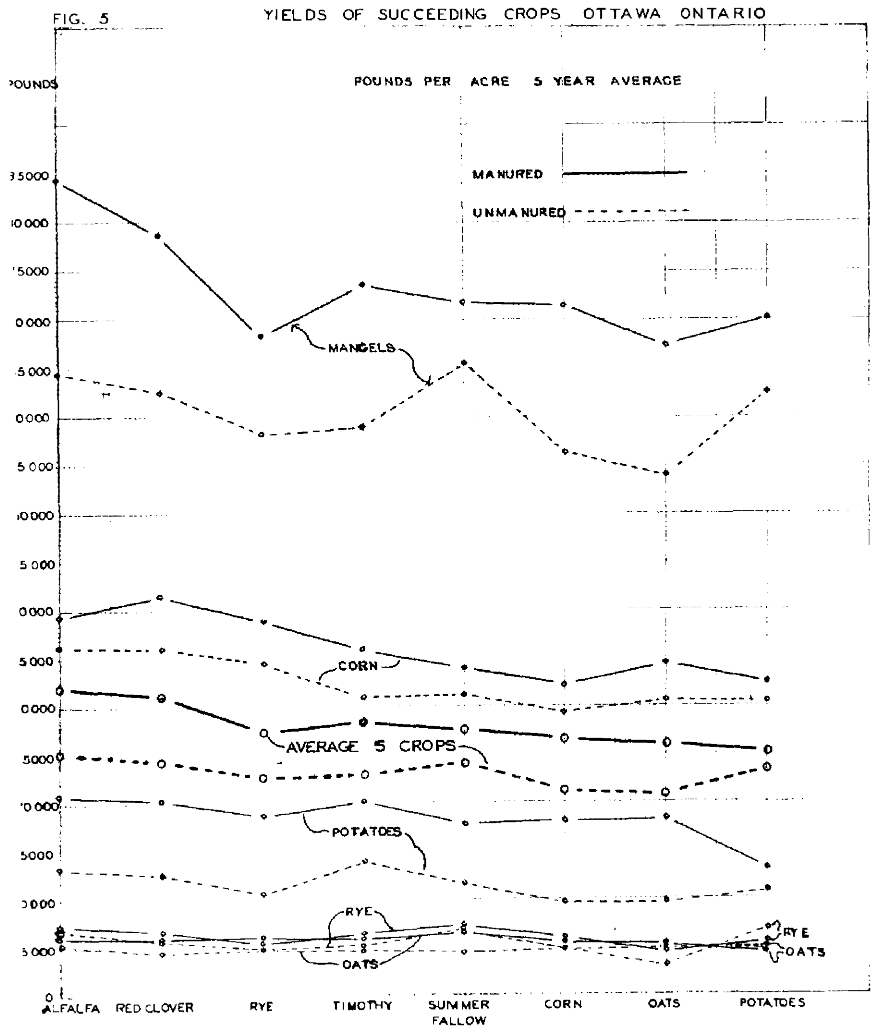
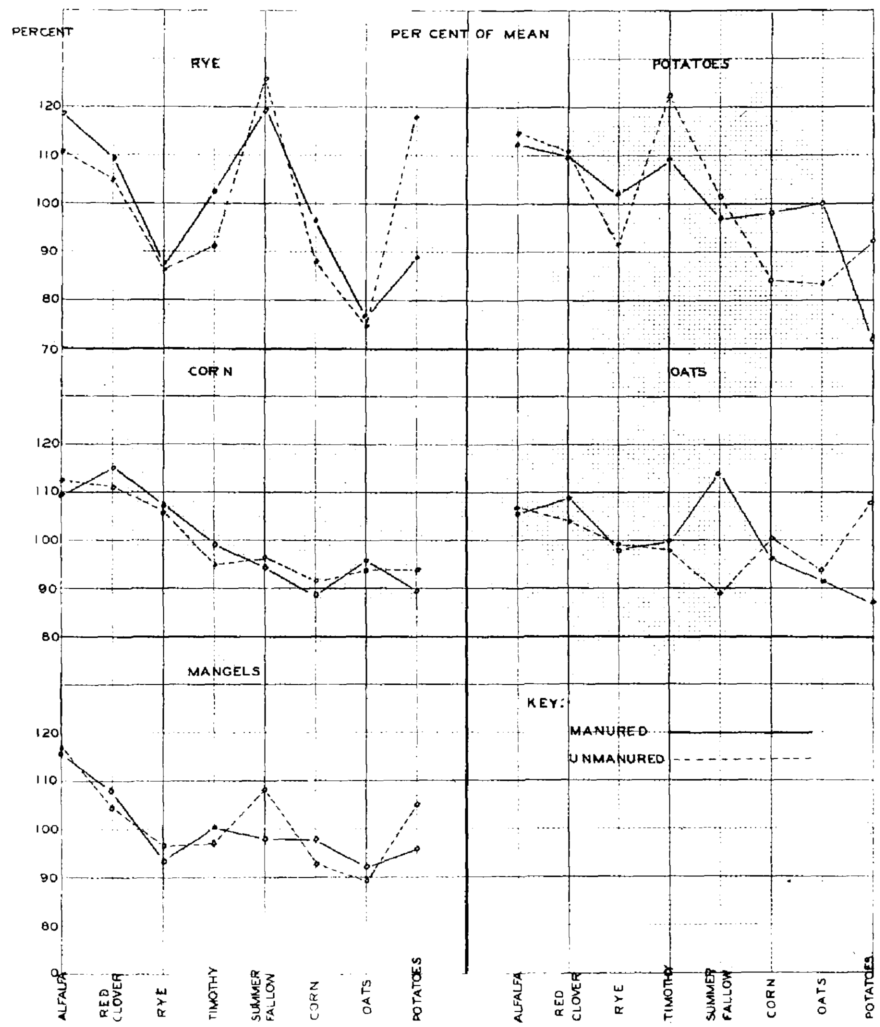

YIELDS OF SUCCEEDING CROPS OTTAWA ONTARIO
POUNDS PER ACRE 5 YEAR AVERAGE
POUNDS
MANURED
UNMANURED
MANGELS
CORN
AVERAGE 5 CROPS
POTATOES
RYE
OATS
ALFALFA
RED CLOVER
RYE
TIMOTHY
SUMMER FALLOW
CORN
OATS
POTATOES

FIG. 6 YIELD OF 5 SUCCEEDING CROPS FOLLOWING 8 PRECEDING CROPS
OTTAWA ONTARIO



In the field experiments at Ottawa the yields of all five "succeeding" crops have been consistently high following the sod crops - alfalfa, red clover and timothy and, with three exceptions, the yields following these crops have ranged in the order named. The exceptions were in the cases of potatoes following timothy on unmanured land, which yielded higher than following red clover or alfalfa and corn and oats following red clover on manured land which were slightly higher than following alfalfa. No particular explanation can be offered as to why these exceptions have occurred. Potatoes were the least affected by legumes as a preceding crop and in fact the yield of potatoes on unmanured land was higher following timothy than following any other crop. Similarly on manured land the yield of potatoes was relatively high after timothy, the yield being only 2.8 bushels per acre lower than following red clover, and 10 bushels per acre lower than after alfalfa.

Rye was a relatively desirable crop preceding corn and the yield of corn silage following rye was exceeded only by the crop following alfalfa and red clover on both manured and unmanured land. Rye preceding the grain crops, rye and oats, was not particularly favourable. Only where rye followed oats was the yield lower than following rye. Preceding oats, rye was slightly better than oats preceding oats.

Corn, oats and potatoes were consistently poor preceding crops particularly on manured land. Corn and oats were also poor on unmanured land, as were potatoes preceding corn and potatoes. Preceding mangels and the grain crops on unmanured land, however, potatoes ranked relatively high.

Summerfallow preceding the five indicator crops used in this experiment has been variable in its benefits. The yield of the grain crops, rye and oats, on manured land, has been consistently high following summerfallow, as has also rye on unmanured land. On the other hand, the lowest yield of oats on unmanured land was secured after summerfallow. Summerfallow preceding mangels has been of considerable benefit especially on unmanured land. Before corn and potatoes, however, summerfallow has shown little benefit.

In order to more readily observe the effect of the various preceding crops upon crops following, they are listed in table 10 in order of their beneficial effect upon each of the five succeeding crops on both manured and unmanured land.

Table 10 - ORDER IN WHICH EIGHT PRECEDING CROPS AFFECTED THE YIELD OF FIVE SUCCEEDING CROPS AT OTTAWA, ONTARIO

		Corn	Mangels	Rye	Oats	Potatoes
			Manured land			
	1	red clover	alfalfa	summer-fallow	summer-fallow	alfalfa
Preceding	2	alfalfa	red clover	alfalfa	red Clover	red clover
crops in	3	rye	timothy	red clover	alfalfa	timothy
order of	4	timothy	summer-fallow	timothy	timothy	rye
affect	5	oats	corn	corn	rye	oats
upon	6	summerfallow	potatoes	potatoes	corn	corn
succeeding crops	7	potatoes	rye	rye	oats	summer-fallow
	8	corn	oats	oats	potatoes	potatoes
			Unmanured			
	1	alfalfa	summer-fallow	summer-fallow	potatoes	timothy
Preceding	2	red clover	alfalfa	potatoes	alfalfa	alfalfa
crops in	3	rye	potatoes	alfalfa	red clover	red clover
order of	4	summerfallow	red clover	red clover	corn	summer-fallow
effect up-	5	timothy	timothy	timothy	rye	potatoes
on	6.	oats	rye	corn	timothy	rye
succeeding	7	potatoes	corn	rye	oats	corn
crops	8	corn	oats	oats	summer-fallow	oats

By arranging the preceding crops in order of their effect upon each of the succeeding crops, as is done in table 10, it is possible to rate them in regard to their relative benefit to the crops generally. Since there are eight crops or treatments they may be rated, giving the most beneficial crop preceding each succeeding crop a score of one and scoring down through the less beneficial crops until the crop which is least beneficial is given a score of eight. On this basis the relative benefits of the preceding crops are shown in table 11.

TABLE 11 - RELATIVE BENEFITS OF PRECEDING CROPS ON FIVE SUCCEEDING CROPS

Preceding crops	Corn	Mangels	Rye	Oats	Potatoes	Relative rating before all crops
			Manured			
Alfalfa	2	1	2	3	1	9
Red clover	1	2	3	2	2	10
Timothy	4	3	4	4	3	18
Summer-fallow	6	4	1	1	7	19
Rye	3	7	7	5	4	26
Corn	8	5	5	6	6	30
Oats	5	8	8	7	5	33
Potatoes	7	6	6	8	8	35
			Unmanured			
Alfalfa	1	2	3	2	2	10
Red clover	2	4	4	3	3	16
Summer-fallow	4	1	1	8	4	18
Potatoes	7	3	2	1	5	18
Timothy	5	5	5	6	1	22
Rye	3	6	7	5	6	27
Corn	8	7	6	4	7	32
Oats	6	8	8	7	8	37

With the preceding crops rated as in table 11, it is quite evident:

(1) On both manured and unmanured land alfalfa and red clover have been consistently favourable crops preceding the five succeeding crops used in this experiment.

(2) Corn and oats have been consistently unfavourable preceding crops.

(3) Timothy and rye have been uniformly midway between favourable and unfavourable with all crops.

(4) Potatoes have been somewhat inconsistent and summerfallow even more so. On manured land potatoes were unfavourable before all crops. On unmanured land they were followed by the highest yield of oats; they stood second preceding rye, third before mangels, seventh before corn and fifth before potatoes.

(5) Summerfallow was most inconsistent in its effect on succeeding crops both on manured and unmanured land. On manured land the highest yields of both rye and oats were obtained after summerfallow while on unmanured land the lowest yield of oats followed summerfallow. The yield of mangels was highest after summerfallow on unmanured land and relatively high where manure had been applied. Corn and potatoes produced low yields after summerfallow on manured land but stood in fourth place on unmanured land.

(6) In each case where crops have followed their own species the yield has been relatively low.

7. On the manured area there has been less variation in the yields following different crops, which suggests that the manure tends to mask the effect of the preceding crops. This effect may be due to the manure levelling out the differences in fertility levels produced by the crops removing different amounts of various nutrients, or the manure may tend to absorb some of the toxic substances produced by different plants as was found by Schriener (91 to 99) and others.

