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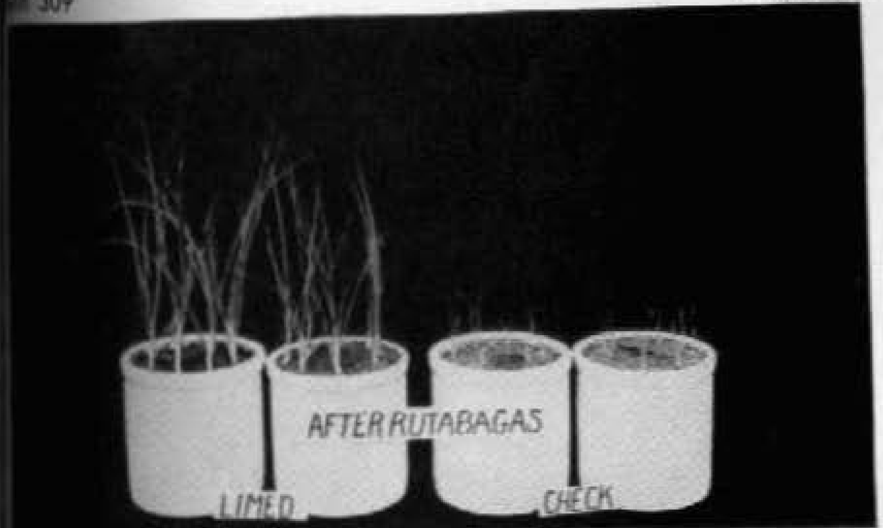

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THIS STUDY IN BRIEF

This is a study of the effect which crop plants have on the growth and yields of those crops which follow. The study began in 19[illegible]; this bulletin reports the results from 1930 to 1942.

Millet, mangels and rutabagas generally seem to be harmful to crops which follow them. Carrots, mangels and millet were least favorable of all crops to mangels. Potatoes did poorest when following potatoes, rutabagas, or millet. Rutabagas yielded low following rutabagas, mangels and millet. Onions were unfavorably affected by preceding crops of mangels, cabbage, or rutabagas.

There is no simple explanation for the effect of crops on those which follow. The relationships are complex and interdependent, and are associated with the physical, chemical and microbial conditions of the soil.

Well fertilized crops in moderately to strongly acid soils apparently produce unfavorable conditions for a succeeding crop for one or more of the following reasons:

1. They deplete basic nutrients with a consequent increase in H-ion concentration, accompanied by possibly harmful concentrations of aluminum or other elements.

2. Unless organic matter is provided, an adequate quantity of water stable aggregates is not maintained so that the soil becomes compact and possesses a poor physical condition unsuitable for maximum crop growth.

3. After certain crops, conditions are more favorable for the growth of plant pathogens and the development of seedling root rot.

4. The chemical, physical and biological conditions of the soil are intimately related and interdependent so that an improvement in one may produce some improvement in the others.

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Cover Picture: Although adding lime increased yields over the check plots, the difference in effect between rutabagas and rye on onions is quite apparent.

THE INFLUENCE OF CROP PLANTS ON THOSE WHICH FOLLOW V

A study of the influence of crop plants on those that follow was begun by Dr. H. J. Wheeler in 1907.

Sixteen miscellaneous crops were to be grown for 2 years followed by a uniform crop on all plots the third year. The crops were grown without farm manure but received annual applications of a complete fertilizer. The experiment was discontinued in 1942 after 36 years of continuous work. A similar experiment in cement frames started in 1933 is being continued. The data obtained during the years 1907-1942 from the original experiment and that from the cement frames from 1933-1948 are reported in this bulletin.

EARLY HISTORY

The general benefits of crop rotations are well known and the scientific literature dealing with crop rotation experiments is extensive. Ripley (17) recently compiled an extensive review of the literature dealing with the effect of certain crops on succeeding crops from the time of Virgil until 1941. Bear (1) published in 1927 a review of some of the principles involved in crop sequence. The Rhode Island Agricultural Experiment Station has published 5 bulletins and several scientific papers concerning the crop sequence investigations.

Hartwell and Damon (7) summarized the results of the first 11 years of the crop sequence experiments at the Rhode Island Station. This experiment is located on an acid soil classified as Bridgehampton very fine sandy loam. The yields of onions after cabbage, mangel beets, rutabaga turnips and buckwheat were very low, ranging from 13 to 17 bushels per acre. Onions grown after mixed timothy and redtop grasses or redtop alone produced as much as 412 bushels per acre. Buckwheat did well following cabbage, mangels and rutabagas but poorly after millet, grasses, corn and clover. The lowest yields of alsike clover occurred after clovers and carrots while rye and redtop were favorable.

The effects of one crop on a succeeding crop were less pronounced in neutralized soil. The influence of one crop on another was thought to be more complex than a simple competition for nutrients since often the crops which removed the largest amount of the scarcest nutrients were not the ones which had the most depressing effect on a succeeding crop.

Supplementary experiments with plants grown in pots in the greenhouse were reported by Hartwell, Pember and Merkle (8). The yields of onions grown after the individual crops that had occupied the soil for 2 or 3 years increased in the following order: Buckwheat, mangels, rye, onions and redtop. The workers reported that high nitrate often seemed to depress the growth of young onions but analyses showed nitrate in the redtop soil where onions did well as high as in the buckwheat soil where onions did poorly.

Further evidence was presented that the smallest yield may not occur after the crop which removed the largest amount of the most needed nutrient. Generally, the best yield of onions followed crops giving rise to the least acidity. Strength of the soil acidity was determined by the Jones calcium-acetate method in terms of calcium oxide required to neutralize the soil. The highest acidity was found in soil in which rye and buckwheat were grown. Onions and redtop were followed by lower acidity and better crops of onions. In this particular experiment, however, mangels were followed by as low an acidity, yet onions grew poorly after them.

In 1924 Burgess (3) contributed further information on the yield and mineral content of crop plants as influenced by those preceding. His soil studies showed that mangels increased the acidity and readily soluble aluminum content of soils. Redtop behaved in an opposite manner, while several crops produced no measurable effect. Mangels also removed large amounts of calcium and magnesium from the soil.

Hartwell (6) and Hartwell, Smith, and Damon (9) reported in 1927 that the liberal use of liming material and phosphate had gradually reduced the high soil acidity present when the experiment was started. Hydrogen ion determinations made in 1921 were around pH 7. In a soil close to neutral the deleterious effects of preceding crops were scarcely noticeable. Mangels made splendid growth following all crops, except where they succeeded themselves.

The aluminum, phosphorus and nitrogen content and the reaction of the plants grown in 1924 were determined. The crops with the greatest ash alkalinity (mangels, cabbage, rutabagas, and buckwheat) were the ones which had exerted an outstanding deleterious effect on onions grown in 1910 when the soil was very acid, low in phosphorus, and high in active alumina. Some evidence was secured that crops for which slightly acid and neutral soils were unsuited were benefited by being preceded by a crop which removed large quantities of basic elements. Hartwell (6) envisioned the crop sequence study as dealing mostly with the effects of crops under highly acid soil conditions, so steps were taken to again increase the soil acidity.

The information concerning depletion of nutrients and crop effects was summarized by Odland and Smith (14) in 1933. They found a significant degree of correlation between nitrogen reserves and corn yields; with rutabagas, mangels and potatoes the evidence was indefinite. Nitrate determinations when mangels were half grown showed 27 p.p.m. of nitrate nitrogen where mangels followed mangels, 20 p.p.m. following oats, 10 p.p.m. following both alsike and red clover and a maximum of but 6 p.p.m. on the remainder of the plots. Yet the mangels and clover areas produced notably small yields of mangels.

It was also found that calcium was negatively correlated with yields of mangels, suggesting that the calcium supply was not the decisive factor in overcoming the effects of preceding crops on the present one. No apparent correlation was discovered between acid-base balance of the ash elements of mangels and the yields of that crop. The results with magnesium were inconclusive. Studies of the effect on crop growth of leachings from soil where certain crops were grown did not produce results consistent enough to indicate whether soil toxins were involved.

Odland, Smith, and Damon (16), in summarizing the results of the experiment up to 1930, concluded that a number of factors were involved in causing the outstanding differences in the influence of crop plants on those that follow.

Increases in soil acidity caused by some crops seemed to be one of the factors which influenced the behavior of succeeding crops. Potatoes and onions, representing favorable crops, created less soil acidity and removed less excesses of basic elements, dry matter and nitrogen than carrots which represented an unfavorable crop. There were small negative correlations between the yields of mangels, rutabagas, potatoes or corn and the H-ion concentration.

Squash, redtop, onions and potatoes were found to be generally favorable for the crops that follow them. Rye, oats, timothy, corn and buckwheat were intermediate, while carrots, alsike clover, and red clover were usually unfavorable. Mangels, rutabagas, cabbage and millet were unclassified because their effects ranged from favorable to least favorable on succeeding crops.

