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EFFECTS OF CLOVER AND ALFALFA IN ROTATION

PART IV

BY WM. P. HEADDEN

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COLORADO AGRICULTURAL COLLEGE
COLORADO EXPERIMENT STATION
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EFFECTS OF CLOVER AND ALFALFA IN ROTATION

BY WM. P. HEADDEN

Some observations on the amount of carbon dioxid in the soil air in fallow land and in that occupied by clover and grasses were given in Bulletin 319 of this station.

The action of carbon dioxid and water upon felspar was given in a rather extended measure because this is of fundamental importance in our considerations. Felspar constitutes the larger portion of our soils, up to 70 percent in most cases and sometimes even more.

CARBON DIOXID GIVEN OFF BY PLANTS

Carbon dioxid is the important agent in effecting chemical changes in the soil. This carbon dioxid is given off by the plants through their roots. The roots continue to give off carbon dioxid freely after removal of the plants from the soil and the tops have been cut off. This is true after the roots have been sterilized by washing in mercuric-chlorid solution but their activity in the soil during the life of the plant is largely dependent upon the aerial portion of the plant. Vigorously growing clover or alfalfa floods the soil with carbon dioxid. If the immature clover be cut and the growing process be thus effectively checked, the carbon dioxid in the soil air falls abruptly to a low figure; some observations indicate that it falls as low or even lower than in adjacent fallow land on the same date.

ACTION OF CARBON DIOXID

The chemical action of the carbon dioxid is to increase the water-soluble potassium in the soil. What its biological effects may be I do not know except that it is favorable to the development of some fungi and also to some bacteria. The presence of this carbon dioxid in the soil is very largely due to the clover or alfalfa or wheat, whichever it may be. Clover and alfalfa are the plants had in view throughout all of this work though wheat and corn were studied also as guides in judging the correctness of our observations on the fallow, clover and alfalfa plots.

BIOLOGICAL CHANGES

There are probably important biological changes which chemical analysis in no measure indicates. We are satisfied that this is true. The observed abundant sporulation of certain fungi and the free germination of fungous spores in an atmosphere rich in carbon dioxid are facts proving the influence of carbon dioxid in this direction. If I am not mistaken it is proved that the spores of some fungi will not germinate in an atmosphere free from carbon dioxid.

The whole practice of rotation is based on the theory that certain crops can advantageously follow certain other crops because the preceding crop leaves the soil in a favorable condition. This favorable condition is often attributed to the different food requirements of the crops. The preceding crop, that is favorable to the succeeding one, has changed the ratio of the plant foods present in a beneficial manner.

Given an adequate supply of phosphoric acid, the potato yield will respond more readily to an increase of potash than of nitrogen. It is a common practice with our potato growers to follow alfalfa with a potato crop. This is good practice and the facts in the case can be made to fit our explanation admirably and no one would deny the probability that the explanation in this case is, in the main, correct, but it is certainly not the whole truth and for another crop, wheat for instance, other factors than those involved in the growing of the potato crop play a more important part. The amount and kind of plant food available are undoubtedly important, but no more so than other conditions. These features of our experiment have been given in some detail in Bulletin 363 entitled The Effects of Clover and Alfalfa in a Rotation, Part III in which the effects of clover, fallow, corn and alfalfa on the growth, yield and character of wheat were studied. The results were not such as would ordinarily be predicted and showed unmistakably that plant food alone is too narrow a basis for a reasonable presentation of the effects.

FOOD SUPPLY NOT THE ONLY FACTOR

The sanitary condition of the soil—the presence of toxic conditions or such as are actively favorable for vegetative growth and tending to retard seed production—is apparently more important than the actual food supply present in the land with which we experimented. Some effects of the food supply are to be recognized as very probable but this is not the determining factor in the size and character of the crop. There is something else. These points are discussed in the Bulletin 363.

Our object in the present bulletin is quite different and at best can only incidentally, if at all, touch upon the crops grown after a 2-years occupancy of the land by clover, alfalfa, corn or fallow.

OPERATIONS OF THE THIRD SEASON

At the end of the second season the whole land, fallow and cropped, was plowed. The corn had been removed by pulling it up so that there was not even stubble to be plowed under, but there was a very heavy growth of clover and alfalfa on the respective plots. We had followed the carbon dioxid in the soil air of these plots for two seasons. In the fallow we found up to 60 p. p. 10,000. Under the wheat that occupied two plots 1 year, and was followed by corn the next year, we found up to 175 p. p. 10,000 at the period of its maximum growth, shortly before maturity; under corn at a similar stage of development about 110 p. p. 10,000; under clover and alfalfa large quantities of carbon dioxid for the greater part of the season, at times reaching 270 p. p. 10,000.

The principal chemical effect established for the carbon dioxid was the bringing of potassium into a water-soluble condition. This was established by experiments given in Bulletin 319 and again by determinations of the water-soluble potassium in the different plots, fallow and occupied by crops. The alfalfa for instance carried twice as much water-soluble potassium as the fallow. The total and nitric nitrogen had also been followed for two seasons.

CHANGED CONDITIONS BY PLOWING UNDER CROPS

When we plowed this land, especially when we plowed under heavy growths of clover and alfalfa, we changed our conditions in these plots radically, but the plowing changed the conditions in the other plots too.

These plots were plowed on 13 Sept., 1927. We had followed the amount of carbon dioxid maintained in the various plots during the preceding two seasons, also the total and nitric nitrogen. We had studied the effects of the crops on the exchange values of this soil and the changes in the amount of water-soluble potassium for one season. We did not appreciate the importance of this factor at the beginning of the first season, not till the experiments recorded in Bulletin 319 demonstrated its importance.

The simple question that we presented to ourselves was how will this land deport itself if cultivated fallow during the succeeding season and how toward crops. The second portion of this question has been presented in Bulletin 362 and we shall endeavor to answer the first portion in the following pages.

THREE CLASSES OF INORGANIC CONSTITUENTS OF SOIL

Concerning the soil, meaning thereby the purely inorganic portions, we have practically divided it into three divisions: First, the strictly mineralogical constituents still retaining their original form and properties practically intact; second, aggregates and incrustations, consisting of products derived from the first, which in our case furnish the plants their mineral constituents; and a third portion consisting of a complex whose exchange value does not differ materially from 13 milligram-equivalents of hydrogen. This complex is not affected by the growing crops. While it is possible that changes occur in this complex under the influence of the crops, the net result leaves it unchanged. The aggregates made up of calcareous clay and clayey incrustations of very porous carbonate of lime carry the readily available potassium and phosphoric acid.

PHOSPHORIC ACID NOT CONSIDERED

The statement concerning phosphoric acid is based on the very easy solubility of a portion of this substance, even in dilute acids. It has been stated elsewhere that we practically leave this factor out of consideration because numerous experiments indicate that there is enough available phosphoric acid in this soil to produce its maximum effects upon a growing crop whether much or little nitric nitrogen be present. The effect of a liberal supply of nitric nitrogen is to lessen the amount of phosphorus taken up by the plants. The presence of a good supply of phosphoric acid, from 0.156 to 0.186 percent, and the ready solubility of at least one-half of this, together with the results obtained by adding it in various amounts in many experiments, justify us in considering it as without interest in this work.

THE QUESTIONS CONSIDERED

There remain the questions of nitrogen supply, especially that of nitric nitrogen, available or water-soluble potassium, and the general sanitary conditions in the soil. This latter depends upon many things, some of them probably not as yet recognized. Among these, however, are the ability of the soil to fix and to nitrify nitrogen, the one helping to maintain the supply of total nitrogen and the other the ability of the soil to transform non-available into available nitrogen for plants, both cultural and those belonging to the soil population.

This soil population is of great importance which we realize more fully when it becomes pathogenic and destroys our crops. In the greater number of cases our soil population is not pathogenic but contributes both directly and indirectly to the better growth of plants. We even inoculate our soil if its population is deficient in certain respects. We desist from planting certain crops for years to starve certain inhabitants of the soil which have proved themselves antagonistic to our interests. These practices recognize the sanitary and unsanitary conditions of our soils for certain crops, dependent upon the organisms forming the population of the soil. There also may be products formed by these organisms and also by the cultivated plants which may be beneficial or harmful to succeeding crops. In the former case, we suggest the name favorins; in the latter they are called toxins.

GROWTH OF CROPS AND SUPPLY OF PLANT FOOD

Great stress has been placed upon the supply of plant foods, phosphoric acid, potassium and nitrogen, and comparatively little upon these sanitary conditions. In discussing the growth of wheat after clover, alfalfa, fallow and corn, we were wholly unwilling to believe that the inferior vegetative power of the wheat after corn was due to a lack of any plant food but believed it to be caused by some other factor which was antagonistic to the plant, while after the clover and alfalfa there was a something decidedly favorable to this function of the plant. In the fallow land this favorable something was in better balance with other conditions and gave us the best results.

The statement of results in total weight of crop, or yield in bushels, gives no adequate idea of the differences in the growth and appearance of the different plots during the growing season. The fact is that the dry matter produced and the grain yielded were not in keeping with the respective appearance, or apparent promise, of the crops. This statement might be considered as needing modification in regard to the crop after fallow but there is no question about the other three; after the alfalfa and clover it fell far behind the promise, but after the corn both the weight of dry matter and the bushels per acre exceeded the promise. The yield of grain was after the fallow 58.2, after the corn 52.5, after clover 46.0, and after alfalfa 40.4 bushels per acre.

The nitrogen of our soils is of animal or vegetable origin. The trace that may be formed by the direct union of elements in the atmosphere is an insignificant quantity. The phosphoric acid and potassium are originally furnished by the constituents of the soil. Carbon dioxid effects the elimination of both phosphoric acid and potassium from these minerals at a comparatively rapid rate, facilitating the building of aggregates of the clay, carbonate of lime, and possibly of other alteration products of these minerals.

CARBON DIOXID AN ACTIVE AGENT

The active agents in bringing about these changes are carbon dioxid and water and the carbon dioxid observed in our experiments was produced by the growing plants and not from dead ones. The fallow plots, especially during the first season while the organic matter, plant debris or of whatever character it may have been was presumably essentially the same in all the plots, gave us a measure of the carbon dioxid that owed its origin to the action of the soil population. The amount is not insignificant up to 60 p. p. 10,000 of the soil air, but the alfalfa increased it up to 270 p. p. 10,000.

OUR PROBLEM CHANGED BY PLOWING UNDER THE CROPS

When we plowed the crops under we changed these conditions. The clover and alfalfa roots, also the tops, were still in the soil. The activity of the aerial parts of the plants was certainly stopped, but that of the roots was not so certainly eliminated.

The fallow ground was plowed at the same time and its conditions were likewise changed.

Our problems now become almost new ones and more involved. What course will the supply of carbon dioxid now take? What will happen in the matter of the water-soluble potassium? Will the nitrogen increase by fixation and if so how will it be affected by the treatment of the different plots? What will be the course taken by the nitric nitrogen? Will it now be more abundant in the soil with the clover and alfalfa plowed under or in the fallow as heretofore? How long will the various effects persist? Can we in one season find the time of their duration or should we try to follow them for a longer time?

We tried the shorter and easier method of measuring the effects of our rotation by the direct method of planting wheat after the rotation. The results are given elsewhere. The effects were very different. Were they due to the plant residues or to some other product? There were no plant residues after the fallow. This had been kept entirely free from vegetation for two seasons. The corn was pulled after having been irrigated, where we left only a comparatively small mass of roots. In the cases of the clover and alfalfa heavy growths were plowed under.

We can only surmise what would have been the result if we could have pulled out these crops as cleanly as we did the corn. It seems to me probable that we would have had the same kind of differences that we actually observed, but not so strongly marked.

TOTAL NITROGEN IN PLOTS ON DIFFERENT DATES

In a former bulletin, Bulletin 362, of this station we gave the results of a somewhat extended study of the amount of total nitrogen and nitric nitrogen in land planted to alfalfa to ascertain whether there was an actual gain in the total or not. The conclusion was that while an increase had probably taken place it was so small that it was negligible. It is so good as impossible to sample even a comparatively small plot, say one-twentieth of an acre, to a depth of 1 foot on two different dates using the same method and the same operator and obtain identical results; there may be variations up to several hundredths of 1 percent. I have elsewhere insisted upon the necessity of recognizing this difficulty and mention it here again. We sampled our alfalfa plots in the spring of 1926 and found for total nitrogen 0.1278 percent. They were again sampled in the fall of 1927 and gave 0.1268, and again in the spring of 1928 and gave 0.1237 percent. These samples were not taken by the same operator but they represent the same depth of soil taken in one 3-inch and one 9-inch section which we have here averaged to represent a depth of 1 foot. The results are unusually close with a maximum difference of 0.0042 percent. Samples taken close together in apparently identical soil may vary ten times this amount in total nitrogen.

These plots were sampled again 10 Oct., 1927, one month after the crops were plowed under and an average of 0.1290 percent was found. This average is raised because there was an apparent increase in one of the plots to 0.1435 percent. The check plot beside this had apparently increased also to 0.1400. The apparent increase is quite certainly not due to the alfalfa plowed under for the fallow has, according to this sampling, increased more than the alfalfa land because it was previously lower than this.

Discussion Confined to One-Foot Samples

While we took the samples in sections and to much greater depths than 1 foot, we believe that this depth represents very fairly the changes in the amount of nitrogen present in the soil. At a depth greater than 1 foot, the falling off in the total nitrogen is so rapid that an average including it would be of little value. The distribution of the nitric nitrogen may be very different from that of the total as a rainfall or an irrigation may affect this very materially. We have found evidence of this at 4 and even 9 feet below the surface. These were extreme cases in our experience.

Effects of Rotation on Fixation and Nitrification

The object in discussing the nitrogen question in this bulletin is a different one from that had in view in preceding bulletins. Previously we were concerned with the actual amounts of total and nitric nitrogen present; now we wish to ascertain whether the soil of the different plots after 2 years in clover, alfalfa and fallow respectively, and after 2 years, 1 in wheat and the other in corn are equally efficient in fixing and nitrifying nitrogen. The plots never had an identical content of nitrogen and we do not know that they were equally efficient in fixing and nitrifying it. We have to depend upon our check plots as guides in these respects. No amendments were added to the plots as our object has been to ascertain what probably took place in the soil during the season that followed the termination of our previous experiments.

Checks at a Disadvantage

Our checks are at a disadvantage in this case, for they had been kept free from vegetation for two seasons and any organic matter that they may have contained at the beginning had suffered loss by oxidation due largely, perhaps mostly, to the action of the soil population. The plots were not only kept fallow during the third season but were irrigated and cultivated the same as those that had had the clover and alfalfa plowed under in the fall of 1927.

Concerning these latter it may be a question whether it was wise to plow under the crops in the fall, because there were 6 months between this plowing and the time when our later observations, sampling and planting could be begun in the following spring, 1928. The destruction of the green alfalfa and clover followed quickly, just how quickly we do not know, but it was not complete for a long time as was shown by the persistency of the stubble and roots and even leaves.

WHAT THE SAMPLES OF 10 OCTOBER, 1927 SHOW

The data given for the total nitrogen by the samplings of 10 Oct., 1927, 27 days after the crops were plowed under, suggest several questions. These samplings show for one set of plots at the north end of our land, one each of alfalfa, fallow and clover, total nitrogen equal to 0.1146, 0.1043 and 0.1190, respectively, which show no increase, while a similar set at the south end gives 0.1435, 0.1400, 0.1472 percent. The averages for the two sets of plots are alfalfa 0.1290, fallow 0.1222 and clover 0.1340 percent. The average for the alfalfa in 1926 was 0.1278 which gives us a difference of 0.0012 percent, a difference so small that it falls well within the limits of the differences between samples taken at the same time. It may be of doubtful advisability to average the two sets when the set from the south end taken by itself is decidedly high compared with the 1926 determinations but this cannot justly be attributed to the alfalfa or clover for the check has increased as much as these. The average for our alfalfa plots on 21 May 1926, was 0.1278 and for the fallow 0.1298. According to this the increase in the alfalfa land is 0.0157 and for the fallow land, 0.0102 percent, and is in both cases more than the nitrogen added with the crops.

NITROGEN ADDED WITH THE CROPS VS. THE ANALYTICAL DATA

These data suggest several questions. One is, Is the amount of nitrogen added with the crops sufficient to affect the analytical results strongly enough to show satisfactorily that an effect has been produced greater than the variations in samples taken at any given time? It would take a considerable amount of nitrogen to do this as this variation may amount to several hundredths of 1 percent. We have shown that the simple occupancy of the land by the alfalfa does not increase the total nitrogen, so any increase must be effected by direct addition with the crop plowed under. We have given the green matter plowed under as approximately 6 tons. This is equivalent to 1.5 tons of hay carrying, in round numbers, 2 percent of nitrogen, or 60 pounds of nitrogen. The stubble to a depth of 6 inches is very close to 4 tons to the acre, equal to a little more than 1.5 tons of dry matter with 1.5 percent of nitrogen, or 47 pounds per acre. This makes a total of 107 pounds, probably added in the form of green alfalfa and its corresponding stubble. The land was plowed to about 6 inches and the crop well covered. We ought to get the total effect of this on the nitrogen content of the soil within the surface foot which we took as a sample.

The weight of this soil per acre foot is a trifle over 4,000,-000 pounds and the nitrogen added is 107 pounds or 27 parts per million, but according to our data the increase from the spring of 1927 to 10 Oct. 1927 is from four to six times as great as the nitrogen added and it must have come from some other source than the crops plowed under. That this is actually the case is indicated by the results obtained with the samples taken from the fallow to which nothing had been added. These statements pertain to the total nitrogen which includes the nitric nitrogen.

Total nitrogen is an active agent in promoting plant development only in the measure that it is converted into nitric nitrogen. The nitrifying power of the soil determines how fast the total nitrogen passes from nitrogen to nitric acid and thereby becomes active. The soil itself has the power of fixing nitrogen by virtue of organisms living in it in a free state and do not need a host plant to function. This power can be affected by the rotation, therefore we incubated samples of this soil after the rotation to see if and how these processes had been affected. Again we depend upon our check plots as criteria by which to judge, assuming that these represent, very nearly at least, what the test plots would have been had the clover and alfalfa not been grown on them and plowed under.

These points were studied by following the total and nitric nitrogen through the season of 1928 from 27 April till 5 October by means of large field samples taken every 10 days, as nearly as conditions permitted; 15 samplings were made during this period, four of which were incubated. Three general samplings were made in the fall and winter of 1927. Of course the nitric nitrogen was studied at the same time.

We have two series of tests, one giving the total and nitric nitrogen for samples as they were taken in the field, 15 samplings. In addition to these seven large field samples were incubated to determine the fixing and nitrifying power of the soils as they lay in the field. This means that our incubation experiments differed in no manner from the same processes that were actually going on in the field except that we made the moisture up to 17 percent and kept the temperature around 27°C. for 40 days. The samples were tested at the end of 30 and again at the end of 40 days.

The water added was ammonia-free, and the incubations made in a room in which no analytical work or other chemical manipulations were carried out. The tables giving the results of these experiments will be given a little later.

WHY CARBON DIOXID IN SOIL WAS FOLLOWED IN 1928

These experiments will present one feature of our study of the conditions obtaining in the soil during the season following the cropping and fallowing for two seasons. This is only one of three bigger features to present themselves. The key to this whole study has been presented as the carbon dioxid given off by the roots of the respective crops during their growth, irrespective of any processes of decay that might be going on. We have presented in other bulletins the observations of six seasons on this subject. The question concerning this factor does not cease with the plowing up of the crops but it extends to the ensuing season. We have followed its quantity in the soil air for 1 year after the destruction of the growing crops. We were not directly concerned about the source of this carbon dioxid but with its quantity and persistency. The reason is evident from the following considerations.