POT EXPERIMENTS

As a supplement to the foregoing field tests at Ottawa an experiment was started in 1937 in which crops identical to those in the field were grown in two-gallon glazed pots. Soil was removed from the unmanured area in the field experiment in the spring of 1937. The soil was thoroughly mixed and sifted through a 1/4 inch mesh sieve to remove the larger pebbles. An equal amount of soil, six kilograms, was then weighed into each pot and the seven preceding crops - alfalfa, red clover, timothy, corn, rye, oats, and potatoes were grown in duplicate in 1937. Another set of duplicate pots was left with no crop to represent summerfallow. The pots were set out in a screened enclosure and subjected to normal climatic conditions in that they received normal sunshine and temperature, and in addition to the normal rainfall they received additional water when required.

In 1938 the five "succeeding" crops used in the field trials, namely, corn, mangels, rye, oats and potatoes were planted following each of the preceding crops grown the year previous. Facilities were also provided to grow crops in a similar sequence in 1939. Thus two years' results are available in which the five succeeding crops have been grown in the pots following eight preceding crops and the average yields for the two years are presented in table 12.

TABLE 12 - YIELD OF SUCCEEDING CROPS GROWN IN TWO-GALLON GLAZED POTS 1938-1939

Preceding Crop	Corn	Mangels	Rye			Oats			Potatoes
			grain	straw	total crop	grain	straw	total crop	1938 only
	grams	grams	grams	grams	grams	grams	grams	grams	grams
Alfalfa	100.97	98.39	4.21	10.61	14.82	3.04	12.83	15.87	148.83
Red clover	82.82	62.07	2.62	6.42	9.04	1.83	8.95	10.78	122.24
Spring rye	100.15	89.34	2.73	9.18	11.91	3.51	10.08	13.59	111.63
Timothy	72.17	75.65	1.60	4.16	5.76	3.63	7.88	11.51	77.93
Summer-fallow	85.46	99.20	4.33	11.18	15.51	3.12	9.64	12.76	124.06
Corn silage	78.84	80.60	3.51	8.65	12.16	3.74	10.77	14.51	99.20
Oats	95.20	88.13	4.35	9.61	13.96	1.77	9.46	11.23	108.09
Potatoes	81.92	69.99	3.38	7.82	11.20	2.26	9.54	11.80	141.75

The most outstanding difference in the effect of preceding crops when grown in pots as compared with similar crops grown in the field is that concerning the red clover and timothy. In the field both of these crops ranked relatively high as beneficial preceding crops. In pots, timothy in general was the most unfavourable preceding crop, being followed by the lowest yield of corn, rye and potatoes and the third lowest yield of mangels and oats. Red clover was very little better as a preceding crop grown in pots, being followed by the lowest yield of mangels and oats, second lowest yield of rye, fourth lowest of corn and fifth before potatoes. Probably poor aeration in the pots retarded the decomposition of the crop residue left after these crops, and this together with the fact that the residue was worked into the soil in the spring just previous to seeding the crops, either produced substances toxic to the growing crops or withheld some important nutrient temporarily from the growing plants.

The remaining five crops and summerfallow affected the succeeding crops in a manner similar to that obtained in the field. Alfalfa was the most favourable preceding crop and the highest yields of corn, oats and potatoes followed this crop and the yields of mangels and rye following alfalfa were exceeded only by those following summerfallow. Unlike red clover and timothy the alfalfa appears to have a favourable physical affect on the soil and the soil in the pots was more open and friable following alfalfa than following the other sod crops.

This effect of alfalfa was suggested also by Haedden (42) and Moore (74).

Summerfallow and rye were relatively favourable crops preceding all five succeeding crops and were particularly favourable before mangels and rye. This was also true on unmanured land in the field experiments. Oats and corn were unfavourable crops in both field and pot experiments. Strangely enough the yield of potatoes after potatoes grown in pots was relatively high.

FIELD AND LABORATORY TESTS TO DETERMINE FACTORS WHICH CONTRIBUTE TO THE EFFECTS OF CROPS UPON CROPS WHICH FOLLOW

It is quite evident from the results of field experiments presented above that crops are capable of exerting a marked beneficial or detrimental effect upon crops which follow them in a rotation. Different investigators (see review of literature) have attributed these effects to certain widely varying factors. It seems apparent that a number of conditions or factors, some desirable and some undesirable, may be produced by different species of plants. Furthermore, the factors introduced by certain species under one set of climatic or soil condition may be entirely absent or ineffective under another set of conditions. Again, factors which are very active and influential in the early part of the growing season may become less effective later in the same season. Such differences have been observed and recorded in the field experiments at Ottawa and are discussed below.

DIFFERENCES IN THE EFFECT OF CROPS ON SUBSEQUENT CROPS AT DIFFERENT PERIODS IN THE GROWING SEASON AT OTTAWA.

It was first observed with corn following summerfallow that the effect of previous cropping on subsequent crops was different in the early part of the growing season than it was later in the season. Each year since the experiment began, corn in the early part of the season, made exceptionally poor growth following the summerfallow treatment, but when the crop was harvested at the end of the season the yield was just as high as following many of the other treatments. In order to show the difference in growth at different periods the height of the crop was measured at approximately two-week intervals throughout the seasons of 1937, 1938 and 1939. As the dates of measurements in 1938 did not coincide with those of the other two years the records for that year are omitted, although they showed the same trend as in the other years. The record of height at four different dates in 1937 and 1939, together with the average for the two years is shown in table 13, and the two-year average height is presented graphically in figure 7.

TABLE 13 - AVERAGE HEIGHT OF CORN FOLLOWING VARIOUS PRECEDING CROPS AT DIFFERENT PERIODS IN THE GROWING SEASON AT OTTAWA

Preceding Crop	July 10			July 24			August 8			September 9		
	1937	1939	Av. 2 yrs.	1937	1939	Av. 2 yrs.	1937	1939	Av. 2 yrs.	1937	1939	Av. 2 yrs.
					Manured							
Alfalfa	48.2	36.5	38.3	80.3	48.5	64.4	99.8	59.0	79.4	109.8	78.0	93.9
Red clover	46.7	26.5	36.6	84.6	45.5	65.0	105.2	56.0	80.6	112.4	90.0	101.2
Rye	40.6	26.0	33.3	81.8	45.0	63.4	101.0	53.0	77.0	111.6	78.0	94.8
Timothy	42.7	24.5	33.6	82.2	39.5	60.8	98.0	50.0	74.0	110.0	78.0	94.0
Summerfallow	29.2	15.0	22.1	58.2	34.0	46.1	77.4	45.0	61.2	102.2	84.0	93.1
Corn	44.5	25.5	35.0	79.6	41.5	60.5	94.4	50.5	72.4	105.4	81.0	93.2
Oats	39.7	23.0	31.3	75.4	41.0	58.2	92.2	51.0	71.6	109.8	81.0	95.4
Potatoes	35.2	23.5	29.3	66.2	40.5	53.3	89.8	50.5	70.1	104.4	78.0	91.2

TABLE 13 (Cont'd.) No Manure

Preceding Crop	July 10			July 24			August 8			September 9		
	1937	1939	Av. 2 yrs.	1937	1939	Av. 2 yrs.	1937	1939	Av. 2 yrs.	1937	1939	Av. 2 yrs.
Alfalfa	35.8	25.5	30.6	70.6	44.0	57.3	94.0	54.5	74.2	104.8	78.0	91.4
Red clover	37.0	25.0	31.0	70.4	43.5	56.9	90.4	54.0	72.2	102.6	78.0	85.3
Rye	33.4	21.0	27.2	65.2	36.5	50.8	81.6	47.0	64.3	102.6	75.0	88.8
Timothy	34.2	21.5	27.8	64.2	38.0	51.1	81.4	48.0	64.7	95.4	69.0	82.2
Summerfallow	23.4	9.5	16.4	50.6	21.0	35.3	71.4	34.5	52.9	90.0	78.0	84.0
Corn	31.0	18.5	24.7	60.8	33.0	46.9	77.8	44.0	60.9	96.6	78.5	87.5
Oats	27.2	20.0	23.6	56.0	35.0	45.5	75.8	45.5	60.6	91.4	66.0	78.7
Potatoes	25.0	16.5	20.7	56.0	30.0	28.0	73.8	43.0	58.4	91.6	75.0	83.3

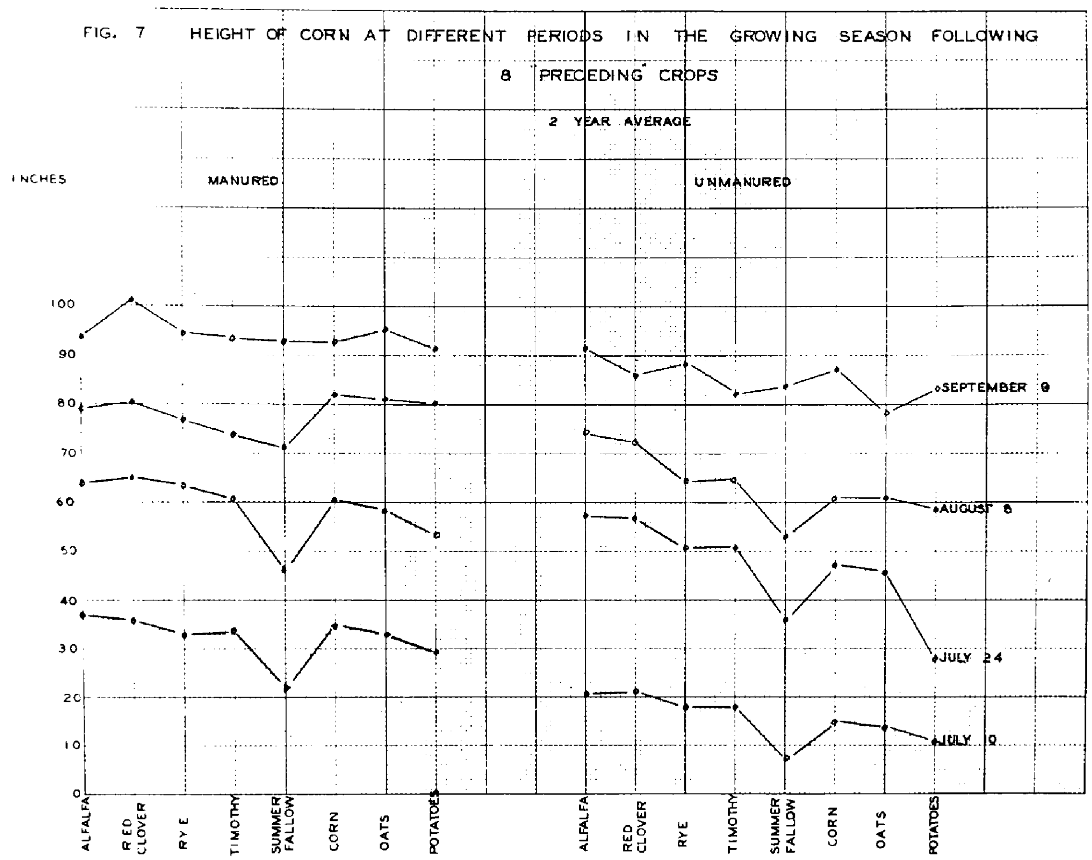


FIG. 7 HEIGHT OF CORN AT DIFFERENT PERIODS IN THE GROWING SEASON FOLLOWING 8 PRECEDING CROPS
2 YEAR AVERAGE
INCHES
MANURED
UNMANURED
100
90
80
70
60
50
40
30
20
10
0
SEPTEMBER 9
AUGUST 8
JULY 24
JULY 10
ALFALFA
RED CLOVER
RYE
TIMOTHY
SUMMER FALLOW
CORN
OATS
POTATOES

The two-year average height of the corn on summerfallow on July 10th was 22.1 inches on manured soil as compared with corn 38.3 inches high following alfalfa. On manured soil on the same date corn following summerfallow was 16.4 inches high and following red clover 31.0 inches high. This relatively slow growth of the corn after summerfallow continued through July 24th and August 8th as shown by the consistently shortest corn at each of these dates of measurement. By September 9th when the corn was harvested, the corn after summerfallow had increased its rate of growth so that it was almost as high as that following the other crops. Between August 8th and September 9th the corn following summerfallow on manured land grew an average of 32.9 inches, while the corn following the other seven crops grew only an average of 19.5 inches. On unmanured land during the same period the corn following summerfallow grew an average of 31.1 inches, while the average growth of the other crops was 20.3 inches. Intermediate measurements at weekly intervals in 1937 showed that the more rapid growth on the summerfallow plot did not start until after August 14th. Thus the most rapid growth on this previously summerfallowed plot occurred during the last three weeks of the growing season. The growth has been similar in each of the other years.

