3 1) Colorado

4) Bulletin 363 December, 1930

EFFECTS OF CLOVER AND ALFALFA IN ROTATION

A COMPARISON OF LEGUME CULTURE WITH FALLOW CULTURE.

PART III

BY WM. P. HEADDEN

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EFFECTS OF CLOVER AND ALFALFA IN ROTATION

PART III

BY WM. P. HEADDEN

Under the title of "Effects of Clover and Alfalfa in a Rotation" we presented in bulletins 319 and 362 the results obtained by five years observation on the carbon dioxid in soil air, in fallow land, and in land under crops, both with and without irrigation. In the former of these bulletins we discussed the action of carbon dioxid and water on felspar because it is the principal mineral in our soil that is capable of change, also upon soil in mass, with its abundant supply of carbonate of lime. In the latter we presented the influence of clover, alfalfa and wheat upon the amount of carbon dioxide in the soil air throughout the year, and compared it with the amount in fallow ground, date for date, during two years or seasons. Alfalfa lives throughout the year but spring wheat and corn live only about 120 to 180 days.

The root systems of these crops are very different and they occupy the land to a very different extent. Our stand of alfalfa was very thick, this means that we had from 250,000 to 500,000 plants per acre, but in the corn experiments we had only 14,000 to 24,000 plants. Alfalfa roots in this land attain a maximum length in excess of eleven feet and most of them exceed six feet. The root system of wheat is fibrous but attains a depth of four or five feet. Red clover, which is the clover that we used, is shallow rooted in comparison with alfalfa but has a root of the same character. Its length is seldom over six feet in our ground. During the period of active growth of the wheat crop the soil air was almost as rich in carbon dioxid as it was under the alfalfa on the same dates. It is not intended to intimate that carbon dioxid is the only substance excreted by the roots. We do not believe that it is, but the excretion of carbon dioxid is a function common to these plants while the other excretions may be very different, in some cases favorable, in others unfavorable to crops that may be planted after them. One benefit of a fallow may be due to the fact that these excretions of crops are changed during this period and rendered harmless, in other words, the soil may become more healthful for crops in general.

In bulletin 362 we also presented the exchange value of the soil studied which involved an extended study of the easily soluble elements of fertility and the manner or extent to which they were influenced by the crops. It was established that there is a complex in our soil whose ability to exchange bases is represented by 13 hydrogen units and this remains practically the same throughout the period of our study, but the easily soluble portions varied with the crops. Potassium was less in parts-per-million of soil in the ammonic chlorid solution than in the solution obtained by neutralizing the carbonate of lime by acetic acid; there were but few instances in which the former equaled the latter. The subsoil is strongly calcareous but the same relation between the acetic acid soluble and ammonic chlorid soluble potassium is maintained throughout. The relations of the postassium are of the greatest interest in this study as the action of carbon dioxid on felspar, of which our soil largely consists, is to eliminate potassium. From forty to seventy-five percent of the total dissolved out of felspar is potash. Calcic carbonate in the soil does not protect it from this action. The complex existing in our soil seems to be practically unchanged by our cropping but the potassium existing in some other form in the soil is changed in quantity as we shall see later.

We were prepared from the very beginning of this experiment to find the relation of the amount of nitrogen, both as total nitrogen and as nitric nitrogen, of considerable interest and not in harmony with prevalent views concerning it. Legumes, and for us especially alfalfa, are generally considered as increasing the amount of this element in the soil. This subject was had in particular consideration from the beginning, in fact, it was a suggestion arising from other studies that alfalfa might produce its beneficial results by some other action than by increasing the amount of total nitrogen in the soil that led to this investigation. In studying the nitrogen supply in land that had been in alfalfa for two years we were surprised to find no establishable difference between this and adjacent land. The soil in question was not rich in nitrogen and two years in alfalfa with a fair growth plowed under made so little difference that it was impossible to assert that it had actually been increased. This contradiction between generally accepted views and our observations led us to study this relation in as great detail and exhaustiveness as was possible. The result was that, if any nitrogen be added in this manner it is wholly negligible. The supply of nitric nitrogen in a soil supporting a growth of alfalfa is very small except, occasionally, on the surface of the ground covered with the fallen leaves and stems, but the ground proper is poor in nitric nitrogen at all depths.

The observations that carbon dioxid is given off very freely by alfalfa, and that this carbon dioxid brings potassium into solution, led to the study of the amount of water-soluble potassium in the fallow and cropped land. If the crop does not use up the potassium set free, there should be enough water-soluble potassium under the alfalfa to enable us to demonstrate its excessive abundance over that in fallow land. This proved to be the case.

At the end of the preceding observations the plots were plowed; the heavy growths of clover and alfalfa were turned under and the present series of observations begun. The object was two-fold:

First, to see what the effects upon a succeeding crop might be. The crop chosen was Kubanka wheat. The pages immediately following will present the observations made.

Second, to note the deportment of the soil, when kept fallow, in its development of carbon dioxid as shown by the soil air; the fixing and nitrifying power of the different plots and the persistency of the water-soluble potassium and the nitric nitrogen under field conditions. These subjects will form the subject of a succeeding bulletin.

The History of the Plots

These experiments began at the close of the second season and continued for one year, thus covering the third season. During the firts two seasons the treatment of the plots was the same, i. e., two of them were cultivated fallow, two were planted to red clover, and two to alfalfa. Two subordinate plots were planted to wheat the first year and to corn the second year. All were plowed at the end of the second season. The clover and alfalfa growths were heavy at this time.

All plots were cultivated the following spring and a portion of one set planted to Kubanka wheat so that we had wheat after clover, fallow, corn and alfalfa, in a series of contiguous plots. The rest of the plots were cultivated fallow for purposes already given.

Arrangement of the Work

Two series of nitric nitrogen determinations were carried on throughout the season, one in connection with the study of the fixation of the nitrogen, the other in connection with the water-soluble potassium. The latter was of course represented by small samples, the former by large samples. The fixation and nitrification series were carried out by Mr. Tobiska, while that in connection with the water-soluble potash was carried out by Mr. Vail. The carbon dioxid determinations were all made by Mr. Douglass to whom fell also the general supervision of the plots.

CROP RESULTS GIVEN PRECEDENCE

Perhaps it will be as well to give the crop results before those obtained from the study of the soil of the plots and its changes, even though we consider the latter more important as they are the causes of the differences in the growth and character of the crop. By discussing the crops first we give the results before the causes. This view assumes that the changes that take place in the land cultivated fallow are so similar in kind and degree to those that take place in the land that is being cropped that they are the determinative factors in the characteristics of the crop both in manner of growth and quality. It must be stated, however, that the two years action of the clover and alfalfa on the soil is to leave an increase in the readily available potash, and to better the general conditions of the soil, so that the changes that take place during the growing of the crop are only contributing and not exclusive causes of whatever characteristics may appear in the crops. We cannot distinguish between the effects of the conditions at planting time and those that actually obtain during the life time of the crop. These conditions are constantly changing but the conditions at the time of planting are of very great importance.

CONDITIONS AT TIME OF PLANTING OF PRIME IMPORTANCE

In illustration of this statement it may be stated that the application of a quantity of sodic nitrate at planting time produced almost as great an effect as one three times as heavy distributed in three equal portions in a period of 65 days. The unit quantity added was 40 pounds of nitrogen, or 250 pounds of Chile saltpetre per acre, which was too heavy an application for our soil. The object of our experiment was to ascertain the specific effects of nitric nitrogen upon the properties of the wheat kernels and not to ascertain the best time to apply it or the best quantity to be applied. The first application immediately after sowing produced almost as great results as the three applications distributed over 65 days which may be taken to indicate that the conditions at the time of planting are of prime importance.

What the changes in the soil during the growth of the plants may be and their importance are really points in question which have not been made out. Attempts have been made to follow the formation of nitrates in soil occupied by growing crops with some success. We have followed this factor in land cropped to alfalfa, clover, wheat, and corn, especially the three former. In these cases the amount of nitrates in the soil was very small. This does not prove that they may not have been formed, but, shows that they were either not formed, or were used up by the plants. The deportment of soil that had been planted to wheat after the crop had been removed, supports the view that their formation was hindered but not entirely suppressed. At harvest time the nitrates in soil that had been planted to wheat were very low but began to increase soon after the removal of the crop and continued to do so till the beginning of winter. We shall give in a subsequent bulletin observations on the deportment of land in this respect after crops of clover and alfalfa have been plowed under. In fact, the object of this bulletin is to set forth, in so far as we can, these relations in the soil after it had been in the crops mentioned—clover, alfalfa, wheat and corn—for two years, also after being fallowed for two years.

This section of the work has two divisions.

This bulletin will present the deportment of wheat sown after the land had been fall plowed whereby heavy growths of clover and alfalfa were plowed under before they had been injured by frost, and a succeeding bulletin will present the deportment of the greater part of the plots cultivated fallow during the season of 1928.

STUDY OF WHEAT CROP ONLY GENERAL

We shall not undertake a detailed study of the wheat crop or enter upon questions of the influence of peculiarities in different sections of the plots which we have observed to persist for the three years that we have had the land under observation. For instance, we have observed that the water-soluble potassium is persistently more abundant in the north half of one plot than in the south half. We have not discovered the reason for this but as stated it is a persistent condition. It might be of interest to study the wheat produced on this half in comparison with that produced on the south half but it is not our purpose to study the crop in this manner. This crop suggests as many questions as we encountered in our study of Colorado wheat, some of them quite different from those presented in our bulletins on this subject—Bulletins 205, 208, 217, 219, 237, 244 and 248 of this station, but we have no intention of endeavoring to discuss them.

Heavy growths of clover and alfalfa were plowed under in the fall before the plants had been injured by heavy frosts. One of our objects in this was to effect the killing of the alfalfa, so that we would not be troubled with volunteer alfalfa during the summer of 1928. A question may be raised as to whether this heavy crop plowed under in late fall was as effective as a lighter one would have been plowed under in early spring. It served our purposes better because we wished to study the soil immediately after as much organic matter as possible had been plowed under and we believed that the soil temperatures were as favorable as they would be in the spring.