The benefits accruing to the soil from a rotation so far as mineral foods are concerned is due to the increased quantity of water-soluble potassium present and not to any actual increase of the nitrogen. The agent that effects this increase in water-soluble potassium is carbon dioxid. Water is of course assumed in the soil or there would be no vegetation. We proposed to study this water-soluble potassium in regard to its amount in the various plots during the season, to ascertain to what extent it persisted and how it varied.

We may here call the reader's attention to the fact that simultaneously with this work we were growing a crop of wheat on portions of these plots. The results obtained are presented in another bulletin.

WATER-SOLUBLE POTASSIUM AND NITRIC NITROGEN IN SOIL IN 1928

In order to follow this water-soluble potassium throughout the seasons, samples were taken weekly from 23 March till 26 Sept. 1928. In these samples we determined the water-soluble potassium and the nitric nitrogen.

This presents the scope of the work forming the basis of this bulletin. The convictions based on it are that the teachings concerning the manner in which plants, the legumes in particular, are efficient in benefiting land by addition of nitrogen to the soil are not correct but that the addition to the available plant food is in the form of water-soluble potassium effected by the action of the carbon dioxid given off by their roots. This is only one of the benefits and while we shall present our study of the persistence of this water-soluble potassium, we shall endeavor to set forth other effects of plant growth upon those soil conditions which affect its fixing and nitrifying power. After we shall have done the best we may to show their effects on the plant foods, it will clearly appear that these crops impart to the soil properties favorable to vegetation that are not of the nature of what is understood by plant foods. When we see something dimly and wish to insist on its reality we call it by some name as a cloak for our ignorance. The sanitary condition of the soil serves my purpose in this case.

OBJECT OF INCUBATION EXPERIMENTS

Our incubation tests constitute an attempt to ascertain the influence of our 2-year experiment upon the fixing and nitrifying efficiency of these plots. These functions are probably depressed by our crops. It is, I think, definitely shown by our results in studying this crop that the wheat crop depresses the nitrifying process. We have previously made no effort to ascertain the effects upon the fixing process. The nearest approach to this was in a study of the effects of a green manuring upon the quality of sugar beets, but the results bore more directly upon the production of nitrates during subsequent cropping than to fixation. This experiment was based upon the fact that the application of excessive nitrates suppresses the sugar content of the beet; further, that large quantities of nitrates developed in the soil and the quality of the beets was low. By green manuring we hoped to anticipate this condition. The results were: Without green manuring the beets carried in round numbers 11.0 percent sugar; after green manuring 16.0

percent. We have grown and plowed under our clover and alfalfa crops. The soil of the alfalfa land was not enriched in total nitrogen and was kept poor in nitric nitrogen. We wish to ascertain by experiment what the soil's deportment in these respects is after the crops have been plowed under and the soil cultivated fallow to avoid the influence of a growing crop. We plowed our crops under on 13 Sept. because at this time the plants were well matured and the crops were heavy. We used the same fallows that we had been observing for the two seasons. This was probably a severe and somewhat unfavorable condition for the fallow as it maintained the fallow for three successive seasons and the original nitrogen content had probably been lessened and the easily nitrifiable nitrogen had probably been diminished disproportionately to the amount of total nitrogen while the green alfalfa and clover plowed under offered a relatively large amount of easily nitrifiable nitrogen and food for a greatly increased micro-population. The amount of total nitrogen added with the crops has been given. It was not more than 27 p.p.m. for the surface foot. The nitric nitrogen added in this way was insignificant. This section of our work is an inquiry into the effects of the green crops upon these nitrogen relations. The following tables present our data obtained. A diagram of the plots is given to avoid confusion of samples.

The whole plot was cultivated fallow in 1928 except a narrow strip on the east side which was planted to wheat. This bulletin presents the results of observations made on the fallow portion for the season of 1928.

DIAGRAM OF EXPERIMENTS AS CONDUCTED DURING SEASONS OF 1926 AND 1927

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Alfalfa 1926 and '27 Fallow 1928	N. Fallow	Clover 1926 and '27 Fallow 1928
W. Fallow 1926, '27 and '28		E. Fallow 1926, '27 and '28
Wheat 1926 Corn 1927 Fallow 1928		Wheat 1926 Corn 1927 Fallow 1928
Clover 1926 and '27 Fallow 1928	S. Fallow	Alfalfa 1926 and '27 Fallow 1928

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The alfalfa and fallow plots were sampled for total and nitric nitrogen in the spring of 1926 at the beginning of our experiments and again in the fall of this year. The results are given as a basis for comparison with later results which, however, are given in much more detail. These samples were taken to a depth of 1 foot in 2 sections of 6 inches each. Unless one has a specific reason for taking samples to a greater depth than 1 foot, there is no good purpose served by doing so. There may be a question into what sections it is best to divide this foot; later we made the sections 3 and 9 inches respectively. As these samples were composite ones of the fallow and alfalfa plots respectively, we have given the averages for the foot sampled as these may be, after all, as fair a basis for comparison as any other.

TABLE 1.—Total and Nitric Nitrogen in the Fallow and Alfalfa Plots in Spring of 1926.

	0-6″		7-12″		Average	
	Total per-cent	Nitric p.p.m.	Total per-cent	Nitric p.p.m.	Total per-cent	Nitric p.p.m.
Fallow Plots						
21 May 1926	.1400	7	.1197	9	.1299	8
19 June 1926	.1302	11	.1134	10	.1218	11
29 June 1926	.1302	12	.1085	8	.1194	10
Alfalfa Plots						
21 May 1926	.1506	2	.1051	1	.1279	2
19 June 1926	.1442	6	.1176	4	.1306	5
21 June 1926	.1428	8	.1166	5	.1299	7

This ground had been cultivated recently and was supposedly well mixed. We did not aim to plow deeper than 5 inches. The same plots were sampled in like manner in the fall with the following results:

TABLE 2.—Total and Nitric Nitrogen in the Fallow and Alfalfa Plots in Fall of 1926.

	0-6″		7-12″		Average	
	Total per-cent	Nitric p.p.m.	Total per-cent	Nitric p.p.m.	Total per-cent	Nitric p.p.m.
Fallow Plots						
25 Sept. 1926	.1337	14	.1120	6	.1228	10
14 Oct. 1926	.1183	12	.1008	3	.1096	8
Alfalfa Plots						
25 Sept. 1926	.1407	7	.1155	3	.1281	5
14 Oct. 1926	.1435	6	.1253	2	.1344	4

All plots were sampled separately 2 Sept. 1927, to the depth of 2 feet in five sections, two of 3 inches and three of 6 inches each. Reference to the diagram of the plots will enable one to locate the individual plots. There is a good deal of need that this should be done because the south end of this piece of land is different from the north end and is regularly higher in total nitrogen than the north end, which difference is constantly to be borne in mind. This piece of land is only about one-half acre in area but it presents several disconcerting differences which will appear later.

TABLE 3.—Total and Nitric Nitrogen in Plots, 2 Sept. 1927, Before Plowing to the Depth of 2 Feet.

		West		East	
	Inches	Total percent	Nitric p.p.m.	Total percent	Nitric p.p.m.
Alfalfa	0-3	.1337	10	.1456	6
	4-6	.1295	3	.1435	3
	7-12	.1204	3	.1120	4
	13-18	.0707	3	.0686	3
	19-24	.0490	2	.0534	3
Fallow	0-3	.1274	20	.1141	19
	4-6	.1253	18	.1169	18
	7-12	.0987	15	.0987	15
	13-18	.0686	15	.0707	12
	19-24	.0525	14	.0525	12
Clover	0-3	.1596	7	.1351	5
	4-6	.1428	3	.1211	1
	7-12	.1190	2	.1029	3
	13-18	.0721	3	.0721	3
	19-24	.0553	2	.0518	3

These results show that for most purposes there is no object in sampling the second foot and also the poverty of the cropped soils in nitric nitrogen compared with the fallow on this date.

On 10 Oct. 1927, we began regular samplings of the plots in an endeavor to follow the course of the nitrogen, total and nitric, in them. We expected to find decided but irregular changes in both directions, i. e., that we would have increases and decreases in both forms of nitrogen but we had no notion of how great the fluctuations might be nor how rapidly they might follow one another.

AZOTOBACTER PIGMENTATION

We have very good reasons for entertaining the view that this land under some conditions may develop a strong fixing power and as the turning brown of the soil in streaks and little patches is a reliable indication, we know that the development of azotobacter may take place under field conditions on a sufficient scale to give it great importance. We have not endeavored to determine the development of these organisms, but the browning of this soil has been observed on various occasions. In such cases we have been more interested in the amount of nitric nitrogen present than in that of the total nitrogen for the pigmentation is indicative of the presence of nitrates which facilitate it. Three years ago we observed such a brown area in a field adjoining the one of which our plot forms a part. The land is level and the question was merely of its being a little farther south than our plot. I made inquiry whether manure had been applied to the land recently and was informed that it had not. This is supported by the fact that the aqueous extract of the soil is colorless except for a slight yellow tinge, a characteristic of extracts of soils which have been browned by azotobacter. The nitric nitrogen in this soil was 1120 p.p.m., equivalent to 6730 pounds of sodic nitrate in the top 3 inches of the soil. This is an unusually large quantity for this soil but in a former study we found, in a small fallow area in a cultivated crop, the equivalent of 332 pounds of sodic nitrate in the top foot of soil.

We do not know the conditions that brought about the formation of these amounts of nitrates but in the case here cited of 1120 p.p.m. of nitric nitrogen there must have been a big increase in the amount of total nitrogen, either this or we must assume that nearly the whole of the total nitrogen had been converted into nitric nitrogen. Our range for total nitrogen in this soil for the top 3 inches is from 0.1274 to 0.1596 percent on 13 Sept. 1927, but the nitric nitrogen in this exceptional sample is 0.1120 percent. These facts concerning the nitric nitrogen found in this soil are given to show that its efficiency in this direction is, even under field conditions, great. We have no observations on its fixing power except some incubation experiments and observations on samples kept in loosely stoppered bottles in the laboratory. The power to accomplish this was satisfactory; it fixed from 4.8 milligrams in 30 days in loosely stoppered bottles to 10.5 milligrams incubated at 27° to 30°C., and the nitric nitrogen increased from 7.99 to 12.5 milligrams per 100 grams of soil in 48 days. The general efficiency of this soil is such as to justify the expectation of interesting results.

Two series of experiments were arranged to study the effects produced by our crops and fallowing. These experiments began 10 Oct., 1927, a little less than 1 month after the crops were plowed under. We did not begin these series earlier because of other work and we thought that the fermentation of the crops would be very active and might interfere with the purpose had in view. Had we to do it over we would begin these series immediately and not wait 27 days—unfinished work might wait. These series began on 10 Oct., 1927, and consisted of soil samples taken to the depth of 1 foot in two sections, 3 and 9 inches each. The total and nitric nitrogen were determined on the fresh samples. Twelve hundred and fifty grams were taken and the moisture brought up to 17 percent by the addition of ammonia-free water. The moist chambers containing these samples were placed in a chamber made for the purpose and incubated for a period of 30 days when samples were withdrawn for the redetermination of the total and nitric nitrogen. The dishes were returned to the chamber and another set of determinations made at the expiration of 40 days. Three sets of samples were taken in 1927 before the ground was frozen. The series was continued in 1928 beginning 13 March.

The incubation chamber was constructed in a room which was given up to this object to avoid an atmosphere possibly contaminated by ammoniacal or nitrous compounds of some sort. The room was kept at 27°C. with very little variation. In the second series we determined only the total and nitric nitrogen in the samples as gathered in the field. The samples taken in the fall of 1927 are included in this series but the series without reference to the incubation experiments really began 13 March, 1928, samples being taken every 10 days.

All samples were air-dried, rubbed to a uniformly even powder, and passed through a 20-mesh sieve. Slight changes took place in drying but this process proceeds rapidly in our atmosphere and these changes are negligible. The plots were cultivated fallow. No vegetation whatever was allowed to grow on them and they were irrigated and cultivated as carefully as though they had been cropped. This gave us the changes in the nitrogen content of the soil under field conditions and those under the conditions of the incubation chamber. Of the field samples we have 20 series, of the incubation samples 7 series.

Our observations are that the surface portions of the soil are the richest in nitrogen, which agrees with the idea that it may be associated with a soil population living in this section of the soil or be due to surface accumulations from other sources; this latter would scarcely apply in the case of a fallow. With this fact in view we laid special stress on the top 3 inches of soil and sampled to this depth.

We have persisted in emphasizing the variability in the nitrogen content of field samples and recognized the importance of obviating this source of error. We, therefore, combined 20 subsamples to form each 3-inch sample throughout the series for incubation and 10 subsamples to form each 3-inch sample in the series to represent the changes taking place under field conditions. This made the taking of samples a difficult task as the 4 to 12-inch samples were also composites of 10 and 9 samples respectively. These precautions were taken to obviate errors in sampling. The field samples not for incubation were taken at intervals of 10 days except during the winter when the ground was frozen. The results obtained are given in Table 4.

These plots were in as good condition in every sense as land under the most careful cultivation is likely to be. There was no attempt to create conditions that would not ordinarily obtain in farm practice. No manure or chemical fertilizer was applied except as stated and these additions were for the purpose of special studies.

CHANGES STUDIED REPRESENT FALLOW, NOT CROPPED LAND

The land was cultivated fallow, after the crops were plowed under for the purposes of our work, to learn as nearly as possible what changes take place in land treated in this manner without crops. We do not wish any one to infer that the changes observed actually represent those that take place in cropped land. They represent the possibilities and trend of changes that may take place, but they will be modified by the growing crops. In previous studies we have endeavored to obtain some data on this point so far as the nitrogen in our soils is concerned, especially in connection with the wheat crop. We grew wheat on parts of these plots in 1928, (see Part III, Bulletin 363, of this study), but not because we had previously studied the amount and changes in the nitrogen content of the soil under this crop. It may here be stated that the crop exhausts the soil of nitric nitrogen to the extent that it is reduced to one or two parts per million or at most to only a few parts per million. The nitric nitrogen begins to increase in the soil shortly after the wheat harvest, at first slowly but quite rapidly after a while. We did not attempt to study the relations of the nitrogen in the cropped and fallow land simultaneously for the simple reason that we could not do the work. Our force and facilities were not adequate. The practical man will have to be satisfied with the one-sided approach that we have been able to present.

TABLE 4.—Nitrogen in Plots, Season of 1927 and 1928, in percentages.

Plot and Depth		10 Oct. 1927		12 Nov. 1927		13 Mar. 1928		27 Apr. 1928		18 May 1928		5 June 1928		15 June 1928		25 June 1928		5 July 1928		16 July 1928	
		Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric
N.W. Alf.	0-3″	.1246	.0008	.1300	.0019	.1267	.0032	.1155	.0016	.1120	.0006	.1218	.0006	.1232	.0014	.1190	.0015	.1134	.0022	.1162	.0012
	4-12″	.1246	.0021	.1288	.0026	.1309	.0030	.1169	.0047	.1204	.0026	.1148	.0020	.1176	.0024	.1092	.0017	.1162	.0024	.1176	.0013
N. Fallow	0-3″	.1036	.0007	.1183	.0018	.1190	.0022	.1029	.0007	.1092	.0005	.1050	.0006	.1036	.0008	.1036	.0008	.1020	.0014	.0994	.0010
	4-12″	.1050	.0014	.1092	.0018	.1160	.0020	.0924	.0014	.0982	.0008	.0924	.0008	.0924	.0006	.0910	.0006	.0910	.0008	.0952	.0006
N.E.Clover	0-3″	.1120	.0007	.1218	.0021	.1218	.0028	.1078	.0014	.1008	.0006	.1064	.0006	.1050	.0013	.1050	.0011	.1078	.0024	.1050	.0012
	4-12″	.1246	.0025	.1246	.0023	.1309	.0030	.1134	.0042	.1134	.0024	.1064	.0017	.1092	.0016	.1078	.0012	.1106	.0024	.0980	.0012
S.E. Alf.	0-3″	.1386	.0007	.1519	.0027	.1470	.0032	.1372	.0018	.1400	.0008	.1072	.0008	.1372	.0016	.1330	.0022	.1358	.0029	.1372	.0018
	4-12″	.1484	.0019	.1512	.0034	.1505	.0034	.1288	.0031	.1358	.0030	.1260	.0037	.1344	.0022	.1274	.0026	.1302	.0026	.1372	.0018
S. Fallow	0-3″	.1400	.0009	.1456	.0032	.1470	.0028	.1300	.0009	.1372	.0008	.1288	.0006	.1274	.0011	.1260	.0014	.1316	.0020	.1274	.0016
	4-12″	.1393	.0017	.1400	.0031	.1505	.0020	.1204	.0021	.1274	.0018	.1176	.0020	.1120	.0016	.1050	.0010	.1148	.0014	.1078	.0010
S.W.Clover	0-3″	.1484	.0007	.1484	.0024	.1505	.0028	.1288	.0016	.1316	.0008	.1344	.0008	.1302	.0016	.1246	.0020	.1330	.0026	.1274	.0016
	4-12″	.1421	.0018	.1456	.0029	.1470	.0026	.1330	.0028	.1260	.0024	.1344	.0025	.1311	.0018	.1162	.0020	.1316	.0025	.1372	.0014
Super-phos.	0-3″					.1141	.0022	.1050	.0008	.1022	.0006	.1064	.0008	.1036	.0012	.1022	.0013	.1008	.0018	.1008	.0016
	4-12″					.1134	.0018	.1064	.0016	.1022	.0014	.1036	.0010	.1022	.0016	.1008	.0010	.0994	.0013	.0994	.0010
Rock Phos.	0-3″					.1281	.0012	.1120	.0006	.1106	.0006	.1162	.0006	.1134	.0010	.1204	.0013	.1176	.0016	.1162	.0010
	4-12″					.1211	.0008	.1120	.0010	.1120	.0010	.1162	.0011	.1120	.0010	.1148	.0010	.1064	.0012	.1078	.0008
Gypsum	0-3″					.1218	.0022	.1064	.0006	.1036	.0004	.1106	.0006	.1064	.0008	.1076	.0007	.1022	.0012	.1050	.0012
	4-12″					.1225	.0020	.1120	.0014	.1092	.0015	.1106	.0013	.1120	.0015	.1106	.0013	.1064	.0015	.1036	.0007

TABLE 4—Continued.