It may also be noted that the growth of corn following potatoes was slow in the early part of the season and was accelerated considerably as the season advanced. The same was true to a lesser extent after rye. The growth of corn following each of the other crops was relatively uniform throughout the season.

It has been suggested that the retarded growth after summerfallow in the early and midseason might be due to lack of moisture. This would seem hardly likely as moisture conditions after summerfallow have been found under the dry farming conditions at Swift Current to be more favourable than after a crop. Barnes (5) and others have demonstrated that there is considerably more moisture retained in the soil the year after summerfallow than after a crop. Furthermore it has been observed in the Ottawa experiments that oats and fall rye, the moisture requirements of which are higher than for corn, make their best growth from early spring until harvest following summerfallow.

This is well demonstrated in the case of rye by measurements which were made in 1939 at three different intervals, the results of which are presented in table 14 and Figure 8.

TABLE 14 - HEIGHT OF RYE AT DIFFERENT PERIODS IN THE GROWING SEASON FOLLOWING VARIOUS PRECEDING CROPS AT OTTAWA, 1939

Preceding Crop	May 31	June 14	July 2
	Manured		
	inches	inches	inches
Alfalfa	23.0	48.0	48.5
Red clover	26.0	50.5	51.0
Rye	19.0	43.5	45.0
Timothy	18.0	45.0	44.5
Summerfallow	26.5	54.5	54.5
Corn	20.5	45.5	46.5
Oats	20.0	45.5	47.0
Potatoes	22.0	46.0	47.5
	Unmanured		
Alfalfa	20.0	46.5	47.0
Red clover	20.0	47.5	49.5
Rye	12.0	33.0	42.0
Timothy	15.5	40.5	44.5
Summerfallow	24.5	50.0	50.5
Corn	17.0	36.5	43.5
Oats	12.0	34.0	44.5
Potatoes	20.5	44.5	47.0

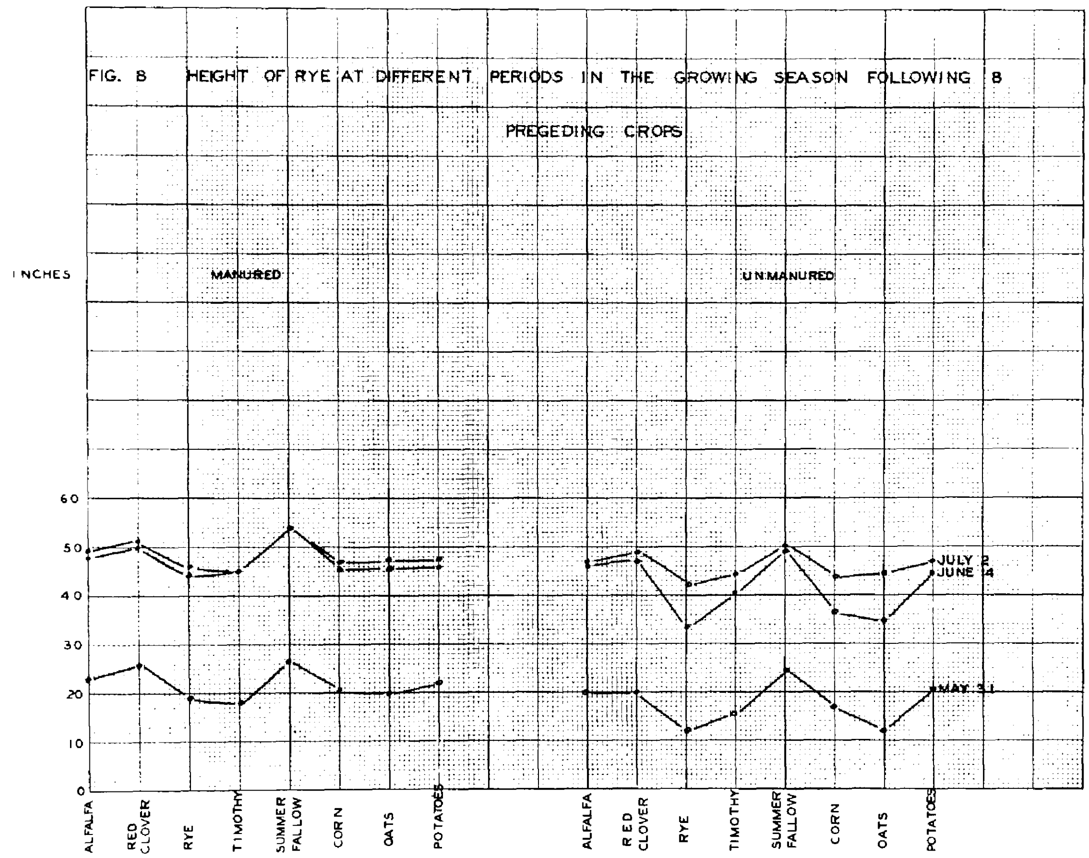


FIG. 8 HEIGHT OF RYE AT DIFFERENT PERIODS IN THE GROWING SEASON FOLLOWING 8 PRECEDING CROPS

Whatever the factor or factors which were responsible for retarding the growth of corn in the early season after summerfallow and potatoes, the opposite effect was apparent with rye. The rye made the best growth on summerfallow from the beginning to the end of its growing period. The growth was also uniformly good after potatoes. There was a tendency on the part of rye to be slow-growing after corn, oats, and rye, in the early season and to experience an accelerated growth as it approached maturity. The growth of rye was more variable on unmanured plots than on the manured plots.

This difference between the growth characteristics of rye and corn after various crops point to the possibility of difference in the amount of readily leachable nutrients in the soil, the presence or absence of which have an opposite effect on the two crops. Corn is a crop requiring a fairly liberal supply of nitrates in the soil to promote a succulent leaf and stem growth. During the summerfallow year preceding corn the nitrates tend to leach out of the soil shortly after they are produced. By the middle of September weather conditions materially limit the formation of nitrates and little or no nitrification takes place until about June 1st the following year. Corn is planted about May 24th in rows and its roots do not develop throughout the soil mass until late in the season and thus the crop is not in a position to make full utilization of the nitrates which are produced in the first two and one-half months of growth. Where a crop is grown the year previous, the nitrates are utilized by the crop and withheld from leaching so that they are retained in the soil by the crop residues and larger amounts are available for the crop the following year when the soil temperature becomes high enough to permit nitrification. This is particularly true of the preceding crops of legumes and grasses and to a lesser extent of the hoed crops.

The difference in the growth of the fall rye may be explained by the fact that rye being produced for grain requires only a relatively small amount of nitrates for optimum growth. Furthermore, the rye being planted in the fall about the first week in September is able to utilize some of the nitrates produced during the summer, preventing its leaching out of the soil and retaining it in the plant to produce early growth the following spring. Furthermore, rye is planted in seven-inch drills and its root system is sufficiently developed early in its growth to enable it to secure nitrates in such quantities as to meet its requirements, although only relatively small amounts may be available in the soil. Oats behave similarly although they do not have the advantage of the fall planting.

RAPID CHEMICAL TESTS ON SOIL AND PLANT TISSUE

In order to determine the amount of various available nutrients present in the soil at different periods of the growing season in the sequence experiment at Ottawa, rapid chemical tests, using the Spurway (104) method, were made on the surface soil for phosphorus, potassium and calcium at three different times during the summer of 1937. Tests were also made for nitrates at approximately two-week intervals from June 5th to September 9th. The plant tissue of the five "succeeding" crops following each of the eight preceding crops was analyzed for nitrogen, phosphorus, and potash, using the method of Thornton et al (107).

The soil tests showed no indication of available potassium in the soil by using the dilute extracting solution of Spurway and only a trace when the reserve test with the stronger extracting solution was used. Similarly tests for available phosphorus showed only a trace of this element in most cases and in no instance was there more than 0.5 parts per million recorded. The low phosphorus and potassium content of these soils as measured by the short tests was later verified by laboratory analyses and also by crop response to applications of potash and superphosphate. Calcium in all tests was relatively high, running from 100 parts per million in most cases to 150 on a comparatively few plots. There was very little difference in the amount of these three elements on the various plots.

Nitrates in the soil on the other hand fluctuated considerably following different crops and at different periods during the season. The results of the tests for nitrates on seven different dates under five of the eight preceding crops on unmanured soil in 1937 are shown in table 15. Due to winter injury to the stands of alfalfa, red clover and timothy in the winter of 1936-37, no results were available under these crops in 1937.

TABLE 15 - PARTS PER MILLION OF NITRATES IN SOIL UNDER PRECEDING CROPS AT OTTAWA, 1937

Preceding Crop	June 14	June 25	July 13	July 26	August 9	August 26	September 9
			Unmanured				
Rye	3.2	7.0	7.4	7.0	16.0	1.0	T.
Summer-fallow	3.0	17.0	8.4	6.0	15.0	2.2	0
Corn	3.8	11.0	7.0	2.6	3.8	T.	0
Oats	3.0	3.2	1.6	2.8	3.2	0	0
Potatoes	3.8	4.2	4.2	4.8	5.4	0	0

The results of the tests presented in table 15 show that nitrate begins to form about June 1, tends to reach a peak by June 25, drops slightly in July and reaches another peak about August 1st and then drops off to just a trace by August 26. The nitrate accumulation was highest on the summerfallowed plot as there was no crop to utilize part of it as it was produced. Nitrate was also relatively high under the hoed crops, corn and potatoes. Under oats it was uniformly low throughout the season indicating that the crop was utilizing most of the nitrate in its growth. The nitrate was relatively high under rye due to some winter injury and the consequent reduction in crop. As this crop matures early there was little or no utilization of nitrate in August with the result that the nitrate was as high on the rye plot on August 9, as on the summerfallow plot.

Even greater fluctuations in nitrate occurred in the soils under the "succeeding" crops. The amount of nitrate recorded in these soils is shown in table 16 and in figure 9.

TABLE 16 - PARTS PER MILLION OF NITRATES IN SOIL UNDER SUCCEEDING CROPS AT OTTAWA, 1937

Corn

Preceding Crop	June 5	June 23	July 10	July 23	August 5	August 23	September 9
Alfalfa	2	5	10	5	25	5	0
Red clover	5	5	10	10	5	5	0
Rye	10	10	2	10	2	T.	0
Timothy	0	2	2	2	5	5	0
Summer-fallow	2	2	10	5	5	T.	0
Corn	2	5	5	5	5	2	0
Oats	2	5	5	-	5	5	0
Potatoes	2	5	5	10	5	2	0
Average of 8 crops	3.1	4.9	6.1	6.7	7.1	3.0	0.0

Mangels

Preceding crop	June 5	June 23	July 10	July 23	August 5	August 23	September 9
Alfalfa	-	5	25	10	25	2	5
Red clover	10	2	10	25	25	10	2
Rye	5	5	25	25	25	10	0
Timothy	0	5	10	10	25	25	10
Summer-fallow	2	5	25	25	25	5	0
Corn	5	2	2	10	10	10	0
Oats	2	2	5	5	5	2	0
Potatoes	2	5	5	10	5	2	0
Average 8 crops	3.7	3.9	13.5	15.0	18.1	8.2	2.1

Rye

Preceding crop	June 5	June 23	July 10	July 23	August 5	August 23	September 9
Alfalfa	0	0	2	5	10	10	0
Red clover	0	0	T	2	2	5	0
				Rye winter killed, land summer-fallowed			
Rye	2	5	5	25	25	10	-
Timothy	0	T.	2	2	2	2	0
Summer-fallow	0	0	2	5	5	5	0
Corn	0	0	2	2	10	5	0
Oats	0	T.	2	2	5	5	0
Potatoes	0	T.	T.	2	2	2	T
Average of 8 crops	0.2	0.6	1.9	2.5	4.5	4.2	0.0

Oats

Preceding Crop	June 5	June 23	July 10	July 23	August 5	August 23	September 9
Alfalfa	5	2	5	5	2	2	0
Red clover	5	2	2	2	2	10	0
Rye	5	2	2	2	2	5	2
Timothy	0	T	2	5	5	2	0
Summer-fallow	2	2	0	2	5	5	0
Corn	5	2	2	5	2	5	0
Oats	2	2	T	2	2	5	0
Potatoes	2	2	2	2	2	5	0
Average of 8 crops	3.2	1.7	1.9	3.1	2.7	4.9	0.2