THE WHEAT CHOSEN AND WHY

Kubanka wheat was sown as early as was convenient on a small portion extending across the end of one set of our duplicate plots. Kubanka was chosen because it is a good grower with a rather stiff straw, is usually free from rust and shows the yellow-berry condition plainly if it is present. The seeding was done with a drill and was alike on all sections. The germination was good so we had a very even stand to begin with and differences in the crops from this point on are ascribed to the effects of the previous crops or treatment of the soil.

CONDITIONS IN OUR CORN PLOT

One plot had been in wheat one year and in corn the succeeding year so that corn immediately preceded this wheat crop. We have no data on the effects of corn upon the soluble potash in the soil and only fifteen composite samples, each containing five subsamples, taken seven inches deep, between 28 July and 1 December, 1926, to show its effect on the amount of nitric nitrogen present. The samples taken in August and September were lower than those taken in October and November, but the average of the 15 samples was 10 p.p.m (parts per million), whereas samples from our fallow plot for the same season taken to the depth of six inches, was 12 p.p.m. Only in the samples taken in August did the nitric nitrogen fall below that regularly present under the alfalfa. The average found under our alfalfa plot was 6 p.p.m. for the same depth. This evidence, so far as it goes, concerning the amount of nitric nitrogen in soil sustaining a growing crop of corn, indicates that it does not depress the supply of nitric nitrogen to so great an extent as alfalfa. The few surface samples taken in this corn field were as rich as similar samples taken in an alfalfa field which included half decayed portions of the plants. We have no data on the water-soluble potassium in land occupied by either a wheat or corn crop.

WATER-SOLUBLE POTASSIUM RELATED TO CARBON DIOXID IN SOIL-AIR

The soluble potassium in our soil is related directly to the amount of carbon dioxid maintained in the soil air by the crop. The water-soluble potassium in soil occupied by clover, alfalfa, and cultivated fallow has been determined for the land that we have used. The atmosphere of fallow land contains less carbon dioxid than that occupied by clover or alfalfa and contains less soluble potassium than either of them, even though the clover and alfalfa are heavy feeders on this element. A ton of alfalfa removes not far from 40 pounds of potassium from the soil, but land planted to alfalfa shows much more water-soluble potassium than fallow land and, during the vigorous growing period of the alfalfa, four or five times as much carbon dioxid in the soil atmosphere. The soil atmosphere in land occupied by wheat becomes very rich in carbon dioxid before the maturation of the crop, but from that time on it falls till it does not differ much from the fallow. The atmosphere under corn became richer in carbon dioxid as the crop approached maturity but, at a depth of 30 inches, the richest atmosphere and the deepest lysimeter under corn, it never became as rich as the corresponding depths under alfalfa or clover, and the same is true of the shallower depths. This does not necessarily mean that corn roots are less active in discharging carbon dioxid, for it is not at all probable that the soil was as thoroughly occupied by the roots in the case of corn as in that of either wheat or alfalfa. No comparison is made here with fallow.

DIFFERENCES IN CROP DUE TO PREVIOUS TREATMENT OF PLOTS

The seeding of the wheat and the treatment of the plots were the same. It was not irrigated. Any differences in the growth, yield and quality of the crop on the different sections are attributable to the previous treatment of the plots or more specifically to differences in the soil conditions produced by the respective crops. I do not recall having seen a specific statement of the changes supposed to be effected in soils by various crops or by a system of rotation. It is generally stated that legumes add nitrogen to the soil and that herein lies their special merit in a rotation. It is certain, that practice shows that in some way they benefit the land or make it capable of producing better succeeding crops, if the crops be the right ones. How long this good effect may last is not given. The result observed is so general that the explanation has been accepted as a proven fact.

POTASSIUM, NOT NITROGEN, INCREASED BY ALFALFA

This is an assumption arrived at from the consideration of the fact that there is more nitrogen in a legume crop plus that which is in the soil at the time of its maturity than was in the soil at the beginning. This was demonstrated to be a fact 75 years ago, but the question of increase in the soil when separated from the plant was not thereby proven and the actual balance in the account has been assumed and not determined. The fact is, as ascertained by our study that the nitrogen added to the soil by alfalfa in four years is negligible. On the other hand the water-soluble potassium present in the soil has been perceptibly increased. We have not attempted to determine directly the effect upon the solubility of the phosphoric acid. The probability seems to be that this is made more available by the very abundant supply of carbonic acid maintained in the soil atmosphere by the alfalfa. But this is assumed and not proven to be true.

PHOSPHORIC ACID MADE SOLUBLE BY CARBON DIOXID

The preceding assumption, however, is based on the following observations: The action of carbon dioxid and water (a) on felspar is to take phosphoric acid as well as potash into solution, 20 p.p.m. of phosphoric acid, P_2O_5,—(b) from soil and subsoil each it dissolved 30 p.p.m. phosphoric acid even in the presence of very large quantities of lime. These facts concerning the action of carbonic acid on the solubility of the phosphoric acid in the soil justify the assumption made.

The results observed are: First, that the nitrogen in the soil is not perceptibly increased after the occupancy of the land for two or even four years by alfalfa; second, that the soil atmosphere is very greatly enriched in carbon dioxid throughout the whole period. The action of this carbon dioxid is to bring very considerable quantities of potassium into a water-soluble condition also to bring phosphoric acid into solution and make it more available even if it be subsequently reprecipitated by the action of carbonate of lime in the soil. That this actually takes place is shown with a high degree of probability, if not with certainty, by the ready solubility of the phosphoric acid in dilute not to exceed 10 percent. hydrocloric acid. I found that one-third of the total phosphoric acid in this soil went into solution in acid of this strength in five minutes, and Mr. Tobiska found that fifty percent of the total went into solution in 10 minutes. This phosphoric acid was apparently as readily soluble as the carbonate of lime which encrusted the soil particles. This phosphoric acid probably formed a part of the incrustation and was probably not dissolved out of the soil particles themselves.

OTHER FACTORS THAN FOOD SUPPLY IMPORTANT

Nitrogen, potassium and phosphoric acid are the nutrient elements usually deemed necessary to consider. There are other things which go to make up the efficiency of the soil. Its mechanical condition or tilth has always been added as of prime importance. How much this overlaps what we understand by its sanitary conditions the writer does not know. But the fixing and nitrifying efficiency of the soil is clearly modified by its cultivation and fertilization. Some years ago Dr. Sackett was kind enough to make a few bacterial counts in some soil samples for me. The results showed that those made on samples to which rock superphosphate had been added were about twice as high as in the others. The total nitrogen determinations made during the season here referred to were higher in the phosphate plots than in the others. These may be accidents, mere coincidences, but they are very strongly suggestive accidents.

The task that we have set ourselves in this bulletin, is to show what we have actually effected by our two years series of experiments, principally with clover, alfalfa, and fallow cultivation. In a preceding bulletin we have presented an extensive view of the state of affairs as they obtained during and at the end of the two years and this completed our project as originally planned.

OUR PRACTICAL QUESTIONS

The practical question of the subsequent deportment of this soil remained. By the practical questions we understand: First, the crop-producing power of the plots on which we had made our observations; second, the fixing and nitrifying power of the same; third, the persistency of the water-soluble potassium and the variation of the nitric nitrogen; fourth, the amount of the carbon dioxid in these soils cultivated fallow. All of these subjects were studied during the season after the clover and alfalfa had been plowed under. The results form the subject of another bulletin.

CROPS OBTAINED

The subject to be first presented is the crops obtained in our experiments of 1928. The treatment of the soil has already been given in sufficient detail. The planting was made as early as was possible, second of April, at the rate of 90 pounds of seed per acre.

DIFFERENCES SHOWN

Differences showed in the plants early in the season. (See photographs Figures 1, 2 and 3, 22 June 1928). The crop after corn lacked the vigorous green color of the other three plots and showed a smaller growth than the others, till near the end of the season, when the greater portion of the plants attained quite as great a height as the others. (Figure 3, photographed 10 July). There was a very