Odland and Smith (15) suggested that the microbiological population of the soil associated with certain crops might be a factor causing detrimental effects to the following crop. The use of chloropicrin partially overcame some of the ill effect of mangels on a succeeding crop of mangels.* No apparent relationship was found between the time of harvest of the various crops and the yields of succeeding crops.

Rynasiewicz (18) determined organic matter and water stable soil aggregates in the crop sequence frames and found that onions, mangels and corn accumulated less organic matter and had a deleterious effect on soil structure, whereas redtop was beneficial. Onions made the best growth on the more highly aggregated soils.

DESCRIPTION OF EXPERIMENTS

The plots in the original crop sequence experiment were two-fifteenths of an acre in area. They were laid out in strips 193.6 ft. long and 30 ft. wide. For 2 consecutive years 16 miscellaneous crops were grown, each crop following itself on the same plot. The third year a uniform crop occupied the whole area. This plan was modified in 1930 so that 4 uniform crops could be grown in duplicate as shown in Figure 1. The uniform crops were planted at right angles to the rows of the preceding miscellaneous crops.

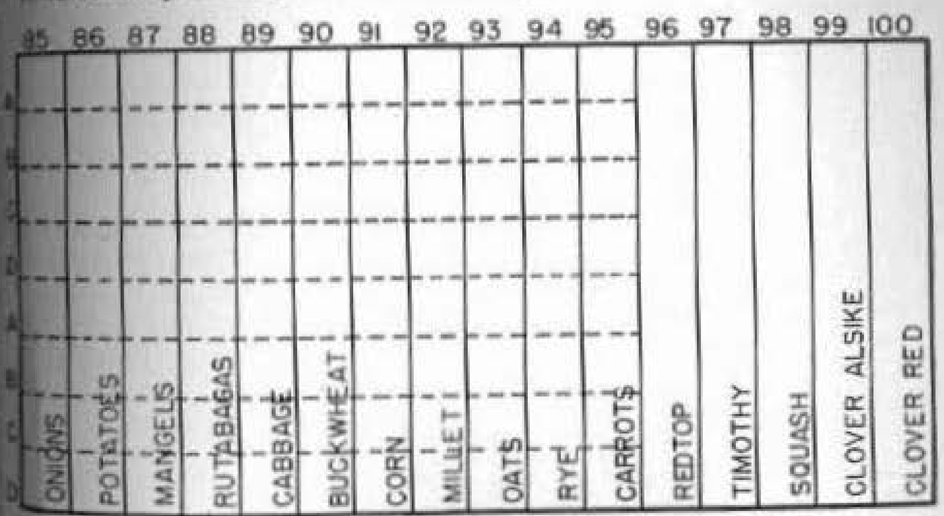

Figure 1—Plan of crop sequence plots. A, B, C and D represent 4 different crops planted in duplicate every third year. Plots 96 to 100 discontinued after 1929.

Redtop, timothy, squash, red clover and alsike clover were discontinued in 1930 leaving 11 plots devoted to onions, potatoes, mangels,

*The authors wish to acknowledge their indebtedness to Dr. F. L. Howard for suggesting the use of chloropicrin, for his help in conducting the tests with this material, and for identification of diseases found.

rutabagas, cabbage, buckwheat, corn, millet, oats, rye and carrots. Rye, oats and buckwheat were harvested before the grains matured and their dry weights determined. The entire area planted to these crops was harvested as a unit and not separated on the basis of the crops which preceded them.

The uniform test crops grown every third year in duplicate strips were as follows:

1930 and 1933: A, corn; B, rutabagas; C, mangels; D, potatoes.
1936: A, potatoes; B, mangels; C, carrots; D, onions.
1939 and 1942: A, potatoes; B, mangels; C, rutabagas; D, onions.

FERTILIZER AND LIME APPLICATIONS

The quantity of fertilizer applied annually was equivalent to 1,000 lbs. per acre of 8-10-10. It contained 2 carriers of nitrogen, 20 lbs. being supplied by nitrate of soda and 60 lbs. by sulfate of ammonia. Superphosphate and muriate of potash supplied 100 pounds of P_2O_5 and K_2O per acre, respectively.

The area received no lime during the period from 1930 to 1942. In 1942 an application of 1,000 lbs. of CaO per acre was applied as hydrated lime.

RESULTS AND DISCUSSION

SOIL REACTION

The pH of the soil in each plot the year preceding the uniform crops is shown in Table 1 in the appendix. The average pH was calculated by averaging the H-ion concentrations. The pH of the soil remained in the range of 5 to 6. The average pH after onions, usually considered to be a beneficial preceding crop, was 5.60. After millet, which often has a deleterious effect, the pH averaged 5.43. Carrots produced the highest acidity, a pH of 5.29. In 1948 Odland and Smith (15) calculated correlation coefficients for potatoes, mangels, rutabagas and onions and found that all were negative. The only significant one was mangels. There was a tendency for mangel yields to decrease as the soil acidity increased. These correlation coefficients are shown in Table 2. According to the soil reaction preference groups established by Morgan (13), the soil was too acid for the best growth of such crops as onions, mangels and possibly cabbage, but probably satisfactory for the others.

Workers at the Rhode Island Station, after considerable research

listed several crops according to the extent to which they remove more basic than acidic elements from the soil. The ratings were as follows:

Low alkalinity:	Corn, oats, rye, timothy, redtop and potatoes. Onions were added to this group later.
Medium alkalinity:	Millet, alsike clover, red clover, cabbage and rutabagas.
High alkalinity:	Buckwheat and mangels.

Results of pot experiments showed that after 3 successive years of cropping with a fertilizer designed to leave only a small residue of soluble salts in the soil, the pH values following the various crops were as follows: Beets 5.66, carrots 5.84, clover 5.76, onions 6.09, timothy 6.19. After a more normal type of fertilizer, leaving a larger residue of soluble salts, the pH values were: Beets 5.31, carrots 5.30, clover 5.32, onions 5.87 and timothy 5.90. When half the pots in the series were limed and planted to onions the yields were equally good. In the unlimed series only onions after onions and after timothy were satisfactory. After clover the onions failed to grow. This experiment demonstrated that different plants may vary in their effect on soil acidity, but did not predict the extent to which this factor was effective in the field.

THE YIELDS OF CROPS

The most data are available for those crops which were used both as miscellaneous crops and uniform crops for 3 or more years; namely, potatoes, mangels, rutabagas and onions. The reaction of these crops in sequence under acid soil conditions has created considerable curiosity. Data for the other crops are not as plentiful but will be discussed briefly. Tables of data for each major crop are presented separately, presenting information on:

a. The effect of the miscellaneous crops on the yield of the uniform crop.

b. The effect of interposing one of the uniform crops in the succession of miscellaneous crops. This is called the single year effect. Average yields of the miscellaneous crops the second year following the uniform crop are included in these tables which are grouped together in the appendix.

c. The effect of partial sterilization of the soil with chloropicrin (tear gas) on subsequent yields of the various crops. The chloropicrin was normally used at the rate of 200 lbs. per acre injected into holes 15 in. apart, 10 or more days before planting.

Mangels

The yields of Golden Tankard mangels, following the 11 miscellaneous crops, are reported in Table 3. The 5-year average shows that millet, mangels, carrots and buckwheat were deleterious to mangels. The average yields after these crops were 10.51, 11.27, 14.08 and 14.00 tons per acre, respectively. Mangels were best following onions and potatoes with yields of 24.72 and 21.32 tons. The effects of the other crops were intermediate. The least significant difference at the 5 percent level is 3.72 tons per acre.

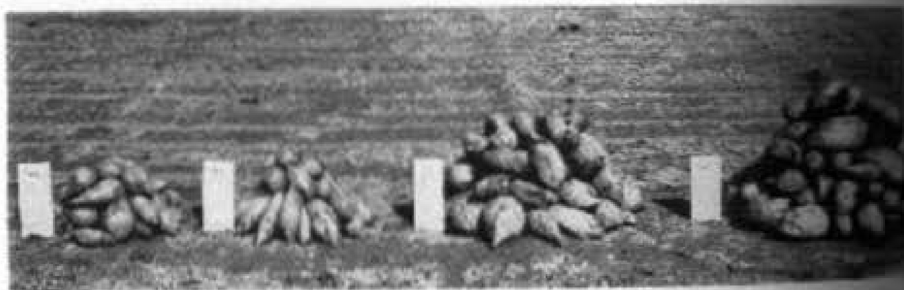

Figure 2—Yields of mangels following, from left to right, mangels, millet, corn and onions.

The yields of mangels following onions were consistently high, fairly so after potatoes, but extremely variable after mangels and millet, the least favorable crops. This suggests that the injurious factor associated with mangels and millet varied in intensity from year to year. In 1939 the yield of mangels following mangels was 3.70 tons per acre, while in 1942 it was 16.71, a difference of 13 tons per acre. Mangels after rye yielded nearly 24 tons per acre in 1930 and 1938, but only one-third as much in 1939. This injurious factor seemed more severe in 1939 than in the other years judging by the low yield in that year. If the factor was a nutritional unbalance or a toxic residue left by the preceding crop, the results should not be so variable from period to period.