Potatoes

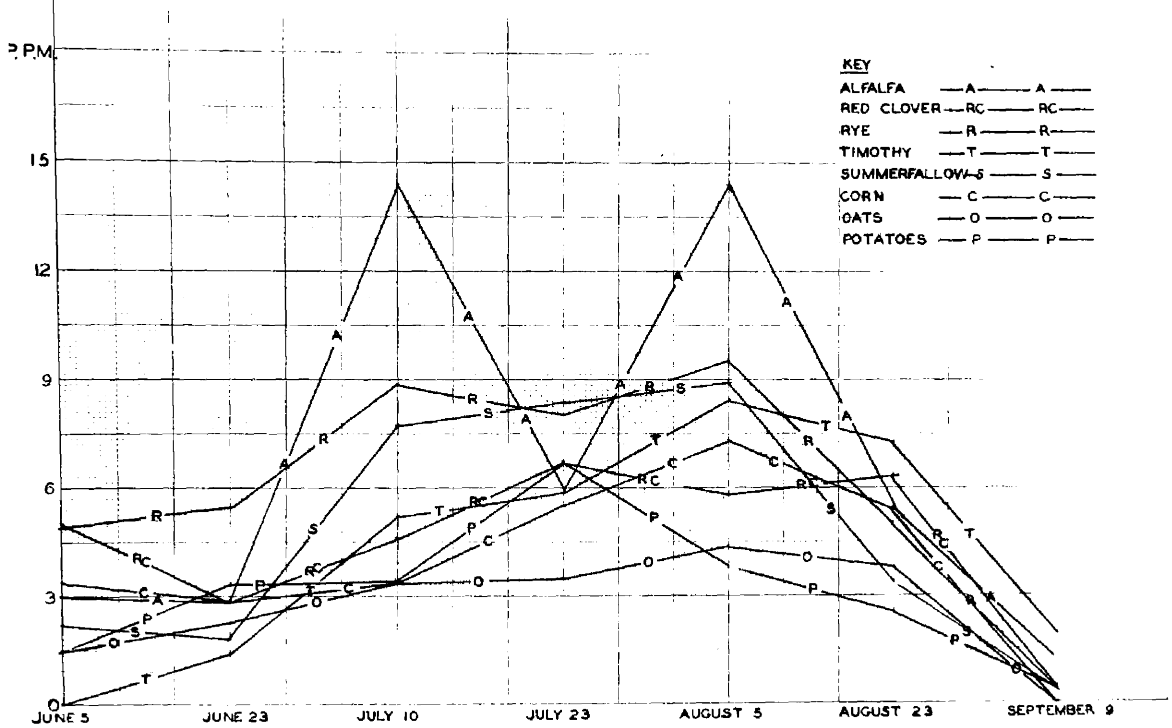
Preceding Crop	June 5	June 23	July 10	July 23	August 5	August 23	September 9
Alfalfa	5	2	25	5	5	10	2
Red clover	5	5	2	5	5	2	0
Rye	2	2	10	5	10	5	0
Timothy	T	0	10	10	5	5	0
Summerfallow	5	2	2	5	5	2	2
Corn	5	5	5	5	10	5	0
Oats	2	2	5	5	5	5	T
Potatoes	5	5	5	10	5	2	2
Average of 8 crops	3.6	2.9	8.0	6.2	6.2	4.5	0.7

AVERAGE NITRATE UNDER FIVE SUCCEEDING CROPS

Preceding Crop	June 5	June 23	July 10	July 23	August 5	August 23	September 9	Average 7 dates
Alfalfa	3.0	2.8	13.4	6.0	13.4	5.4	1.4	6.6
Red clover	5.0	2.8	4.8	6.8	5.8	6.4	0.4	4.6
Rye	4.8	5.4	8.8	8.0	9.7	5.0	0.5	6.1
Timothy	0.0	1.4	5.2	5.8	8.4	7.4	2.0	4.3
Summer-fallow	2.2	1.8	7.8	8.4	9.0	3.4	0.4	4.7
Corn	3.4	2.8	3.4	5.4	7.4	5.4	0.0	4.0
Oats	1.6	2.2	3.4	3.5	4.4	3.8	0.0	2.7
Potatoes	2.2	3.4	3.4	6.8	3.8	2.6	0.4	3.2
Average all crops	2.8	2.8	6.3	6.4	7.9	5.0	0.6	4.5

Nitrates under the succeeding crops as showing in table 17, behaved similarly to those under preceding crops in table 16, being higher under the hoed crops than under grain crops. The nitrates were considerably higher under mangels than under any of the other succeeding crops. This was partly due to the fact that mangels being a hoed crop does not utilize the nitrates in the soil as fast as they are produced, and partly to the fact that, due to cut worm damage, there were parts of some of the plots on which the crop was partially or completely missing, thus allowing for a greater accumulation of nitrates. The mangel plots following the eight preceding crops showed an average nitrate content throughout the season of 9.6 parts per million, potato plots average considerably less at 4.6 parts per million, corn 4.4 parts per million and the grain plots 2.5 for oats and 2.0 for rye. In practically all tests nitrates were low or entirely missing on June 5th, gradually

FIG. 9 AVERAGE NITRATES IN SOIL UNDER 5 SUCCEEDING CROPS AT 2 WEEK INTERVALS FOLLOWING 8 PRECEDING CROPS



increased until a peak was reached in August after which the production dropped off almost completely by September. The average accumulation under all crops was 2.8 parts per million June 5, 2.8 June 23, 6.3 July 10, 6.4 July 23, 7.9 August 5, 5.0 August 23, and 0.6 September 9.

There was a general tendency for nitrate production to be higher after preceding crops of alfalfa, rye, summerfallow, red clover and timothy than after corn, potatoes and oats. This would appear to bear some relationship to the growth of the various crops since the yields of succeeding crops after the eight preceding crops followed somewhat the same order both in field and pot tests. With both fall rye and oats the nitrates were low in the soil in the early part of the season when the crop was making its greatest growth, and was considerably higher in August when the crops were ripening or had been harvested, and were using less nitrates in their growth. This tendency was evident with all crops but seemed more pronounced in the case of the grain crops.

Tissue tests by the Thornton (107) method on the five succeeding crops showed corn to be deficient in nitrogen following all crops on unmanured land with a low to medium content of phosphorus and potash. This may explain in part the relatively low and variable growth and yield of corn previously mentioned. On manured soil all three elements were relatively high in corn. Rye showed no indication of the presence of nitrogen when tested. It is probable that this crop was too mature when the test was made and this may have affected the nitrogen content. All other tests indicated a relatively high content of the three elements. Thus, in spite of the fact that the Spurway test on the soil indicated a deficiency of phosphorus and potash, the plants generally appeared able to extract enough of these elements from the soil for reasonable growth, although subsequent tests showed both phosphorus and potash to be too low for maximum growth.

It is concluded from these rapid chemical tests on the field soils that differences in the nitrate content of the soil following the various preceding crops is a factor more closely associated with variations in the yield of succeeding crops than is the amount of available phosphoric acid, potassium or calcium. However, the available phosphoric acid and potassium being uniformly low on all plots appear to be affected by crops such as alfalfa and red clover which remove relatively large amounts of these elements. This point will be discussed later under chemical analyses of soils.

NITRIFICATION STUDIES IN THE LABORATORY

In order to throw some further light upon factors which may affect the influence of crops on those which follow, certain laboratory experiments have been conducted. In the fall of 1938 soil was taken from each of the plots occupied during the previous growing season by each of the eight preceding crops, on both manured and unmanured land. The soil was thoroughly mixed, sifted, and 100 grams of dry soil from each plot was made up to optimum moisture and placed in glass jars in the laboratory. One gram of dried blood was mixed with each 100 grams of soil to provide energy material from which the bacteria in the soil could draw, to commence their activity. This was done in case the nitrogen content of the soil was too low to promote sufficient nitrate development for accurate determination.

Enough samples were set up from each plot to provide for nitrate and ammonia determinations in triplicate after incubation for periods of 2, 4, 6, 8 and 10 weeks. Triplicate samples of each soil were also used for similar determinations on the dry soil previous to incubation. The nitrate and ammonia were determined at the end of each period by the distillation and titration method in which ammonia and nitrate converted into ammonia was distilled into a 4 per cent boric acid solution and titrated against standardized 0.1 N. sulphuric acid using bromo phenol blue as the indicator.

The amount of ammonia and nitrate accumulated during the various incubation periods is an indication of the nitrifying capacity of the respective soils, and is presented in table 17 and graphically in figures 10 and 11.

TABLE 17 - NITRATE AND AMMONIA ACCUMULATION IN SOILS TREATED WITH DRIED BLOOD AFTER EIGHT PRECEDING CROPS AT VARIOUS PERIODS OF INCUBATION

Preceding Crop	Incubation Period: Ammonia - Milligrams per 100 grams soil: Dry soil	2 weeks	4 weeks	6 weeks	8 weeks	10 weeks	Nitrate - Milligrams per 100 grams soil: Dry soil	2 weeks	4 weeks	6 weeks	8 weeks	10 weeks	Av.
Manured													
Alfalfa	1.25	7.95	0.90	1.95	0.94	0.90	1.65	28.54	42.73	39.79	43.00	43.95	33.28
Red clover	1.10	8.55	0.80	1.95	0.75	1.00	1.15	26.35	43.45	43.50	39.79	46.50	33.46
Timothy	0.87	12.83	0.75	0.82	0.64	0.70	2.25	25.95	42.75	41.05	43.84	39.75	32.60
Summerfallow	0.90	13.95	1.39	1.11	0.79	0.85	3.60	21.64	40.95	42.75	34.15	43.65	31.12
Corn	1.39	10.27	0.64	0.79	0.64	0.60	2.50	25.99	40.45	36.30	42.55	39.90	31.28
Rye	1.08	9.70	0.69	0.70	0.70	0.65	1.65	26.35	41.50	43.34	36.40	44.25	32.26
Oats	0.85	11.25	0.64	0.67	0.90	0.75	2.10	24.64	42.34	43.15	40.50	40.50	32.20
Potatoes	0.79	12.34	0.54	0.60	0.64	0.94	1.80	22.99	40.80	42.75	42.90	41.40	32.11
Average	0.92	10.85	0.79	1.07	0.75	0.80	2.09	25.31	41.87	41.58	40.39	42.49	32.29
Not manured													
Alfalfa	1.50	12.75	2.14	0.94	1.05	0.70	3.45	20.05	37.90	41.65	40.45	46.20	31.32
Red clover	1.05	14.29	1.24	0.94	0.85	0.70	1.55	16.05	38.55	39.49	40.20	46.50	30.39
Timothy	1.35	12.34	1.00	0.94	1.00	0.64	1.69	20.65	39.79	42.34	40.30	39.90	30.78
Summerfallow	1.15	14.44	0.90	0.85	0.90	0.75	3.90	20.74	40.00	41.65	43.00	44.10	32.23
Corn	1.35	15.45	1.00	0.79	0.55	0.79	1.09	15.00	37.60	39.40	40.99	43.50	29.60
Rye	1.20	10.24	0.75	1.05	0.55	0.79	1.94	21.55	38.10	41.14	38.70	45.00	31.07
Oats	1.05	10.35	0.79	0.90	0.60	0.90	1.90	21.75	36.30	40.35	41.80	44.70	31.13
Potatoes	1.05	12.94	1.00	0.85	0.55	0.90	1.60	16.95	33.85	39.25	38.14	41.85	28.61
Average	1.21	12.85	1.10	0.91	0.75	0.77	2.14	19.09	37.76	40.66	40.45	43.97	30.64