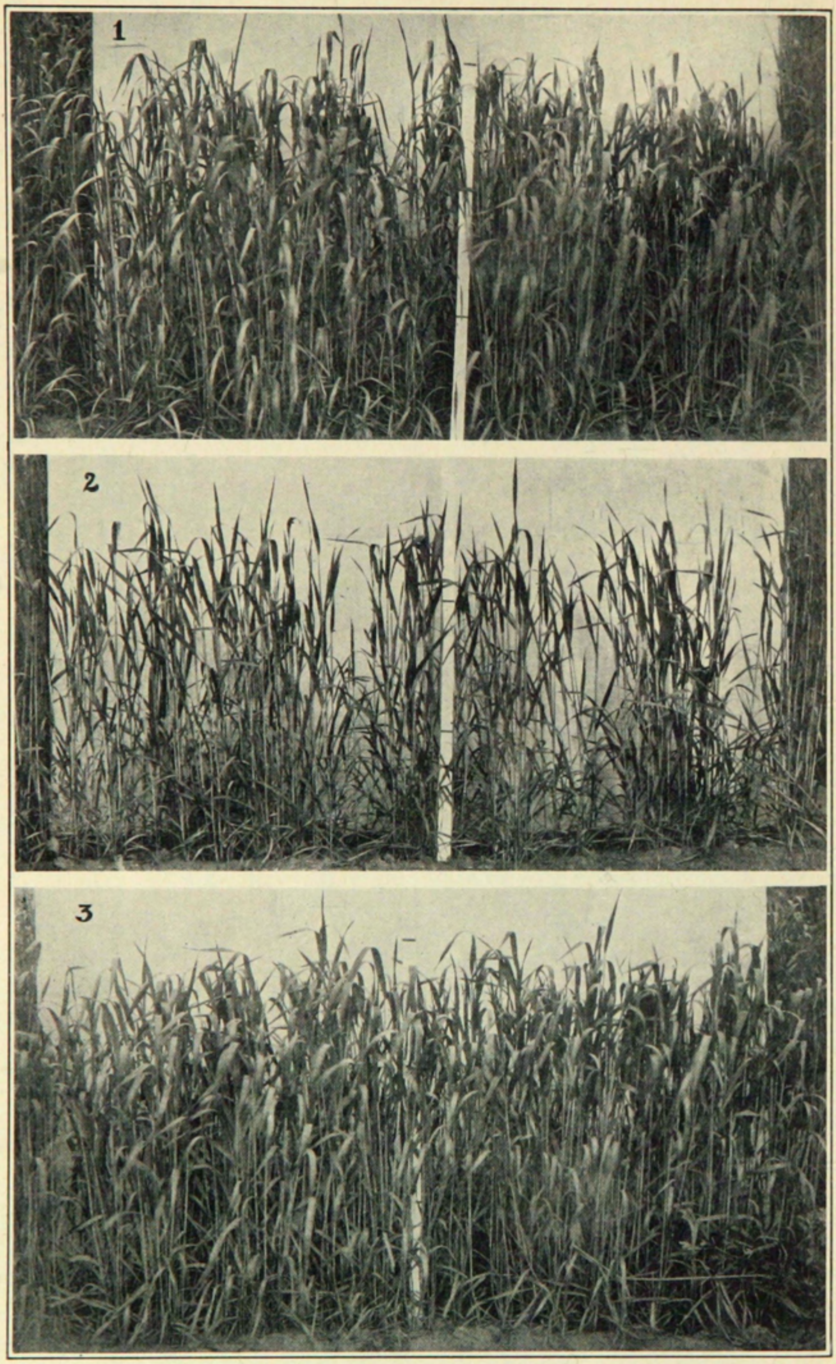

Plate I.—From photographs taken 22 June, 1928. 1—After clover; 2—After corn; 3—After alfalfa.

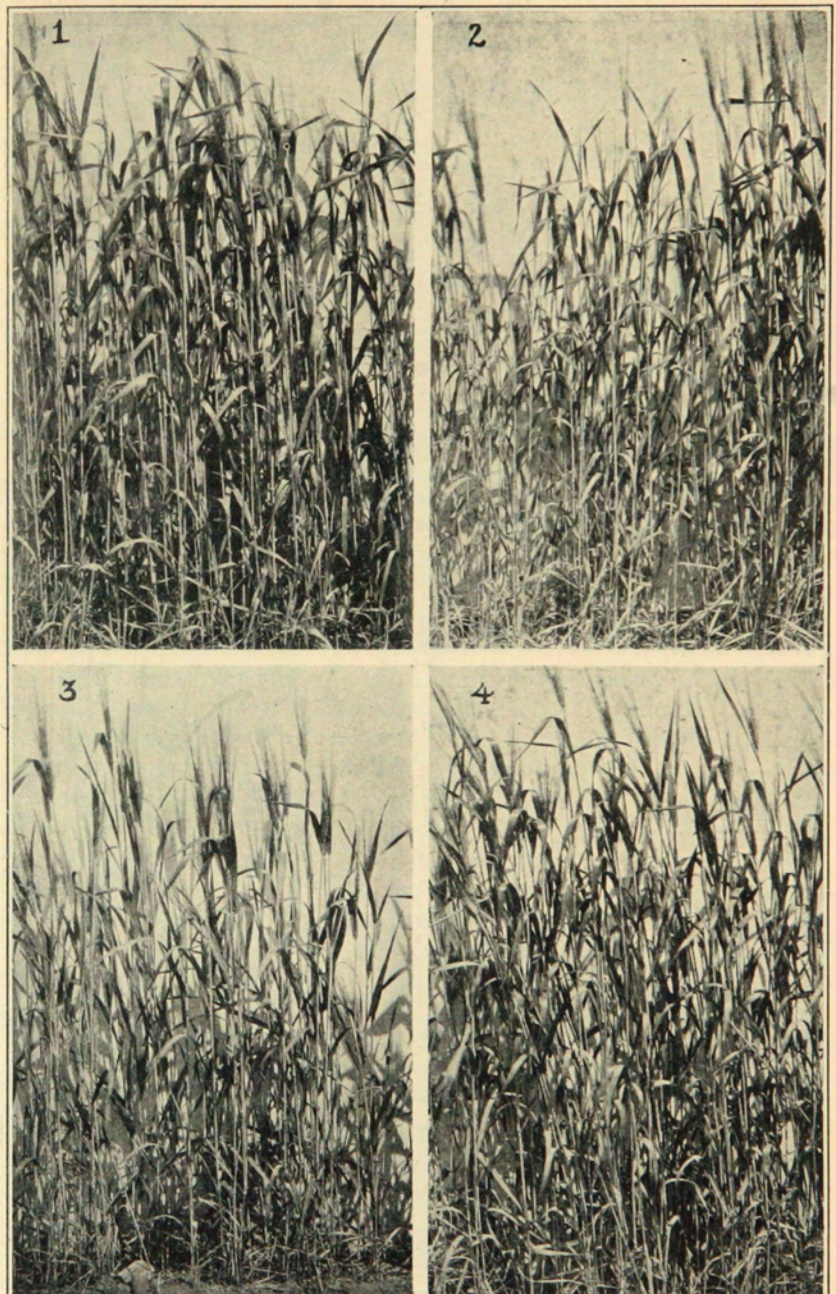

Plate II.—From photographs taken 29 June, 1928. 1—After clover; 2—After fallow; 3—After corn; 4—After alfalfa.

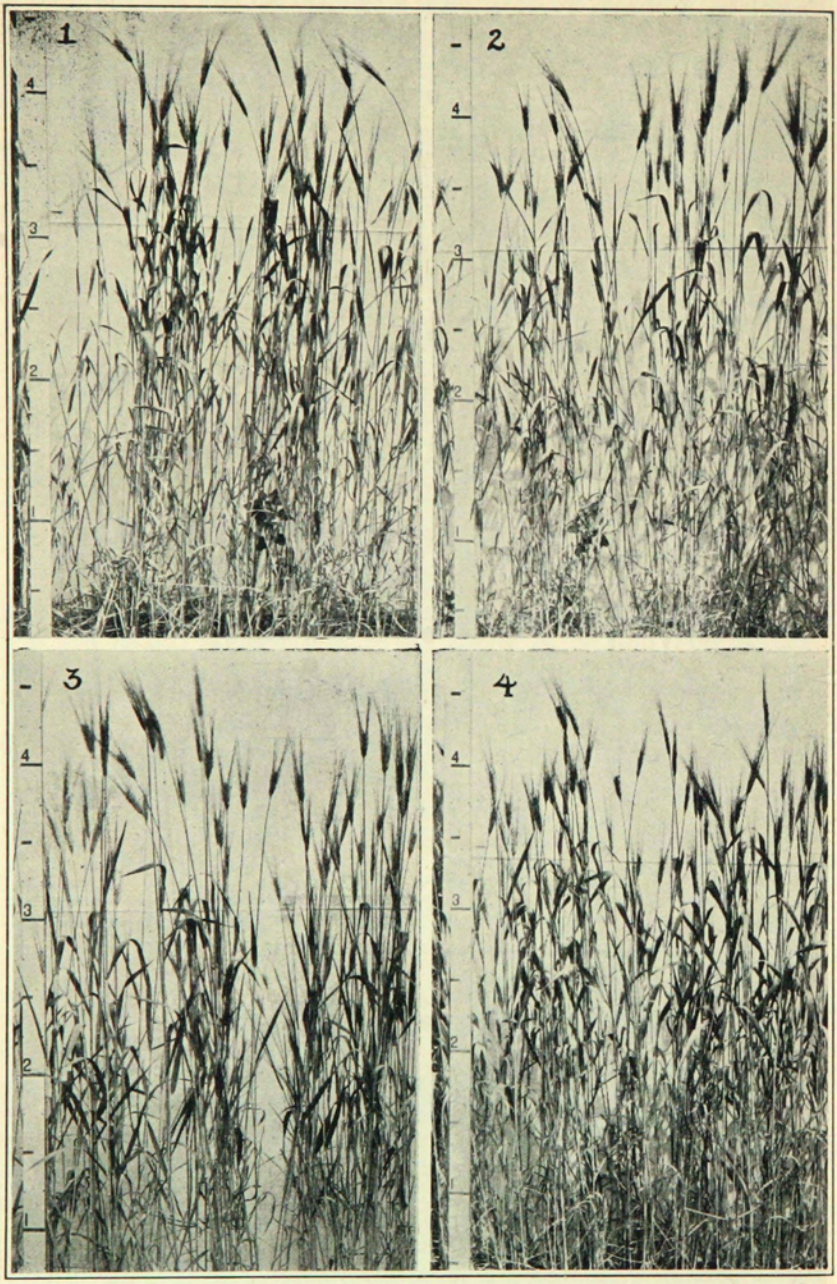

Plate III—From photographs taken 10 July, 1928. 1—After clover; 2—After fallow; 3—After corn; 4—After alfalfa.