Table 4 contains the single year effects following the uniform crops. When a crop of potatoes, onions or corn was interposed in a

continuous succession of mangels the results were beneficial. The yields of mangels were nearly double following the onion, potato and corn crops. Excepting corn, these beneficial effects for an intervening crop were not apparent after a crop of mangels was grown again on the soil. One crop of mangels made the soil conditions less favorable for the subsequent crop.

The yields of mangels were extremely low in 1938. A seedling root rot reduced the stand of mangels to almost nothing in part of the untreated area, while the disease was absent in areas fumigated with chloropicrin. Since chloropicrin produced increases in yields of mangels in 1937, 1938 and 1939, it can be assumed that the seedling root rot disease was present but less severe in 1937 and 1939 than in 1938. The yields of mangels in tons per acre with and without chloropicrin treatment of the soil and the percent increases above the yield of the untreated plots are shown in Table 5.

Mangels, which normally grow well after onions, produced practically nothing after the onions in 1938 when the root rot severely injured the mangels in the unfumigated soil. Where the disease was controlled with chloropicrin, onions produced the usual favorable effect on mangel yields. Likewise, the favorable effect after potatoes was materially reduced in 1938 because of root rot damage. Where chloropicrin controlled this disease, the yields were more favorable for the potato-mangel rotation than for the mangel-mangel rotation. This suggests other factors besides the root rot were influencing production, since chloropicrin did not entirely overcome the deleterious effect of mangels on a succeeding crop of mangels.

The yields of mangels for 1939 following 11 miscellaneous crops are interesting because no apparent benefit to mangels was found from the chloropicrin treatment following cabbage and only a small amount following the beneficial crop, onions, and following the deleterious crop, millet. This is further evidence that there are specific effects of these crops on yields of mangels that operate when seedling root rot is not severe. Chloropicrin did not eleviate the depressing effect of millet on mangels, the yield being 4.90 and 4.30 tons per acre. The deleterious effect of mangels on mangels, however, seemed to be largely due to a build-up of seedling root rot disease which was controlled by chloropicrin. The 3-year average for mangels after mangels was 3.92 tons per acre without chloropicrin treatment of the soil, but 9.70 tons where partial sterilization took place. The percent increase in yields over the checks due to chloropicrin ranged from 73 to 416 percent.

Potatoes and onions, which were favorable crops, were sprayed occasionally with Bordeaux mixture. Calomel with lime was used on onions to control maggots. While the amounts per acre are small, it is conceivable that over a period of years the copper and mercury accumulating in the soil might lessen the severity of the root rot of mangel seedlings.

Macleod and Howatt (12) reported that 10 to 15 lbs. per acre of mercuric or mercurous chloride applied directly in the row helped to control common scab and black scurf of potatoes and was capable of preventing club root of turnips as well as certain damping off diseases of ornamentals. The treatments were not deleterious to the growth of wheat, oats, barley, clover and timothy or to the useful activities of nitrogen-fixing bacteria. The effect of the use of fungicides of copper and mercury over a period of years should not be overlooked in crop sequence studies.

It will be remembered that when the soil was limed back in the early twenties, mangels produced equally well after all crops but mangels. It seems possible that even in those days the root rot disease was prevalent where mangels were grown continuously and was the principal force inducing low yields.

Crop residue effects should not be overlooked, particularly in the case of millet which was usually deleterious to a succeeding crop of mangels. Cochrane (5), in a report on crop residues as causative agents of root rots of vegetables, said the experimental evidence supported the hypothesis that certain plant residues cause an increase in root rot and a decrease in yields of succeeding crops. The effect was not explicable on the basis of nutrient starvation nor on the grounds of simple pathogenesis by a nematode or pathogen. Rather, the data strongly suggested that plant residues in the soil exert a direct toxic effect on the roots of susceptible plants, probably complicated by the action of secondary rot-producing microorganisms. Head lettuce following sweet corn with vetch cover crop, clover, or timothy was afflicted with severe root rot, but soybean residues favored the growth of lettuce. The addition of corn stover to soil in the greenhouse caused root rot in lettuce transplants. Residues which were allowed to decompose for 30 days at high temperature and moisture were no longer injurious. The favorable or deleterious effect of certain crop residues has been reported by several other writers. West and Hildebrand (24) found that the strawberry root rot disease was almost completely controlled in a naturally infected soil in which crops of soybeans were

incorporated, while clover used in a similar manner produced severe root rot.

Cochrane (5) reported that application of chloropicrin to the soil resulted in significant increases in yield and reduction in root rot of lettuce, spinach and potatoes. He did not attribute the stimulating effect of chloropicrin to any correction of residue damage by the fumigant, since the effect of chloropicrin was usually as great on control plots as on those containing injurious residues.

Stark, Howard and Smith (19, 20) concluded that the benefits of soil fumigation with chloropicrin are largely due to the control of undesirable organisms, especially fungi. They found that the increases in plant growth after low dosages of this gas could not be accounted for by increases in available nitrogen and that chloropicrin in solution was detrimental rather than stimulative to plant growth. Figure 3 shows mangels grown on a plot formerly occupied by millet. Note how few mangel plants survived in this plot. Millet may have promoted an unfavorable microbial condition for a subsequent crop of mangels.

Figure 3—The stand of mangels on land previously in millet for 2 years.

The favorable effects of certain crops on subsequent crops may be due to the growth of microorganisms on their residues which produce antibiotic effect on pathogens of the subsequent crop. Weindling (23) says, "The study of specific antagonistic phenomena in culture media and sterilized soils has led to the pertinent observation that pathogens are most effectively suppressed under conditions favorable for their antagonist. Most of these are saprophytes common in natural soil. Treatments favoring saprophytes in general, or special groups, enhance natural biological control against certain pathogens. This has been proved to be true for the control of cotton root rot and cereal root rots by introducing organic manures. . . . These practices were known to be beneficial even before their microbial effect was recognized."

The zone of microbial activity next to the roots of plants known as the rhizophere has also been studied. Katznelson (10) examined the rhizosphere effect of mangels on certain groups of soil microorganisms and concluded that this crop exerted a striking selective action on the number of bacteria, actinomyces, fungi and protozoa. Aerobic cellulose-decomposing bacteria were preferentially stimulated by mangel roots and anaerobic bacteria were consistently stimulated, particularly gas-producing *clostridia*, closely related to *clostridium pasteurianum*. The implication of rhizosphere effects in crop sequence studies is not clear. Timonin (21) investigated the microflora of the rhizosphere in relation to manganese deficiency disease of oats. He discovered that partial sterilization of soil with chloropicrin, calcium cyanamide, or formaldehyde greatly reduced or completely eradicated bacteria capable of oxidizing manganese. This caused oats to be free of the manganese deficiency disease known as grey speck.

Wallace and Lockhead (22) studied the influence of various crop plants on the nutritional groups of soil bacteria and found significant differences in rhizosphere effects between certain groups of crops. These workers suggested that the investigation of the microorganisms of the rhizosphere might contribute to a better knowledge of the nature of root excretions and of factors related to crop rotation and the control of soil-borne diseases of crops. Katznelson, Lochhead and Timonin (11) of Canada, and Clark (4) of the U. S. Department of Agriculture have recently published comprehensive reviews of the literature dealing with soil microorganisms and the rhizosphere.

In summarizing the factors which may have influenced the yields of mangels, lack of nitrogen, phosphorus or potassium did not seem to be limiting. No evidence has been found to indicate that a deficiency of minor elements is associated with the crop sequence phenomenon. Mangels have a higher lime requirement and yields showed a tendency to decrease as the soil became more acid. Evidence gained in 1938 from chloropicrin treatment indicated that seedling root rot may be common where the soil is cropped to mangels year after year. The severity of the disease is lessened by chloropicrin treatment or by interposing other crops. From observations made over a period of years it is evident that more than one factor is responsible for the

influence of a preceding crop on a subsequent crop. These factors are broadly classified as the physical, chemical, and biological conditions of the soil and are intimately related, a change in one causing a compensating shift in the other. A crop which leaves a soil in a good physical condition may promote the growth of beneficial soil microbes with consequent favorable growth of the following crop. This experiment indicates that in future crop investigations the physical and biological aspects of the problem must be studied and related to the chemical factors. This should lead to a clearer understanding of the basic principles underlying crop sequence responses.

Potatoes

Green Mountain potatoes produced the highest average yields following rye, oats and onions; 394, 391 and 390 bushels per acre, respectively. Millet, rutabagas, and potatoes proved to be the least favorable to potatoes with yields of 298, 308 and 315 bushels, respectively. Calculations show that 39 bushels difference is necessary for significance at the 5 percent level. Mangels, cabbage and corn were not as deleterious as the millet, rutabagas and potatoes, but yields were significantly lower than the best yields of potatoes after rye or oats according to the figures in Table 6.