Plot and Depth		25 July 1928		4 Aug. 1928		15 Aug. 1928		25 Aug. 1928		4 Sept. 1928		14 Sept. 1928		25 Sept. 1928		5 Oct. 1928		Ave. for 1928		Ave whole time	
		Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric
N.W. Alf.	0-3″	.1218	.0018	.1190	.0024	.1190	.0027	.1162	.0026	.1176	.0024	.1162	.0023	.1232	.0028	.1204	.0038	.1183	.0020	.1197	.0020
	4-12″	.1176	.0013	.1190	.0016	.1190	.0023	.1134	.0022	.1190	.0022	.1102	.0016	.1176	.0019	.1190	.0018	.1169	.0021	.1187	.0022
N.Fallow	0-3″	.1078	.0012	.1050	.0015	.1050	.0016	.1078	.0017	.1064	.0012	.1022	.0019	.1064	.0017	.1134	.0015	.1053	.0012	.1067	.0013
	4-12″	.0966	.0006	.0938	.0007	.0966	.0008	.0910	.0008	.0938	.0008	.0882	.0007	.0938	.0008	.0994	.0008	.0937	.0008	.0961	.0009
N.E.Clover	0-3″	.1064	.0018	.1064	.0021	.1120	.0032	.1064	.0024	.1092	.0028	.1036	.0026	.1092	.0021	.1148	.0028	.1071	.0019	.1089	.0019
	4-12″	.1022	.0014	.1078	.0018	.1134	.0018	.1036	.0014	.1036	.0018	.1022	.0017	.1078	.0015	.1148	.0014	.1076	.0018	.1108	.0019
S.E.Alf.	0-3″	.1428	.0026	.1288	.0028	.1358	.0030	.1316	.0029	.1400	.0029	.1302	.0030	.1156	.0037	.1428	.0041	.1370	.0024	.1385	.0024
	4-12″	.1470	.0020	.1274	.0019	.1372	.0021	.1232	.0024	.1288	.0018	.1232	.0028	.1330	.0029	.1330	.0025	.1315	.0025	.1346	.0025
S.Fallow	0-3″	.1344	.0018	.1274	.0022	.1232	.0022	.1218	.0029	.1358	.0032	.1302	.0026	.1344	.0033	.1330	.0032	.1299	.0020	.1323	.0020
	4-12″	.1204	.0012	.1134	.0012	.1204	.0016	.1120	.0019	.1218	.0021	.1134	.0008	.1246	.0017	.1176	.0016	.1167	.0015	.1210	.0016
S.W.Clover	0-3″	.1386	.0021	.1274	.0022	.1302	.0024	.1274	.0027	.1344	.0029	.1288	.0026	.1372	.0029	.1358	.0033	.1313	.0021	.1343	.0021
	4-12″	.1302	.0016	.1162	.0017	.1232	.0018	.1232	.0021	.1344	.0026	.1294	.0021	.1330	.0022	.1330	.0022	.1287	.0021	.1310	.0022
Super phos.	0-3″	.1050	.0014	.1022	.0018	.1036	.0018	.1190	.0016	.1022	.0016	.1050	.0016	.1232	.0028	.1036	.0021	.1056	.0015	.1062	.0015
	4-12″	.0994	.0008	.0994	.0010	.1022	.0010	.1106	.0012	.1022	.0010	.1022	.0009	.1064	.0010	.0980	.0010	.1023	.0011	.1030	.0011
Rock Phos.	0-3″	.1204	.0012	.1134	.0018	.1204	.0018	.1134	.0022	.1204	.0019	.1148	.0017	.1232	.0020	.1190	.0019	.1168	.0014	.1174	.0014
	4-12″	.1162	.0008	.1106	.0012	.1218	.0014	.1050	.0018	.1134	.0016	.1162	.0013	.1218	.0014	.1190	.0012	.1137	.0012	.1141	.0012
Gypsum	0-3″	.1092	.0012	.1064	.0016	.1092	.0017	.1008	.0014	.1106	.0015	.1092	.0017	.1120	.0020	.1106	.0019	.1073	.0012	.1082	.0013
	4-12″	.1120	.0008	.1036	.0012	.1120	.0014	.1162	.0008	.1092	.0010	.1064	.0012	.1148	.0012	.1134	.0014	.1101	.0012	.1109	.0012

TABLE 5.—Gains and Losses in Total and Nitric Nitrogen, Field Experiments, p. p. m.

		Original 10 Oct. '27		12 Nov. '27		13 March '28		27 Apr. '28		18 May '28		5 June '28		15 June '28		25 June '28		5 July '28	
	Inches	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric
N.W.	0-3″	1246	8	54	11	23	24	— 91	8	—126	— 2	— 28	— 2	— 6	6	— 56	7	—112	14
Alfalfa	4-12″	1246	21	42	5	63	0	— 77	26	— 42	5	— 98	— 1	— 70	3	—154	— 4	— 24	3
N.	0-3″	1036	7	147	11	154	15	— 7	0	56	— 2	14	— 1	0	1	0	1	— 14	7
Fallow	4-12″	1050	14	42	4	56	6	—126	0	— 70	— 6	—126	— 6	—126	— 8	—140	— 8	—140	— 6
N.E.	0-3″	1120	7	98	14	98	21	— 42	7	—112	— 1	— 56	— 1	— 70	6	— 70	4	— 42	17
Clover	4-12″	1246	25	0	— 2	63	5	—112	17	—112	— 1	—182	— 8	—154	— 9	—163	—13	—140	— 1
S.E.	0-3″	1386	7	133	20	84	25	— 14	11	14	1	— 14	1	— 14	9	— 56	15	— 28	22
Alfalfa	4-12″	1484	19	28	15	21	15	—196	18	—126	11	—224	18	—140	3	—210	7	—182	7
S.	0-3″	1400	9	56	23	70	14	—156	0	— 84	— 1	—118	— 3	—126	2	—100	5	—184	11
Fallow	4-12″	1393	17	7	14	112	3	—191	4	— 79	1	—217	3	—273	— 1	—343	— 7	—245	— 3
S.W.	0-3″	1484	7	0	14	21	21	—196	9	—168	1	—140	1	—182	9	—238	13	—154	19
Clover	4-12″	1421	18	35	11	14	8	— 91	10	—161	6	— 77	7	—105	0	—259	2	—105	7
Super-	0-3″					1141	22	— 91	—14	—119	—16	— 77	—14	—105	—10	—119	— 9	—132	— 4
phosphate	4-12″					1134	18	— 70	— 2	—112	— 4	— 98	— 8	—112	— 2	—126	— 8	—140	— 5
Rock	0-3″					1281	12	—161	— 6	—175	— 6	—119	— 6	—147	— 2	— 77	1	—105	3
Phosphate	4-12″					1211	8	— 91	2	— 91	2	— 49	3	— 91	2	— 63	2	—147	4
Gypsum	0-3″					1218	22	—154	—16	—182	—18	—112	—16	—154	—14	—142	—15	—196	—10
	4-12″					1225	20	—155	— 6	—133	— 5	—119	— 7	—105	— 5	—119	— 7	—161	— 5

TABLE 5.—Continued.

		16 July '28		25 July '28		4 Aug. '28		15 Aug. '28		25 Aug. '28		4 Sept. '28		14 Sept. '28		25 Sept. '28		5 Oct. '28	
	Inches	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric
N.W.	0-3″	— 24	4	— 23	10	— 56	16	— 56	19	— 84	18	— 86	16	— 86	15	— 14	20	— 42	30
Alfalfa	4-12″	— 70	— 8	— 70	— 8	— 56	— 5	— 56	2	—112	1	— 56	1	— 84	— 5	— 70	— 2	— 56	— 3
N.	0-3″	— 42	3	42	5	14	8	14	9	42	10	28	5	— 14	12	18	10	98	8
Fallow	4-12″	— 98	— 8	— 84	— 8	—112	— 7	— 84	— 6	—140	— 6	—112	— 6	—168	— 7	—112	— 6	— 56	— 6
N.E.	0-3″	— 70	5	— 56	11	— 56	14	0	25	— 56	17	— 28	21	— 84	19	— 28	14	28	21
Clover	4-12″	—266	—10	—224	—11	—168	— 7	—112	— 7	—210	—11	—210	— 7	—224	— 8	—168	—10	— 98	—11
S.E.	0-3″	— 16	11	42	19	— 98	21	— 28	23	— 70	22	14	20	— 84	23	70	30	42	34
Alfalfa	4-12″	—112	— 1	— 14	1	—210	0	—112	2	—252	5	—196	— 1	—252	9	—154	10	—154	6
S.	0-3″	—126	7	— 56	9	—126	13	—168	13	—182	20	— 42	23	— 98	17	— 56	24	— 70	23
Fallow	4-12″	—315	— 7	—189	— 5	—259	— 5	—189	— 1	—273	2	—175	— 4	—259	— 9	—147	0	—217	— 1
S.W.	0-3″	—270	9	— 98	14	—210	15	—182	14	—210	20	—140	22	—196	19	—112	22	—126	26
Clover	4-12″	— 49	— 4	—119	— 2	—259	— 7	—189	0	—209	3	— 77	8	—147	3	— 91	4	— 91	4
Super-	0-3″	—133	— 6	— 91	— 8	—119	— 4	—105	— 4	48	— 6	—119	— 6	— 91	— 6	91	6	—105	— 1
phosphate	4-12″	—140	— 8	—140	—10	—140	— 8	—112	— 8	— 28	— 6	—112	— 8	—112	—19	— 70	— 8	—154	— 8
Rock	0-3″	—119	— 2	— 77	0	—147	6	— 77	6	—147	10	— 77	7	—133	5	— 49	8	— 91	7
Phosphate	4-12″	—113	0	— 49	0	—105	4	7	6	—161	10	— 77	— 8	— 49	5	7	6	— 21	4
Gypsum	0-3″	—168	—10	—126	—10	—154	— 6	—122	— 5	—210	— 8	—112	— 7	—126	— 5	— 98	— 2	—112	— 3
	4-12″	—189	—13	—105	—12	—189	— 8	—105	— 6	— 63	—12	—133	—10	—168	— 8	— 77	— 8	— 91	— 6

We have already stated that we began taking samples of this soil for our present purpose a little less than 1 month after we plowed the crops under—also that it was the third year that the fallow plots had been cultivated in this manner. It is important that these differences in the conditions of the plots should be borne in mind. The fallows given in the statements of Table 3 are east and west fallows; in these tables, 4 and 5, they are north and south fallows but the members of neither pair agree with one another. But the east and west ones agree better than the north and south pair. This is in keeping with all of our observations on the distribution of nitrogen in this piece of land, to wit: The south end is richer in nitrogen than the north end. We have no reason to assign for this. We shall find in studying the distribution of water-soluble potassium a similar fact for which we have not yet been able to find an explanation.

EXPLANATION OF MINUS SIGN IN TABLES

We have taken the samples of 10 Oct., 1927, as our initial ones and the table of gains and losses in total and nitric nitrogen for the year are reckoned from these. A minus sign throughout the table means less than on 10 Oct., 1927, and no sign means more than on this date. It may seem that it would have given us a different view of these changes had we taken the sample of March or April, 1928, as the initial ones for this season. We would have been unable to present changes of the whole year in one table, besides the table is quite as easily read as it is, as it would have been had we taken either the March or April series as our initial one. If we had taken the March series the differences would have been of the same sign and a little larger than they are in the table. The reader has simply to consider whether the difference given is larger or smaller than it was on any date with which he may wish to compare it. Further explanation of this is unnecessary.

The table of gains and losses has been written out to enable the reader to see at a glance the course of the nitrogen developments. We have been accustomed to consider this the point of greatest importance in a rotation involving alfalfa as a member. In Part II of this study we have given in detail the results of our study of the effect of the growing alfalfa crop upon the amount of both total and nitric nitrogen. We found that it does not increase the total and exhausts the nitric to from 1 to 6 or 8 p.p.m. of the soil, as much as 8 p.p.m. being found only in the surface portions of the soil. We here present our study of the deportment of the soil after the crop was plowed under. The effects of red clover are presented in a parallel series of experiments and both are compared with the effects of fallow culture.

NITRE SPOTS MAY DISAPPEAR

It may be well to weigh some other considerations before one ventures to interpret the results with too much confidence. I refer to the variation in the fixing and nitrifying power of the soil due to free living organisms. We have a great many examples of this fact in Colorado. Even in the land of our experiment station farm we sometimes have the azotobacter pigmentation strongly marking certain areas, a fact previously mentioned and the nitrates present increasing to as much as 3.33 tons in the surface 3 inches of soil per acre. These two processes, fixation and nitrification, vary from year to year. If the fixation occurs it is probable that nitrification is always amply provided for. Many specific instances of this variation could be cited showing both their appearance and disappearance. Of their appearance, thousands of acres of orchard land on which old or well-established orchards have been destroyed bear witness.

Only one of very many instances will be given and that briefly. The orchard was 27 years old, the land a sandy loam, drainage excellent; the greater part of the orchard was killed in the course of one season. The water-soluble salts in the air-dried soil representing the surface 4 inches ranged from 2.4 to 6.9 percent and carried nitric acid corresponding to from 4 to 10 percent of the total. These nitrates were formed in the soil where we found them. They were not brought in from other land nor up from below. We have had very many instances similar to this. Of disappearances we have also seen instances. One of the richest spots that I have seen involved the bank of a canal, the public road and a portion of an adjoining field. The nitric acid in the soil scraped off the surface of this spot corresponded to the presence of 13 percent of sodic nitrate. Several years lapsed between my visits to this spot. One of our fieldmen asked me while visiting in that section to show him a typical occurrence of nitre. We sought out this spot. The neighboring field had a fairly good growth of vegetation and the spot had practically disappeared. In another instance I visited a field formerly very bad indeed, the nitric acid present corresponding to 13 tons of sodic nitrate in the top 3 inches of soil per acre. It had entirely disappeared.

On the different sections of our station farm I have seen in different seasons 4-pound beets with 7-pound tops due to an excess of nitrates. We have had 5 to 12 percent, also 15 to 16 percent sugar in crops of different seasons. These differences were attributed to the different supplies of nitrates during the respective seasons. The possibility of such varying conditions must be borne in mind in venturing any interpretation of such facts as present themselves in this study of nitrogen changes. Neither the total nor the nitric nitrogen in the soil is a fixed quantity. The nitric nitrogen is constantly changing and so is the total nitrogen but very much more slowly.

Our table shows that from 10 Oct., 1927, to 13 March, 1928, there was an increase in the total nitrogen in our soil. Of 24 samples taken on 12 Nov., 1927, and 13 March, 1928, every one shows an increase in total nitrogen over that present on 10 Oct., 1927.

On 13 March six additional samples were included and these become the initial members of the subordinate series. Every one of the 18 samples taken 27 April, 1928, shows a decrease in the amount of total nitrogen. From this date till 5 Oct., 1928, the rule is that the total nitrogen is below that of the initial samples. This is true of both the 3-inch and the deeper, 4 to 12-inch, samples. This is not the case with the nitric nitrogen, which does not fall below the initial samples except in cases where we added fertilizers till 18 May, 1928, when they are only slightly below the initial samples, with some samples showing an increase over them. This state of affairs continues till the end of the season. The nitrates remain quite high throughout the season as is best shown in Table 4.

THERE IS A LOSS OF TOTAL NITROGEN

The total nitrogen remained lower than in the initial samples. This does not mean that there was no variation in them, but simply that only exceptionally did they exceed the initial samples. Perhaps the best illustrations of this in the table are the samples designated S. E. Alfalfa and S. Fallow, which may at the same time serve another purpose in that they furnish a comparison of the most favorable case for the alfalfa with a contiguous fallow. The nitrogen in the initial samples is quite high, .1386 and .1400 in the respective 3-inch samples and .1484 and .1393 in the 4 to 12-inch samples. These are the highest percentages appearing in the series taken 10 Oct., 1927, and are very high for this land. All four samples showed an increase on 12 Nov. and also on the next sampling 13 March, 1928, but by 27 April, 1928, there was a decided loss of total nitrogen. The 3-inch sample from the alfalfa plot showed an increase of .0133 from .1386 to .1519 from 10 Oct. to 12 Nov., 1927, and from 10 Oct., 1927 to 13 March, 1928, there was a gain of .0084 or from .1386 to .1470 but from 12 Nov., 1927, to 13 March, 1928, there had been a loss, .0049. The gain actually occurred between 10 Oct. and 12 Nov., 1927, and there was a loss between 12 Nov., 1927, and 13 March, 1928, but this loss was less than the gain from 10 Oct. to 12 Nov. The corresponding samples of the fallow showed a gain of .0056 in Nov. and this increased to .0070 by March, 1928, but by 27 April, 1928, both sets of samples, 3 and 9-inch samples of both the alfalfa and fallow, had fallen below the initial samples. The alfalfa 3-inch sample gained .0133 by 12 Nov. and fell to .0014 below the initial sample by 13 March or a loss of .0147 between these dates; the 9-inch sample gained .0028 by 12 Nov. and fell to .0196 below the initial by 27 April, 1928, making a loss of .0224 in this time. The 3-inch section of the fallow showed its biggest gain on 13 March, 1928, of .0070; by 27 April it had fallen to .0156 below the initial, or a variation of .0226; the 9-inch sample gained between the dates just given, .0112, and by 27 April had fallen to .0191 below or a variation of .0303 percent. It will be observed that the gains in total nitrogen are practically confined to the period before 13 March, 1928, and from this date on the total nitrogen was as a rule less than in the original or initial sample. There were variations from sampling to sampling but they seldom rose to the level of the original. The results explained represent in general the amount of variation in the total nitrogen for the year over which our observations extended. Our greatest losses were in June, July and August. In the latter part of September and in October there was an upward tendency but the total nitrogen was still below that of a year before. There was less variation in the nitric nitrogen but the customary unit is small, usually one ten-thousandth of 1 percent. The averages for the surface foot on 10 Oct. 1927, the beginning of these observations, for 25 July, 1928, about the middle, and for 5 Oct., 1928, the end of our experiment, are given in Table 6.

TABLE 6.—Some Averages for the Nitric Nitrogen in the Surface Foot of Soil.

	10 Oct. 1927 p.p.m.	15 July, 1928 p.p.m.	5 Oct. 1928 p.p.m.
N. W. Alfalfa	18	14	28
N. Fallow	12	7	10
N. E. Clover	20	15	18
S. E. Alfalfa	16	22	29
S. Fallow	15	14	24
S. W. Clover	15	17	25

In the case of the N. fallow, on 15 July 1928 alone is the amount of nitric nitrogen below the usual maximum for good agricultural land but we were concerned not with the absolute amount but with the deportment of the different plots in its formation. The table is clearly divided into two groups, the north and south. In both groups the alfalfa land was a little more favorable than the others but in the south group the difference is of no practical importance owing to the liberal quantities present. In the north fallow on 15 July, 1928, the difference might have had some practical significance. Nineteen hundred and twenty-eight was the third successive season that this land had been fallow and it was the first season for the alfalfa land.

As stated elsewhere both fallows suffer from this disadvantageous condition for the easily nitrifiable nitrogenous organic matter has certainly diminished during the previous seasons and perhaps even approached its stable lower limit. The south fallow, however, both at the beginning of our experiment, 10 Oct., 1927, and at the end, 5 Oct., 1928, shows that neither the alfalfa nor the clover has produced any marked effect upon the process and that the differences in the two series of plots were as important as any other factor. We have made no allowances for temperatures, rains or irrigations but have assumed that these had the same and equal influence on all plots, which is not strictly justified. Our problem is distinct from but not altogether independent of this detail and while our results may have been modified in some measure, their bigger features, with which alone we endeavor to deal, appear plainly, i. e., the influence of the crops upon these questions is much less than we had hoped to find and not of the same character.

The continued loss of total nitrogen throughout the season and the very moderate increase in the nitric nitrogen with only comparatively small variations were not anticipated. The deportment of the south fallow in particular indicates that the influence of the crops has not changed very greatly, the usual processes going on in the soil so far as the nitrogenous compounds are concerned. The growth of our wheat after fallow compared with that of the same variety of wheat after clover and alfalfa (see Part III of this bulletin), bears the same testimony.

EFFECTS OF ROTATION ON NITROGEN QUESTIONS

Stated briefly, the principal purpose of this section of our work was to study the effects of alfalfa and clover on the variations of the total and nitric nitrogen in comparison with those taking place in fallow ground date by date and under the same conditions of temperature and moisture. These changes run parallel and are so similar that we are compelled to consider their influence in this direction negligible during the year following the plowing under of heavy crops. In this comparison we have two plots each of clover, alfalfa and fallow. The clover and alfalfa had stood two seasons and the crops were plowed under at the end of the second season. This land was cultivated fallow during the third season. We considered this the most favorable condition that we could produce for this soil, and it is an imitation of a very common practice. On the other hand, this compelled us to compare land that was being cultivated fallow for the third successive season with land cultivated fallow for the first season, a condition which we did not desire but could not well avoid.

We cannot justly compare the south plots with the north plots. A glance at the preceding table will show that to compare the S. Fallow with the N. W. Alfalfa would present them as almost exactly equal in regard to the nitric nitrogen present. The total nitrogen content and soil conditions in general are different in the two plots. Why these things are so and are so persistent we have not found out. The history of the two sets of plots has been the same for a number of years—20 years at least.