Plate IV —The harvest. 1—After clover; 2—After fallow; 3—After corn; 4—After alfalfa.

preceptible difference in the stooling, it being much scantier than in the other cases, particularly in the crop after alfalfa in which the stooling was very good. The wheat after fallow was very good in color, stooled moderately and showed only a slightly less growth, even in the early season, than that after clover or alfalfa. (Figure 2, 29 June and 10 July.) There was still less difference between the crop after clover and that after alfalfa, but there was a differnece in favor of the alfalfa in both respects, especially in the amount of stooling. We had all three of the plots, clover, corn, and alfalfa, photographed on 22 June. The first or outside drill-row was pulled up so that the photograph shows the conditions in the inside of the plots. There were two drill rows in front of the screen. While these photographs show the difference in the density of the growth, leafiness and height of the plants, they give no idea of the differences in the color. The clover and alfalfa plots had a much darker green color than the corn plot. The apparently thinner stand on the corn plot is not due to lighter seeding but because the plants did not stool so freely as those on the clover and alfalfa plots. The plants on the corn plot did not, up to 22 June, make the growth that the others did; they were nearly six inches shorter. The next set of photographs (29 June) was taken one week later and included the fallow plot, completing the series. The rate of growth cannot be judged from this set because there is no measuring rod but they show the rapid development of the plants, especially on the corn plot. The third set that we will use was taken 10 July when the big difference between the height of the plants had very largely disappeared. The pictures, especially the portion outside of the screen, give the impression that the fallow was quite as good as either the clover or alfalfa and decidedly better than the corn plot. This is correct. The plots showed no differences in the time of ripening and equal areas from each of the plots were harvested on 9 August. The bundles gathered were very different in volume as the photographs show. The bundles were wrapped in shock-covers to protect them from rain and birds and the tops of the bundles were flattened. Counting from the reader's left to right they represent clover, fallow, corn and alfalfa. The bundle from the corn plot is very much smaller than any of the others. The weights, however, at the time of threshing when they were well dried out, do not stand in the apparent order of the photographs but as follows: Clover, 35 pounds; fallow 41.5 pounds; corn, 37 pounds; alfalfa, 30 pounds. While the alfalfa bundle appears to be the largest, it weighs the least. This is quite in keeping with the physical quality of the straw which was soft.

The yield from equal areas of cleaned and dried wheat stood in the following order; taking the yield from the alfalfa plot as 1, the clover was 1.15, corn 1.30, and fallow 1.44. Calculated in bushels per acre, the results stand; alfalfa 40.4, clover 46.0, corn 52.5, and fallow 58.2, counting 60 pounds to the bushel. The fallow ground produced 44 percent more grain than the alfalfa ground, and the corn ground produced 30 percent more and the clover 13 percent more.

If we take the crop on the fallow land as our unit, we see that the alfalfa has reduced our crop by more than one-third and the clover a little more than one-fifth. In other words these crops were almost equally disadvantageous compared with the fallow, so far as the volume of the crop was concerned.

The weights per 1,000 kernels stood in a different order; for corn, 37.8; alfalfa, 34.4; fallow, 32.4 and clover 31.1 grams. These weights per 1,000 kernels are low for Kubanka wheat. Kubanka grown in 1913 ranged from 42 to 43 grams, in 1915 from 35 to 39.1 grams. The year 1913 was a favorable year and 1915 a much less favorable one. The grain after alfalfa and clover was decidedly shrunken and that after fallow and corn was somewhat so. This grain was grown without irrigation and the shrunken condition may be due to this in part; we think it is. Some of the kernels of wheat grown after corn are very large and plump. A thousand of these large kernels weighed 48.5 grams.

NITRATES PRODUCE SHRUNKEN WHEAT

The factor that contributed to the shrinking of the wheat was probably the nitrates in the soil. We have frequently observed that shrunken grain is associated with the presence of excessive nitrates, whether the crop was grown on soil naturally rich in nitrates or on land to which we applied sodic nitrate. An amount of sodic nitrate equivalent to 10 p.p.m., of nitric nitrogen in the soil, to the depth of one foot, was sufficient to produce a heavy growth of plants with broad green leaves, but weak plants that lodged badly, having soft straw and shrunken, flinty grains. The nitric nitrogen in the top foot of soil at the time this application was made was different in the three sections of land on which our experiments were made. These sections had been cropped the previous year, partly to oats and partly to wheat, and had been plowed that spring eleven inches deep. The nitric nitrogen in the surface foot of this land averaged 5.4 p.p.m., the average of six samplings. We applied to each of the three plots 10 p.p.m. of nitric nitrogen and in each case produced the effects stated. We repeated this five times with each of three varieties of wheat, or fifteen times in all, with uniform results. There were then, at the time of planting, a little over 15 p.p.m. of nitric nitrogen in the soil. The growth of the plants on these plots was so different from that of those on check plots that it was a matter of comment by casual observers. The wheat compared with that from the check plots was small grained, flinty and shrunken. The crop on the check plot was 41.3 bushels, weight per bushel 62.5 pounds; on the nitrate plot 29.0 bushels, weight 61.5 pounds. This was for Defiance wheat. The effect of the 10 p.p.m. of nitric nitrogen applied at planting time was almost as great as 30 p.p.m applied in three successive portions of 10 p.p.m. each in about 65 days. This emphasizes the fact that 15 p.p.m. of nitric nitrogen in the top foot of soil at planting time may be decidedly injurious to the crop provided some other factor does not change tending to counterbalance its effects. These older experiments were made on the same land but not on the plots used in this rotation.

These data are introduced to give justification for placing a good deal of importance upon the part played by nitric nitrogen in our results. The wheat was planted on 2 April and a series of soil samples was taken on 4 April, or two days after planting, in which the nitric nitrogen was determined for the top six inches which are usually a little richer in nitric nitrogen than the second six inches, but not always. These nitrates are easily moved downward in the soil. The rule, however, is as stated, i. e., the top six inches are apt to be richer in nitrates than the second six inches. It may be added that they diminish rapidly with depth unless there has been water enough to disturb their distribution.

NITRATES IN PLOTS AT TIME OF PLANTING

The samples from the alfalfa, clover and fallow sections of our plot gave the following results: After alfalfa 18.5 p.p.m., after clover 24.5 p.p.m., and after fallow 15 p.p.m. of nitric nitrogen. It may be well to add that, in the sample representing the fourth six inches of these plots, we found a different distribution of the nitrates. In the alfalfa and clover plots we found 4 and 8 p.p.m. respectively, and under the fallow 15 p.p.m.

These statements are made in terms of nitric nitrogen but the term nitrates is also used as a general term indicating the salts corresponding to nitric nitrogen. The principal nitrate used as a fertilizer is the sodic nitrate or Chile saltpetre. One part of nitric nitrogen is equivalent to six parts of Chile saltpetre, so that in terms of this salt, 17 p.p.m. of nitric nitrogen in the surface six inches means that it would require about 204 of Chile saltpetre per acre to add as much nitrogen as we found in the top six inches of this alfalfa land, and about 404 on the clover land, and 180 pounds on the fallow land. The fourth six inches of the fallow land, on the other hand, contains the equivalent of 180 pounds Chile saltpetre, but only 48 to 96 pounds under the alfalfa and clover respectively. It appears from the data that we have given that the nitrates will produce the effects upon the wheat plant that we have observed, also that there was an abundance of them present at the time our wheat was sown to exert a big influence upon the crop. We are not concerned about where these nitrates came from at this time; it suffices that they were present as shown by the samples taken.

NITRATES AND POTASSIUM AFFECT YELLOW-BERRY

In a former study of wheat we showed that the prevalence of yellow-berry was due to an unfavorable ratio between the available or nitric nitrogen and the available potassium. The addition of the former prevented the appearance of yellow-berry and the addition of potassium increased it, so that the presence or absence of yellow-berried kernels indicates a favorable or unfavorable ratio of these two fertilizers. Phosphoric acid apparently played no part in this feature of the wheat crop.

The wheat grown after alfalfa and clover was somewhat shrunken, rather more so than after the fallow and corn, but the weights per 1,000 kernels were nearly alike, as has already been stated.

The nitrates modify the characteristics of the plants in a chemical sense but this may not be the only way in which they bring about the observed results. For instance, we have observed that abnormal ripening may be pronounced, the central portions of the harvested sheaf may be much moister or more immature than the ends. It also induces tillering so that with an equal seeding and an equally good stand the nitrate plots sustain a much denser growth, too dense in fact for the development of the crop. In what measure this may be the cause of the soft, weak straw, and small grains has not been ascertained. We have never tried seeding lightly with the application of nitrates, but observation on single plants suggest that it might obviate, in a measure, some of the disadvantages arising from too big a supply of nitrates, and the same applies to sowing wheat after alfalfa. Our plots in the season of 1928 had the same seeding but the photographs show that the density of the growth on the corn land was much less than on the alfalfa land immediately to the south of it; the yield of grain, however, was 52.5 bushels against 40.4 bushels per acre after the alfalfa and 46.0 bushels after the clover which also shows a much denser growth than after corn but produced less wheat. The number of plants per yard of drill was probably very nearly the same but the tillering after the alfalfa and clover made the growth injuriously dense. Our seeding was supposed to be at the rate of 90 pounds per acre or six pecks per acre. Had it been 40 pounds per acre after the alfalfa and clover we would have had a more satisfactory crop, (as other experiments, not given here, prove).

MEALINESS INDICATES LOWER QUALITY

The mealiness of the kernels, that is, the number of kernels affected by yellow-berry, is a measure of the quality of the crop. The volume of the crop is often larger when this condition is prevalent than when it is absent, or present in a less degree.

In these crops of 1928 we found, after alfalfa and clover, only two percent of affected kernels or practically none, after fallow 21 percent, and after corn 41 percent. In this count all cloudy or opaque berries were counted as affected. This means that 98 percent of the kernels grown after clover or alfalfa were clear, translucent ones, but only 59 percent were such after the corn. The plumpest, largest berries were found in wheat grown after corn; 1,000 of these weighed 48.3 grams against 31.1 grams for 1,000 kernels, taken without choice, grown after clover. One thousand kernels taken without choice grown after corn weighed 37.8 grams against the 31.1 for those grown after clover.

By far the best crop was returned after fallow, 58.2 bushels against 40.4 after alfalfa, 46 after clover and 52.5 after corn. The growth here was less dense than in the case of the clover and alfalfa but more so than after corn and the rate of development was intermediate between the corn and the other plots. The kernels are not large, 1,000 weigh 32.2 grams against 34.4 grams for those grown after alfalfa and 37.8 after corn.

We believe that these differences are due to the difference in the mechanical and sanitary conditions of the soil and the relative supplies of nitrogen in the form of nitric nitrogen and soluble potassium. We omit phosphoric acid because, in a series of experiments with this fertilizer extending over a period of five years and conducted on this land, we failed to observe any effect on either the volume or quality of the crop, sufficient to justify its consideration

In this connection we may digress to state that our conditions of fertility are changing rapidly and the time is not far distant when it will be to our advantage to use phosphoric acid on some of our crops, but they must be more remunerative than wheat which is scarcely remunerative at all and is rather unlikely to be. But, if we do grow wheat, we want to get the best crop, both in volume and quality, that we can.