The result of interposing a uniform crop in what otherwise would be a continuous cropping with potatoes is shown in Table 4. Since one of the uniform crops was potatoes, the area where this occurs has grown potatoes continuously. The results in this table are not strictly comparable because not all of the uniform crops were grown the same number of years. For potatoes and mangels 4 years' results are available; for rutabagas, 3 years; onions and corn, 2 years; and carrots, 1 year.

Interruption of continuous potatoes by the uniform crop of mangels or rutabagas depressed the yields slightly compared to continuous potatoes. This small depression is still evident in the second year following these crops. Potatoes after potatoes averaged 320 bushels while after mangels and rutabagas they yielded 295 and 309 bushels. The 2-year results after onions indicate, as did the previous data, that high yields of potatoes were produced after the onion crop.

Calculation of the correlation coefficient (Table 2) between the H-ion concentration and potato yields showed no significant relationship. Why oats and rye were more beneficial than millet is not clear since they are all grass-like in growth. Rye, of course, is fall planted, oats are planted in early spring, while millet is usually seeded about June 1. Ripley (17) reported that, in Canada where moisture conditions were favorable, summer fallow was definitely unfavorable preceding potatoes, but beneficial preceding mangels. Millet was not favorable in this case to either potatoes or mangels.

The millet usually was harvested 2 to 4 weeks later than oats or rye, so less time was available for the decomposition of residues in the fall, but more time was available in the spring since millet was planted later. No observations were made for root rot such as Cochrane (5) observed on potatoes grown after timothy.

Onions were beneficial while rutabagas and potatoes were unfavorable to the following potato crop. Onion yields were usually low so more residual fertility may have remained for the subsequent potato crop. The average increase in bushels of potatoes per acre was 23 percent for the chloropicrin treatment in 1938. It is possible that rutabagas and potatoes favored the growth of microbes which were inimical to maximum development of the potatoes. Chloropicrin treatments of the soil in 1937 and 1939 did not increase potato yields. Injury to the potato sprouts and delayed emergence occurred. Apparently the chloropicrin had not dissipated sufficiently before planting time.

Rutabagas

The annual yields of Macomber rutabaga turnips are recorded in Table 7. The 4-year averages show that a preceding crop of rutabagas, millet or mangels was deleterious to rutabagas. The yields after these 3 crops were 400, 497 and 551 bushels per acre, respectively. Onions were followed by the highest yield, 648 bushels of rutabagas. Corn, oats, rye and cabbage also proved to be favorable with yields ranging from 605 to 617 bushels per acre. The difference necessary for significance at the 5 percent level is 118 bushels.

The first year effects of the uniform crops are shown in Table 4. The results vary. In 1931 and again in 1940, rutabaga yields were lower following a previous crop of rutabagas than after the uniform crop. In 1934, however, the continuous rutabaga plot produced the highest yield. The 3-year average shows that, in general, introducing potatoes or corn in the rotation improved the yields. The average second year results indicate that rutabaga production decreases more rapidly after rutabagas, mangels, or potatoes than after corn. This favorable second year effect of corn was also observed after potatoes and mangels.

The results of treating part of the rutabaga plot with chloropicrin are shown in Table 8. In all but one instance the partial sterilization of the soil had a favorable effect on rutabagas. The largest increases from use of the fumigant occurred in 1937, ranging from 78 percent after potatoes to 101 percent after carrots. The smallest increases were found in 1939, the maximum increase being 20 percent after onions.

Unfortunately, rutabagas after rutabagas occurred only in 1939 and no increase in yields was found where chloropicrin was applied. If the unfavorable effect of rutabagas on rutabagas was due to a build-up of disease organisms, chloropicrin should have improved the yields. If the chloropicrin was not thoroughly dissipated from the soil it may have temporarily delayed the growth of the rutabagas, thus nullifying the beneficial effect of disease control. Partial sterilization of the soil nearly equalized the yields of rutabagas following potatoes and mangels in 1937 and 1938. The differences were a little greater in 1939. Chloropicrin more nearly equalized the yields of rutabagas following potatoes and mangels than it did yields of mangels following potatoes and mangels. No diseases were recorded for rutabagas during this period.

No correlation was found between rutabaga yields and H-ion concentration. The favorable effect of onions may be related to more residual fertility because of small growth of that crop, and perhaps to the effect of the mercury residues on the microflora of the soil. The onions were treated with calomel and lime and occasionally with bichloride of mercury or Bordeaux mixture in an attempt to control its pests. Why the grain crops with the exception of millet were favorable is still conjectural.

The rutabaga roots were examined for several years for evidence of boron deficiency. Only in 1940 was evidence of this found. The deficiency was general throughout the plots and did not seem related to previous crop effects.

Cos Lettuce Experiment

Cos lettuce was grown in the greenhouse in pots of soil from the rutabaga plot and the rye plot of the crop sequence experiment. The unlimed soil had a pH of 5.2. Each series received liberal amounts of nitrogen and potash. Phosphate was applied at 3 rates, with and without a moderate application of lime. There was a response to phosphate, but with the largest application, the green weight of 10 plants was only 9 grams after rutabagas and 18 grams after rye. After liming to pH 6, the comparative yields were 32 and 39 grams, demonstrating the equalizing effect of lime. When chloropicrin was used in connection with these treatments, large increases in yields were obtained. Where chloropicrin was used with high phosphate, without lime, lettuce after rutabagas weighed 118 grams and after rye 67 grams. With lime, the comparable yields were 179 and 106 grams respectively. This reversal indicates that the detrimental effect of rutabagas on cos lettuce was eliminated by chloropicrin. No root examinations were reported so it is not known whether a root rot similar to that described by Cochrane (5) existed where the lettuce was unproductive.

When the soil and its microbial population were subjected to chloropicrin vapors for 10 days the yields of cos lettuce were materially increased but adequate lime was needed for maximum results. Whether the improvement was due to changes in the rhizosphere, to destruction of pathogens or to the amelioration of toxic residues cannot be conclusively stated.

Onions

The yields of Yellow Globe onions following 11 miscellaneous crops for 1936, 1939, and 1942 are presented in Table 9. Onion yields were variable as onion maggots caused damage during several years in spite of applications of calomel and lime. In this series, production was more satisfactory in 1936 than in 1942. The maggot injury was so severe in 1940 that no yields were obtained. Rye was outstanding as a preceding crop for onions. The 3-year average yield was 404 bushels of onions per year. Rutabagas were the least favorable preceding crop with average yields of 116 bushels of onions. The difference necessary for significance at the 5 percent level was 142 bushels per acre. Cabbage was deleterious also, being followed by only 276 bushels of onions. This raises an interesting speculation as to whether rutabagas and cabbage favored the attack of onion maggots. Onion maggots, *Hylemya antiqua Meig.*, belong to the same genus as the cabbage maggot which also attacks turnips.

Oats, buckwheat, and corn were favorable crops to precede onions. The beneficial effect of buckwheat and rye on onions is in contrast to the results obtained in 1910 when the soil was much lower in reserve fertility. On the other hand, cabbage and rutabagas were deleterious to onion yields in 1910 as they are now. This seems to indicate that the deleterious effect of cabbage and rutabagas on onions has biological as well as chemical implications.

Table 4 contains the yields of onions in bushels per acre following the uniform crops. The yields of onions were very low in 1931, much better in 1934, but poor in 1937. In 1934, when 2 years of onions were interrupted by 1 year of rutabagas, the effect was favorable. This is in contrast to the usually depressed yields of onions following 2 years of rutabagas. One crop of rutabagas was not as depressing to the yield of onions as several rutabaga crops in sequence.

Onions were perhaps more sensitive to chloropicrin than some of the other crops. The results were not uniform in 1937 and 1938. The onions were severely injured in 1939 and had to be replanted. The yields of onions were extremely poor in 1938 but in 3 out of 4 sections increases in yields from 23 to 33 percent were found by the partial sterilization of the soil with chloropicrin.

Effect of Lime and Other Soil Amendments

A small experiment was performed in the greenhouses during 1938, 1939 and 1940 comparing the growth of onions in soil taken from a plot where rutabagas were grown for 2 years out of 3 with that from a plot where rye was grown similarly. The purpose of the experiment was to study the relative effects of lime, phosphate and chloropicrin on the growth of onions in the 2 soils. The soil was placed in pots and maintained as nearly as possible at 20 percent moisture. The treatments, which were in triplicate, and the average yields of onion bulbs in grams per pot are shown in Table 10.

Judging by the 1938 and 1939 yields, lime without phosphate was more effective than phosphate without lime, which indicates that lime was the greater limiting factor for growth. An application of lime and phosphate was decidedly better than either alone. When phosphate was omitted the onions growing in soil from the rutabagas plot averaged only 13 grams. The same treatment on soil from the rye plot produced 5 times as much, 69 grams.