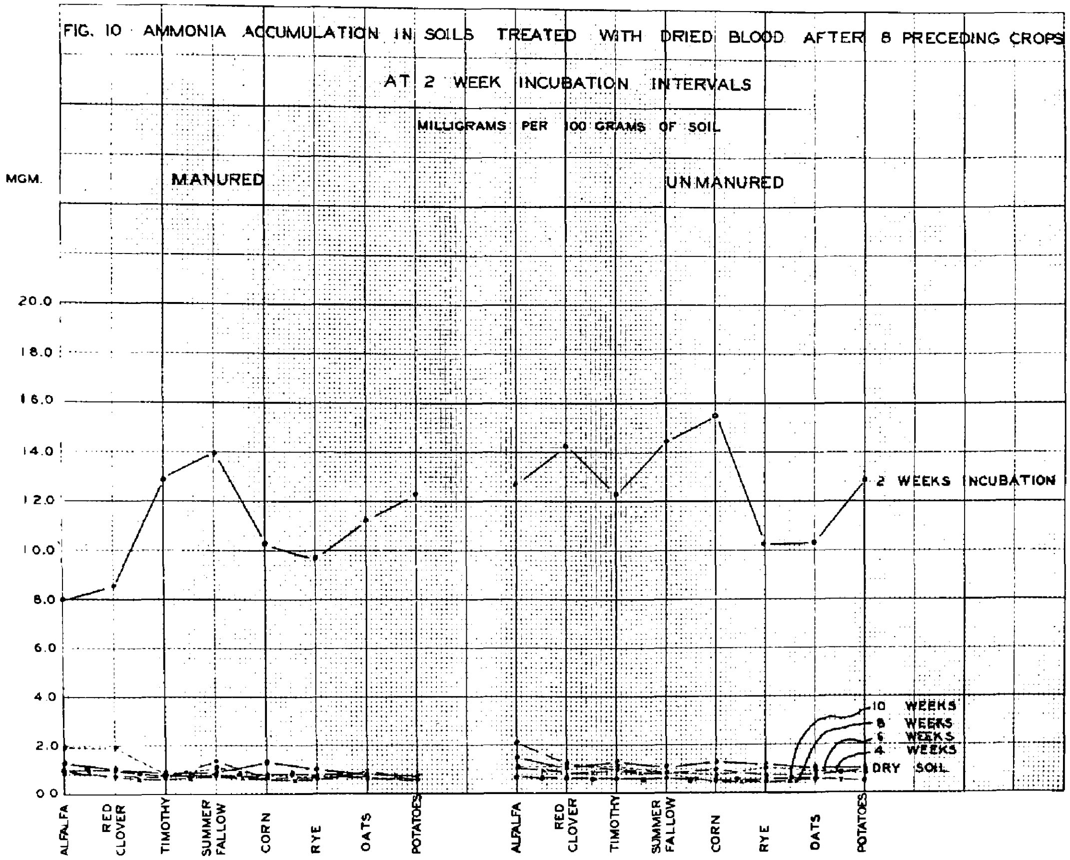
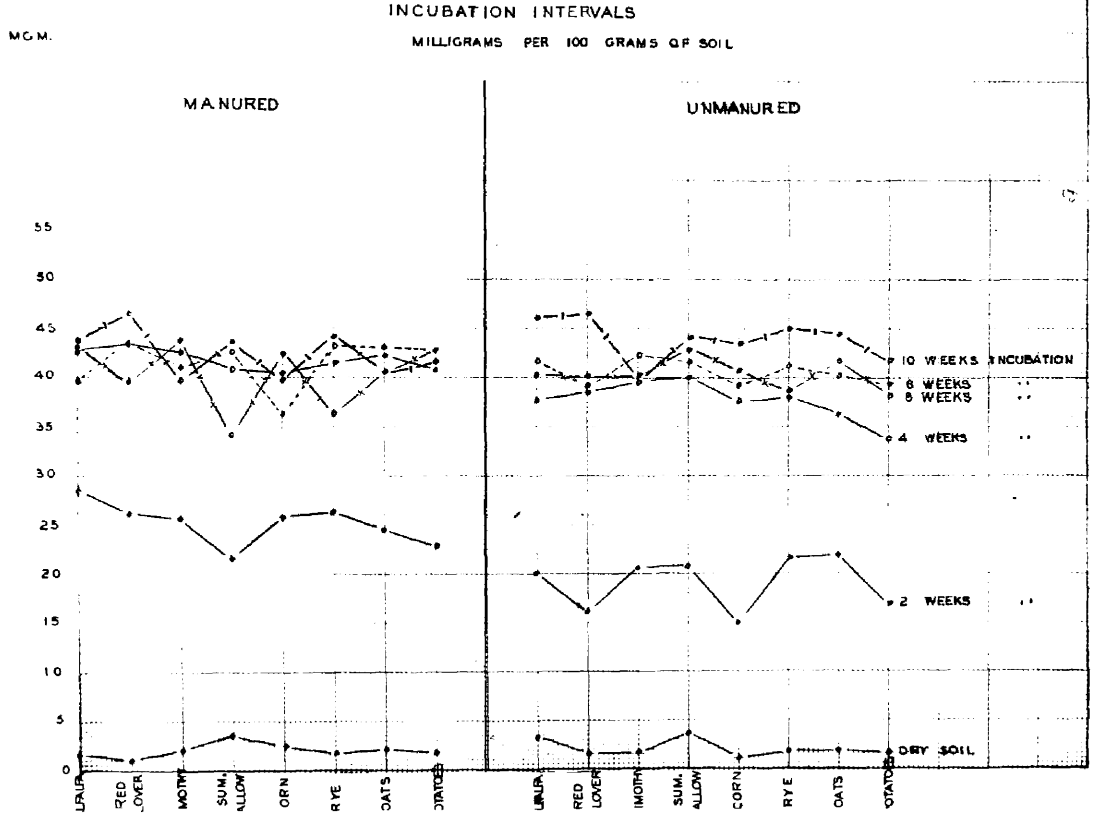


FIG. 10 AMMONIA ACCUMULATION IN SOILS TREATED WITH DRIED BLOOD AFTER 8 PRECEDING CROPS
AT 2 WEEK INCUBATION INTERVALS
MILLIGRAMS PER 100 GRAMS OF SOIL
MGM.
MANURED
UNMANURED
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
2 WEEKS INCUBATION
10 WEEKS
8 WEEKS
6 WEEKS
4 WEEKS
DRY SOIL
ALFALFA
RED CLOVER
TIMOTHY
SUMMER FALLOW
CORN
RYE
OATS
POTATOES

FIG. 1 NITRATE ACCUMULATION IN SOILS TREATED WITH DRIED BLOOD AFTER 8 PRECEDING CROPS AT 2 WEEK INCUBATION INTERVALS



There was very little ammonia or nitrate found in the dry soil. At the end of the first two-week period ammonification and nitrification had both become evident and there was an average of 10.85 milligrams of ammonia nitrogen on the manured soil and 12.85 on the unmanured soil, while the nitrate nitrogen was 25.31 milligrams on manured soil and 19.09 on unmanured. Nitrification was slightly more rapid on the manured soil as indicated by the higher amount of nitrate and the lower amount of ammonia, the ammonia being more rapidly converted into nitrate.

By the end of 4 weeks the ammonia was being converted into nitrates as fast as it developed as there was less ammonia than in the dry soil. Nitrates, on the other hand, reached almost their peak of accumulation at this time, and there was an average of 41.87 milligrams of nitrate nitrogen on the manured soil and 37.76 milligrams on unmanured soil. The nitrates continued to rise slightly on the unmanured soil until the end of the six-week period and then remained more or less constant. On the manured soil the peak was reached at the end of the four-week period after which there was very little change.

A matter of passing interest was the apparent rhythmical nature of nitrate formation at different periods. This was especially noticeable on the manured soil at the six, eight and ten week period. Although the determinations at the respective periods were made on soils from different containers and the amount of nitrates remained at the same general level, there was this distinct rhythmic, high reading, followed at the next period by a low reading and again by a high reading at the last period. This action may be of no particular significance but similar activity has been noted by other investigators. One of the most recent references is that of Smith, Brown and Millar (102) of Iowa. These workers referred to a similar investigation by Johansson (51) in which it was suggested that the periodicity in the rate of carbon dioxide production attributed to micro-organisms in the soil could be explained if one assumes a variation in the rate of metabolism of the soil micro-organisms or fluctuations in the growth velocity.

In these series of laboratory studies there appeared to be little or no significant difference in the nitrifying capacity of the soil. There was a slight tendency for the nitrates to be higher after alfalfa and red clover on manured soil and slightly lower after summer-fallow and corn. It was thought that the addition of the dried blood which contained 13.0 per cent of nitrogen may have had a tendency to mask any difference there might have been in the nitrifying capacity of the respective soils. Consequently in the winter of 1939-40 a similar series of soils was set up in the laboratory to which no dried blood was added. The same incubation periods were followed but nitrates only were determined. For these determinations the phenoldisulphonic acid method was used.

The nitrate accumulation was considerably lower than in the series where dried blood had been added to the soil, but some very consistent differences were noted in the soils following the various preceding crops. The amounts of nitrates in milligrams per 100 grams of soil are shown in table 18 and graphically in figure 12.

TABLE 18 - NITRATE ACCUMULATION IN UNTREATED SOILS AFTER EIGHT PRECEDING CROPS AT VARIOUS PERIODS OF INCUBATION AT OTTAWA

	Period of Incubation						
Preceding Crop	Dry soil	2 weeks	4 weeks	6 weeks	8 weeks	10 weeks	Average
			Manured				
	mgm.	mgm.	mgm.	mgm.	mgm.	mgm.	mgm.
Alfalfa	4.16	8.92	16.66	17.85	20.83	20.83	14.87
Red clover	3.12	8.92	14.71	15.62	19.23	19.23	13.47
Rye	2.50	5.68	11.36	11.36	13.15	13.88	9.65
Timothy	1.19	4.16	7.81	8.33	10.41	10.86	6.99
Summer-fallow	2.77	5.20	10.41	10.41	12.50	13.15	9.07
Corn	1.91	6.25	9.61	9.61	11.36	12.50	8.54
Oats	2.50	6.25	11.36	11.36	12.50	13.15	9.52
Potatoes	2.08	5.20	8.92	8.33	10.41	11.36	7.72
Average	2.53	6.33	11.35	11.61	13.80	14.37	9.99

Preceding Crop	Dry soil	2 weeks	4 weeks	6 weeks	8 weeks	10 weeks	Average
			Unmanured				
Alfalfa	3.59	10.41	13.88	14.71	17.85	19.23	13.28
Red clover	4.16	10.41	13.15	13.88	16.66	17.85	12.68
Rye	2.08	6.25	9.61	9.61	11.36	13.15	8.68
Timothy	1.25	4.16	7.56	7.81	8.92	10.00	6.62
Summer-fallow	1.56	4.46	9.61	10.00	11.36	12.50	8.25
Corn	1.78	5.68	8.33	8.33	10.41	11.36	7.65
Oats	2.50	5.68	10.41	11.36	13.88	12.50	9.39
Potatoes	2.77	4.65	7.81	9.61	12.50	12.50	8.31
Average	2.46	6.46	10.04	10.66	12.89	13.64	9.35

This series behaved similarly in some respects to that which had been treated with dried blood, in that nitrates increased considerably at the 2-week and 4-week periods after which the increase was much less. Similarly, also, the nitrates were slightly higher on the manured soil than on unmanured soil.

The soils without dried blood were in marked contrast to those which had received this additional nitrogen, in that there was considerable and consistent differences in the nitrates following the different preceding crops. On both manured and unmanured soil nitrates were outstandingly high after alfalfa and red clover, indicating the higher nitrifying capacity of soils following these legume crops.