THE EFFECT OF AMENDMENTS

In some former field experiments we observed that a plot to which superphosphate had been added was richer in total nitrogen than the others. This suggested a possible action of the superphosphate. The simple fact that the plot showed more nitrogen than the others proved nothing for the plot may have had more nitrogen in it than the other plots before this addition. To test this matter we added some rock superphosphate to one plot which had been fallow for 2 years, ground rock phosphate to another which was fallow but had been in corn the previous year, and gypsum to a third which had been fallow for 2 years. Observations were made on these plots just as our field observations were made on the others. The variations of the total nitrogen in these plots were parallel to those to which no amendment had been added. This series of observations began with the samples of 13 March, 1928. There are no observations pertaining to this series corresponding to those on the field samples of 10 Oct. and 12 Nov., 1927.

The results are given in the general table and constitute the last six members. It will be noted that the loss of total nitrogen was parallel with that in the case of the field samples but the loss in nitric nitrogen was more general and larger in amount, and gypsum is perhaps a little more efficient in these respects than the superphosphate which contains calcic sulfate as well as the gypsum.

The object had in view in adding gypsum was to obtain some idea of what part the calcic sulfate in the superphosphate might play. It seems that we could not explain our former observation by attributing a possible increase of nitrogen to the application of superphosphate. Attention is again directed to the fact that these additions were on fallow land.

INCUBATION EXPERIMENTS

Field experiments may be interfered with by a variety of things. Fortunately ours ran their courses smoothly. Incubation experiments on the other hand can be controlled and are exempt from some if not all of the accidents that may befall a field experiment. The field experiment gives the results that the cultivator actually meets with but we are more interested in the unmodified course of events. For this purpose we created our own conditions and incubated the soils. We have presented the course of the changes in the nitrogen in the soil and we shall next examine the results obtained by incubation.

The fixation of nitrogen and its nitrification are not the only biological activities going on in the soil but they are the only ones that it was practical for us to attempt to measure. It is customary to attach prime importance to these processes while the others are not so generally emphasized. In the field we have variations in the sunshine, winds, temperature, moisture and a varying depth of earth mulch. It is possible that the nitrates may be moved below the 3 inches to which depth we took our first section and even below 9 inches, the depth of our deeper sample. These dangers of translocation do not appear in the incubation tests. Besides the light or absence of it, the moisture and temperature, 27°C, are constant. The total duration of our incubation was 40 days, about one-sixth as long as our land generally remains unfrozen. It is not intended to intimate that biological activities in the soil are suspended by freezing but they are in some measure abated and our sampling was practically prohibited. In the principal series of incubations no amendments were added; these experiments were imitations of what was taking place in the field. The samples were air-dried, rubbed up and sifted to obtain an even mixture, placed in a moist chamber that conveniently held 1250 grams of soil and the moisture brought up to 17 percent. These dishes were placed in a chamber kept in a room whose atmosphere was free from ammoniacal and nitrous fumes. No chemical work was done in this room and no flames were kept burning in it as there is in a work room.

The samples were taken with the greatest care to obtain representative ones. Of the 3-inch samples, 20 subsamples were united to form the composite one and 12 subsamples of the 9-inch ones were united. All determinations were made in duplicate which of itself indicates that they were carefully made. Whatever our results may be we have no excuses to offer for them. We believe that they represent what would take place in the field under favorable and constant conditions. The results obtained are given in the following tables.

TABLE 7.—Incubation Experiments for Fixation and Nitrification of Nitrogen, in Percentages.

		10 October, 1927						12 November, 1927					
		Original		30 Days		40 Days		Original		30 Days		40 Days	
		Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric
N.W. Alfalfa	0-3″	.1246	.0008	.1218	.0036	.1309	.0042	.1300	.0019	.1351	.0037	.1253	.0043
	4-12″	.1246	.0021	.1344	.0056	.1337	.0058	.1288	.0026	.1397	.0041	.1268	.0049
N. Fallow	0-3″	.1036	.0007	.1118	.0024	.1176	.0023	.1183	.0018	.1204	.0030	.1190	.0030
	4-12″	.1050	.0014	.1106	.0032	.1148	.0032	.1092	.0018	.1190	.0033	.1160	.0039
N.E. Clover	0-3″	.1120	.0007	.1127	.0026	.1218	.0048	.1218	.0021	.1190	.0036	.1274	.0037
	4-12″	.1246	.0025	.1218	.0056	.1309	.0054	.1246	.0023	.1302	....	.1169	.0037
S.E. Alfalfa	0-3″	.1386	.0007	.1414	.0034	.1128	.0036	.1519	.0027	.1372	.0039	.1358	.0050
	4-12″	.1484	.0019	.1456	.0058	.1547	.0062	.1512	.0034	.1393	.0053	.1351	.0061
S. Fallow	0-3″	.1400	.0009	.1400	.0032	.1421	.0032	.1456	.0032	.1365	.0042	.1337	.0054
	4-12″	.1393	.0017	.1435	.0040	.1407	.0040	.1400	.0031	.1344	.0044	.1253	.0051
S.W. Clover	0-3″	.1184	.0007	.1477	.0036	.1421	.0034	.1484	.0024	.1323	.0041	.1260	.0045
	4-12″	.1421	.0018	.1470	.0060	.1481	.0056	.1456	.0029	.1475	.0045	.1442	.0054
Super-phosphate	0-3″	....	....	....	....	....	....	.1106	.0021	.1148	.0037	.1167	.0038
	4-12″	....	....	....	....	....	....	.1148	.0025	.1141	.0040	.1190	.0044
Rock Phosphate	0-3″	....	....	....	....	....	....	.1260	.0012	.1309	.0029	.1309	.0036
	4-12″	....	....	....	....	....	....	.1267	.0010	.1239	.0031	.1281	.0037
Gypsum	0-3″	....	....	....	....	....	....	....	....	....	....	....	....
	4-12″	....	....	....	....	....	....	....	....	....	....	....	....

TABLE 7—Continued

		13 March, 1928						27 April, 1928					
		Original		30 Days		40 Days		Original		30 Days		40 Days	
		Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric
N.W. Alfalfa	0-3″	.1267	.0032	.1309	.0052	.1302	.0058	.1155	.0016	.1092	.0034	.1176	.0040
	4-12″	.1308	.0030	.1360	.0052	.1302	.0057	.1169	.0047	.1106	.0050	.1240	.0056
N. Fallow	0-3″	.1190	.0022	.1239	.0034	.1197	.0045	.1029	.0007	.0980	.0024	.1064	.0026
	4-12″	.1106	.0020	.1169	.0030	.1099	.0044	.0924	.0014	.0910	.0030	.1008	.0034
N.E. Clover	0-3″	.1218	.0028	.1190	.0038	.1190	.0054	.1078	.0014	.0994	.0034	.1064	.0038
	4-12″	.1309	.0030	.1274	.0050	.1253	.0062	.1134	.0042	.1078	.0050	.1148	.0054
S.E. Alfalfa	0-3″	.1470	.0032	.1459	.0040	.1428	.0060	.1372	.0018	.1306	.0038	.1358	.0038
	4-12	.1505	.0034	.1456	.0058	.1414	.0066	.1288	.0031	.1300	.0054	.1316	.0056
S. Fallow	0-3″	.1470	.0028	.1470	.0044	.1358	.0056	.1300	.0009	.1218	.0032	.1246	.0034
	4-12″	.1505	.0020	.1316	.0026	.1239	.0047	.1204	.0021	.1232	.0040	.1246	.0044
S.W. Clover	0-3″	.1505	.0028	.1414	.0048	.1379	.0066	.1288	.0016	.1300	.0054	.1316	.0050
	4-12″	.1407	.0026	.1449	.0044	.1491	.0058	.1330	.0028	.1330	.0062	.1330	.0056
Super-phosphate	0-3″	.1141	.0022	.1106	.0042	.1141	.0046	.1050	.0008	.1022	.0038	.1022	.0038
	4-12″	.1134	.0018	.1099	.0041	.1136	.0048	.1064	.0016	.1008	.0048	.1022	.0044
Rock Phosphate	0-3″	.1281	.0012	.1288	.0038	.1267	.0042	.1120	.0006	.1120	.0034	.1148	.0034
	4-12″	.1211	.0008	.1158	.0044	.1232	.0038	.1120	.0010	.1120	.0036	.1120	.0038
Gypsum	0-3″	.1218	.0022	.1190	.0042	.1232	.0048	.1064	.0006	.1064	.0028	.1036	.0030
	4-12″	.1225	.0020	.1158	.0047	.1246	.0049	.1120	.0014	.1148	.0042	.1092	.0044

		15 June, 1928						4 August, 1928					
		Original		30 Days		40 Days		Original		30 Days		40 Days	
		Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric
N.W. Alfalfa	0-3″	.1232	.0014	.1246	.0032	.1162	.0028	.1190	.0024	.1176	.0040	.1176	.0044
	4-12	.1176	.0024	.1232	.0040	.1162	.0036	.1190	.0016	.1162	.0030	.1148	.0036
N. Fallow	0-3″	.1036	.0008	.1120	.0020	.1022	.0022	.1050	.0015	.1064	.0028	.1036	.0028
	4-12″	.0924	.0006	.0940	.0018	.0910	.0018	.0938	.0007	.0952	.0020	.0938	.0022
N.E. Clover	0-3″	.1050	.0013	.1106	.0026	.1008	.0028	.1061	.0021	.1078	.0032	.1078	.0036
	4-12″	.1092	.0016	.1120	.0030	.1036	.0030	.1078	.0018	.1078	.0034	.1120	.0036
S.E. Alfalfa	0-3″	.1372	.0016	.1456	.0028	.1330	.0032	.1288	.0028	.1316	.0044	.1386	.0042
	4-12″	.1344	.0022	.1386	.0034	.1274	.0038	.1274	.0019	.1240	.0038	.1330	.0042
S. Fallow	0-3″	.1274	.0011	.1358	.0024	.1274	.0026	.1274	.0022	.1232	.0034	.1330	.0040
	4-12″	.1120	.0016	.1246	.0026	.1176	.0030	.1134	.0012	.1148	.0030	.1232	.0032
S.W. Clover	0-3″	.1302	.0016	.1428	.0032	.1288	.0034	.1274	.0022	.1288	.0038	.1414	.0046
	4-12″	.1316	.0018	.1358	.0038	.1274	.0040	.1162	.0017	.1218	.0042	.1302	.0036
Super-phosphate	0-3″	.1036	.0012	.1078	.0028	.1092	.0028	.1022	.0018	.1162	.0032	.1022	.0030
	4-12″	.1022	.0016	.1078	.0028	.1078	.0028	.0994	.0010	.1092	.0022	.0980	.0024
Rock Phosphate	0-3″	.1134	.0010	.1218	.0022	.1190	.0026	.1134	.0018	.1120	.0028	.1092	.0030
	4-12″	.1120	.0010	.1162	.0024	.1134	.0026	.1106	.0012	.1008	.0028	.1078	.0026
Gypsum	0-3″	.1064	.0008	.1092	.0018	.1176	.0022	.1064	.0016	.0980	.0026	.1050	.0028
	4-12″	.1120	.0015	.1148	.0036	.1092	.0036	.1036	.0012	.1106	.0028	.1078	.0028

TABLE 12—Continued.

		25 September, 1928					
		Original		30 Days		40 Days	
	Inches	Total	Nitric	Total	Nitric	Total	Nitric
N.W. Alfalfa	0-3″	.1232	.0028	.1232	.0036	.1274	.0044
	4-12″	1176	.0019	.1302	.0038	.1288	.0038
N. Fallow	0-3″	.1064	.0017	.1106	.0030	.1106	.0030
	4-12″	.0938	.0008	.1050	.0022	.1064	.0024
N.E. Clover	0-3″	.1092	.0021	.1162	.0030	.1162	.0038
	4-12″	.1078	.0015	.1078	.0032	.1134	.0034
S.E. Alfalfa	0-3″	.1456	.0037	.1428	.0032	.1358	.0045
	4-12″	.1330	.0029	.1372	.0036	.1344	.0044
S. Fallow	0-3″	.1344	.0033	.1372	.0038	.1316	.0040
	4-12″	.1246	.0017	.1274	.0028	.1246	.0034
S.W. Clover	0-3″	.1372	.0029	.1442	.0034	.1414	.0044
	4-12″	.1330	.0022	.1386	.0038	.1316	.0038
Super phosphate	0-3″	.1232	.0028	.1064	.0038	.1050	.0036
	4-12″	.1064	.0010	.1022	.0024	.1064	.0022
Rock Phosphate	0-3″	.1232	.0020	.1176	.0034	.1218	.0034
	4-12″	.1218	.0014	.1176	.0034	.1190	.0032
Gypsum	0-3″	.1120	.0020	.1106	.0030	.1162	.0030
	4-12″	.1148	.0012	.1106	.0028	.1176	.0028

TABLE 8.—Gains and Losses of Total and Nitric Nitrogen in Incubation Experiments, p.p.m.

		10 Oct., 1927				12 Nov., 1927			
		30 days		40 days		30 days		40 days	
		Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric
N.W.	0-3″	—18	28	63	34	51	18	—47	24
Alfalfa	4-12″	98	35	91	37	9	15	—20	23
N.	0-3″	112	17	170	21	21	12	7	12
Fallow	4-12″	56	18	98	18	94	15	14	21
N.E.	0-3″	107	19	98	41	—28	15	56	16
Clover	4-12″	—28	31	63	29	56	0	—77	34
S.E.	0-3″	28	27	42	29	—127	12	—161	23
Alfalfa	4-12″	28	39	63	43	—119	19	—161	27
S.	0-3″	0	24	21	24	—91	10	—119	22
Fallow	4-12″	42	23	14	23	—56	13	—147	20
S.W.	0-3″	— 7	29	—63	27	—161	17	—224	21
Clover	4-12″	49	42	63	38	19	16	—14	25
Super-	0-3″	....	....	....	....	34	16	63	17
phosphate	4-12″	....	....	....	....	— 4	15	42	29
Rock	0-3″	....	....	....	....	49	17	49	24
Phosphate	4-12″	....	....	....	....	—28	21	14	27
Gypsum	0-3″	....	....	....	....	....	....	....	....
	4-12″	....	....	....	....	....	....	....	....

TABLE 8, Continued.

		13 March, 1928				27 April, 1928			
		30 days		40 days		30 days		40 days	
		Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric
N.W.	0-3″	42	20	35	26	63	18	21	24
Alfalfa	4-12″	51	22	—7	27	—63	3	34	9
N.	0-3″	49	12	7	23	—49	17	45	19
Fallow	4-12″	63	10	93	24	—14	16	84	20
N.E.	0-3″	—28	10	—28	26	—84	20	—14	24
Clover	4-12″	—35	20	—59	32	—36	8	14	12
S.W.	0-3″	—11	8	—42	28	—66	20	—14	20
Alfalfa	4-12″	—49	24	—91	32	12	23	28	25
S.	0-3″	0	16	—112	28	—82	23	—54	25
Fallow	4-12″	—189	6	—266	17	28	19	42	23
S.W.	0-3″	—91	20	—126	38	12	38	24	34
Clover	4-12″	42	18	84	32	0	34	0	28
Super-Phosphate	0-3″	—35	20	0	24	18	30	18	30
	4-12″	—35	23	2	30	—56	32	—42	28
Rock Phosphate	0-3″	7	22	—14	30	0	28	28	28
	4-12″	—53	36	21	30	0	26	0	26
Gypsum	0-3″	—28	20	14	26	0	22	—28	24
	4-12″	—67	27	21	29	28	28	72	30

		15 June, 1928				4 Aug., 1928			
		30 days		40 days		30 days		40 days	
		Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric
N.W.	0-3″	14	18	—70	14	—14	16	—14	20
Alfalfa	4-12″	56	16	—14	12	—28	14	—42	20
N.	0-3″	84	12	86	14	14	13	—14	13
Fallow	4-12″	16	12	—14	12	14	13	0	15
N.E.	0-3″	56	13	—42	15	10	11	10	15
Clover	4-12″	28	14	—56	14	0	16	42	18
S.E.	0-3″	84	12	—42	16	28	16	98	14
Alfalfa	4-12″	42	12	—70	16	—14	19	56	23
S.	0-3″	84	13	0	15	42	12	56	18
Fallow	4-12″	126	10	56	14	14	18	98	20
S.W.	0-3″	106	16	—14	18	14	16	140	24
Clover	4-12″	42	20	—42	22	56	25	140	10
Super-Phosphate	0-3″	42	16	56	16	140	14	0	12
	4-12″	56	12	56	12	98	12	—14	14
Rock Phosphate	0-3″	84	12	56	16	14	10	—42	12
	4-12″	42	14	14	16	—98	16	—28	14
Gypsum	0-3″	28	10	112	14	—84	10	—14	12
	4-12″	28	21	—28	21	70	16	42	16

TABLE 8—Continued.

		25 Sept., 1928							
		30 days		40 days		30 days		40 days	
		Total	Nitric	Total	Nitric	Total	Nitric	Total	Nitric
N.W. Alfalfa	0-3″	0	8	42	16				
	4-12″	126	19	112	19				
N. Fallow	0-3″	42	13	42	13				
	4-12″	112	14	126	16				
N.E. Clover	0-3″	70	9	70	17				
	4-12″	0	17	56	19				
S.E. Alfalfa	0-3″	—28	—5	—98	8				
	4-12″	42	7	14	15				
S. Fallow	0-3″	28	5	—28	7				
	4-12″	28	11	0	17				
S.W. Clover	0-3″	70	5	42	15				
	4-12″	56	16	—14	16				
Super-Phosphate	0-3″	—228	10	—182	8				
	4-12″	—42	14	0	12				
Rock Phosphate	0-3″	—56	14	—14	14				
	4-12″	—42	20	—28	18				
Gypsum	0-3″	—14	10	42	10				
	4-12″	—42	16	28	16				

The gains and losses in the table for the incubation sets are of course calculated for the samples taken on the date given. The general course of developments is, however, evident. The samples taken 10 Oct., 1927, showed in three instances moderate loss of nitrogen whereas nine showed no loss and some of them rather heavy gains at the end of 30 days, and only one showed a loss at the end of 40 days. The nitric nitrogen gained in all these rapidly. In the November samples the tendency to loss of total nitrogen was decidedly marked in both periods and the gains in nitric nitrogen were smaller though all samples showed gains. The April samples showed the tendency to lose total nitrogen still more strongly and the gains in nitric nitrogen were again smaller, but were not insignificant. The June samples showed no losses in total nitrogen at the end of the 30-day period. On the contrary, all samples gained and there were moderate increases in nitric nitrogen throughout the series. At the end of the 40-day period, however, nine of the twelve samples had lost total nitrogen but the gains in nitric nitrogen were still significant. The August samples show much less tendency to less of total nitrogen and the gains in nitric nitrogen were a little higher perhaps than in June. The September samples show a single instance of loss of total nitrogen at the end of the 30-day period and two at the end of the 40-day period.

While the quantities are not identical, the course of the changes is parallel to those observed in the field, namely, an increase in the total nitrogen from Oct., 1927 till March, 1928, followed by a period of loss extending till near the end of the season when there was a tendency to increase again. The course of the nitric nitrogen in the field was fairly even with a downward tendency till Sept. when there was an irregular increase. In the incubation series the quantities are larger but the general course is the same, namely, a decrease from April till June and then a tendency to increase.

ADDITION OF FERTILIZERS

In the incubation tests there was a preliminary test started with the addition of amendments on 10 Oct., 1927. The results of this test may be given to indicate what may be expected and for its cumulative value. There were five members in the series, two representing the originals and three to which amendments were added.

Number 1 was soil that had been cultivated fallow for the two preceding seasons; No. 2 was fallow at the time the sample was taken but had been planted to corn (maize) the preceding season. These are the original samples. No. 3 is the same as No. 1 with the addition of rock superphosphate, 0.07 percent. No. 4 is the same as No. 2 with the addition of ground rock phosphate, 0.075 percent. No. 5 was the same as No. 2 with 0.075 percent of gypsum added.

TABLE 9.—Preliminary Incubation Experiments with Addition of Amendments.