In the preceding paragraphs we have stated that mealiness in wheat is increased by a high ratio of potassium to the nitrates in the soil, also that the application of nitrates equal to 10 p.p.m. of nitric nitrogen to our land in a series of experiments extending over five years was sufficient to throw this balance too far toward the nitrate side and made smaller yields of flinty berries, whereas the application of potassium increased the mealiness over our check plots. We have just stated that our clover and alfalfa land at the time of planting had as much or even more nitric nitrogen in the top six inches than we had found to be detrimental in preceding experiments. We have not before stated in this connection the result of our cropping to alfalfa and clover upon the amount of water-soluble potassium in this soil. If the statement previously made that the flintiness and mealiness of the berries are determined by the ratio of these elements, we may maintain this ratio by increasing the one when the other is increased up to a limit where the amount present becomes too great for the successful growth of the crop.

In a preceding paragraph we have stated that with Defiance wheat we ruined our crop by raising the nitric nitrogen to 15 p.p m. at the time of planting. We did not at this time increase the soluble potassium in the soil. Had we done so, it would have tended to produce an opposite effect upon the character of the grain as shown in cases where we applied it alone.

The amount of nitric nitrogen in our alfalfa land at the time of planting was sufficient to have produced very bad results, much worse than we observed, i. e., a reduction of the crop from 58.2 bushels after fallow to 40.4 after alfalfa. In explanation of this we present again the effect of the alfalfa through the large amount of carbon dioxid it maintained in the soil upon the water-soluble potassium. The aggregate of this effect in two years was equivalent to the application of 1,600 pounds of potassic sulfate per acre. The addition of one-half this quantity in former experiments increased the yellow-berry in the wheat. This increase varied with the variety of wheat used, besides our experiments were not well conducted to study this feature of the crop for we grew wheat after wheat with the same fertilization year after year, but the nitrate always produced flinty wheat and the potassium mealy wheat. While the nitrates in the alfalfa and clover plots at the time of planting were high, the increase in water-soluble potassium in the alfalfa land during the two years that it had supported the crop was equivalent to a very heavy dressing of potassic sulfate.

WHEAT NOT BEST CROP TO FOLLOW ALFALFA

We have used wheat to measure the effect of red clover and alfalfa, upon the soil in two years because it suits our purpose well. The crop in itself has no value for us but it does show that a rotation of wheat after alfalfa is less advisable than wheat after fallow. The dry-land farmer is practically compelled to plant after fallow and he often obtains both good volume and quality of crop. If he omits the fallow and plants wheat after wheat he will have both smaller crop and poorer quality. I have seen dry-land wheat grown after wheat for several years so badly yellow-berried that the present day miller would discriminate against it strongly. We pointed out the fact that dry-land wheat may be very badly affected in this manner in refutation of the idea that this condition might be caused by irrigation. The fact is, it is caused by an excessively high ratio of available potash to the nitric nitrogen.

WE ARE NOT INCONSISTENT

It may appear to the reader, not conversant with chemical distinctions, that our statement of results is not in harmony with our general thesis that the benefit accruing to land planted to alfalfa is not due to an increase of the nitrogen supply but to some other factors, specifically, to the sanitary and mechanical conditions of the soil and to the increased soluble potash. The increase in the total nitrogen is negligible and the exhaustion of the nitric nitrogen from the soil by alfalfa is very marked even when no allowance is made for the surface of the land often well covered by fallen leaves and parts broken off in haymaking. It was found to be seven parts per million in the top six inches against eleven in fallow land and in the second six inches only three parts aganist eight in the fallow.

CROP PLOWED UNDER

In the case of the land used in these experiments a heavy growth of alfalfa was plowed under in the fall. The second cutting had been made very early to give a longer time to the growing of the third crop, which was as heavy at the time it was plowed under as a very good first crop and was not far from the rate of six tons of green matter to the acre. By the time our wheat was sown, 2 April, 1928, this crop had disappeared almost totally and the roots were so far destroyed that they gave no trouble in sampling. This mass of organic matter probably had some influence on the amount of nitric nitrogen present in the top foot of the soil. But how the total amount of nitric nitrogen compares with that in the fallow land is probably more faithfully shown when we unite the first and fourth six inches. When we do this we find the sum in the alfalfa land to be 22.5 p.p.m. and that in the fallow land 30 p.p.m.

The total nitrogen in the alfalfa plots at the beginning of our experiment in the spring of 1926 was 0.1278 percent; in the fall of 1927 just before the crop was plowed under, it was 0.1286. The average for the fallow at the beginning was 0.1298 and when the land was plowed in the fall of 1927 it was 0.1071. The apparent gain in the alfalfa land in two seasons was only 0.0008 percent, an amount much less than we find the variation to be in samples taken from the same plot at the same time. The fallow seems to have lost nitrogen in the two seasons. Allowance in this case, too, must be made for variation in samples even when the greatest care has been exercised in taking them. The apparent change, however, is in the right direction as it has been noted by others that our western soils lose nitrogen when broken up more rapidly than can be accounted for by the cropping. This apparent loss of 0.0227 percent in two seasons may be actual but it is within the limits of variation found in samples taken within an area of 150 square feet. Each foot in such an area (in the same piece of land on which these experiments have been made) was sampled to a depth of one foot (150 samples taken) and the total nitrogen determined. There were only a few samples identical in their nitrogen content and the greatest difference between any two samples, taken one foot deep, was 0.0344 percent which is more than one-half greater than the apparent loss of introgen from our fallow ground. These facts are stated to guard against too much importance being attached to differences in determinations of nitrogen made on different samples taken even from the same plot in an identical manner on the same date, but those given for our fallow were taken, one in the spring of 1926, the other in the fall of 1927.

IMPORTANCE OF THE FORM OF THE NITROGEN

The importance of a large nitrogen supply is that it furnishes nitrogen for the formation of nitric nitrogen which is practically the only form of nitrogen available to the plants. It is very necessary to bear in mind this distinction between the two forms of nitrogen, and further to realize that the difference is important. In a series of experiments made some years ago, a large amount of nitrogen was applied in the form of farmyard manure, 18.5 times as much as we applied in the form of sodic nitrate, without producing any effect upon the quality of the wheat and only a small effect on the volume of the crop and that mostly on the amount of straw produced. Whereas the application in the form of sodic nitrate, though less than one-eighteenth of the amount applied in the manure, changed the character of the kernels and the growth of the plants. The amount added was too great and the total effect was prejudicial.

Other samplings of these plots than those given were made in the spring of 1928 but the crops were plowed under in the fall of 1927. The preceding samples given do not show an increase in total nitrogen over the fallow or an increase over the preceding years. We cannot in this place give too many samplings but we may give the results of one made 13 March, 1928, about three weeks before our wheat was sown. The average percentage of total nitrogen in the surface foot of the land that had been in clover was 0.1279; in that of the alley between the east and west series of plots which had been kept fallow 0.1496; and in that of the alfalfa 0.1496 percent. We have here no definite indication that two seasons in clover or alfalfa together with the heavy crops plowed under have increased the total nitrogen.

The range in the percentages of total nitrogen given in the preceding paragraphs may be said to be identical with that obtained for this land for a number of years. Our first sampling of this land was made twenty years ago. In the case of the 150 samples taken on the same date and previously referred to the range was from 0.1102 to 0.1445 percent and the average of 53 samplings of a four-year-old alfalfa field to a depth of one foot was 0.1220.

THE NITRIC NITROGEN IN OUR SOIL FULLY ADEQUATE

If we now recall that the nitric nitrogen at the time of planting was 20 p.p.m. for the top foot of soil, we are prepared to understand why the growth of the plants was vigorous, the leaves green, the kernels flinty and shrunken. These are the effects that we produced in the crops when by addition of sodic nitrate we raised the amount of nitric nitrogen to about 16 p.p.m. at the time of planting. The difference between 16 and 20 p.p.m. has but little significance if any at all. We added two and three times our minimum amount in two and three portions but the larger amounts produced no perceptibly greater effects on the crop than the minimum which brought the total supply of nitric nitrogen to 16 p.p.m. The other additions brought it to 26 and 36 parts per million. Applied to Defiance wheat, these quantities were practically ruinous, on Red Fife and Kubanka, they were not deleterious to the same extent.

It is not intended in this place to discuss where this nitric nitrogen present in the soil in the spring of 1928 came from but we may state that it had been formed in the soil, for the growing alfalfa had reduced it to five parts per million in the top foot of soil from which it had increased to 21 p.p.m. The inference is, that the nitrogen of the alfalfa that we plowed under had been nitrified to this extent. This explanation would be entirely satisfactory if the fallow ground had not contained 30 p.p.m., against 21 p.p.m. in the afalfa. The presence of liberal quantities of nitric nitrogen in fallow ground is not an accident; it is the rule. The inequality of the quantities present does not prove that the suggested explanation is wrong but it does show that it is not necessarily right and may be very doubtful, even though we would like to think it correct, because it would suit our purposes well.

THE EFFECTS UPON THE WATER-SOLUBLE POTASSIUM

The matter stands quite otherwise in regard to the water-soluble potassium. The fallow land, or rather the soil atmosphere contained in it, carries from 30 to 65 parts of carbon dioxid per 10,000. To take an average of 40 parts per 10,000 for the year may be a little high but it is not far wrong. That in the alfalfa soil contains up to 270, or practically seven times as much carbon dioxid. The significance of this is that the carbon dioxid acts on the soil particles, even on the unaltered felspar particles in it, to bring potassium into solution. This action under the alfalfa goes on throughout the growing season at a rapid rate and continues through the winter months reaching a minimum in the early spring. We have repeatedly demonstrated this experimentally, and also assert it as the result of observation on the amount of water-soluble potassium under alfalfa and in fallow. The water-soluble potassium was determined weekly throughout the season of 1927, beginning 27 May. The samples taken represented the first, fourth and sixth six inches of the soil. The latter depths were chosen because they correspond to the depths of our lysimeters. The averages for the first and fourth sections of the fallow and alfalfa plots, portions of which were planted to wheat in 1928, were, for June, as follows:

Fallow: First six inches		19.2 p. p. m.
Fourth six inches		11.2 p. p. m.
Average	15.5	p. p. m.
Alfalfa: First six inches		39.8 p. p. m.
Fourth six inches		25.9 p. p. m.
Average	32.9	p. p. m.
For August		
Fallow: First six inches		31.3 p. p. m.
Fourth six inches		12.4 p. p. m.
Average	21.9	p. p. m.
Alfalfa: First six inches		59.5 p. p. m.
Fourth six inches		39.6 p. p. m.
Average	49.6	p. p. m.