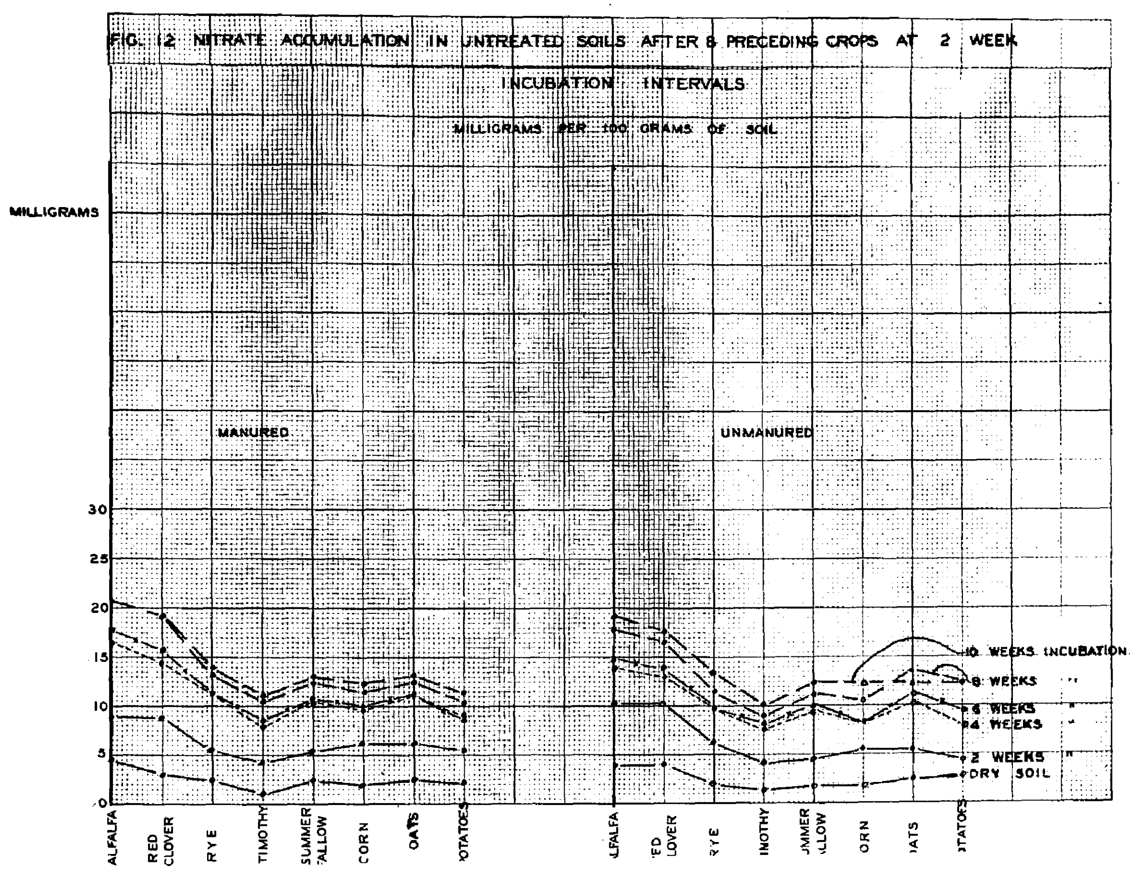


FIG. 12 NITRATE ACCUMULATION IN UNTREATED SOILS AFTER 8 PRECEDING CROPS AT 2 WEEK
INCUBATION INTERVALS
MILLIGRAMS PER 100 GRAMS OF SOIL
MILLIGRAMS
MANURED
UNMANURED
30
25
20
15
10
5
0
ALFALFA
RED CLOVER
RYE
TIMOTHY
SUMMER FALLOW
CORN
OATS
POTATOES
10 WEEKS INCUBATION
8 WEEKS
6 WEEKS
4 WEEKS
2 WEEKS
DRY SOIL

This is in accord with the nitrate tests in the field (table 16) using the Spurway rapid tests and bears a close relationship to the higher yields (table 8) following these crops. Lyon (67) suggests the nitrogen in the soil is more active after a legume crop. Albrecht (1, 2) has also shown marked differences in nitrate production under various crops and subjected to different cropping treatments. Nitrates were also relatively high in this series following rye and summer-fallow which is also in accord with the field tests and yield data. In similar agreement is the low nitrate accumulation and yields after corn and potatoes. Conrad (22) found a similar reduction in nitrogen after sorghums and attributed this to the high sugar content in the roots of the sorghum which supplied extra energy-producing materials, thus increasing the numbers of micro-organisms in the soil which compete more actively with the following crop for the available nitrogen. This may apply to conditions following potatoes and corn.

Some inconsistency appears in the nitrates found in the laboratory tests in that they were lowest after timothy and relatively high after oats. This is not in agreement with the field tests for nitrates nor with the yields which were both relatively high after timothy and consistently low after oats. On the other hand, crops grown in two-gallon pots (table 12) yielded very low after timothy and relatively high after oats which was in agreement with the laboratory tests for nitrates, and indicates that laboratory and pot tests have some factors in common which may not be the same in the field.

CARBON DIOXIDE PRODUCTION IN SOILS INCUBATED IN THE LABORATORY

Another factor which has been suggested by some investigators, Russell (88) Starkey (105) Kellermann and Robinson (54) which is affected by previous cropping, and which is closely related to the production of succeeding or associated crops is that of the biological activity in the soil. The CO_2 production in the soil has been used, Gainey (30) Turk (108) and Andrews (3, 4) as a measure of the biological activity, and indirectly as a measure of crop response.

In the crop sequence experiments at Ottawa the CO_2 production in soils which had previously grown eight preceding crops was measured after incubation in the laboratory for various periods. Soil from each of the respective plots was thoroughly mixed and screened through a 2 millimeter seive. Duplicate 100 gram samples of dry soil were made up to optimum moisture with distilled water in which manitol had been dissolved, in an amount equivalent to one gram of manitol per 100 grams of soil. The treated soil was placed in air-tight 500 c c Erlenmeyer flasks and incubated for 4, 8, 12 and 16 day periods, and at the end of each period the CO_2 was drawn off, collected in ascarite in absorption bulbs, and weighed on an analytical balance.

These measurements were made on three series of soil, one taken in the fall of 1937, one in the spring of 1938 and one in the fall of 1938. After measuring the CO_2 produced at the various 4-day intervals, it was found that the early 4 and 8 day measurements gave the most accurate results; in later readings there was considerable fluctuation. Andrews (4) found that the use of manitol as energy material for soil micro-organisms usually reduces the time of incubation to 24 hours, and only one CO_2 determination is necessary. Where cellulose was used by some investigators in place of manitol, as much as 30 days and several determinations were apparently necessary. For purposes of this study the CO_2 production at the end of 4 days incubation, on two series of soils is presented together with the average of the two, in table 19 and figure 13.

Table 19 - CARBON DIOXIDE PRODUCTION IN SOILS AFTER EIGHT PRECEDING CROPS

Preceding crops	Sampled Fall 1937	Sampled Spring 1938	Sampled Fall 1938	Average of three determinations
	Grams per 100 grains of soil			
	Manured			
Alfalfa	.1705	.1824	.1349	.1626
Red clover	.1559	.1564	.0932	.1352
Timothy	.1649	.1847	.0933	.1476
Summerfallow	.1597	.1598	.1046	.1414
Corn	.1446	.1506	.0837	.1263
Oats	.1368	.1667	.0699	.1245
Potatoes	.1549	.1585	.0545	.1226
	Unmanured			
Alfalfa	.1414	.1440	.0668	.1174
Red clover	.1217	.1618	.0533	.1123
Timothy	.1222	.1493	.0483	.1066
Summerfallow	.1267	.1417	.0540	.1075
Corn	.1182	.1404	.0456	.1014
Oats	.1021	.1288	.0368	.0892
Potatoes	.1203	.1408	.0535	.1049

Soil from the fall rye plot was not used in this test because the crop was winter killed in the winter of 1936-37 and thus had no effect on the soil. Certain definite relationships are seen to exist between the CO_2 production, the nitrate accumulation and crop yields. This point is illustrated in figure 14. For instance all three are higher on manured soil than on unmanured soil. Crop yields in the field and in pots and nitrate and CO_2 production have almost invariably been higher after alfalfa than after any other crop or treatment. Crop yields, nitrates and CO_2 production have tended to be relatively high after summerfallow and all tend to be rather low after corn and oats. CO_2 production was in particularly close agreement with crop yields on unmanured soil. On manured soil the decomposition of the organic matter of the manure, and increased crop residues may have tended to affect the CO_2 production. The most outstanding irregularity was apparent in the CO_2 production after red clover, which was particularly low on manured soil. The CO_2 production after timothy was exceptionally high which is in reverse ratio to the low nitrate accumulation. This apparent irregularity ran through each of the three different series of tests.

CHEMICAL ANALYSES OF SOILS

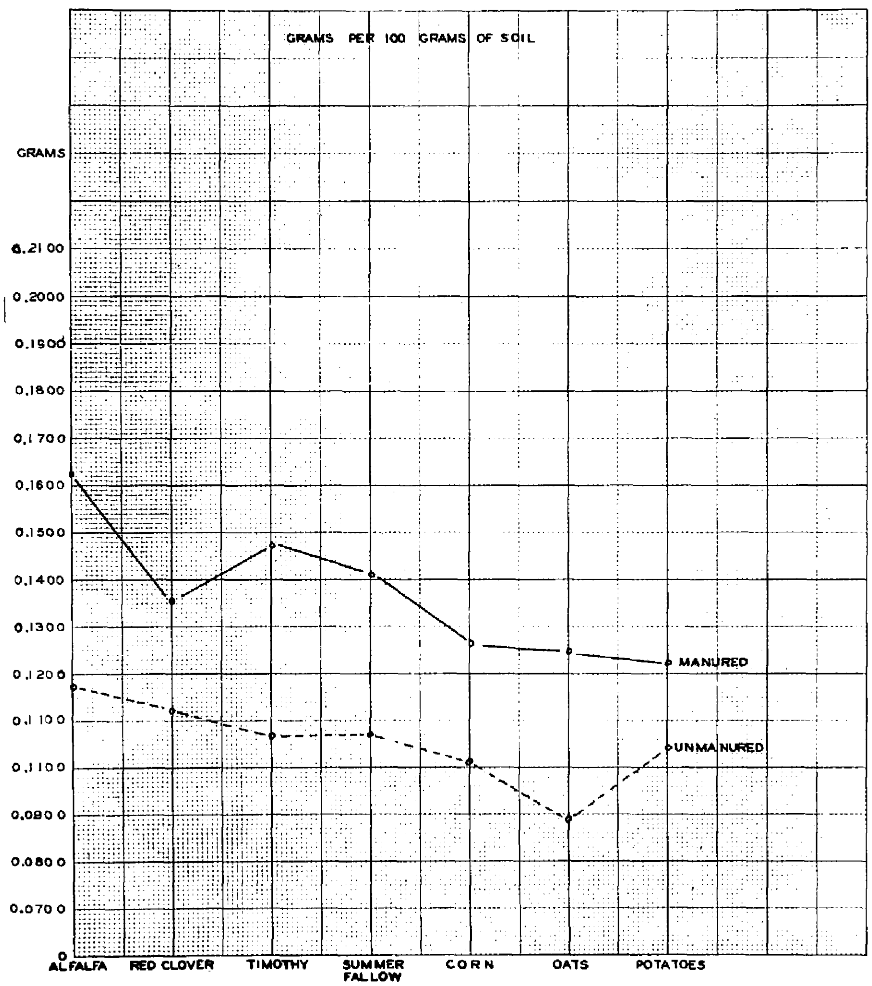
As a further check on the fertility levels and chemical condition of the soils used in the Ottawa sequence experiments, a number of chemical determinations were made in the laboratory, on soils taken in the fall of 1939, after having grown each of the preceding crops. The pH determinations were made using a glass electrode. Organic matter was determined by the hydrogen peroxide method, total nitrogen by the Kjeldahl digestion method, soluble phosphorus by the Truog method and exchangeable potash by the ammonium acetate extraction and cobaltinitrite method. The chemical data are shown in table 20 and figure 15.