		Nitrogen Original	Nitrogen after 30 days	Gain	Nitrogen after 40 days	Gain
No. 1	Total	.1106	.1162	.0056	.1176	.0076
	Nitric	.0021	.0026	.0005	.0024	.0003
No. 2	Total	.1148	.1316	.0168	.1253	.0105
	Nitric	.0012	.0005	—.0007	.0007	—.0005
No. 3	Total	.1106	.1120	.0014	.1134	.0028
	Nitric	.0021	.0038	.0017	.0039	.0018
No. 4	Total	.1148	.1260	.0112	.1232	.0084
	Nitric	.0012	.0035	.0023	.0038	.0026
No. 5	Total	.1148	.1141	—.0007	.1092	—.0056
	Nitric	.0012	.0044	.0032	.0048	.0036

With the exception of the soil to which gypsum was added we have gains in the total nitrogen and only No. 2, one of the original samples, shows any recession in the nitric nitrogen. The nitric nitrogen was only moderately abundant for these soils to begin with. This sample was taken in a fallow after corn. This land will not be discussed in this bulletin but some features of its deportment toward the growth of wheat have been given in Part III of this study. It must be considered that this is only a preliminary series and too much importance is not to be attached to the results but it is interesting to note that the gain in total nitrogen was reduced by both the superphosphate and the ground rock phosphate and converted into a loss by the gypsum but the gains in nitric nitrogen were increased. Subsequent observations do not support the latter statement.

These experiments were repeated in the field with soils No. 1 and 2. The phosphate was applied 10 Oct., 1927, but the gypsum not till April, 1928, and then to land that had been fallow during the two preceding seasons so this was the third season in fallow for this land. The results obtained in the field experiments have been given as the last six members of Tables 4 and 5, and those obtained in the series of incubations constitute the last six members of Tables 7 and 8. An examination of the table of gains and losses, Table 8, will bring out that the samples of June and August show the low points in the amount of nitric nitrogen, while August and the first 30-day period of September, the low point for the total.

We know nothing about the development of bacteria not involved in fixation and nitrification in these samples. The only count that we have, giving us any light upon this subject, is a single count which showed that the addition of superphosphate had increased the number by 75 percent. We know nothing about this relation in our incubation experiments. We know only the gross result in terms of total and nitric nitrogen and that these changes have taken place in the soil and are due to biological agencies. The general result is that none of these amendments caused a marked and constant increase in the fixation of nitrogen but at seasons caused, or at least was accompanied by, a loss of total nitrogen. The gains in nitric nitrogen are relatively higher than in the regular field samples because the initial quantities present were smaller, but the general parallelism between the two series is sufficient to confirm one another and with this, the field experiments.

FIXATION AND NITRIFICATION VARY FROM YEAR TO YEAR

We are convinced from long observation that there are considerable, if not great, annual variations in the increase and decrease of the nitrogen compounds in the soil, and that only repeated observation, covering a series of years, can give the definite relations of these changes to the effects produced in the soil by a rotation of alfalfa or other legume. We further believe that the results here presented force us to conclude, somewhat against our former conviction, that these crops do not add nitrogen to the soil, and that they do not increase, in a period of 1 year after the crops are plowed under, the amount of fixation that takes place, but rather favor the loss of nitrogen (see Table 5). Further, they do not promote the nitrification after the first few weeks.

We interpret our results as indicating that other factors common to both the fallow and cropped land have controlled these processes during the time of our observations, i. e., that there was some seasonal condition that determined the results obtained. Had these experiments been made some other year, we might have obtained different results. There is a periodicity in these conditions but how long the cycle may be, or what conditions determine it, we do not know. This view is also suggested by the varying sugar content of beet crops grown on this land, some years 8 or 10 percent as a maximum, others 16 percent. The growth of the crops was in harmony with the harvest results.

WATER-SOLUBLE POTASSIUM IN SOIL SAMPLES OF 1928

In Bulletin 319 of this station, Part I of this study, we present first the effect of crops upon the carbon dioxid content of the soil atmosphere. This subject is greatly extended in Part II. In the second section of Part I we present the action of carbon dioxid on the principal mineralogical constituent of the soil studied, viz., felspar. It is there shown that its action is to eliminate potash, K_2O, principally under ordinary conditions, and that the presence of other salts, especially chlorids, increases the action. These two facts led us to study the amount of water-soluble potassium in these soils and the results are given in Part II. It was found that water dissolved much more, twice as much, potassium out of the soil in which alfalfa was growing as out of the fallow check plot.

During this work other surprising relations were revealed. One of these was that the land varied greatly in the amount of water-soluble potassium that it would yield to a standard method of treatment. The plot had in mind was practically divided in two by an east and west line. This plot was in alfalfa. The north half always yielded more potassium to water than the south half. This fact necessitated a knowledge of the respective plots and considerable care in sampling. The method used in determining the potassium was, as stated elsewhere, one devised by the Bureau of Soils of the United States Department of Agriculture. The results found in 1927 are given in Part II and those of 1928 follow. The determination of the instantaneously soluble nitric nitrogen was added to that of the water-soluble potassium in the 1928 series.

The samples for these potassium and nitric nitrogen determinations were not taken on the same dates nor to the same depths as those given in preceding tables devoted wholly to the discussion of the nitrogen questions. The results given in the former tables were obtained by using large samples and treating them in a manner aimed to give us the whole of the nitric nitrogen present and the sampling was confined to the first 12 inches divided in two sections of 3 and 9 inches each. The samples in the potassium series were taken with just as great care as were those for the nitrogen series, each sample as given being composed of two subsamples. The samples represent 6 inches of soil in each case, the first and fourth 6 inches. The surface 6 inches were taken because we find the greatest changes so far as the nitrogen is concerned within this depth. Carbon dioxid is least abundant in this zone, possibly due to diffusion into the atmosphere, though we have no conclusive proof that this is the cause. We endeavored to show this by covering the ground with an air-tight covering and creating a limited atmosphere between the covering and the soil. The covering was double and each layer was water-proof and if we did not succeed perfectly in preventing diffusion into the air we should have impeded it to such an extent that we should have found large amounts of carbon dioxid in this limited atmosphere. We did not find this to be the case. This is the reason why we have not assigned diffusion as the cause of the regularly smaller amounts of carbon dioxid in the soil atmosphere to a depth of 6 inches than at greater depths. The fourth 6 inches were chosen because we had lysimeters at a depth of 18 inches. In the series of 1927 we found regularly much more water-soluble potassium under the growing alfalfa than in the fallow land and at the same time very much more carbon dioxid, three and four times as much. We wished to learn if possible how this matter stood in fallow ground succeeding alfalfa, also clover.

The results given for nitric nitrogen in this series are not comparable with those given in the preceding series of samples because they do not represent the same sections, were not taken at the same time, i. e., on the same dates, and were determined by different procedures. They are not for this reason of less interest, but rather of more, because they give us different views of the question which is the more valuable as they are actually parallel to as great an extent as the depth and methods used justify one in expecting.

There are no other water-soluble potassium determinations for the year 1928 than those presented in the following tables. The method of extraction is an empirical one, made in exactly the same way each time and the results give the amount of potassium soluble upon this treatment. The same is true of the nitric nitrogen given in this series. The results do not represent anything more than the potassium in the soil that is actually easily soluble and therefore available to plants at the time the samples were taken. We believe that the method gives us this information very satisfactorily, which from a practical standpoint is what we want. It is true that a subsequent extraction of the residual soil in the same manner would give us an additional quantity of potassium but it is less readily soluble than the first portion and not of the same value from the point of availability. The method is the most efficient one that has come to my notice. These statements concerning potassium do not apply so fully to the nitric nitrogen for we find that 30 minutes standing is not sufficient to make a complete extraction of the nitric nitrogen which is wholly available but in comparison with the potassium it is easily extracted.

The following tables give the water-soluble potassium and nitric nitrogen in the land the first year after the alfalfa and clover crops were plowed under, after two seasons occupancy of the ground. In other words, the third season of the experiment all plots were cultivated fallow and the water-soluble potassium and nitric nitrogen in the soil was followed throughout the season, 1928. The fallow plots were again cultivated fallow. This was the third season in fallow and we have the cumulated effects of this practice, some of which by this time are certainly becoming disadvantageous. The results, however, give us a comparison of the conditions in the fallowed land after 2 years cropping to legumes and cultivated fallow. As stated, I think that the conditions tend to place the results of the cropping to legumes in a more favorable light than if we had been able to compare them with a fallow which had been fallowed only one season. How long the effects of a cropping will last has not been determined, so far as I know, but for more than 1 year. On the other hand, fallowing for 1 year may be good but it is a question whether cultivating fallow for three successive seasons may not be too long. In this time the easily changed nitrogen compounds present at the beginning of the fallow may be materially diminished and the formation of nitrates, for instance, lessened. The opposite of this, perhaps an exaggerated case, is presented by the effects of plowing under our crops upon the amount of nitric nitrogen in the soils. Nitrification set in vigorously and then declined.

Tables 10 to 13 inclusive show that the water-soluble potassium is more abundant in the clover and alfalfa land throughout the season after the crops were plowed under than in the fallowed land. For further comparison the averages for the season of 1927 while the crops occupied the land are given. These show several instances in which the soluble potassium was two or more times as great as in the fallow and no individual difference in favor of the fallow exceeds 7 p.p.m. for either section given. These differences persist throughout the succeeding year.

Matters stand differently with the nitric nitrogen. The fallow in 1927 averaged much higher in nitric nitrogen than the cropped land. The amount present was from three to seven times as great as in the cropped land. After the crops were plowed under, 13 Sept., 1927, the nitric nitrogen increased rapidly for a while at the expense of the easily nitrifiable material of the crops. The average amount of nitric nitrogen in the alfalfa plots just before plowing them up was 4.4 p.p.m.; in the clover 3.2 p.p.m., and in the fallow 18.5, taken to a depth of 1 foot. It had increased by 10 Oct. to 17.0 p.p.m. in the alfalfa; to 17.0 in the clover and was 13.5 in the fallow; it increased further in November, when our field sampling ceased till the following March, 1928, when it was still high. It began to fall in April and continued to lose till the following fall. We are not justified in attributing this fall in the nitric nitrogen during this season to the crops plowed under because the fallow plots lost too. This was the case with the total nitrogen also.

TABLE 10.—Water-Soluble Potassium and Nitric Nitrogen in Fallow Plots, 1928, in p.p.m.

	West Fallow							
	0 to 6 Inches				19 to 24 Inches			
	South		North		South		North	
Date	K	N	K	N	K	N	K	N
23 March	30.9	19	27.6	14	19.9	18	17.5	14
4 April	38.1	11	52.4	12	24.1	19	33.6	22
11 April	40.0	11	47.2	14	23.4	18	34.9	19
19 April	22.5	14	24.3	10	13.2	19	14.5	18
25 April	42.4	7	42.4	5	21.4	10	32.5	14
8 May	59.4	4	69.4	4	25.3	13	31.3	14
18 May	32.5	2	42.1	2	23.7	16	40.3	18
24 May	33.8	2	33.8	2	19.9	6	19.2	7
31 May	38.3	1	47.4	1	25.0	12	23.9	14
6 June	17.2	1	32.8	1	16.2	11	26.5	18
13 June	28.6	2	35.4	2	17.3	8	18.9	18
20 June	23.3	6	27.0	4	17.5	14	21.9	24
27 June	31.8	6	32.6	8	15.4	18	18.7	12
5 July	37.9	14	37.7	10	22.2	18	24.2	14
11 July	36.7	2	44.2	5	24.5	2	26.1	6
16 July	28.1	6	34.5	8	25.2	3	23.4	6
25 July	31.5	10	35.5	11	15.6	10	21.7	11
1 Aug.	35.7	10	33.1	10	17.7	3	21.1	2
8 Aug.	28.9	12	29.5	10	15.4	2	18.5	2
16 Aug.	35.1	14	38.7	12	15.9	2	23.1	10
23 Aug.	34.8	13	35.0	2	17.5	2	20.7	2
29 Aug.	45.2	22	21.5	24	36.8	14	29.6	14
5 Sept.	48.6	6	25.1	6	15.5	2	18.3	2
12 Sept.	25.9	6	30.8	6	15.8	2	17.3	2
19 Sept.	30.1	13	32.1	21	19.1	1	29.8	2
26 Sept.	32.0	10	43.5	7	23.1	2	23.3	2

TABLE 10—Continued.

	East Fallow							
	0 to 6 Inches				19 to 24 Inches			
	South		North		South		North	
Date	K	N	K	N	K	N	K	N
23 March	27.0	6	27.7	6	17.3	14	17.6	16
4 April	37.0	16	34.7	14	20.1	19	15.2	11
11 April	34.1	14	34.9	6	19.1	2	18.8	2
19 April	42.8	17	41.3	11	24.0	18	25.8	14
25 April	55.4	6	56.1	6	26.9	14	26.1	18
8 May	39.5	6	39.0	6	23.9	18	19.9	19
18 May	39.4	2	37.7	2	19.1	16	21.1	14
24 May	37.0	1	39.3	1	29.2	10	19.3	6
31 May	31.0	2	30.9	1	16.6	19	18.6	18
6 June	29.9	2	26.4	1	14.9	14	16.6	14
13 June	27.4	3	29.7	2	19.6	16	17.1	16
20 June	29.1	6	34.9	4	15.7	22	14.5	18
27 June	41.4	6	36.7	5	18.1	14	16.8	10
5 July	40.3	12	38.7	11	17.4	18	16.2	10
11 July	35.8	10	29.1	7	18.1	20	15.6	11
16 July	32.1	20	29.3	18	18.7	18	17.8	18
25 July	40.9	32	32.1	11	15.1	18	15.2	16
1 Aug.	27.9	8	32.5	10	15.3	6	14.7	10
8 Aug.	38.4	14	37.3	14	19.1	12	15.6	8
16 Aug.	37.2	14	37.2	16	15.5	14	17.6	11
23 Aug.	41.4	29	40.5	15	23.2	16	20.0	14
29 Aug.	30.1	16	29.4	22	13.3	16	15.8	12
5 Sept.	29.1	10	31.9	6	12.2	6	15.4	6
12 Sept.	38.5	13	27.8	14	14.9	10	11.7	6
19 Sept.	36.1	10	38.0	12	19.4	10	18.8	6
26 Sept.	39.8	22	42.0	22	24.3	14	28.6	10

TABLE 11.—Water-Soluble Potassium and Nitric Nitrogen in Clover Plots, 1928, in p.p.m.

	West Clover							
	0 to 6 Inches				19 to 24 Inches			
	South		North		South		North	
Date	K	N	K	N	K	N	K	N
23 March	40.5	29	23.9	21	21.9	6	20.2	6
4 April	67.1	21	58.5	32	66.5	10	37.0	6
11 April	69.9	29	59.1	35	51.7	6	37.6	3
19 April	49.0	29	47.7	35	43.8	6	33.1	5
25 April	51.6	18	39.8	15	38.3	6	29.9	5
8 May	44.2	27	37.2	19	22.9	6	21.8	3
18 May	52.9	6	48.8	3	68.0	10	38.9	8
24 May	65.0	6	53.6	2	33.1	3	27.9	6
31 May	32.0	6	30.6	3	20.4	6	13.9	5
6 June	57.1	6	50.9	2	57.8	7	43.5	6
13 June	42.6	12	32.2	6	29.6	10	43.9	8
20 June	66.4	18	42.4	14	37.1	18	33.0	18
27 June	49.6	16	56.2	21	39.9	18	18.1	18
5 July	48.9	20	40.9	18	22.4	14	24.6	8
11 July	69.5	37	38.7	6	54.2	19	35.3	8
18 July	39.7	21	24.5	18	27.6	14	20.0	10
25 July	41.9	21	32.6	17	38.1	16	21.3	18
1 Aug.	36.1	18	28.5	13	35.5	12	15.6	6
8 Aug.	52.4	22	40.3	16	35.4	14	28.5	9
16 Aug.	67.4	24	61.4	22	60.7	14	33.2	12
23 Aug.	38.7	22	29.6	14	37.4	9	25.6	6
29 Aug.	45.2	22	21.5	24	36.8	14	29.6	14
5 Sept.	79.6	26	45.5	18	42.3	8	31.3	6
12 Sept.	65.4	21	35.4	20	34.8	10	16.4	6
19 Sept.	71.3	18	47.0	21	53.0	6	24.4	6
26 Sept.	48.5	22	44.3	21	38.8	10	20.3	6

TABLE 11.—Continued

	East Clover							
	0 to 6 Inches				19 to 24 Inches			
	South		North		South		North	
Date	K	N	K	N	K	N	K	N
23 March	21.8	35	30.4	51	11.5	5	54.8	14
4 April	28.8	27	49.3	22	20.3	10	58.2	7
11 April	27.1	10	42.7	14	21.4	3	53.3	6
19 April	19.4	24	29.6	21	13.6	4	20.0	3
25 April	25.5	7	37.3	9	17.2	3	67.2	4
8 May	21.8	19	28.8	10	15.6	6	26.0	6
18 May	21.2	7	29.5	2	16.4	6	71.8	11
24 May	19.0	2	32.2	2	17.9	13	37.2	6
31 May	20.7	6	26.1	6	14.3	8	44.3	8
6 June	18.4	2	23.4	8	12.6	8	18.1	10
13 June	19.1	3	28.8	6	14.7	8	25.1	11
20 June	24.0	10	37.0	14	15.6	20	70.0	18
27 June	28.2	14	36.5	14	16.2	14	37.3	10
5 July	38.9	27	36.8	18	19.8	14	67.4	13
11 July	28.5	14	32.3	7	17.6	18	43.7	16
18 July	33.2	24	31.3	19	24.1	18	39.0	16
25 July	25.1	20	30.2	14	15.1	18	36.1	10
1 Aug.	25.0	18	28.8	11	17.5	6	52.9	10
8 Aug.	37.1	22	32.4	18	14.6	14	34.7	14
16 Aug.	28.7	27	34.0	22	13.6	14	36.3	14
23 Aug.	23.7	6	30.5	10	13.6	10	33.1	10
29 Aug.	20.7	12	28.2	10	10.9	6	30.5	12
5 Sept.	23.2	10	32.4	11	13.5	6	28.8	7
12 Sept.	25.0	22	36.3	18	16.5	8	67.5	10
19 Sept.	27.4	13	39.2	12	19.3	6	46.8	6
26 Sept.	30.6	21	40.2	20	17.7	10	33.9	10

TABLE 12.—Water-Soluble Potassium and Nitric Nitrogen in Alfalfa Plots, 1928, in p.p.m.