We have given these data for June and August only but they suffice to present the fact that in spite of the large amount of potassium being taken out of the soil by the growing alfalfa, there was an excess of it, soluble in water, that was more than twice the amount present in the fallow.

This very liberal supply of soluble potassium tends to balance the effects of the nitric nitrogen that developed in the soil after the alfalfa had been plowed under. From the standpoint of the farmer, wheat was probably not the most advisable crop to plant; sugar beets would have been a better one, or potatoes, provided this were a good crop for our section, for these are crops that need potash and, while both are sensitive to too liberal a supply of nitrates they are not so easily injured as the wheat, which is induced to tiller freely, grow rankly and rust easily, producing, at best, a soft straw and shrunken berries of good quality.

In regard to the quality we have the weight per 1,000 kernels and the percentage of yellow-berried or opaque kernels. These were practically absent from the wheat produced on the clover and alfalfa plots but decidedly abundant in that produced on the corn plot. We add another feature of the wheat, its protein content, calculated from the total nitrogen in the wheat multiplied by 5.7, which is conventional.

Nitrogen in Wheat grown after Clover, Fallow, Corn and Alfalfa

	Moisture Percent	Nitrogen in Wheat		Protein in Dried wheat Percent
		Not Dried Percent	Dried at 108o C Percent	
Clover	10.19	2.758	3.071	17.51
Fallow	10.07	2.723	3.028	17.26
Corn	10.39	1.995	2.226	12.69
Corn, big kernels	10.00	2.107	2.341	13.35
Alfalfa	10.30	3.010	3.355	19.13

The quality of this grain as indicated by the protein (N x 5.7) contained is good, but that produced on the corn land, even the selected kernels, is four perecent lower than that from the clover or fallow land, and still more inferior to that grown in the alfalfa land. The yield is higher than that given by the clover or alfalfa but lower than that obtained from the fallow. The weight per 1000 kernels is the highest of the four.

The big kernels from the wheat after corn are given because they appeared to promise to show the highest quality of this wheat that could be obtained by careful selection, but it is only seven-tenths of one percent above the average sample, and is four percent below that from the clover and fallow plots.

This experiment on the corn plot was not in our original plan which accounts for the fact that the data are not as complete as in the other cases.

Phosphoric Acid Not Considered

We have omitted all consideration of phosphoric acid in the preceding, because, in experiments made on this land, in which we applied from small to excessively large amounts of phosphoric acid, 45 experiments in all, we could not perceive that it produced any effect upon quality or crop, and the crop was wheat on land that had been planted to wheat or oats the preceding year. This was the case in each of the five years that we continued the experiment. This is a valid reason for assuming that, so far as plant foods are concerned, the addition of phosphoric acid would have played no part in our results; the ones remaining, nitrogen and potassium, must have caused, according to accepted views, all the differences that we observed.

Food Supply Not the Only Factor

While the supply of these three factors, nitrogen, phosphoric acid, and potassium, all of which may be supplied to the soil, are very important and the lack of any one of them may bring about crop failure, it is difficult to believe that there was an actual lack of nitrogen, for instance, in the corn land sufficient to produce the characteristics of growth observed. This particular land was not sampled for the determination of nitric nitrogen in the spring of 1928 when the wheat was sown, except a single sampling. This gave 14 p. p. m. an entirely adequate amount. We have no data to show that the corn crop planted 3 by 3 feet is either very exhaustive of or antagonistic to the development of nitrates in the soil. During the season of 1926 we made 15 samplings of soil in the section adjoining this on the south that was planted to corn. The samples were taken seven inches deep and their average content of nitric nitrogen was 10 p. p. m while that found in our fallow plot during the same season to a depth of six inches was 12 p. p. m. The surface portion of the soil in the cornfield was higher than in the seven-inch samples. A sample taken with a shovel, probably to a depth of two inches, carried 17 p. p. m. and a surface sample 47 p. p. m. The growth of this corn was very vigorous at the time these samples were taken. The 15 sets of samples were taken from 28 July to 1 December, 1926. Our data do not give us any reason to infer that the process of nitrification has been disadvantageously affected. While we have no determination of the nitric nitrogen during the season of 1928 except the single sampling that showed 14 p. p. m. in the surface six inches, we have no demonstrated facts to show that this factor was wanting except the deportment of the wheat crop which did not show the vigorous growth and deep green color of wheat produced by the application of nitrates.

THE WATER-SOLUBLE POTASSIUM IN THE SOIL CORRELATES WITH THE CARBON DIOXID IN THE SOIL-AIR

In regard to the supply of potassium, we have no reason to assume that there was as much soluble potassium as was present in the clover or in the alfalfa ground. We observe that the soluble potassium is greater in alfalfa land than in fallow, also that the amount of carbon dioxid maintained in this soil greatly exceeds that present in the fallow, in other words, the amount of soluble potassium in the soil correlates rather closely with the amount of carbon dioxid that is present in it over any considerable time. For instance, the first, fourth and sixth six-inch sections of our fallow plot in 1927 showed the presence of an average of 23, 12.4 and 14.6 p. p. m. respectively, for the season (22 samplings), while our alfalfa plot showed 49.8, 33.2 and 17.3 p. p. m. for the same number of samplings. The carbon dioxid in soil-air under the alfalfa was, at all times, even in the winter months, higher than in the soil-air under the fallow.

We have no determinations of the water-soluble potassium in the corn land as we have already stated, but we have the record of the carbon dioxid in this corn land throughout the season of 1927 while it was producing the corn crop. There were nine sets of samples taken from 25 July to 24 September. The corn had been removed just before the last date. The water-soluble potassium is regularly greater under the clover and alfalfa, taking the samples in six inch sections, the first, fourth and sixth six inches. The first six-inch sample under clover was not always found richer than the corresponding sample of fallow soil but the fourth and sixth six inches were in accordance with our statement. Further, it may be stated that the carbon dioxid increased too with the depth. If this correlation holds and we know the amount of carbon dioxid in two pieces of land for three or more months we have reason to believe that there is more water-soluble potassium in that land whose soil-air showed the larger amount of carbon dioxid throughout the period. A single sampling might be of no import in this connection but we believe that consistent results obtained throughout a series, the more in the series the better, justify the assertion that there is more water-soluble potassium uniformily associated with the larger amount of carbon dioxid in the soil-air.

The fallow and the corn plot here considered lay side by side, in fact a portion of our original fallow plot was taken for the corn plot, so the character of the soil and other conditions may be considered identical and the results given in the following table are more striking than they would be if they had been portions of different sections of land though the results ought to hold in such a case.

Carbon dioxid in the soil-air in land cropped to corn and cultivated fallow in parts per 10,000

	Corn			Fallow		
Depth	**6"**	**18"**	**30"**	**6"**	**18"**	**30"**
Date - 1927						
25 July	38	77	93	18	45	53
1 Aug.	58	107	108	17	38	54
8 Aug.	47	81	103	17	36	47
15 Aug.	67	98	105	14	31	40
22 Aug.	39	96	119	15	27	50
29 Aug.	34	96	115	15	33	43
6 Sept.	32	77	114	17	28	50
12 Sept.	50	73	119	24	34	47
Corn removed and plots plowed 13 Sept.						
24 Sept.	22	73	105	24	53	73
28 Sept.	14	45	91	9	19	34
4 Oct.	8	36	73	12	17	29

If our statement is true that the water-soluble potassium correlates with the carbon dioxid in the soil-air, then there was more soluble potassium in the corn land than in the fallow.

This table shows another thing in harmony with our other observations. The soil-air in land planted to wheat and other grasses, as well as in land planted to clover or alfalfa, is always several times as rich in carbon dioxid as is that in fallow land. Actively growing wheat, mixed grasses, clover, and alfalfa maintain the carbon dioxid in amounts varying from 150 to 250 parts per 10,000 at depths of 18 or 30 inches. The corn has increased the carbon dioxid at a depth of 30 inches to twice as much as was under the fallow.

THE NITRIC-NITROGEN-POTASSIUM RATIO IMPORTANT

Our previous statements have maintained the view that the pivotal point in the whole matter is the ratio between the supply of nitric nitrogen and water-soluble potassium. The phosphoric acid in our case is present in sufficient quantity to produce optimum results. This ratio is best in our fallowed land where we had the largest crop of good wheat, 58.2 bushels, per acre, with 1000 kernels weighing 32.4 grams, and 21 percent yellow-berry, and the deportment of the plants, their growth and color, was only a little behind that of the clover and alfalfa, and the protein in the kernels was 17.26 percent

NITRIC NITROGEN AND POTASSIUM SUPPLY IN CORN LAND

Our data concerning the deportment of the wheat on corn ground do not justify the inference that there was any insufficiency of nitric nitrogen to produce vigorous, freely tillering, green plants. Relative to this point we have the following: That seven to ten parts per million of nitric nitrogen in the soil at the time of planting is sufficient to produce good crops, up to 60 bushels. That land in corn carried an average of 10 parts per million to a depth of seven inches, while fallow carried 12 parts per million and the single sampling of this land at the time of planting showed 14 p. p. m. But the wheat after our corn crop did not tiller like the other crops nor did it show the vigor or the strong green color indicative of a liberal supply of nitric nitrogen.