The addition of phosphate increased the average yields of onions after rutabagas to 27 grams, but produced no significant result in the rye soil. The addition of lime and phosphate increased the yields of onions following rutabagas to 63 grams and following rye to 98. Chloropicrin treatment was not as effective as lime in removing the deleterious effect of rutabagas on onions.

Lime, phosphate and chloropicrin were each effective in improving yields of onions after rutabagas, but only lime and chloropicrin were effective after rye. It does not seem that the difference in phosphate reaction could be due to a greater concentration of toxic aluminum or iron in the rutabaga soil since the H-ion concentrations were practically identical. The pH readings for the rutabaga plot were 5.51, 5.35, and 5.37 and from the rye plot 5.49, 5.23, and 5.49, respectively, for the years 1939-1940.

Additional treatments of boron, magnesium and steam sterilization were used in 1940. No benefit was derived from adding magnesium or boron with the complete fertilizer. Chloropicrin produced some increase in yields, steam sterilization was even better and boron plus sterilization was still more effective. Lime and complete fertilizer increased yields more than either chloropicrin or steam sterilization, the comparative weights being 131, 69, and 100 grams per pot, respectively. Boron reduced the efficiency of lime and increased the efficiency of the 2 sterilization treatments in the rutabaga soil. Surprisingly boron had an opposite effect in the rye soil, reducing the effect of the sterilization treatments and accentuating the lime effect on yields. With data for only one year and the variable results, it would seem that boron is of doubtful importance in explaining the difference in effect of these 2 preceding crops on the yields of onions.

None of the treatments made the soil from the rutabaga plots as satisfactory as the soil from the rye plots for a subsequent crop of onions. Certain treatments, however, such as lime, chloropicrin, and steam sterilization caused great improvement in the yields of onions grown on the rutabaga soil but smaller increases when grown on the rye soil. Since liming and soil sterilization have a parallel effect in improving yields it may be postulated that both treatments cause favorable changes in the microbial population of the soil which in turn benefits the onions. The exact nature of the unfavorable biological condition is still to be determined. It may be associated with a less favorable physical condition of the soil after rutabagas than after rye. It is general knowledge that the physical condition of a soil is better after fibrous-rooted, close growing crops than after cultivated root crops. This is further demonstrated by the correlation for onion yields, and the organic matter and soil aggregation after redtop shown by Rynasiewicz (18).

Effect of Crop Residues on Onions

In order to gain information on the influence of various crop residues soil was removed from the section of a plot in which onions were grown from 1934 to 1938. It was placed in Wagner pots and the dried and ground roots of mangels, rutabagas, redtop and corn were incorporated at the rate of 2 tons to the acre. One set was reserved as a check and another set received a native peat at the same rate as the root amendments. The standard rate of fertilization was used and soil moisture was maintained at 20 percent. The results are shown in Table 11.

The average yield of onion bulbs from the control soil was 69 grams. Where rutabaga roots were added the maximum yield of 116 grams was obtained. Roots of mangels, corn and redtop also produced favorable effects on the yields of onions. Redtop roots, however, were less effective than the others. Native peat uniformly reduced the yields below those of the check, the average being 50 grams per pot.

These results indicate that the possibility of crop residues being the direct detrimental factor in this experiment seems slight. Other experiments at this station have shown that buckwheat roots produced no depressing effect on a subsequent crop of buckwheat or cos lettuce.

Redtop has been outstanding as a favorable preceding crop for onions and potatoes. Its beneficial effect must be associated with its favorable influence on the physical, microbial, and chemical condition of the soil. Bell, Odland and Owens (2) in a previous rotation study attributed the greater yield of potatoes from the non-legume rotation not only to a more satisfactory supply of nutrients but also a more favorable balance of K, Ca and Mg ions, and better physical condition of the soil.

Corn and Carrots

Rhode Island White Flint corn was grown as a uniform crop in 1930 and 1933. Carrots replaced it in the 1936 trials. The bushels per acre of corn and carrots after 11 miscellaneous crops are shown in Table 12. The corn yields were computed at 14 percent moisture. Growing conditions in 1930 were exceptionally favorable for corn; the average yield being close to 100 bushels per acre. In 1933 the production was only half as great. Stewart's disease and magnesium deficiency symptoms recorded in 1933 were more pronounced after mangels, buckwheat, millet and carrots but the yields of shelled corn showed no direct relationship with these deficiency symptoms. No positive evidence is available to indicate that differences in magnesium content of the soil were a principal factor in the crop sequence results.

The first and second year effects shown in Table 4 substantiate the observation that corn when well fertilized is not particularly sensitive to the preceding crop. Corn after corn seems less favorable than other sequences.

Carrots were used as a uniform crop only in 1936. The yields ranged from 953 bushels where carrots followed carrots to 1429 bushels when they were preceded by cabbage. Onions and mangels were also favorable preceding crops, for the following harvest of carrots was 1370 and 1324 bushels per acre, respectively. The yields of carrots after millet, corn and rutabagas range from 1179 to 1183 bushels. The last mentioned crops were not as favorable to carrots as were oats, buckwheat and potatoes. The 3 most favorable crops—cabbage, onions and mangels—were those which have a high lime requirement. Carrots, on the other hand, are better adapted to acid soils. The first and second year effects are shown in Table 4. The annual yields following mangels are more variable than after potatoes. For 2 years out of 4 the yields of carrots following mangels were greater than after potatoes. The annual production after potatoes was relatively uniform. The unpredictable influence of mangels indicates that its unfavorable effect may be associated with some external condition such as the weather. Carrots after carrots were unfavorable probably because of a greater concentration of microbes detrimental to this crop.

The yields of carrots from soil with and without chloropicrin treatments are recorded in Table 13. A root disease destroyed a high proportion of the seedlings in certain of the untreated areas in 1938. This was the second year carrots were grown on the area since the uniform crops. Increases in production due to partial sterilization of the soil ranged from 42 to 252 percent. In 1937, the year following the uniform crops, the greatest improvement in yields from partial sterilization occurred after carrots.

Cabbage and Millet

Cabbage and millet were grown as miscellaneous crops and the annual production of these crops, along with the average yields the first and second year following uniform crops, are presented in Table 4. As in the case of the miscellaneous crops already reported the data are not strictly comparable because not all the uniform crops were grown each time. Rutabagas and corn were the most deleterious preceding cabbage which produced only 4.56 and 4.58 tons per acre after these crops. Onions were the most favorable, for the cabbage following produced 9.19 tons. Potatoes and carrots appeared satisfactory and mangels were intermediate in effect. The average yields 2 years after the uniform crops still showed the deleterious effects of rutabagas and corn and the favorable influence of onions and carrots.

Club root disease caused considerable difficulty. This disease is usually more active in acid soils than in those that are nearly neutral. In 1937 the plants in the ground treated with chloropicrin were free of club root while 23 percent of those from the controls were infected. Similar results were obtained in 1938. The result of partial sterilization of the soil before cabbage and millet is shown in Table 14. No response was found in 1937 following potatoes and mangels but a 41 percent increase was found following onions. In 1938, when cabbage was grown on all the plots, little difference in yield was found from the untreated area. The greatest increase in yield, 55 percent, occurred where onions were grown 2 years previous and the smallest increase, 9 percent, resulted where potatoes were grown at the earlier period. The lack of response of cabbage to chloropicrin following potatoes and the excellent response following onions suggests that the microbial population of the soil engendered by these 2 crops must differ considerably.

Average yields of millet when preceded by potatoes, mangels and rutabagas were 2.59, 2.61, and 2.36 tons per acre, respectively. Rutabagas were slightly less favorable than mangels and potatoes. Tons of millet per acre obtained in 1937 are shown in Table 14. The percent increases in yield from chloropicrin varied from 29 after mangels to 55 after potatoes.

CROP SEQUENCE EXPERIMENT IN CEMENT FRAMES

In order to preserve the crop sequence experiment on a small scale for further study a series of 36 cement frames was constructed in the fall of 1930. Each frame enclosed an area one thousandth of an acre in extent. Fresh soil similar to that in the older crop sequence area was placed uniformly in the frames. In 1931 mangels were grown on all plots, followed by winter wheat in 1932. The sequence studies were begun in 1933. The experiment was planned in such a way that once it became established, the yields of the uniform crops and the yields of miscellaneous crops following them could be compared simultaneously each year. In order to do this the frames were divided into 3 blocks of 12 each. While the uniform crop was planted on one block, the first year of the miscellaneous crop appeared in the second block and the second year of these crops was growing in the third block. The miscellaneous crops, mangels, buckwheat, corn and redtop, were replicated 3 times in each block.

The same fertilizer was used in this experiment as in the previous one, equivalent to 1,000 pounds of 8-10-10 per acre. Hydrated lime was applied in 1942 and 1946 at rates of 1,000 and 500 pounds of CaO per acre, respectively.