	West Alfalfa							
	0 to 6 Inches				19 to 24 Inches			
	South		North		South		North	
Date	K	N	K	N	K	N	K	N
23 March	98.8	52	72.6	27	64.5	6	76.3	10
4 April	51.7	37	58.4	19	29.5	6	103.0	8
11 April	43.8	42	51.3	26	61.8	5	78.1	3
19 April	53.1	42	52.7	42	33.9	6	95.5	6
25 April	38.3	16	54.9	10	44.9	3	86.4	4
8 May	75.1	30	75.5	14	56.2	6	107.0	16
18 May	28.8	6	41.5	2	31.1	10	111.1	18
24 May	24.9	2	29.8	2	30.9	2	69.7	2
31 May	51.2	8	45.3	3	49.5	6	107.0	6
6 June	22.9	1	34.8	2	21.6	6	110.9	8
13 June	30.3	6	39.3	5	27.0	18	68.7	10
20 June	34.1	10	44.5	8	43.1	18	92.3	20
27 June	34.8	20	46.2	20	42.7	14	105.5	16
5 July	34.0	20	51.2	20	38.2	14	72.1	16
11 July	33.3	10	41.4	10	24.2	7	77.1	10
18 July	31.6	6	37.8	10	20.1	2	63.7	14
25 July	38.6	18	45.1	18	31.4	10	73.0	18
1 Aug.	32.0	22	37.4	22	44.0	14	72.3	14
8 Aug.	29.5	14	40.1	14	27.7	6	60.1	10
16 Aug.	34.7	14	39.9	22	27.5	6	84.5	13
23 Aug.	42.0	22	35.7	10	16.2	3	49.1	10
29 Aug.	24.6	14	40.5	26	15.2	2	75.9	15
5 Sept.	24.8	14	29.0	14	30.4	13	59.8	11
12 Sept.	37.5	22	38.7	22	25.8	6	56.1	10
19 Sept.	27.2	32	34.7	16	19.9	6	74.7	6
26 Sept.	34.4	20	47.0	14	23.1	6	59.7	11

TABLE 12.—Continued

	East Alfalfa							
	0 to 6 Inches				19 to 24 Inches			
	South		North		South		North	
Date	K	N	K	N	K	N	K	N
23 March	71.9	51	31.6	18	69.1	2	35.3	4
4 April	65.0	18	57.8	19	42.1	5	59.7	3
11 April	87.8	16	59.2	21	44.6	3	49.9	6
19 April	69.0	16	40.2	18	62.3	7	34.3	3
25 April	95.8	17	64.4	27	76.9	6	48.2	5
8 May	72.9	30	57.9	29	76.0	10	66.2	6
18 May	38.3	6	41.8	3	53.2	10	57.2	8
24 May	52.1	2	43.4	3	25.0	6	30.4	6
31 May	40.8	19	27.1	6	31.4	5	26.0	6
6 June	46.8	8	40.5	2	38.7	14	42.6	12
13 June	51.2	18	29.4	4	49.1	6	48.2	6
20 June	52.4	14	49.3	16	47.1	18	93.5	14
27 June	66.2	14	57.2	16	32.6	10	23.6	16
5 July	72.3	30	67.7	32	68.8	18	66.8	21
11 July	54.9	6	39.7	10	69.8	11	32.7	6
18 July	45.6	14	38.7	10	96.1	10	42.8	10
25 July	52.8	19	50.4	21	40.4	11	65.5	10
1 Aug.	42.9	22	26.9	23	34.3	12	23.7	17
8 Aug.	62.5	20	65.5	16	43.2	8	45.1	6
16 Aug.	68.2	22	42.8	24	44.2	11	39.6	10
23 Aug.	48.8	18	42.6	16	52.9	14	67.7	11
29 Aug.	55.7	27	39.9	18	50.0	14	46.8	8
5 Sept.	64.9	22	42.5	19	47.0	6	31.1	11
12 Sept.	68.1	27	44.2	18	44.7	8	33.0	5
19 Sept.	63.9	22	51.1	22	57.2	8	44.4	6
26 Sept.	73.1	22	42.9	21	69.3	12	40.1	6

TABLE 13.—Average Water-Soluble Potassium and Nitric Nitrogen in Different Plots, 1928, also 1927, in p.p.m.

	West							
	0 to 6 Inches				19 to 24 Inches			
	South		North		South		North	
	K	N	K	N	K	N	K	N
Alfalfa	38.9	19	44.8	15	33.9	8	80.4	11
Clover	53.6	20	41.2	13	40.3	10	27.9	8
Fallow	34.2	20	36.8	13	20.2	10	·24.2	8

	East							
	0 to 6 Inches				19 to 24 Inches			
	South		North		South		North	
	K	N	K	N	K	N	K	N
Alfalfa	60.9	19	46.0	17	52.5	9	45.9	9
Clover	25.5	15	33.2	14	16.2	10	43.6	10
Fallow	36.1	11	35.0	9	18.9	14	18.1	12

The plots were all fallow during 1928 but occupied by the crops given in 1927. Corresponding data for same plots in 1927, crops growing*.

	West							
	0 to 6 Inches				19 to 24 Inches			
	K	N	K	N	K	N	K	N
Alfalfa	30.0	6.5*	44.2	6.5	31.2	2	81.4	2
Clover	45.9	5.0	45.8	5.0	29.2	2	22.0	2
Fallow	35.3	22.0	31.6	22.0	17.2	14	26.8	14

	East							
	0 to 6 Inches				19 to 24 Inches			
	K	N	K	N	K	N	K	N
Alfalfa	60.8	45.0	45.4	4.5	35.2	3	35.8	3
Clover	18.7	3	26.7	3	11.9	3	42.0	3
Fallow	23.2	18.5	22.6	18.5	13.1	12	11.4	12

The K here is the average of the determinations made before the plots were plowed up 13 Sept., 1927.

*These samples represented the whole plots, not the north and south halves. Therefore the amounts are given as the same in the two halves.

MINOR VARIATIONS IN WATER-SOLUBLE POTASSIUM

While the effects of the crops upon the amount of soluble potassium in the land are evident, in that they increased it to double that in the fallow, it is not at all apparent to what the minor variations are due. Rainfall and irrigation may in a slight degree affect the distribution; definite instances of this are not conspicuous. The moisture was determined in every sample and the range for the whole year for the 19 to 24-inch samples of the east alfalfa, is scarcely more than 2 percent, but there are very strong variations in the amount of water-soluble potassium. It must be noted, however, that the moisture is given in percentages while the potassium is given in p.p.m., and 0.5 percent is 5000 p.p.m. This fact, however, does not explain much for we have too many irregularities, i. e., contrary direction of the changes. It does not seem probable that the amount of water that acts on this soil should leach out the potassium to a sufficient extent to account for the variations noted which appear on examination of the tables.

Water percolating through soils is not effective in removing potassium. Drain waters seldom carry more than traces and irrigation waters that carry some potassium have lost it when they reappear as return waters. Such water may have remained in contact with varying soils for a longer time than the rain and irrigating waters can ever be in contact with the surface soils in a cultivated field. These waters may have been more efficient in transferring water-soluble potassium from a higher to a lower horizon than the composition of drain and return waters would lead one to infer.

We have followed the water-soluble potassium for two depths only, the first and fourth 6 inches of the soil. The first 6 inches are frequently much richer in soluble potassium than the fourth. We infer, but do not know, that the potassium is rendered soluble more rapidly near the surface than at greater depths. Our observations show that the first 6 inches are richer than the fourth 6 inches and they in turn much richer than the sixth 6 inches. The soluble potassium decreases from the top 6 inches to a depth of 3 feet. In a section 11 feet deep we found the fourth, fifth, sixth, seventh and eighth poor, the ninth, tenth and eleventh foot decidedly richer. In another section of the same depth the increase in the soluble potassium began in the eighth foot. This distribution of the soluble potassium may have been effected by percolating water. This suggestion is made a little more plausible than it at first seems by the fact that the nitric nitrogen increases at the same time and we have assumed that the nitric nitrogen indicated the limit of the penetration of a given rainfall or irrigation. It may be here stated that the water plane in this land is about 22 feet below the surface, so the nitric nitrogen, for instance, is not likely to be carried into the ground water and lost in this way. A 6-foot section taken from one of our alfalfa plots on 15 Oct., 1926, may illustrate this.

TABLE 14.—Distribution of Water-Soluble Potassium in Alfalfa Soil on 15 Oct., 1926 to a Depth of 6 Feet.

Depth in Inches	6	12	18	24	30	36	42	48	54	60	66	72
p.p.m.	47.9	51.5	42.6	23.9	11.2	10.4	8.8	10.4	15.9	14.3	17.6	18.3
Nitric Nitrogen	4.5		3.5		3		1		1		1	

The nitric nitrogen here given is for composite samples of the same soil.

The soluble potassium in this sampling reached its minimum in the fourth foot. There had been a rainfall of 0.7 inch during the 3 days previous to the taking of these samples. The amount of water might be appealed to account for the excess of 9 p.p.m. in the second 6 inches over the third 6 inches by having moved some from the top 6 inches to the second 6 inches, but this is doubtful.

We made a percolation test through a 15-inch column of soil to see how rapidly the potassium would probably be moved downward through this soil. We used distilled water at room temperature about 15° or 17°C. We repeated the application of water in portions of 2.5 litres 10 times and determined the potassium in the percolate. Two and a half litres of water were equal to a column of 45 inches having a section equal to that of the soil section. This is as much water as would have fallen upon or been added to the soil as irrigation water in about a year and a half.

The first percolate carried 10 p.p.m. of potassium. This shows that the amounts of potassium involved in this movement during the time of our experiment were probably not large enough to deserve consideration and indicates that the present distribution of the potassium is a comparatively permanent one which makes any attempt to account for its irregularities difficult on the basis of a movement of solutions in the soil. There were no experiments made with carbonated water. The only approach we made to this was to ascertain how much more potassium carbonated water would dissolve out of this soil than water free from carbonic acid, following the method used in extracting the soil. The carbonated water dissolved 2.3 times as much as water free from carbonic acid. This is a gain of 130 percent. While this may be a factor in the question it is by no means clear how it is related to the question especially in the soil in place. The amount of carbonic acid in the soil is fairly large and much larger in the alfalfa and clover soils than in the fallow but how great a part it may play in this phase of the question is not made out.

If the data obtained be really applicable and the whole of the potassium taken into solution by 45 inches of water were deposited just below a depth of 18 inches, it would not account for the amounts that we find as it would involve only 19 p.p.m. in 1.5 years. We find very much larger quantities under both the clover and alfalfa, but the fallow shows only small variations.

We have referred to the part possibly played by carbon dioxid or carbonic acid. This again cannot be appealed to as a sufficient and satisfactory cause to account for the variations. This is true, however, our results may be arranged in groups or the average for the whole season be taken. There is a tendency to a period of maximum potassium in the spring, during March and April, then a small falling off in May followed by a rise but not to the level of the spring maximum which is maintained till November when it rises again. No samples were taken during the winter months but the potassium was higher in March than in November. These statements pertain to the plots cultivated fallow. As shown in the last preceding table the cropped land was very much richer in soluble potassium than the fallow and this varied with the crop. The potassium was highest under the alfalfa, next under the clover and least under the fallow. This is the order of abundance of carbon dioxid in the soil air, but the maximal quantities of carbon dioxid and soluble potassium do not fall together, in fact they fall out.

The period of the minimum carbon dioxid under the alfalfa and clover also, is in March and April but it is not marked in the case of the fallow. In 1927, for instance, the maximum in alfalfa land was 267 p. p. 10,000 when the crop was growing vigorously and the minimum was in March, 50 p. p. 10,000. In 1928 when all plots were fallow there was in the alfalfa land 190 p. p. 10,000 in Sept. and 52 parts in March.

The fallow showed 40 p. p. 10,000, 19 Sept., 1927 and 22 p. p. 10,000 on 26 March, 1928. The period of high carbon dioxid is during the growing period, June, July, August and September, but that of high potassium is in March and April after which it comes to a varying but in general only a moderately high level till the late fall when it apparently goes up, beginning in late October or November. This is the general course for all plots.

Carbon Dioxid and Potassium Correlate with the Crop

While there is no close relation observable between the variations in the quantities of soluble potassium in the soil and the carbon dioxid in the soil air, there is a correlation between the different crops; the amount of carbon dioxid in the soil air and the soluble potassium in the soil which is apparent on a comparison of these three factors. The alfalfa fills the soil air with carbon dioxid to a greater degree than the clover and the soluble potassium is greater; so too the clover when compared with the fallow.

Variations in Water-Soluble Potassium Not Due to Sampling

We are usually inclined to make some allowance for variation in the soil samples but we believe the variations cannot be attributed to this cause. We tried to eliminate this error by taking a good many samples, and we believe that the parallelism of the determinations throughout the two seasons that these determinations were made, shows that the variations actually occur in the soil and are not due to sampling.

It is true that we did not make a perfect exhaustion of the soil but the results should, and we believe do, give us the amount of readily soluble potassium with all needful accuracy for the work in hand.

Our object in 1926 and '27 was to find out if possible to what the good effects of alfalfa, or other legume, in a rotation are due. Our object in 1928 was to further establish the work of the preceding 2 years and to ascertain how these plots of land deported themselves, and the persistency of the effect observed in the preceding years.

We did not find any addition of nitrogen by either the clover or alfalfa. We did find a decided increase in the soluble potassium associated with an abundant supply of carbon dioxid by both the clover and the alfalfa.

First Effects on Nitric Nitrogen of Crops Plowed Under

When we incorporated the crops in the soil we added as large an amount of easily nitrifiable organic matter as would ever be added by any ordinary green crop and it was followed by a period of active nitrification. This is well shown by the determinations made on the samples taken for the purpose of following the soluble potassium and also by the larger samples taken to follow the course of the nitrogen. On 23 Sept., 1927, the nitric nitrogen in the west series was, for the top 6-inch samples, averages of north and south halves, alfalfa 6.5 p.p.m., clover 9.0 p.p.m., fallow 22 p.p.m. By 25 Oct. these averages had become 14 p.p.m. for alfalfa, 15.5 for clover, and 18.5 for the fallow. By 22 Nov., the last sampling for the season, we had 28 p.p.m. for alfalfa, 28.5 for clover, and 23.5 for fallow. The next sampling was made 23 March, 1928, when we found 39.5 p.p.m. for alfalfa, 25 p.p.m. for clover and 16.5 for fallow. By the end of April this period of high nitric nitrogen ceased even in the top 6 inches of the soil.

DISTRIBUTION OF NITRIC NITROGEN IN FALLOW PLOTS

There was a marked difference in the cropped and fallow plots. This high nitric nitrogen in the cropped land was largely confined to the top 6 inches while in the fallow plots it was still high at a depth of 2 feet so that the average aggregate quantity was much higher in the fallow than in the cropped land. The average given above for the west alfalfa, top 6 inches, is 39.5 p.p.m. but the average for the fourth 6 inches on this date was 8 p.p.m.; the average for the top 6 inches of the fallow is given as 16.5 p.p.m.; the average for the fourth 6 inches for the same sampling is 16.0 p.p.m. This difference between the cropped and fallow plots in regard to the distribution of the nitric nitrogen persists throughout the season. It is just as marked in the clover ground as in the alfalfa, the average given above for clover on 23 March is 25 p.p.m. for top 6 inches; it was 6 p.p.m. for the fourth 6 inches.

LOSS OF NITROGEN

Our tables for the total nitrogen show a loss varying from date to date but always below the initial amount present after the March samples. There was an increase between Sept., 1927, and March, 1928, but from March onward there was a continuous difference between the totals found in favor of the initial samples. This strong tendency to loss in total nitrogen was not overcome by changing the conditions of temperature and moisture as happened when we incubated the samples. We found frequent losses in this series of experiments also, extending over a period of 1 year. This deportment does not seem to be characteristic of the cropped soils but is also shown by the fallow plots therefore one can not attribute it to the effects of cropping. The potassium is decidedly higher in the cropped soils than in the fallow and the differences continue in the same sense in 1928 when fallow, as in 1927 when cropped.

CARBON DIOXID IN PLOTS, 1928

In regard to the carbon dioxid in the soil air we present the continuation of our observations throughout the year 1927. Concerning the effects of crops upon the amount of this in the soil, we have shown by results obtained through 5 years of observation that growing plants fill the soil with it and that it is directly related to the growing of the plants. Under wheat it increases till the plant reaches maturity and then falls till it finally reaches the level of fallow ground which is in the same season of its growth. Corn has the same effect but the time of its maturity is not the same. Clover shows this relation probably better than any other plant that we have used. If this be cut while the plant is not yet nearly mature, at a time when it has not yet prepared to send up a second growth, there is a sharp check in its development while there is a period of preparation for the next crop. In this case there is a sharp fall in the carbon dioxid in the soil air; if maturity has been reached the preparation for the second crop has been provided for by the plant, and the depression in the carbon dioxid is not so pronounced.

The roots removed from the soil and treated with mercuric chlorid give off carbon dioxid abundantly for some time. For how long I do not know. This might be a source of carbon dioxid in the soil for a time after the crops were plowed under. The putrefaction of the plants possibly has for a time some effect upon the amount of carbon dioxid in the upper portions of the soil. At least this would seem to be a legitimate inference, owing to the incorporation of a considerable amount of green, succulent, easily fermentable material. The carbon dioxid found in the 6, 12 and 18-inch lysimeters do not agree with this. The question of diffusion may enter here concerning the 6-inch lysimeters, but we consider it an open question. The effect upon the amount of carbon dioxid was wholly negligible. The carbon dioxid in the air at 18 inches below the surface may be given for the alfalfa and clover plots. The mean atmospheric temperature was 69.4°F. when the crops were plowed under and did not fall materially below 50°F. till the last few days of the month.

The carbon dioxid in parts per 10,000 in soil air from 18-inch lysimeter for Sept., 1927, was:

Date	6	12	19	23	28
W. Alfalfa	195	194	193	155	136
E. Alfalfa	229	173	188	186	137
W. Clover	147	155	157	158	98
E. Clover	87	114	86	85	71

This gives us the carbon dioxid for 2 weeks before and 3 weeks after the crops were plowed under. The general course of the carbon dioxid at this season of the year is downward. The maximum is reached at this depth in August, and a little later at greater depths. The other depths, 6 and 30 inches, show similar results. This particular point was of decided interest to us but was not the object had in view in plowing the crops under. This object was, as presented in the cases of the nitrogen and potassium, to see what might be the deportment of the land during the succeeding season. The nitrogen might have been and probably was affected in two ways by the addition of nitrogen in the crops and by inducing increased bacterial activity. The latter might be favorable or unfavorable to an increase of nitrogen; the general results indicate that it was unfavorable to an increase of total nitrogen.

In regard to the soluble potassium we observed that both the clover and alfalfa increased it and that this increase over the fallow plots persists through the succeeding year. This increase in soluble potassium has been ascribed to the action of the excessive carbon dioxid maintained in the soil by the clover and alfalfa during their growth. Both of these crops maintain a considerable excess of carbon dioxid in the soil over that present in the fallow at all times, but this amount reaches its minimum in early March from which time on it increases till the plants are killed by frost.

The residual effects of a crop are often important and we attempted to ascertain this for our rotation in regard to the carbon dioxid in fallows after the various crops.

TABLE 15—Carbon Dioxid in Fallow after Alfalfa, p. p. 10,000, 19 Sept., 1927, to 4 October, 1928.

	West Alfalfa						East Alfalfa			Surface under cover, W. Alfalfa
Depth in Inches:	6	18	30	60	84	132	6	18	30	
19 Sept., 1927....	129.7	93.4	177.5	195.4	243.5	....	119.8	188.9	228.2	12.5
23 Sept.	101.4	155.7	177.5	226.1	280.4	....	75.2	186.7	214.8	
28 Sept.	94.3	135.9	153.4	192.2	281.8	....	57.8	137.8	187.4	
4 Oct.	82.2	123.5	126.1	200.6	293.0	289.1	53.9	133.2	182.2	6.4
9 Oct.	74.8	184.4	137.3	229.0	276.7	222.0	59.2	134.5	156.3	11.5
19 Oct.	71.8	126.4	108.8	181.1	228.3	231.8	46.0	127.6	145.6	8.5
26 Oct.	55.4	105.0	108.1	176.9	257.0	255.7	38.0	117.0	140.0	6.2
4 Nov.	45.5	85.5	97.0	....	212.0	217.9	29.7	119.1	127.1	
12 Nov.	38.3	65.2	80.3	146.2	200.8	204.6	31.4	92.0	101.0	5.2
21 Nov.	26.5	67.1	78.4	130.9	185.6	191.7	30.3	85.8	96.6	Frozen
16 Dec.	25.3	66.5	64.5	97.8	141.8	136.3	14.4	58.1	76.3	Frozen
4 Jan. 1928	25.6	Frozen	61.1	83.8	126.1	134.2	13.9	74.9	76.3	Frozen
20 Jan.	32.7	Frozen	57.7	80.9	119.4	131.8	17.8	71.3	78.9	Frozen
6 Feb.	31.2	Frozen	57.8	77.2	112.8	99.9	6.2	66.0	81.4	3.1
24 Feb.	34.8	Frozen	50.0	77.5	108.4	100.6	12.3	67.3	73.1	
7 March	28.6	50.1	45.4	69.5	103.8	98.0	10.8	62.3	70.7	3.8
26 March	30.5	44.0	54.8	61.7	102.5	95.6	20.0	63.0	68.9	
20 April	38.4	49.5	57.2	74.0	114.0	95.5	31.5	65.2	73.2	4.6
5 May	27.1	51.1	58.0	69.6	104.2	94.6	32.6	63.6	68.2	2.3
18 May	49.1	54.9	62.2	73.3	102.3	95.2	38.3	86.9	79.6	
28 May	77.1	85.0	85.8	93.4	131.5	125.8	62.0	102.3	102.1	3.8
6 June	88.3	103.9	86.9	103.8	146.6	....	78.4	100.0	113.6	
15 June	97.7	118.3	91.7	107.4	152.3	124.1	75.3	112.6	113.8	
23 June	73.7	122.3	93.9	134.3	179.1	113.7	72.7	124.7	123.8	4.6
2 July	79.9	121.7	111.1	133.8	181.1	124.9	68.9	133.9	133.2	3.1
11 July	88.7	131.9	....	107.4	210.7	109.9	84.4	136.5	131.5	
23 July	100.2	161.7	105.9	146.6	228.8	130.6	66.5	147.6	156.4	4.6
2 Aug.	85.0	161.8	112.9	157.4	204.6	135.3	67.6	144.1	146.7	
13 Aug.	87.7	160.4	127.8	155.7	207.5	147.8	59.8	147.1	150.8	2.3
25 Aug.	82.2	161.3	118.2	154.6	239.2	146.9	43.0	123.2	124.0	4.7
6 Sept.	91.4	135.7	117.2	148.3	241.6	154.2	43.4	118.2	128.3	
20 Sept.	58.9	115.5	93.1	141.4	204.0	161.3	40.1	104.2	118.1	3.8
4 Oct.	24.0	94.2	66.7	130.2	189.7	195.9	26.0	82.4	103.2	3.8

TABLE 16.—Carbon Dioxid in Fallow after Clover, 19 Sept., 1927, to 4 October, 1928, p. p. 10,000.