Table 20 - CHEMICAL ANALYSIS OF SOILS IN SEQUENCE TESTS

OTTAWA

Preceding Crop	pH	Organic matter	Nitrogen	Soluble phosphorus Truog method	Exchange-able K_2O
		Manured			
	-	per-cent	per-cent	per-cent	per-cent
Alfalfa	7.49	4.35	0.264	0.0062	0.008
Red clover	7.38	4.30	0.257	0.0062	0.007
Rye	7.45	4.65	0.257	0.0066	0.005
Timothy	7.51	4.30	0.247	0.0066	0.002
Summer-fallow	7.61	3.50	0.197	0.0066	0.005
Corn	7.45	3.70	0.209	0.0064	0.007
Oats	7.42	4.45	0.225	0.0060	0.003
Potatoes	7.54	3.80	0.215	0.0060	0.004
		Unmanured			
Alfalfa	7.41	3.95	0.210	0.0022	trace
Red clover	7.52	4.40	0.215	0.0021	0.004
Rye	7.54	4.50	0.210	0.0022	0.016
Timothy	7.61	4.00	0.197	0.0026	0.003
Summer-fallow	7.60	3.35	0.174	0.0034	0.025
Corn	7.66	3.95	0.186	0.0044	0.023
Oats	7.53	4.05	0.180	0.0016	0.010
Potatoes	7.66	3.85	0.186	0.0034	0.004

FIG. 13 CARBON DIOXIDE ACCUMULATION IN INCUBATED SOILS AFTER 7 PRECEDING CROPS



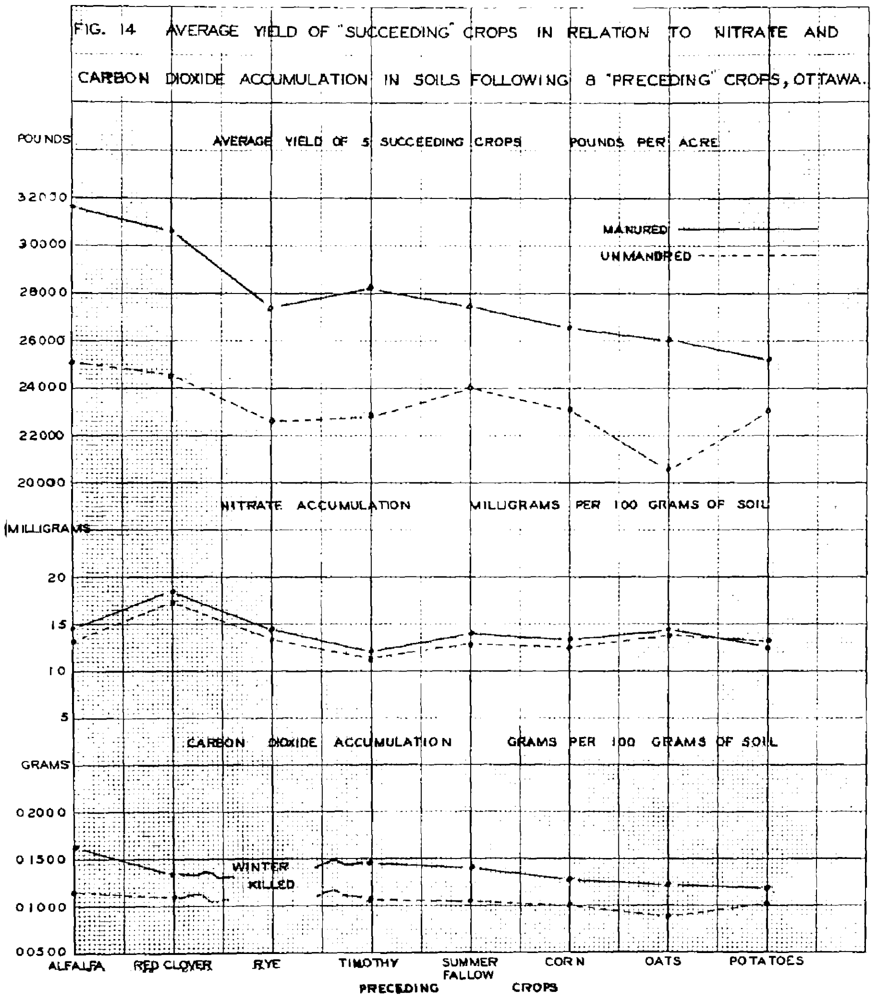
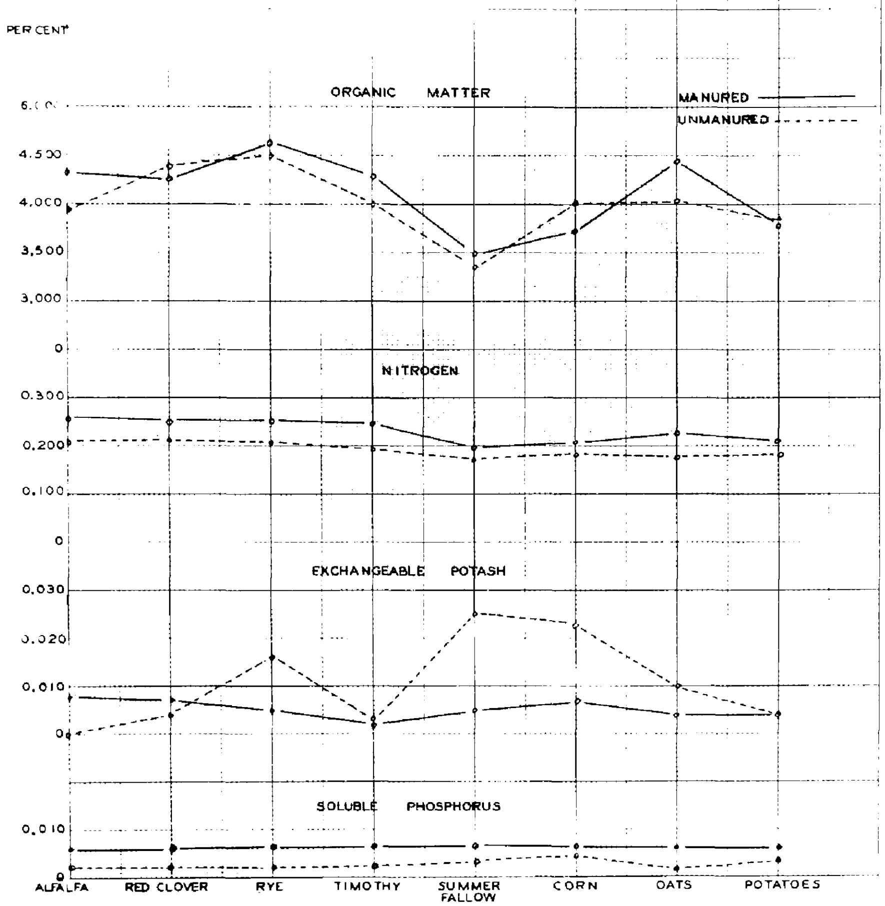


FIG. 14 AVERAGE YIELD OF "SUCCEEDING" CROPS IN RELATION TO NITRATE AND CARBON DIOXIDE ACCUMULATION IN SOILS FOLLOWING 8 "PRECEDING" CROPS, OTTAWA.
POUNDS
AVERAGE YIELD OF 5 SUCCEEDING CROPS POUNDS PER ACRE
32000
30000
28000
26000
24000
22000
20000
MANURED
UNMANURED
NITRATE ACCUMULATION MILLIGRAMS PER 100 GRAMS OF SOIL
MILLIGRAMS
20
15
10
5
CARBON DIOXIDE ACCUMULATION GRAMS PER 100 GRAMS OF SOIL
GRAMS
0.2000
0.1500
0.1000
0.0500
WINTER KILLED
ALFALFA
RED CLOVER
RYE
TIMOTHY
SUMMER FALLOW
CORN
OATS
POTATOES
PRECEDING CROPS

FIG. 15 CHEMICAL ANALYSES OF SOILS AFTER GROWING 8 PRECEDING CROPS IN 1939 AT OTTAWA ONTARIO



The chemical analyses data presented in table 20 throw some further light upon factors at work in the effect of crops on those which follow.

(1) Soil pH

Under the conditions of the field experiment at Ottawa the slight variations in the pH of the soil which may be produced by different crops would seem to have no influence on the growth and development of succeeding crops. The soil is slightly alkaline and the small variation in pH ranging from 7.38 to 7.61 on manured soil and from 7.41 to 7.66 on the unmanured soil would hardly be expected to affect to any appreciable extent the crops which have been grown. Odland et al (78) reported that on the acid soils of the Rhode Island Experiment Station an increase in acidity produced by the growing of alsike or red clover, although very slight, had a definite deleterious effect on certain crops grown the following year. On the neutral to alkaline soil at Ottawa this factor must be considered of little or no significance.

Organic Matter

Considerable variation is shown in the organic matter found in the soil following the growing of various crops. The summerfallowed plot showed the lowest percentage of organic matter on both manured and unmanured soil. The organic matter was relatively low following the growing of the hoed crops, corn and potatoes, and considerably higher following rye, oats, red clover, timothy and alfalfa. The denser and more fibrous root systems of these latter crops apparently tended to add more decomposable organic material. The organic matter tended to be slightly higher on manured soil than on unmanured soil. It is doubtful if the organic matter content of the soil affected the yield of succeeding crops to any extent. It may be assumed that the organic matter content on all plots was sufficiently high for general crop requirements, as a soil of this texture containing from 3.00 to 4.00 per cent of organic matter is considered moderately well supplied.

Total Nitrogen

The total nitrogen was consistently higher following alfalfa, red clover, fall rye and timothy, than following summerfallow, corn, oats and potatoes. The increase in total nitrogen following the legumes, alfalfa and red clover, is in accord with the findings of other workers, Metzger (69) Brown (18) and Lyon (67). It is difficult to explain why the nitrogen should be so high following timothy. The nitrogen was lowest following summerfallow on both manured and unmanured soil and was consistently higher on manured soil than where no manure was applied. The total nitrogen bears a close relationship to nitrate production and tends to vary directly as the average crop yields secured in this experiment.

Soluble Phosphorus

The soluble phosphorus in all cases was exceptionally low, since readings below 0.0070 per cent are considered to show a deficiency by this method. There was very little difference from plot to plot but the phosphorus was higher in all cases on manured soil than on unmanured soil.

Exchangeable Potash

The analyses for exchangeable potash shows considerable variation from plot to plot, particularly on unmanured soil. Except where alfalfa and red clover were grown the exchangeable potash was higher on unmanured soil than on manured soil. There is a tendency for potash to be higher following summerfallow, corn and rye, and on manured soil it is high after red clover, and alfalfa. The laboratory analyses for potash is in accord with analyses of the soil made with the Spurway rapid tests; both showed a low potash content.

Relationship of Chemical Analyses of the Soil to Crop Yield

It was illustrated in figure 14 that the yield of crops following various "preceding" crops showed a close relationship to the accumulation of nitrates and carbon dioxide in the soil. A further comparison may be made by comparing the yield data in figure 14 with the analyses data in figure 15. As pointed out previously there appears to be little or no relationship between the pH of the soil, the soil organic matter and crop yields. The nitrogen, phosphoric acid and potash in the soil would seem to have a definite effect upon crop yields and these elements are affected by the species of crops grown on the soil the previous year.

Nitrogen is definitely higher following legumes than after most of the other crops. It is also high following rye. It is high following the legumes presumably because of the nitrogen added by the legumes as they obtain it from the atmosphere. It is no doubt high after rye because of the relatively low requirements of rye for nitrogen (table 21) and thus less is removed by the crop than by other crops. The yields of crops following legumes, although higher than of those following other crops, did not show as great response as has been obtained by other workers, Headden (42) and Lyon (66 and 67). This apparent lack of a marked response of crop development following legumes as compared to non-legumes in the Ottawa studies has led to further investigations to determine the reason. In the tests conducted the explanation seems to lie in the content of nitrogen, phosphoric acid and potash in the soil.

Nitrogen is normally high in these soils, and, although a slight increase in nitrogen due to legumes has been associated with a small increase in yields, such an increase in nitrogen in a soil already well supplied with this element could hardly be expected to produce outstandingly higher yields, particularly, if another more limiting factor is present. Apparently, a more limiting factor is the deficiency of phosphoric acid and potash.

Reference to the amounts of plant food elements removed by crops tends to throw further light on this point. The amount of these elements in crops similar to those used in the Ottawa experiment was reported by Miller (71) as shown in table 21.

Table 21 - AMOUNT OF PLANT FOOD ELEMENTS IN FARM CROPS

Crop	Yield per acre	Nitrogen	Phosphorus	Potassium	Calcium
		lb.	lb.	lb.	lb.
Alfalfa	3 tons	147.0	30.0	126.0	83.5
Red clover	2 tons	84.0	20.0	80.0	45.7
Rye	30 bu.grain 1 ton straw	29.1	15.8	23.7	4.8
Timothy	2 tons	50.0	22.0	40.0	7.1
Corn silage#	12 tons	86.8	14.4	72.0	14.8
Oats	50 bu.grain 1.25 tons straw	48.0	18.0	40.8	9.1
Potatoes	150 bu.	31.5	13.5	45.0	1.8

Morrison Feeds and Feeding.

The data in table 21 shows that the legumes, alfalfa and red clover remove relatively large amounts of nitrogen. The soil analyses (table 20) shows, however, that the crop adds more nitrogen to the soil than is removed in the crop. Of greater significance is the large amount of both phosphorus and potash removed by these crops. On soils so low in these two elements as are the Ottawa soils, it is quite conceivable that the detrimental effect of this removal tends to offset the beneficial effect of added or activated nitrogen. Rye, which has been a relatively good preceding crop, removes relatively small amounts of all these elements.

Corn for silage, oats and potatoes, have been consistently unfavourable preceding crops and all three crops remove relatively large amounts of potash.