SOIL REACTION

The average pH of the soil after each miscellaneous crop was determined for the period 1933 to 1941 and, following the addition of lime, for the period 1942 to 1948. These pH values shown in Table 15 were derived by averaging the annual H-ion concentrations. Three pH values from Table 1 are included for reference.

While the differences in pH are very small, the soil is slightly more acid after mangels than after buckwheat, corn or redtop. The pH after mangels for the first period was 5.45 and for the second period 5.36. The pH following redtop was more constant and slightly higher, being 5.52 and 5.53, respectively, for the 2 periods. Comparison of the total average from the cement frame experiment and the previous one shows a small but distinct trend for greater average acidity following mangels than following buckwheat. Likewise, the average acidity is slightly greater following buckwheat than following corn. The chance that these slight differences in soil acidity are major factors in the effect of one crop on a succeeding crop is not great.

EFFECT OF THE MISCELLANEOUS CROPS

The uniform crops were mangels for 3 years, 1934-1936; onions for 8 years, 1937-1944; and potatoes for 4 years, 1945-1948. The onion crop failed in 1943 and no weights were obtained. The annual yields and average yields of each uniform crop are reported in Table 16. The single year effects and second year effects are recorded in Table 17. Uniform crops were not grown at the same time and so comparison between crops is not as valid as in the earlier experiment. The comparison of first and second year effects are comparable, however, starting the second year following the introduction of any uniform crop. First and second year averages are available for 7 years. Yields of grain corn were not obtained in 1940 and 1948 due to damage by cows. No yields of mangels were recorded for 1943 and yields of redtop were not available for 1943 and 1944.

Mangels

The average yields of mangels for the period 1934-1936 varied from 14.14 tons per acre after corn to 17.74 tons after redtop. Redtop and buckwheat were equally beneficial and mangels did not have the depressing effect on mangels in this relatively fresh soil that was

found later when a seedling root rot became troublesome. In 1938, when this condition was very severe in the field experiment, mangels after mangels in the cement frames yielded only 0.71 tons. The figures in Table 17 show that the interruption of continuous mangels by onions every third year was a favorable procedure, the average yield of mangels the first year after onions being 11.84 tons per acre compared with 7.01 the second year.

During June, 1949, the mangels in the cement frames previously planted to mangels were examined for root rot since many of the seedlings were dead and others were stunted. It was found that the stunted plants were severely afflicted with a root rot condition. Mangels growing where potatoes were previously grown were larger, more numerous and possessed healthy tap roots covered with hair roots. The diseased mangels had very few fine roots. Representative plants from the 2 different treatments are shown in Figure 4.

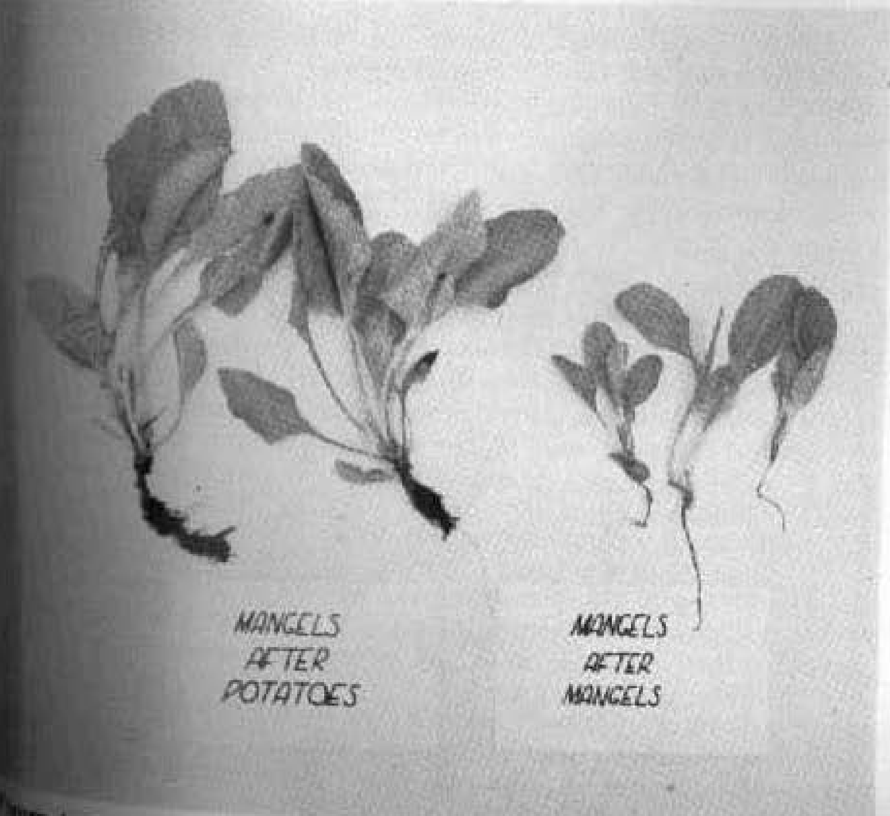

Figure 4—Mangel seedlings from cement frames showing damage from root rot where mangels followed mangels.

Onions

Onion yields are available for 7 years. A general trend exists for low yields after mangels and high yields after redtop with corn and buckwheat intermediate in effect. The average yields of onions after mangels, buckwheat, corn and redtop were 127, 185, 194 and 383 bushels per acre, respectively. In 1944 the yields of onions after redtop were very low, probably due to a local attack of onion maggots. The results of this experiment were similar to those previously reported.

Potatoes

The yields of potatoes are available for 4 years. The production was unusually high in 1947 averaging more than 600 bushels per acre. In 1948 the potatoes yielded less than 300 bushels, emphasizing the extreme variations in production which may be principally controlled by weather conditions.

Redtop was the most favorable crop to precede potatoes, the potatoes averaging 467 bushels. After mangels the yields were only 3 bushels less than following redtop. During the 4 years that potatoes were used as a uniform crop, corn was the least favorable as a preceding crop. The yields averaged 370 bushels per acre after corn which is significantly lower than the others.

Buckwheat, Corn, and Redtop

The first and second year average yields of buckwheat, corn and redtop following the uniform onion crop are recorded in Table 17. The average dry weight of buckwheat was 2.06 tons when preceded by onions and 1.77 tons when preceded by buckwheat. The yields of corn stover, likewise, were higher following onions than after corn. The yields of corn grain, however, were approximately the same following onions and following corn, 40.7 and 42.5 bushels per acre, respectively.

The average yield of redtop was 1.84 tons of dry weight the first year and 2.96 tons the second year. This is logical since perennial grasses normally produce more the second year after planting than they do the year they are seeded.

SUMMARY

This bulletin contains the results of the crop sequence experiments for the period 1930 to 1942. The previous crop sequence experiments which started in 1907 are briefly reviewed along with other recent publications. The crop sequence experiment is being continued on a small scale in cement frames. The results of this test are also included.

The original experiment was modified in 1930 so that the standard miscellaneous crops which were grown 2 years in succession were followed the third year by 4 uniform test crops in duplicate strips. The plots received a complete fertilizer annually but were probably too acid for the optimum growth of some of the test crops since the soil reaction was more acid than pH 6.

The least favorable crops to precede mangels were carrots, mangels and millet. Potatoes, rutabagas, and millet were most deleterious to a subsequent crop of potatoes. Low yields of rutabagas followed mangels, millet or rutabagas, while onions were unfavorably affected by preceding crops of mangels, cabbage or rutabagas. It seems significant that for 3 crops out of 4, millet, mangels and rutabagas proved to be deleterious. Rye, oats and onions were usually followed by high yields of the subsequent crops.

One-year crop effects were studied where the continuous culture of the miscellaneous crops was interrupted every third year by the uniform crops. The unfavorable effects of mangels upon mangels were partially overcome by interposing such crops as potatoes, corn or rutabagas. The yields of onions after 1 rutabaga crop were higher than following 2 crops which shows that the unfavorable effect of rutabagas was accumulative.

No simple explanation exists for the effect of crop plants on those that follow. The relationships are complex and are associated with the chemical, physical and microbial conditions in the soil. These conditions are interdependent. An unfavorable soil reaction, for example, may accentuate a poor physical condition of the soil and retard vital microbial activity.

In the earlier phases of the research attention was focused on the effect of crops on the subsequent supply of plant nutrients, the amount of soluble aluminum and the residual acidity of the soil. Those crops which removed the most nutrients were not the ones which were often least deleterious to the succeeding crop. The supply of nitrogen, phosphorus and potassium was normally adequate since the soil annually received liberal applications of a complete fertilizer. Deficiencies of minor elements were infrequent and were not associated with any particular crop sequence.

In moderately to strongly acid soil those crops which removed the largest quantities of basic materials were generally least favorable to the succeeding crop. The soil was more acid after mangels, an unfavorable crop, than after rye, which was favorable. Correlation studies showed, however, that increases in H-ion concentration and decreases in basic materials were not the dominating factors. Nevertheless, they must be contributing factors.