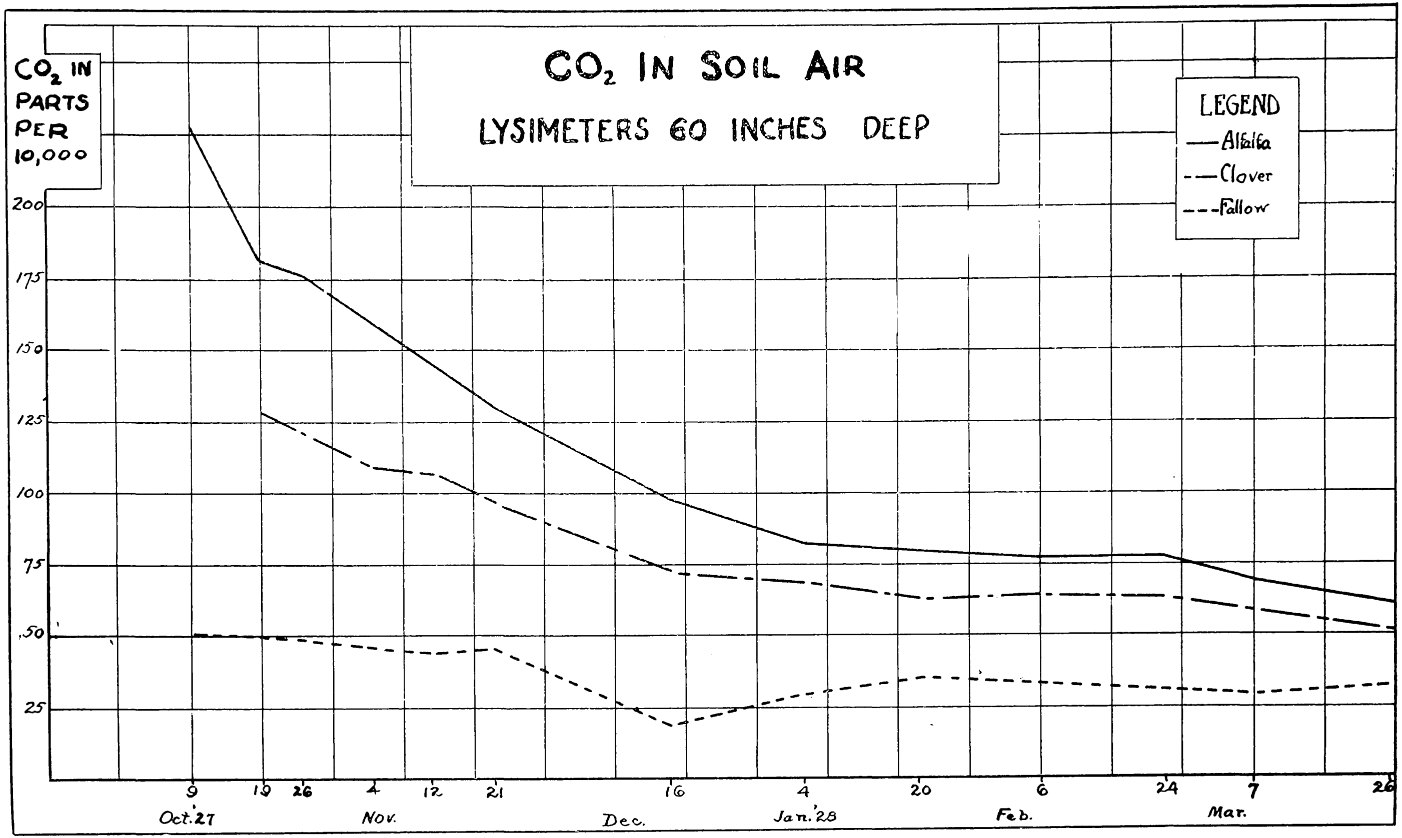
	West Clover						East Clover		
Depth in Inches:	6	18	30	60	84	132	6	18	30
Date									
19 Sept., 1927	86.5	157.3	180.3	....	....	....	40.4	86.9	127.6
23 Sept.	64.8	158.6	158.7	....	....	....	41.9	85.3	117.8
28 Sept.	57.0	97.8	148.7	....	....	....	30.0	72.0	104.3
4 Oct.	71.1	100.6	142.0	....	....	....	23.0	69.6	104.4
9 Oct.	64.7	105.4	122.8	....	139.0	172.6	31.9	68.5	101.8
19 Oct.	63.3	95.6	126.6	128.3	140.2	139.1	30.9	67.9	100.2
26 Oct.	45.9	91.9	106.5	....	137.5	143.6	23.7	67.6	97.8
4 Nov.	28.3	75.0	107.7	109.8	116.1	134.3	16.5	51.8	66.8
12 Nov.	29.8	63.5	98.7	107.4	108.5	132.1	14.1	49.4	62.3
21 Nov.	21.0	55.7	77.4	97.8	106.9	129.4	12.5	47.0	55.3
16 Dec.	Frozen	54.0	72.2	73.8	79.6	93.9	12.5	35.0	39.5
4 Jan., 1928	Frozen	44.9	69.1	69.6	63.6	89.1	12.3	32.2	41.5
20 Jan.	Frozen	40.8	69.8	63.7	62.8	80.2	11.6	32.5	46.8
6 Feb.	Frozen	53.3	65.3	63.9	66.5	75.6	19.9	32.3	41.5
24 Feb.	Frozen	44.8	60.1	63.1	64.7	63.3	12.4	32.5	50.3
7 March	15.3	39.4	47.0	58.1	64.9	64.9	10.2	29.5	48.4
26 March	14.8	40.8	46.0	52.9	57.1	70.7	11.4	28.3	42.7
20 April	22.1	44.9	51.3	63.1	60.7	62.9	13.2	38.6	45.9
5 May	22.1	39.7	49.0	58.7	55.6	63.2	13.8	36.8	39.9
18 May	46.7	47.5	59.7	54.1	67.9	66.2	12.6	41.8	49.4
28 May	35.5	71.4	76.2	62.9	81.2	77.1	27.8	48.5	62.2
6 June	41.0	58.0	73.7	65.8	87.3	91.0	35.4	53.8	69.2
15 June	49.1	64.7	73.0	67.2	80.6	81.7	36.7	54.9	65.9
23 June	36.0	77.3	83.8	91.3	79.4	89.7	33.9	60.9	71.1
2 July	43.8	86.2	103.7	83.9	83.9	96.8	33.3	70.4	78.8
11 July	57.6	84.1	90.5	66.6	77.2	86.0	31.4	85.1	84.9
23 July	56.5	83.5	100.5	89.2	88.5	100.2	25.5	78.6	91.5
2 Aug.	48.4	89.8	95.2	92.1	89.8	101.8	27.1	76.6	86.7
13 Aug.	42.3	80.1	108.3	91.8	91.8	105.5	27.7	66.0	97.1
25 Aug.	37.7	79.1	97.1	75.9	97.9	97.9	30.9	69.8	82.3
6 Sept.	33.8	76.6	95.9	94.0	99.9	99.8	19.2	61.2	78.8
20 Sept.	24.6	53.7	79.5	83.1	83.1	109.9	16.9	55.4	69.9
4 Oct.	17.7	51.9	68.7	81.1	84.9	108.1	10.8	41.5	59.9

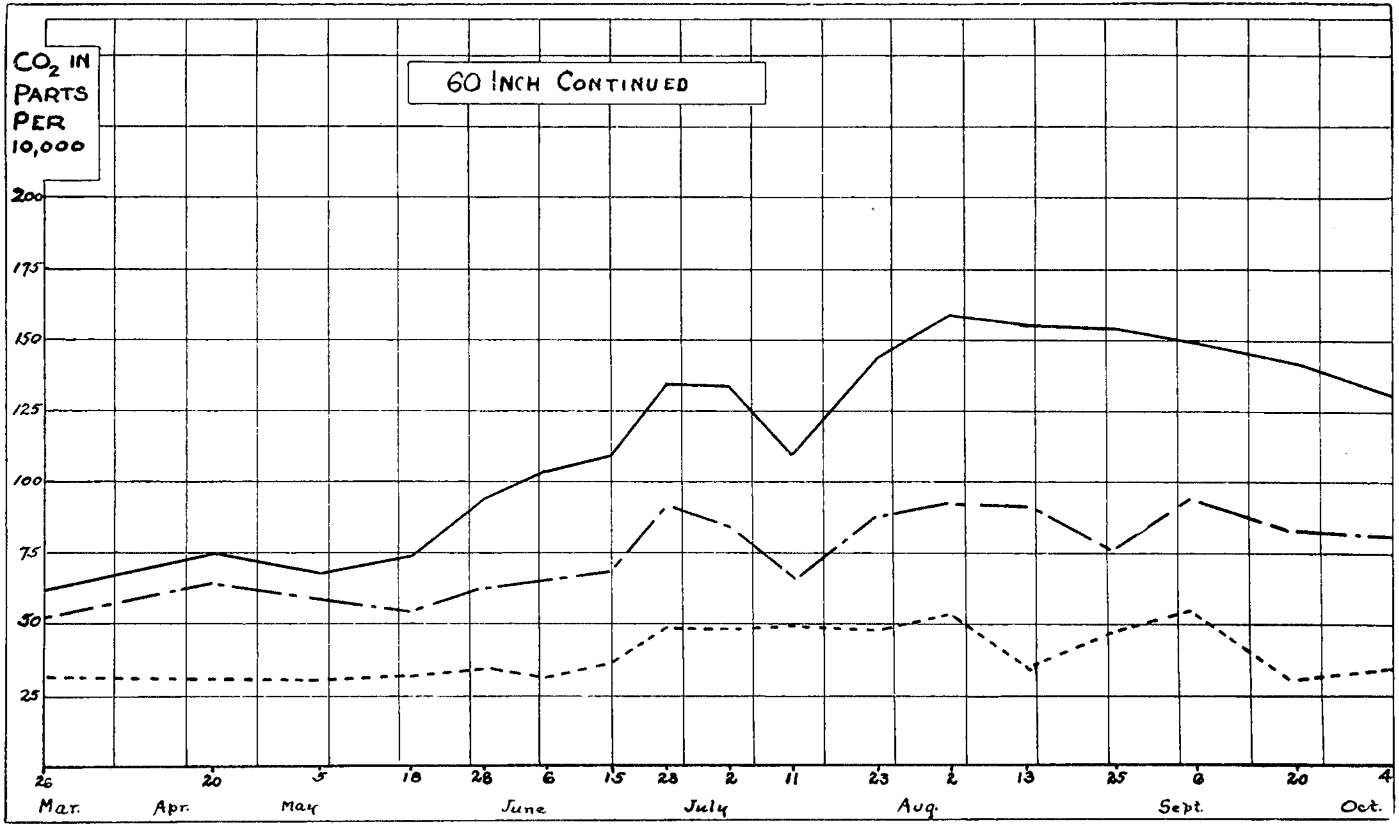
TABLE 17.—Carbon Dioxid in Fallow after Fallow, 19 Sept., 1927, to 4 Oct., 1928, p. p. 10,000.

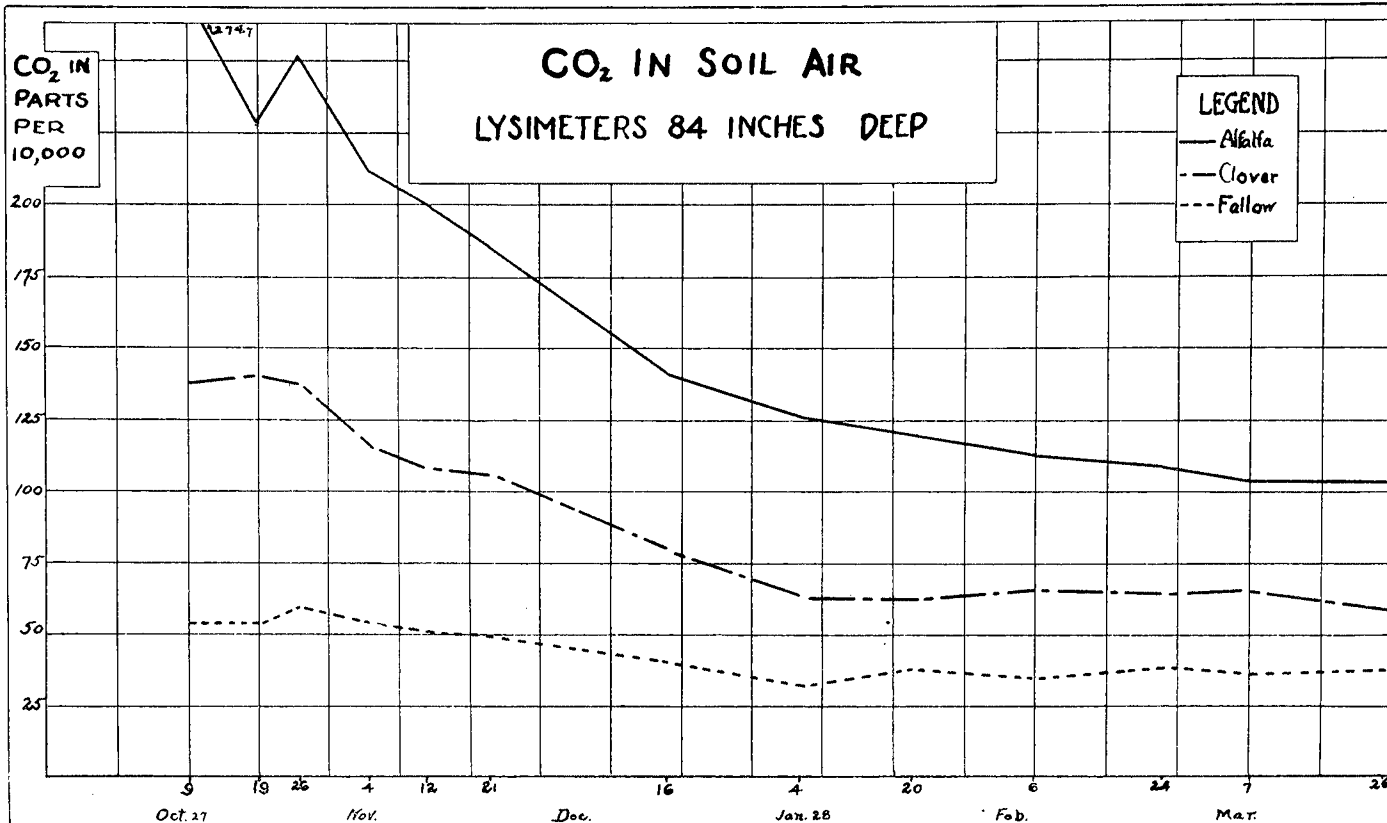
	West Fallow						East Fallow		
Depth in Inches:	6	18	30	60	84	132	6	18	30
Date									
19 Sept., 1927	20.4	43.5	71.2	....	....	....	23.8	34.7	52.3
23 Sept.	11.5	39.8	61.1	....	....	....	14.0	17.8	34.1
28 Sept.	7.5	30.8	58.3	....	....	....	9.2	19.1	33.6
4 Oct.	8.4	20.6	43.5	57.8	58.1	....	12.3	16.9	29.2
9 Oct.	10.7	24.4	43.0	51.6	53.1	136.7	9.9	15.3	24.3
19 Oct.	10.0	23.1	42.4	50.0	52.9	132.4	7.7	15.5	33.3
26 Oct.	11.5	30.8	42.5	48.6	58.5	119.4	11.5	17.6	31.4
4 Nov.	10.0	29.3	42.3	45.2	53.1	123.2	10.6	17.3	30.2
12 Nov.	10.6	25.9	39.1	45.4	51.5	116.6	11.4	15.2	30.4
21 Nov.	12.9	21.6	38.8	46.0	49.8	114.7	10.0	16.1	24.6
16 Dec.	9.1	14.4	31.1	19.4	40.5	97.2	7.8	20.3	17.2
4 Jan., 1928	7.7	15.5	30.9	29.5	32.1	83.5	8.5	21.5	19.2
20 Jan.	5.5	28.5	31.2	36.9	37.6	75.1	7.7	11.6	28.7
6 Feb.	6.9	30.8	36.9	34.6	34.6	64.0	3.8	19.2	28.2
24 Feb.	7.6	21.8	38.5	31.7	38.8	67.7	7.8	21.8	24.9
7 March	9.9	22.4	34.1	29.9	36.2	72.8	12.1	19.3	21.3
26 March	9.1	13.3	30.1	31.8	37.1	63.6	13.7	19.8	24.5
20 April	6.8	18.8	39.1	30.8	34.6	57.3	19.2	26.8	23.8
5 May	7.5	12.0	31.6	30.7	35.2	58.0	16.9	25.3	23.0
18 May	9.3	28.0	35.5	32.0	37.3	60.9	12.6	26.7	27.5
28 May	22.0	26.5	40.7	34.5	42.6	60.9	17.0	27.0	29.5
6 June	22.1	35.7	42.6	31.3	48.9	63.2	26.4	28.7	30.2
15 June	19.1	34.3	40.4	36.7	44.3	75.6	19.1	26.8	37.1
23 June	23.0	38.4	53.1	48.9	55.5	78.0	16.8	31.3	37.4
2 July	16.9	39.7	54.2	47.3	59.6	82.4	11.4	32.0	45.7
11 July	18.4	35.3	48.0	49.0	48.2	71.2	15.3	30.7	36.4
23 July	15.4	36.9	53.9	47.7	49.3	86.2	3.9	38.6	46.4
2 Aug.	17.1	37.3	45.1	53.6	51.2	88.0	6.2	36.4	39.1
13 Aug.	17.2	40.7	43.8	36.0	53.6	78.9	8.4	36.0	39.8
25 Aug.	11.6	37.0	40.3	47.9	54.0	80.8	7.7	32.5	39.3
6 Sept.	9.3	32.2	40.6	55.2	53.8	76.8	9.2	30.7	40.7
20 Sept.	9.3	26.4	37.4	30.0	47.6	92.6	6.2	24.6	37.4
4 Oct.	10.0	25.4	36.4	34.8	43.0	92.2	4.7	23.3	28.8

TABLE 18.—Carbon Dioxid in Fallow after Corn, 19 Sept., 1927, to 4 October, 1928, p. p. 10,000.