We have not any series of determinations of the water-soluble potassium but we have of the carbon dioxid which correlates with it and which gives us as strong evidence as such an argument can adduce that there was a sufficiency of water-soluble or available potassium, probably as much as there was in the fallow land, but less than there was in the clover or alfalfa land. We have one set of samples taken from the corn land 11 April, 1928, and the results are nearly identical with those for the fallow land on the same date. The crop was 52.5 bushels of 60-pound wheat and 1000 kernels weighed 37.8 grams and had 41 percent yellow-berried kernels. Large kernels that remained on our sieve weighed 48.5 grams per 1000 with very few yellow berries but I did not count them. These big kernels are beautiful wheat. The protein in the kernels was 13.35 percent and in the average kernels 12.69 percent.

THE SUPPLY AND RATIOS OF THE PLANT FOODS DO NOT EXPLAIN EVERYTHING

These more or less puzzling facts associated with our corn plot have been given in this detail for the purpose of emphasizing the fact that the supply of plant foods and their ratios are not the only important factors in soil fertility. It is intended further to suggest that the deportment of a crop following a preceding one may not be more dependent upon the plant food than the sanitary condition in which the preceding crop leaves the soil. The Bureau of Soils of the United States Department of Agriculture suggested twenty some years ago that infertility in soils was not necessarily due to lack of plant food but might be due to the presence of poisonous substances in it. This did not meet with general acceptance but there is probably a big basis of fact in it.

Alfalfa does not enrich the soil by increasing the total nitrogen and is not a crop advantageously followed by wheat but there is no doubt about its being a valuable member in a rotation.

After the corn, the wheat did not have the strong green color or tiller and grow as it did after the application of nitrate of soda but, after the alfalfa and clover it did. The determinations of nitric nitrogen in the clover and alfalfa lands showed the presence of larger quantities of this than we found prejudicial in previous experiments. The amount of water-soluble potassium is also large, in the top six inches 50 p. p. m., in the fourth six inches 33 p. p. m., and in the sixth six inches 17 p. p. m., against 23, 12 and 14 p. p. m. for corresponding sections of fallow.

So far as our data go they indicate that the soil was slightly poorer in nitric nitrogen and richer in soluble potassium when the carbon dioxid in the soil was twice as abundant.

The fallow land produced the largest crop of very good wheat, 58 bushels per acre. Only 21 percent of the kernels were yellow-berried or showed opacity. The corn land produced the next best crop, 52 bushels of fairly good wheat with 41 percent of more or less opaque or spotted berries. The clover land produced the next crop in size, 46 bushels, with so good as no opaque berries, and alfalfa land the smallest crop, 40 bushels with no opaque berries.

In weight per 1000 kernels the wheat grown on the corn land stands first and that from the clover stands last.

All of these relations are consonant with results observed in studying the effects of nitric nitrogen and potassium upon the properties of wheat. But the growth of the wheat plants is not in keeping with any of our former observations.

These differences cannot be attributed to water supply or to the mechanical condition of the soil, or to difference in seeding, or to weather conditions and temperature of the soil. The characteristics of these wheats attributable to the supply and ratios of plant foods that come in question are expressed in the prevalence of flinty berries and in the shrunken condition of the product from the clover and alfalfa land, also in the bulky, light and soft straw from these, in the better yield of wheat with only 21 percent yellow berries on the fallow, and the bigger kernels and prevalent yellow berry in that from the corn land. It is very difficult to connect the lack of tillering and the slow development and poor color of the plants on the corn land with the food supply or with the mechanical conditions of the soil. But these differences were very marked and we see no suggestion of an explanation except that the land had been rendered, in a certain measure, not included in any condition heretofore mentioned, more or less hostile to the growth of the wheat plant.

SUMMARY

The reader is cautioned to distinguish between the conditions in the fall of 1927, before the land was plowed and the clover and alfalfa crops were plowed under, and in the spring of 1928, six months later, when the wheat discussed in this bulletin was planted. Decided changes had taken place in this time. The nitric nitrogen had increased in the surface portion of the alfalfa plot, but changes had taken place in the fallow plot also, and when allowance is made for its different distribution in the two plots, we cannot, with any certainty, attribute the increase to the alfalfa that we plowed under as we expected to be able to do.

It has been believed for many years that legumes, alfalfa, clover, peas, etc., actually increase the total nitrogen in the soil on which they grow. Total nitrogen includes all forms of nitrogen that may be present in the soil, but we distinguish between nitric nitrogen which is directly available to growing plants and other forms which are not directly available, The nitric nitrogen present in a soil varies from time to time and also with the crop that occupies the soil. This is by far the more important form as it constitutes the immediate supply

of nitrogen for the plants, but this form is derived from the other forms of nitrogen that may be present in the soil. These other forms may be easily or only with difficulty converted into nitric nitrogen.

As alfalfa is still the principal legume used in a rotation by our people, though sweet clover is now being advocated, we have presented the facts arrived at by a study of alfalfa, principally, and red clover in comparison with it. There is no question but that they benefit the soil in some way but it is not by increasing the total nitrogen as supposed. In our case the amount added in two years was wholly negligible. The total nitrogen at the beginning of our experiment was 0.1278 and at the end 0.1286 percent. The former sample was taken in the spring of 1926 before the alfalfa was sown, and the latter in the fall of 1927 before the third cutting was plowed under. This difference of 0.0008 percent in total nitrogen has no significance. This statement would not apply to nitric nitrogen.

Nitric nitrogen, the form that corresponds to the nitrates in the soil, is at all times comparatively small and diminishes rapidly with depth, so that in the second six inches of soil, it is quite small—about 3 p. p. m.—and from this to a depth of six feet it is very low, mostly 1 p. p. m. in land occupied by alfalfa.

The leaves and stems that fall or are broken off in haymaking add a little nitrogen, the most of which seems to be dissipated by subsequent irrigation, winds and fermentation, but some of it remains and is changed into the nitric form, so that the loose dirt and the partly decayed material that may be scraped off the surface sometimes shows fairly large amounts of nitric nitrogen. The little mounds of dirt that accumulate about an alfalfa crown are not rich in either form of nitrogen as one would expect.

The nitrates in the soil are probably those of lime and magnesium but, as we generally use the nitrate of soda, or Chile saltpetre, as a fertilizer, we will give their equivalent in this salt. One part per million of nitric nitrogen is equal to 6.07 parts per million of sodic nitrate.

The average amount of nitric nitrogen in the top six inches of our fallow plot from 31 May to 10 Nov. 1926 was 12 p. p. m. or 72 pounds of sodic nitrate for each million pounds of soil. Each three inches of this soil weighs one million pounds or, in the top six inches of the fallow, there was an average of 144 pounds of sodic nitrate, but under the alfalfa there was only 72 pounds. In the second six inches under the fallow, during the same period there was 96 pounds, and 36 pounds under the alfalfa. The average for the top foot of the fallow land is a maintained supply of 240 pounds of sodic nitrate per acre and, under the alfalfa, 108 pounds. For depths greater than one foot the nitrates under the alfalfa decrease to about 24 pounds of sodic nitrate per acre foot, while under the fallow, we found 5 to 8 times this amount.

In regard to the water-soluble potassium, we have entirely different relations. The whole of the nitrogen in the soil is derived from living things, from their dead bodies, their voidings or as direct products of their processes and is a variable quantity, especially in the form of nitrates. This is not the case with the potassium. It is a constituent of the soil particles. All of our sandy, loamy and even heavier soils consist largely of potash felspars. This mineral in an unaltered condition, carries from 9 to 13 or 14 percent of potash (K_2O).

The felspars in the soil are already altered to some extent but the soils containing them carry from 2.25 to 2.50 percent of potash and this supply cannot be increased, except by direct addition, as when we add the sulfate or muriate of potash. This mineral, felspar, is considered insoluble in water. Soluble and insoluble are relative terms but from the ordinary standpoint felspar is insoluble in water, just as insoluble as the rocks in our mountains, but even these are attacked by water which extracts from them some of their constituents, particularly potash. This is why we find this substance in the waters of our mountain streams where it occurs as carbonate of potash. It is usual to state that this carbonic acid comes from the air in the form of carbon dioxid; much of it may actually come from this source but plants also furnish large amounts.

We cannot materially increase the total amount of potash in the soil and, with 2.25 percent present, which means 90,000 pounds per acre foot, we have no reason to try to increase this already big total. This potash, so long as it is locked up in felspar particles, is so good as unavailable to plants, but not wholly so. Therefore we have given many data on the water-soluble potassium. It might have been better to give it as water-soluble potash but it is the potassium in the potash that we are after.

The potassium in these potash felspars is extracted from them by water, but very slowly. Carbonic acid (carbon dioxid plus water), whether it comes from the air or from plants, makes the water containing it much more active than pure water, from nine to thirteen times as active. The water in the soil is saturated with this carbon dioxid for long periods.

The amount of this carbon dioxid in the soil-air and consequently in the soil moisture is an important agent in supplying the plants with potassium. This means making the potassium in the felspar available to the plants by increasing the amount of available potassium in the soil.

We generally state that the supply of carbonic acid, in our mountain waters, for example, is obtained by dissolving the carbon dioxid out of the air which contains about three parts in each 10,000. The soil also has an atmosphere and this is much richer in carbon dioxid than our ordinary atmosphere. The purely inorganic portion of the soil does not give off carbonic dioxid. Some of the inorganic constituents take it up or fix it, as lime, when it becomes carbonate of lime or marl, but the soil-air is heavily laden with carbon dioxid; usually ten to twenty times as heavily as the ordinary air. The carbon dioxid comes from the activities of the organisms that live in the soil. We think of them as producing decay of organic matter. This is a convenient way of thinking of them. This source of carbon dioxid is very small compared with growing plants. We will recall the effects of alfalfa only in this respect because it is the principal subject of our study, and for the further reason that its period of activity is very long, in fact, throughout the year. The ordinary air contains about three parts of carbon dioxid in each 10,000 parts. The soil-air in fallow ground contains up to 60 parts but the soil-air under alfalfa contains up to nearly 300 parts or is nearly one hundred times richer than our ordinary atmosphere. Clover is also a very active producer of carbon dioxid throughout its growing period. Carbon dioxid is the active agent in making the potassium soluble and is also probably an important factor in determining the biological conditions that exist in the soils.