Time of planting and harvesting of the crop was not an important factor in determining how one crop influenced the next. This, coupled with the fact that the addition of crop residues to pots of soil proved favorable to plant growth, indicated that toxic crop residues were not responsible for the depressing effect of some crops on the yield of a following crop.

Certain crop rotations were found to maintain a better aggregation of soil particles than others. Redtop, a favorable preceding crop, caused the soil to remain well aggregated. Less aggregation was found following mangels which was often a deleterious crop. Yields of onions grown in rotation with mangels, buckwheat, corn and redtop, respectively, were directly correlated with the amount of water stable aggregates in the soil. A higher state of aggregation provides more suitable air and water relationships and may promote the development of a desirable microbial population.

The microbial condition of the soil following one crop may not be favorable to the next, particularly if it promotes the development of pathogenic organisms. Chloropicrin partially sterilized the soil and prevented a root rot condition on mangels and other crops. Crop rotations which favored the production of a poor physical condition in the soil and some increase in acidity and soluble aluminum also favored the root rot condition. The fact that liming and partial sterilization of the soil both tend to ameliorate the effect of such deleterious crops as rutabagas on a subsequent crop of onions suggests that both treatments caused the development of a more favorable soil microflora and possibly some improvement in soil tilth.

While the use of chloropicrin materially increased the yield of mangels following mangels, the previous deleterious effects of the crop were still in evidence. In other words, while chloropicrin destroyed many unfavorable microbes it did not improve the physical condition of these plots nor the calcium supply and soil reaction. Since maximum crop growth is dependent on a favorable physical condition, microbial activity and nutrient supply, any treatment alleviating one unfavorable condition could not be as beneficial as treatments which would improve all.

A justifiable general conclusion from these studies is that in moderately to strongly acid soils well fertilized crops may produce unfavorable growing conditions for a subsequent crop because:

a. They deplete basic nutrients with a consequent increase in H-ion concentration, accompanied by possibly harmful concentrations of aluminum or other elements.

b. Unless organic matter is provided, an adequate quantity of water stable aggregates is not maintained so that the soil becomes compact and possesses a poor physical condition unsuitable for maximum crop growth.

c. After certain crops, conditions are more favorable for the growth of plant pathogens and the development of seedling root rot.

d. The chemical, physical and biological conditions of the soil are intimately related and interdependent so that an improvement in one may produce some improvement in the others.

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APPENDIX

Table 1—Soil pH of Plots in Crop Sequence Study in Year Preceding Uniform Crops

Misc. Crop	Year 1929	1932	1935	1938	1941	Ave.*
Potatoes	5.84	5.94	5.82	5.63	5.41	5.65
Rye	5.80	5.97	5.68	5.49	5.42	5.63
Onions	5.81	5.98	5.71	5.49	5.32	5.60
Oats	5.71	6.00	5.63	5.49	5.34	5.59
Corn	5.65	5.94	5.70	5.51	5.37	5.58
Rutabagas	5.85	5.98	5.36	5.51	5.22	5.49
Millet	5.74	5.98	5.25	5.33	5.26	5.43
Buckwheat	5.76	5.72	5.43	5.33	5.14	5.41
Cabbage	5.83	5.85	5.41	5.36	5.07	5.40
Mangels	5.81	5.90	5.13	5.16	5.12	5.31
Carrots	5.55	5.73	5.14	5.24	5.11	5.29

*Calculated from average H-ion concentrations

Table 2—Correlation Between Yields of Potatoes, Mangels, Rutabagas and Onions, and the pH of the Soil the Year Preceding Each Crop

	Coefficient of Correlation
Yield of Potatoes and H-ion Concentration	−0.166 ± 0.198
Yield of Mangels and H-ion Concentration	−0.6191 ± 0.125
Yield of Rutabagas and H-ion Concentration	−0.245 ± 0.191
Yield of Onions and H-ion Concentration	−0.201 ± 0.195

Table 3—The Yields of Mangels in Tons per Acre Following 11 Miscellaneous Crops*

Preceding Crop	1930	1933	1936	1939	1942	5-Year Average
Onions	28.12	22.30	27.98	20.85	24.35	24.72
Potatoes	32.10	15.06	23.45	17.20	18.79	21.32
Cabbage	26.10	15.24	28.04	13.65	14.65	19.54
Rutabagas	28.42	10.87	21.77	12.65	16.20	17.97
Corn	23.22	13.65	19.85	16.55	12.40	17.15
Rye	23.85	15.76	25.67	7.75	12.91	16.79
Oats	22.65	15.52	20.09	10.05	10.01	15.84
Buckwheat	23.80	9.82	19.90	9.60	10.27	14.69
Carrots	20.32	14.32	16.80	7.65	13.30	14.08
Mangels	11.47	9.34	15.14	3.70	16.71	11.27
Millet	17.40	7.44	12.48	4.30	10.95	10.51
Least Significant Difference, 5% Level						3.72

*The miscellaneous crops were grown for 2 years and were followed by the mangels the third year.

Table 4—The Acre Yields of Crops the Year Following the Uniform Crops and the Average Yields the Second Year Following These Crops

Preceding Uniform Crop	1931	1934	1937	1940	Average Yields First Year	Average Yields Second Year
	Tons of Mangels Per Acre					
Potatoes	10.05	10.96	11.75	8.80	10.28	6.06
Mangels	5.97	6.88	7.09	2.20	5.54	5.13
Rutabagas	7.68	10.99		3.00	7.22	7.94
Onions			11.34	8.10	9.72	2.24
Corn	9.70	13.78			11.74	10.11
Carrots			6.94		6.94	4.11
	Bushels of Potatoes Per Acre					
Potatoes	353	313	313	374	338	[illegible]
Mangels	321	249	328	351	312	[illegible]
Rutabagas	355	285		344	320	[illegible]
Onions			349	426	387	[illegible]
Corn	351	306			329	[illegible]
Carrots			303		303	[illegible]
	Bushels of Rutabagas Per Acre					
Potatoes	407	452	401	454	429	[illegible]
Mangels	328	447	376	355	376	[illegible]
Rutabagas	262	570		260	364	[illegible]
Onions			393	383	387	[illegible]
Corn	289	550			420	[illegible]
Carrots			341		341	[illegible]
	Bushels of Onions Per Acre					
Potatoes	146	550	205		300	[illegible]
Mangels	125	529	100		251	[illegible]
Rutabagas	122	602			362	[illegible]
Corn	120	607			363	[illegible]
Onions			245			[illegible]
Carrots			322			[illegible]
	Tons of Cabbage Per Acre					
Potatoes	4.84	4.60	8.36	11.26	7.27	[illegible]
Mangels	4.29	4.51	7.50	9.23	6.38	[illegible]
Rutabagas	3.46	4.97		5.24	4.56	[illegible]
Onions			7.54	10.84	9.19	[illegible]
Corn	3.22	5.94			4.58	[illegible]
Carrots			7.03		7.03	[illegible]
	Tons of Millet Per Acre					
Potatoes	3.03	3.04	2.56	1.71	2.59	[illegible]
Mangels	3.02	3.38	2.12	1.92	2.61	[illegible]
Rutabagas	2.66	2.64		1.78	2.36	[illegible]
Onions			2.12	1.86	1.99	[illegible]
Corn	2.86	2.54			2.70	[illegible]
Carrots			2.40		2.40	[illegible]
	Bushels of Corn Per Acre					
Potatoes	72.6	31.2	40.1	50.9	48.7	[illegible]
Mangels	68.6	37.8	40.9	47.0	48.6	[illegible]
Rutabagas	70.9	42.6		43.1	52.2	[illegible]
Onions			36.1	47.4	41.8	[illegible]
Corn	73.8	26.9		50.4	50.4	[illegible]
Carrots			34.7		34.7	[illegible]
	Bushels of Carrots Per Acre					
Potatoes	408	523	523	632	521	[illegible]
Mangels	326	614	384	637	491	[illegible]
Rutabagas	351	586		591	509	[illegible]
Onions			486	723	605	[illegible]
Corn	427	647			537	[illegible]
Carrots			317		317	[illegible]

Table 5—The Yields of Mangels in Tons per Acre With and Without Chloropicrin Treatment of the Soil and Percent Increase in Yields

Preceding Crop	1939		1938		1937		Average		Percent Increase		
	With Chloro-picrin	Without Chloro-picrin	With Chloro-picrin	Without Chloro-picrin	With Chloro-picrin	Without Chloro-picrin	With Chloro-picrin	Without Chloro-picrin	1939	1938	1937
Potatoes	20.00	17.20	7.44	3.45	16.20	11.75	14.55	10.80	16	116	38
Mangels	11.90	3.70	4.95	0.96	12.24	7.09	9.70	3.92	222	416	73
Carrots	9.20	7.65	2.61	1.11	13.82	6.94	8.38	5.23	20	135	92
Onions	22.10	20.85	6.48	0.45	19.62	11.34	16.07	10.88	6	1340	73
Rutabagas	17.20	12.65							36		
Cabbage	13.40	13.65									
Buckwheat	13.20	9.60							38		
Corn	18.90	16.55							14		
Millet	4.90	4.30							14		
Oats	18.70	10.05							86		
Rye	16.70	7.75							116		

Table 6—The Yields of Green Mountain Potatoes in Bushels per Acre Following 11 Miscellaneous Crops*

Preceding Crop	1930	1933	1936	1939	1942	5-Year Average
Rye	453	341	439	332	405	394
Oats	463	343	446	321	385	391
Onions	391	345	470	314	429	389
Buckwheat	363	344	431	312	353	366
Carrots	362	345	371	343	379	360
Mangels	369	307	407	274	380	348
Cabbage	325	316	440	206	277	325
Corn	391	303	358	247	308	321
Potatoes	382	270	384	257	280	315
Rutabagas	384	251	329	243	332	308
Millet	328	267	294	289	314	298
Least Significant Difference, 5% Level						39

*The miscellaneous crops were grown for 2 years and were followed by potatoes the third year.