On soils low in phosphorus and potash it is probable that the beneficial effects of legumes in adding nitrogen may be offset by their requirement of large amounts of the minerals. Other crops which remove considerable amounts of these elements may deplete the soils to such an extent as to seriously affect succeeding crops.

Crop Response to Treatment with Minerals.

As further evidence of the deficiency of available phosphorus and potash in the Ottawa soils, crops of timothy, red clover and alfalfa grown in the soils in 6-inch pots in quadruplicate in 1939 showed a marked response to treatments with these minerals. The soil in the respective pots were treated as follows: (1) Check, no treatment. (2) Superphosphate 300 pounds per acre. (3) Muriate of potash 100 pounds per acre. (4) Superphosphate 300 pounds, muriate of potash 100 pounds. (5) Superphosphate 450 pounds, muriate of potash 150 pounds. Two crops of hay were harvested from each pot and the total yields of green hay and dry matter are shown in table 22.

TABLE 22 - YIELD OF HAY CROPS FOLLOWING APPLICATIONS OF MINERAL FERTILIZER

Grams per Pot

Treatment	Alfalfa		Red Clover		Timothy	
	Green weight	Dry matter	Green weight	Dry matter	Green weight	Dry matter
1. Check	56.29	10.21	60.69	11.48	38.91	14.61
2. Phosphorus	58.83	14.20	62.05	12.79	42.95	15.05
3. Potash	73.52	18.19	76.61	14.60	42.50	15.51
4. 300 p 100 K	65.59	15.51	64.18	12.79	46.17	16.37
5. 450 P 150 K	76.66	19.91	77.06	13.70	52.25	17.28

All three crops have shown consistent response to both phosphorus and potash. The response to potash was greater than to the phosphorus applications. All of the indications point to a deficiency of minerals in these soils and this has had a marked bearing on the influence of crops upon those which follow.

SUMMARY AND CONCLUSIONS

1. Data are presented, herewith, covering investigations dealing with the influence of crops upon those which follow. Field experiments have been conducted at Dominion Experimental Stations at Lacombe, Alberta, Swift Current, Saskatchewan, Kapuskasing, Ontario, and Ottawa, Ontario. Pot tests were also conducted at Ottawa and laboratory experiments were carried on at Ottawa and at the Michigan State College of Agriculture, East Lansing, Michigan.

2. Under dry farming conditions at Lacombe and Swift Current moisture is the limiting factor in regard to crop production. At these stations summerfallow treatments and cultivated crops, which have relatively low moisture requirements, were the most beneficial cropping treatments to precede crops grown on the

same area the following year. The cropping treatments at these stations ranked in order of benefit to the succeeding crops as follows: Summerfallow, corn, potatoes, peas, millet, oats, wheat.

3. In Eastern Canada at both Kapuskasing and Ottawa where moisture is abundant, the legumes, alfalfa and red clover, were beneficial preceding crops,and oats, barley, sunflowers, corn, and potatoes were less favourable.

4. Although summerfallow was beneficial under dry farming conditions, it was not particularly favourable under conditions of ample rainfall in Eastern Canada. At Kapuskasing, in Northern Ontario, it was definitely unfavourable preceding potatoes, but was beneficial preceding the grain crops, oats and barley. At Ottawa summerfallow was, likewise, unfavourable preceding potatoes and also before corn, but was beneficial preceding mangels, oats and fall rye.

5. The results of the Ottawa experiments indicate that the factors involved in the influence of crops upon those which follow were more active at certain seasons of the year than at others. Thus rye and oats, which mature earlier in the season and also differ from corn in their growth characteristics were affected by preceding crops in a manner quite different to that of corn.

6. Preceding crops have a marked effect on the nitrate accumulation in the soil the following year which is reflected in differences in the growth of "succeeding" crops.

Rapid chemical tests of the soils by the Spurway method showed a relatively high nitrate content in soils after alfalfa, red clover, rye, summerfallow and timothy and the yield of succeeding crops were relatively high after these crops. On the other hand, nitrates were low following corn, oats and potatoes, and these crops were found at Ottawa to be the most unfavourable "preceding" crops.

7. Nitrate accumulation in soils treated with dried blood and incubated in the laboratory following the growing of various preceding crops was comparatively uniform on all soils regardless of the crop grown. Apparently, the nitrate developed from the nitrogen in the dried blood tended to mask the differences in nitrate production from the natural nitrogen of the soil. Similar soils incubated in the laboratory but receiving no treatment with dried blood show considerably more nitrate accumulation following alfalfa, red clover, and fall rye, than after any of the other crops.

8. Carbon dioxide production in incubated soils was higher after alfalfa, red clover, timothy and summerfallow than after corn, oats and potatoes and thus followed the same general trend as crop yields.

9. Chemical analyses of the Ottawa soils revealed a soil reaction slightly above neutral and an organic matter content of from 3.35 to 4.65 per cent and it is quite unlikely these two factors contributed to the differences affected by preceding crops on those which followed. Total nitrogen in the soil was higher after alfalfa, red clover, fall rye and timothy than after the other crops but was relatively high in all of

the soils. Available phosphorus and exchangeable potash were both very low in these soils.

10. The fact that the legumes, alfalfa and red clover did not exert a greater influence from the standpoint of increased yields was no doubt due to the fact that they added nitrogen to a soil already rich in this element, and being gross feeders on phosphorus and potash removed relatively large amounts of these minerals both of which were deficient in the soils. It is conceivable that the growing of such crops on soils very high in nitrogen and very low in phosphorus or potash might become detrimental rather than beneficial.

11. Applications of manure have increased yields of crops, organic matter in the soil, nitrates and total nitrogen, carbon dioxide accumulation and to a slight degree available phosphorus. It has also tended to smooth out or mask the differences in the effect of preceding crops.

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Alfalfa has been a beneficial preceding crop

Timothy although not as favourable as alfalfa has been followed by fair yields of most crops.

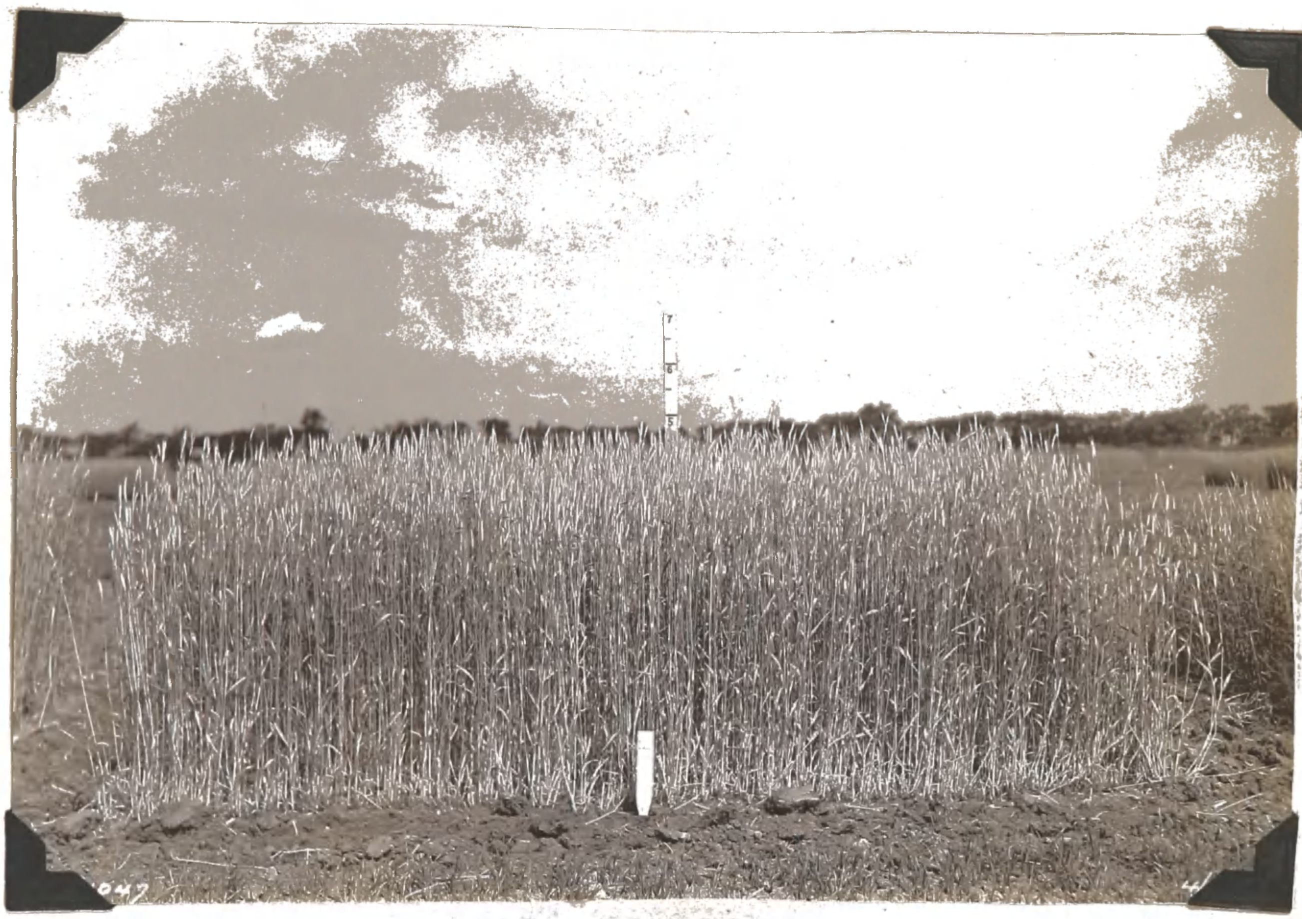
Corn at Ottawa has not been a favourable preceding crop.

Rye requires relatively small amounts of nitrogen, phosphorus and potash for good growth and is a good preceding crop.

Oats have been one of the most unfavourable preceding crops at Ottawa.

Potatoes as a preceding crop have not been very favourable.

Rye following alfalfa, average yield, grain and straw, manured 7342 pounds per acre, 6397 lb. unmanured.



Rye following red clover, average yield grain and straw manured 6769 lb. per acre, unmanured 6089 lb.

Rye following tomothy, average yield, grain and straw, manured 6339 pounds per acre, unmanured 5314 pounds.

Rye following summerfallow, average yield grain and straw, manured 7402 pounds per acre, unmanured 7289 pounds.

Rye following corn, average yield grain and straw, manured 5959 pounds per acre, unmanured 5084 pounds.

Rye following rye, average yield grain and straw, manured 5415 pounds per acre, unmanured 5001 pounds.

Rye following oats, average yield grain and straw, manured 4713 pounds per acre, unmanured 4290 pounds.

Rye following potatoes, average yield grain and straw, manured 5500 pounds per acre, unmanured 6882 pounds.

The five year average yield of corn on unmanured land was following alfalfa, left, 18.23 tons, and red clover, right, 18.08 tons per acre.

The five year average yield of corn on unmanured land was, following red clover, left, 18.08 tons, and timothy, right, 15.40 tons.

In the early part of the growing season corn makes very poor growth following summerfallow, left, as compared with following corn, right.

The yield of corn over a five year period on unmanured land was, following rye, left, 17.23 tons, and oats, right, 15.29 tons.

The yield of corn over a five year period on unmanured land was following oats, left, 15.29 tons, and potatoes, right, 15.25 tons. The growth following potatoes was slow in the early part of the season.

Rye following timothy which had been treated from left to right with (1) 450 lbs. superphosphate and 150 lbs. muriate of potash, (2) 300 lbs. superphosphate and 100 lbs. muriate of potash, (3) 300 lbs. superphosphate (4) 100 lbs. muriate of potash, and (5) check, no fertilizer.

Rye following alfalfa which had been treated from left to right with (1) 450 lbs. superphosphate and 150 lbs. muriate of potash, (2) 300 lbs. superphosphate and 100 lbs. muriate of potash, (3) 300 lbs. superphosphate, (4) 100 lbs. muriate of potash, and (5) check. Nitrogen added by the legume was very effective when supplemented by applications of mineral fertilizer.

Corn grown in 2 gallon glazed pots in 1939 yielded in grams per pot from left to right after alfalfa 100.97, after clover 82.82, timothy 72.17, summerfallow 85.46, corn 78.84, rye 100.15, oats 95.20, potatoes 81.92. Corn after summerfallow grew very slowly in the early part of the season but made better growth when approaching maturity. The apparently luxuriant growth of crops early in the season is not always a criterion of what the ultimate yield may be.