We determined the soluble potassium in fallow ground and under alfalfa, also under clover, to see how this matter actually stood in the field. We found the soluble potassium more than twice as high under the alfalfa as in the fallow land. This was the rule throughout the season and not simply for two months as given in the text of this bulletin.

There was nothing on or in the fallow land to use up the available potassium except the soil population itself whereas the alfalfa was producing a heavy crop and it is a heavy feeder especially so on potassium. The net result of the occupancy of the land for two seasons by the alfalfa, during which time we had removed four heavy cuttings of alfalfa, was an increase of the water-soluble potassium equivalent to 1600 pounds of sulfate of potash in the top two feet of soil. This is in strong contrast to the results obtained for the total nitrogen which was not increased, while the nitric nitrogen was reduced to a small amount.

The third element of plant food, phosphoric acid, has been omitted, because the results of many experiments indicate that the supply in the soil is adequate to produce its maximum effect upon the production of crops and their quality. The effect of the carbon dioxid on the availability of the phosphoric acid present seems to have been very favorable, rendering it easily soluble. A goodly portion of the phosphoric acid in the soil has probably been brought into solution and redeposited with the calcareous material now incrusting the soil particles.

This does not merely mean that the sand grains composing the mass of the soil are now covered with such material but that all particles, even the clay aggregates, are loaded with such calcareous matter.

While the nitrogen, potash and phosphoric acid are the fertilizing factors that we can effectively modify, and so much stress is laid on them, we might think that they are the only ones to be considered, this is not so. The acidity of the soil and its lime requirements, the tilth and mechanical condition of the soil are factors always taken into consideration, but usually they are evident and scarcely need specification. Our soil is alkaline (pH=7.6), and carries an abundance of lime as calcic carbonate. The soil tends to puddle on the surface but this is easily obviated and the tilth is thoroughly satisfactory.

At the end of our main experiment our further work proceeded in two somewhat different lines, the one presented in this bulletin, the deportment of the land toward crops, and a second one, the changes that take place in it when cultivated fallow. This latter feature is not presented herein but will form a separate subject. Of course the changes that take place in the fallowed land may also take place in the cropped land but they are modified by the crop and, on the other hand, the crop is modified by them. The crop grown was wheat. We have given, in the preceding pages, an account of the results.

Our best crop was after the fallow. In volume it exceeded that after alfalfa by a little more than 18 bushels per acre. In quality it was excellent being practically the same as that after clover.

The second best crop was after corn. This plot had been in wheat in 1926 and in corn in 1927. The protein in this wheat was only fairly high, 12.69 percent, while that from the fallow was 17.26 and from clover plot 17.51. The wheat from the alfalfa carried 19.13 percent protein but was decidedly shrunken though the kernels weighed more per 1000 than those from the fallow.

The growth and development of the plants on these different plots presented opportunity for numerous observations.

The plants on the alfalfa land were vigorous, stooled freely, had broad green leaves, produced shrunken kernels with bulky soft straw and the yield was 40 bushels against 58 on the fallow.

Earlier experiments establish the fact that as much as 15 p.p.m. of nitric nitrogen present in the top foot of soil at the time of planting is sufficient to be detrimental to the crop. We find the average nitric nitrogen in the top foot of the alfalfa plot from 31 March to 8 May, 1928, to have been 14.2 p.p.m. This statement covers only the month of April because the growing crop probably had not yet materially modified the conditions in the portion of the plot occupied by it. That portion of the plot that was free for sampling was at all times throughout the season of 1928 very rich in water-soluble potassium, 51 p.p.m. against 30 p.p.m. in the fallow. This should have operated to offset the effects of the nitric nitrogen according to our previous observations. It may have done so to some extent but it did not prevent the appearance of the results associated with the application of nitric nitrogen.

The remarks just made apply also to the crop grown after clover, but in a slightly less degree.

The crop after fallow was our best one; it gave the highest yield of grain. This grain carried 17.26 percent of protein (NX5.7) while wheat after clover carried 17.51 percent, but one-fifth of the kernels was affected more or less by yellow-berry. The average nitric nitrogen present in the top six inches of the fallow was 12.5 p.p.m. and the water-soluble potassium was 29.9 p.p.m. We evidently had, according to the deportment of the plants, the yield, and character of the grain more favorable conditions in this plot for the wheat than in either the alfalfa or clover plots. The plants had an excellent color, made a good growth, tillered a little less freely than those on the alfalfa and produced a much better yield than the alfalfa plot, 18 bushels more per acre, but 21 percent of the kernels showed the yellow-berry condition in some degree.

The ratio of nitric nitrogen to water-soluble potassium for April, the month of planting, was, for the alfalfa land from 14.2 p.p.m. to 51 p.p.m.; in the fallow land it was 12.5 p.p.m. to 30 p.p.m., or, for alfalfa, one of nitric nitrogen to three of potassium, and one to two and fourth-tenths for the fallow. Had we added enough nitric nitrogen to land carrying 18 p.p.m. of water-soluble potassium to bring the total nitric nitrogen to 14 p.p.m., we would have had more unfavorable results, still this ratio for the alfalfa land justifies the question, why were the results not more favorable? With a lower ratio in the fallow we have more favorable results; in fact, we have both a good crop, 58.2 bushels, and very good wheat, 17.26 percent protein. After the alfalfa we had 40 bushels and the wheat was very high in protein, 19.1 percent.

All of this shows that we have not considered all of the factors; the ratio of the nitric nitrogen to the water-soluble potassium is a very big factor but not the only one. The alfalfa and the clover also have produced some condition in the soil, in this case conducive to vegetative growth, that did not exist in the same degree in the fallow soil.

This suggestion made by these crops, that the supply of plant foods and their ratios, while very important, may be considered too exclusively and estimated too highly is even more strongly suggested by the crop grown after corn. This crop was our second in volume, 52.5 bushels per acre, and lowest in protein, 12.75 percent. The yield compared with either of the other plots, judging by the appearance of the plants and their growth during the season, is decidedly surprising and the quality of the wheat compared with that produced on the fallow is quite as much so.

There are other factors than the amounts and ratios of the plant foods which may at times become the controlling ones. In the alfalfa land, the conditions favoring vegetative functions were undoubtedly favorable and, had we seeded our plot at the rate of 40 pounds or even less to the acre, we would almost certainly have had better results, but we did not know how to take advantage of the conditions in the soil that might have proven favorable.

After the corn we have different conditions which cannot be attributed to the food supply with the support of any compelling conviction that this was the real cause.

The seed germinated just as freely as in the other plots, the plants grew slowly, did not tiller well, did not have the strong growing characters, did not have the deep green color of the plants on the other plots and developed late. On 22 June they were six inches shorter than the other plants, but by 10 July they were almost as tall.

This deportment cannot be attributed to the supply of plant food, nor to any physical condition of the soil. The plot lay between the fallow and alfalfa plots and had received the same treatment. All were in excellent condition. The deportment of the plants and the characteristic of the kernels were different, 41 percent of them were more or less affected with yellow-berry and their protein content was 12.5 percent against 17.29 in those from the fallow.

The most perplexing question for us is that of plant food. The land had been in wheat during the season of 1926, was fallow till following spring, 1927, was then planted to corn which was removed leaving no stubble in early September when it was plowed and left in that condition till the following April when the wheat was sown.

The unplanted portion of this plot was sampled 11 April, 1928, and the fallow along side of it on 4 April. The nitric nitrogen in the top six inches of the corn plot was 10 p.p.m, in the fallow 15 p.p.m., and in the clover plot it was 12 p.p.m. While it is the lowest of the three, the amount present is sufficient to produce a luxuriant growth of wheat but the growth was not such. In regard to the water-soluble potassium, the corn plot carried 34.5 p.p.m., the fallow 35.9 p.p.m., and the clover 34.9 p.p.m. The wheat on the clover plot with 12 p.p.m. of nitric nitrogen in the top six inches and with 34.9 p.p.m. of water-soluble potassium stooled freely, had a strong green color and grew rankly, all marks of over-fed plants. That on the corn land with 10 p.p.m. of nitric nitrogen and 34.5 p.p.m. of water-soluble potassium was decidedly inferior in appearance and growth to that on the clover land, also to that on the fallow, till it was threshed, when the yield was found to be better by more than six bushels per acre than that from the clover land, and almost as much below the fallow. In spite of its lack of promise compared with the other plots it gave a good yield, 52.5 bushels, and the second largest of the four.

Perhaps we can correctly account for the 41 percent of yellow-berry by attributing it to the ratio of water-soluble potassium to the nitric nitrogen, 3.5 to 1, but we certainly cannot explain the differences in either growth or yield or both between the clover and the corn plot by the differences in the supply of plant food at the time of planting. If the supply in general is sufficient, this is the important period. The nitric nitrogen in the clover land, top six inches, was 12 p.p.m., in the corn land, 10 p.p.m.; the water- soluble potassium in the clover land was 34.9 p.p.m., in the corn land 34.5 p.p.m. There was more difference between the plants on the clover land and those on the corn land than between those on the fallow and the corn.

There is something in the land after two years in clover or alfalfa besides any modification in the amount of plant foods that is favorable to the vegetative functions of the plant; in this case we have this effect contrasted with that of the corn which is not favorable to the vegetative functions of the wheat plant; it is toxic. This toxic property is absent from the fallow land and the favorable effect of alfalfa or clover is, in a large measure, wanting. We have indicated this as a sanitary condition of the soil which does not adequately indicate the condition. The corn land influenced the development of the wheat plants unfavorably; it was toxic.

In this case we believe that there is something present whose nature is not more nearly known, but we speak of it as a toxin. In the case of clover and alfalfa there is something that favors growth. We might call it favorin.