Table 7—The Yields of Rutabagas in Bushels per Acre Following 11 Miscellaneous Crops*

Preceding Crop	1930	1933	1939	1942	4-Year Average
Onions	763	622	488	718	[illegible]
Corn	565	600	550	754	[illegible]
Oats	637	641	562	629	[illegible]
Rye	608	650	427	743	[illegible]
Cabbage	900	482	445	594	[illegible]
Carrots	577	629	524	629	[illegible]
Potatoes	672	521	482	961	[illegible]
Buckwheat	528	574	519	643	[illegible]
Mangels	506	529	465	712	[illegible]
Millet	481	508	478	622	[illegible]
Rutabagas	417	289	332	561	[illegible]
Least Significant Difference, 5% Level					[illegible]

*The miscellaneous crops were grown for 2 years and were followed by rutabagas the third year.

Table 8—The Yields of Rutabagas in Bushels per Acre With and Without Chloropicrin Treatment of the Soil and Percent Increase in Yields

Preceding Crop	1939		1938		1937		Average		Percent Increase		
	With Chloro-picrin	Without Chloro-picrin	With Chloro-picrin	Without Chloro-picrin	With Chloro-picrin	Without Chloro-picrin	With Chloro-picrin	Without Chloro-picrin	1939	1938	1937
Potatoes	528	487	367	287	713	401	536	391	9	28	78
Mangels	504	455	365	245	716	376	528	359	11	49	91
Carrots	584	524	337	272	684	341	535	379	11	24	101
Onions	584	488	415	304	727	393	576	395	20	37	85
Rutabagas	312	332									
Cabbage	457	445							3		
Buckwheat	607	516							18		
Corn	631	550							15		
Millet	641	478							34		
Oats	598	562							7		
Rye	439	427							3		

Table 9—The Yield of Onions in Bushels per Acre Following 11 Miscellaneous Crops*

Preceding Crop	1936	1939	1942	3-Year Average
Rye	779	607	426	604
Oats	578	570	332	494
Buckwheat	601	517	335	485
Corn	673	483	306	484
Carrots	623	474	326	474
Onions	685	394	182	420
Millet	634	452	169	418
Potatoes	668	297	97	354
Mangels	572	357	78	336
Cabbage	480	271	77	276
Rutabagas	93	195	60	116
Least Significant Difference, 5% Level				142

*The miscellaneous crops were grown for 2 years and were followed by the onions the third year.

Table 10—Average Yields in Grams Per Pot of Onion Bulbs Grown in the Greenhouse in Soil from the Rutabaga and Rye Plots

Treatments*	1938		1939		1940		3-Year Average	
	Rutabagas	Rye	Rutabagas	Rye	Rutabagas	Rye	Rutabagas	Rye
NK	9	36	1	24	29	147	13	69
NKL	37	35	14	34				
NPK	25	30	9	25	46	151	27	69
NPKL	30	55	26	54	131	186	63	98
NPK Mg					32	182		
NPKB					30	184		
NPK Clpn	17	36	33	51	69	184	40	90
NPK Clpn B					105	175		
NPKL B					101	196		
NPK Steam					100	171		
NPK Steam B					145	153		

*NPK—complete fertilizer approximately equal to 1,000 lbs. of 8-16-16 per acre; L—approximately 1½ tons per acre $Ca(OH)_2$; MG—200 lbs. $MgSO_4$ per acre; B—5 lbs. sodium tetraborate per acre; Clpn—chloropicrin.

Table 11—Yields of Onion Bulbs in Grams per Pot Following Application of Root Residues

Treatment	1938	1939	Average
Mangel roots	84	105	[illegible]
Rutabaga roots	112	121	[illegible]
Redtop roots	53	107	[illegible]
Corn roots		100	
Native peat	52	48	[illegible]
Check	67	70	[illegible]

Table 12—The Average Bushels of Corn and Carrots Following 11 Miscellaneous Crops

Preceding Crop	Corn*			Carrots
	1930	1933	2-Year Average	1936
Onions	101.2	46.0	73.6	1370
Potatoes	107.5	41.4	74.5	1273
Mangels	100.0	48.4	74.2	1324
Rutabagas	107.5	47.5	77.5	1183
Cabbage	101.2	47.1	74.2	1429
Buckwheat	100.8	54.6	77.7	1272
Corn	76.3	47.5	62.4	1180
Millet	93.9	56.4	75.2	1179
Oats	107.7	56.1	81.9	1221
Rye	96.9	51.9	74.4	1277
Carrots	92.6	53.1	72.9	953

*Shelled corn, 14 percent moisture

Table 13—The Yields of Carrots in Bushels per Acre With and Without Chloropicrin Treatment of the Soil and Percent Increase in Yields

Preceding Uniform Crop	1937		1938		Percent Increase	
	With Chloropicrin	Without Chloropicrin	With Chloropicrin	Without Chloropicrin	1937	1938
Potatoes	720	523	227	122	37	85
Mangels	560	384	214	150	46	42
Carrots	570	317	210	83	80	154
Onions	748	486	178	50	54	252

Table 14—The Yields of Cabbage and Millet in Tons per Acre With and Without Chloropicrin Treatment of the Soil and Percent Increase in Yields

Preceding Uniform Crop	1937		1938		Percent Increase	
	With Chloropicrin	Without Chloropicrin	With Chloropicrin	Without Chloropicrin	1937	1938
Cabbage						
Potatoes	6.44	8.36	7.46	6.87		9
Mangels	7.14	7.50	8.21	6.70		22
Carrots	7.41	7.03	8.70	7.00	5	24
Onions	10.66	7.54	9.60	6.21	41	55
Millet						
Potatoes	3.96	2.56			55	
Mangels	2.73	2.12			29	
Carrots	3.46	2.40			44	
Onions	3.33	2.12			36	

Table 15—The Average pH of the Soil in the Cement Frames the Year Preceding the Uniform Crop

Crop	1933-41	1942-48	Average 1933-48	Ave. from First Table
Corn	5.49	5.59	5.54	5.58
Redtop	5.52	5.53	5.53	
Buckwheat	5.48	5.42	5.45	5.41
Mangels	5.45	5.36	5.40	5.31

Table 16—Effect of Mangels, Buckwheat, Corn, and Redtop on Yields of Mangels, Onions and Potatoes in Cement Frames

Preceding Crop	Tons of Mangels 1934	1935	1936	Average
Mangels	18.90	11.37	14.82	[illegible]
Buckwheat	18.15	15.48	19.03	[illegible]
Corn	16.10	11.07	15.27	[illegible]
Redtop	20.55	14.67	18.02	17.74
Least Significant Difference, 5% Level				[illegible]

	Bushels of Onions 1937	1938	1939	1940	1941	1942	1944	Ave.
Mangels	96	35	124	140	174	251	68	127
Buckwheat	187	67	235	88	259	321	136	[illegible]
Corn	108	11	323	289	136	408	103	[illegible]
Redtop	309	187	437	726	439	525	60	[illegible]
Least Significant Difference, 5% Level								[illegible]

	Bushels of Potatoes 1945	1946	1947	1948	Average
Mangels	410	472	674	300	[illegible]
Buckwheat	316	476	610	293	[illegible]
Corn	341	409	520	210	[illegible]
Redtop	341	523	656	347	[illegible]
Least Significant Difference, 5% Level					[illegible]

Table 17—The Average Yields of Mangels, Buckwheat, Redtop, and Corn Stover in Tons and of Corn in Bushels per Acre Following the Uniform Crop of Onions

Crop		
Mangels	First Year	[illegible]
	Second Year	[illegible]
Buckwheat	First Year	[illegible]
	Second Year	[illegible]
Corn (grain)	First Year	[illegible]
	Second Year	[illegible]
Redtop	First Year	[illegible]
	Second Year	[illegible]
Corn Stover	First Year	[illegible]
	Second Year	[illegible]