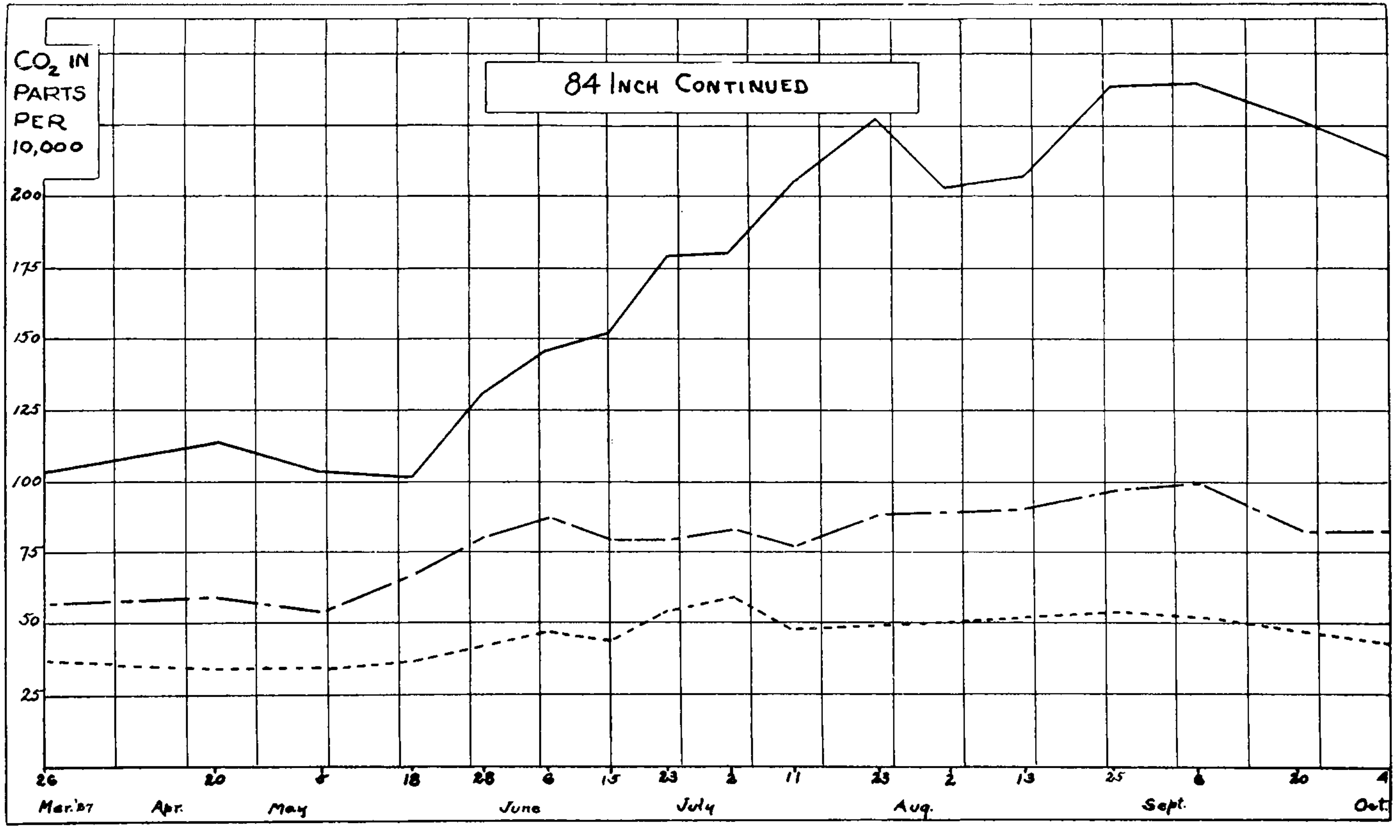
	West Corn			East Corn		
Depth in Inches:	6	18	30	6	18	30
Date						
19 Sept., 1927	51.7	89.6	113.8	22.4	73.2	105.8
23 Sept.	29.0	91.5	114.3	10.3	62.5	97.5
28 Sept.	22.7	68.3	88.7	13.6	43.9	91.2
4 Oct.	13.7	51.1	75.8	7.7	36.2	73.1
9 Oct.	33.5	64.7	84.5	16.8	41.9	71.6
19 Oct.	33.8	66.1	84.5	18.4	42.6	69.0
26 Oct.	19.2	58.4	80.1	21.2	33.7	62.0
4 Nov.	18.0	45.2	61.7	19.2	26.4	50.3
12 Nov.	21.3	40.3	54.4	21.3	28.9	49.5
21 Nov.	18.2	39.5	50.5	13.7	15.4	49.3
16 Dec.	10.2	24.6	40.9	15.5	15.7	40.2
4 Jan., 1928	14.8	Frozen	36.5	13.1	21.9	47.0
20 Jan.	19.5	Frozen	33.4	15.5	19.4	34.1
6 Feb.	6.9	Frozen	39.1	13.7	19.8	32.8
24 Feb.	10.6	21.4	34.8	15.4	17.1	36.3
7 March	3.1	21.6	24.5	3.8	25.5	34.2
26 March	15.2	22.7	24.6	4.5	25.3	38.3
20 April	9.2	16.5	26.0	6.9	24.5	39.1
5 May	18.0	27.0	34.4	9.2	21.5	41.0
18 May	23.8	26.5	38.4	24.5	23.0	40.5
28 May	33.7	48.5	46.6	26.4	37.2	48.5
6 June	32.7	47.9	49.4	37.2	41.6	50.6
15 June	34.3	53.4	50.7	39.1	44.0	56.3
23 June	30.0	62.5	53.7	30.5	44.6	57.2
2 July	26.0	69.7	71.0	34.4	57.2	63.3
11 July	37.6	73.3	61.5	36.8	39.4	58.2
23 July	28.7	60.0	64.2	25.2	47.9	65.7
2 Aug.	11.6	60.6	71.3	23.3	46.5	63.5
13 Aug.	30.7	59.8	69.3	34.5	48.2	72.7
25 Aug.	23.1	53.2	67.7	32.5	68.3	72.0
6 Sept.	23.2	46.2	49.6	23.1	44.6	66.8
20 Sept.	23.2	39.5	48.9	14.7	30.1	46.6
4 Oct.	25.7	......	40.1	3.9	28.6	51.0

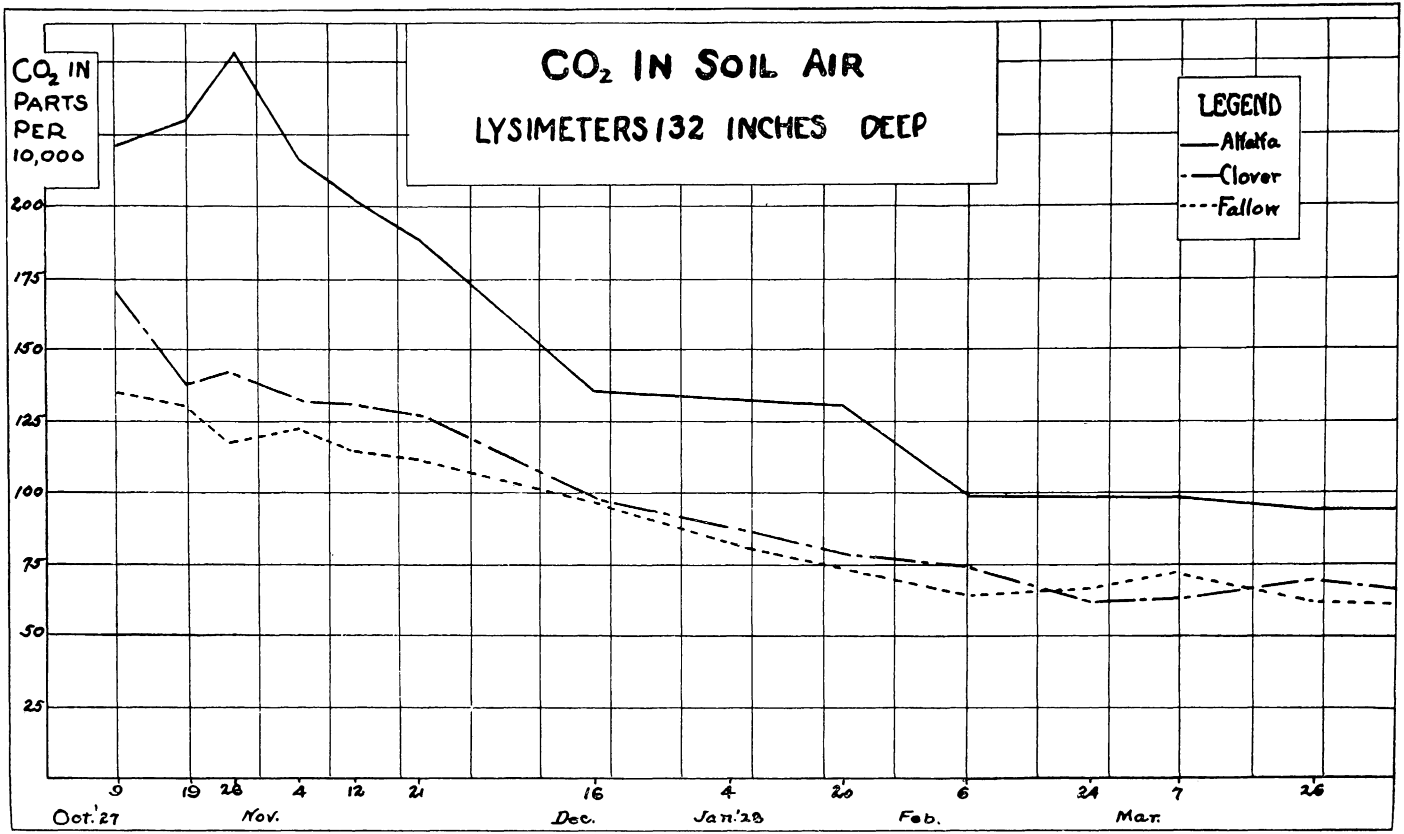

CO2 IN SOIL AIR
LYSIMETERS 60 INCHES DEEP
CO2 IN PARTS PER 10,000
LEGEND
Alfalfa
Clover
Fallow
200
175
150
125
100
75
50
25
9
19
26
4
12
21
16
4
20
6
24
7
26
Oct.'27
Nov.
Dec.
Jan.'28
Feb.
Mar.

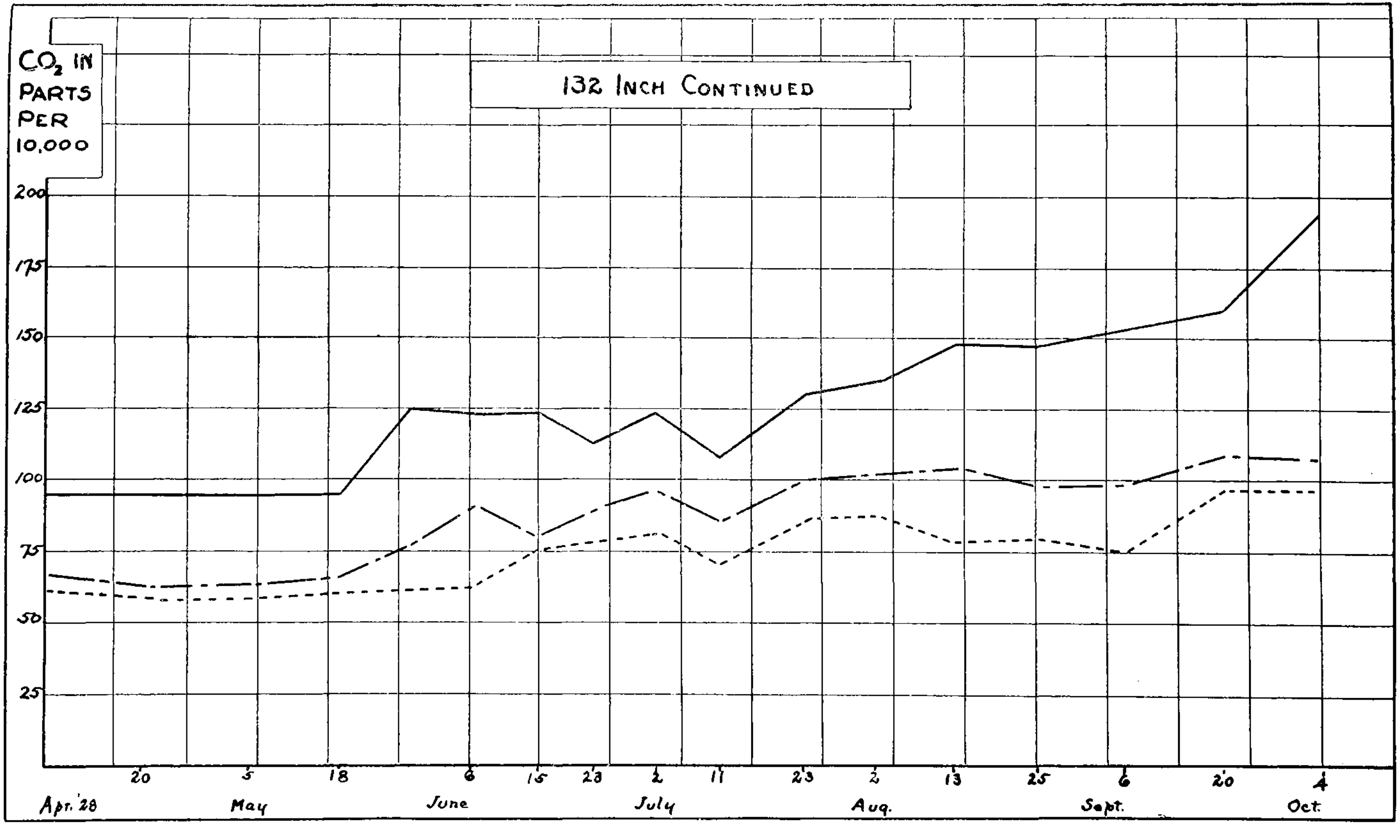

60 INCH CONTINUED
CO_2 IN PARTS PER 10,000
200
175
150
125
100
75
50
25
26 Mar.
20 Apr.
5 May
18
28
6 June
15
28
2 July
11
23
2 Aug.
13
25
6 Sept.
20
4 Oct.



CO₂ IN SOIL AIR
LYSIMETERS 84 INCHES DEEP
CO₂ IN PARTS PER 10,000
LEGEND
Alfalfa
Clover
Fallow
274.7
200
175
150
125
100
75
50
25
9
19
26
4
12
21
16
4
20
6
24
7
26
Oct. 27
Nov.
Dec.
Jan. 28
Feb.
Mar.


84 Inch Continued
CO_2 in parts per 10,000
200
175
150
125
100
75
50
25
26
20
6
18
28
6
15
23
2
11
23
2
13
25
6
20
4
Mar. '07
Apr.
May
June
July
Aug.
Sept.
Oct.


CO₂ IN SOIL AIR
LYSIMETERS 132 INCHES DEEP
CO₂ IN PARTS PER 10,000
LEGEND
Alfalfa
Clover
Fallow
200
175
150
125
100
75
50
25
9
19
28
4
12
21
16
4
20
6
24
7
26
Oct.'27
Nov.
Dec.
Jan.'28
Feb.
Mar.



132 Inch Continued
CO_2 in Parts Per 10,000
200
175
150
125
100
75
50
25
Apr. '28
20
May
5
18
June
6
15
23
July
2
11
23
Aug.
2
13
25
Sept.
6
20
Oct.
4

The graphs simply afford another way of presenting the tables but give a clear and easily understood presentation of the whole year's observations.

There are at least two sources for the carbon dioxid; the growing plants respiring it through their roots and the soil population which may give it off in their own respirations and produce it by the breaking up of carbohydrates in the soil. The two processes may go on at the same time. An alfalfa root may be surrounded by an area with a very dense soil population because of favorable conditions prevailing in the vicinity of the root—especially by a greater abundance of material for them to feed on. We have depended upon the amount of carbon dioxid in the fallow land as a measure of the activity of this population in our soil but the conditions may not be so favorable as in the cropped land. We have treated it as though the fallow were wholly comparable to cropped land, perhaps a little more favorable for the soil population than it would be if it were sustaining a crop.

I do not think that we have erred greatly in abiding by the fallow land as our standard. The limits of variation in the carbon dioxid found in the soil atmosphere throughout the period of 6 years indicate that it is fairly constant. We thought that 3 years in succession in fallow would appreciably lessen the amount of carbon dioxid owing to depletion of food material for this soil population. There may have been great changes that we know nothing about, but the variation in the amount of carbon dioxid from year to year did not indicate that they seriously affected the gross problem with which we were engaged. The general range was so nearly the same and the seasonal differences were so alike that we have no hesitancy in holding the fallow as giving reliable results. These were so inferior in volume to those obtained with grasses and legumes that there remains no doubt about the source of the carbon dioxid. If this difference were not so great that it practically leaves no possible doubt, the fact that when we cut the clover at an early period in its growth the carbon dioxid in the soil fell immediately thereafter to a level only a little above that of the fallow would furnish proof that the soil population is at most accountable for only a small part of the carbon dioxid found. The figures here involved were about 50 p.p. 10,000 for the fallow and 175 p.p. 10,000 for the clover which fell to 76 p.p. 10,000 or less when the clover was cut. It also fell in land planted to mixed grasses but not to so low a point. Similar results were observed with alfalfa. These crops all produce new growths and the carbon dioxid is increased in the soil air at the same time.

GROWTH AFTER IRRIGATION INCREASES CARBON DIOXID

That the carbon dioxid is produced by the growing of the aerial parts of the plants is further shown by the effects of water applied to the plants. The crop on which this was observed in a marked way was wheat. Irrigation was postponed until its need was evident. The amount of carbon dioxid evolved showed that the plants had been feeling the need of water for rather more than 2 weeks. The air samples were drawn every 3 days so we could follow the needs of the plants and their effects upon the amount of carbon dioxid in the soil air; beginning on 17 June, 1926, we had the following series 171, 167, 141, 139, 131, 112 and 98 p.p. 10,000 on 6 July. The plots were irrigated on this date and the carbon dioxid increased immediately to 101, 142 and 147 parts by 16 July. The wheat plants did not show, so far as we could see, any damage but had we withheld water a few days longer it is doubtful whether they would have fully recovered as they apparently did. This was the critical period in the life of these plants. This observation explains the remarkable effects sometimes observed by our farmers produced by a delay of 1 day or perhaps even less in irrigating any given crop.

The fallow plots were irrigated at the same time as the wheat mentioned above and samples of soil air were taken on the same dates but they show no effect similar to that shown by the wheat. The soil-air samples showed for the same dates as given for the wheat 59, 60, 52, 62, 59, and 58, before irrigation; 54, 59 and 57 p. p. 10,000 after irrigation. The effects of irrigation on the development of carbon dioxid in fallow ground are the same as was observed in a series of experiments that extended throughout one season and part of a second, i. e., that with our seasonal rainfall the soil air in irrigated and unirrigated fallow land scarcely differs at all. The usual amount of moisture available suffices for their full development in fallow ground. How this may be modified by the presence of a crop is not demonstrated but judging by the observations on the effects of clover these facts are not materially changed.

So far as this feature of the question is concerned, the source of the carbon dioxid in the soil air is principally due to the activity of the aerial portions of the plants. Some plants may die and then they fall a prey to the soil population. This is a different thing from the living plants and in a young stand, such as we had to experiment with, is a wholly negligible source of carbon dioxid. Even in older stands this death of the plants and their decay is spread over years and while the aggregate effect is not negligible, that of any one season may be.

The statements apply to the conditions of the first two seasons of our experiment at the end of which we plowed our crops under and changed things radically for the third season. It does not need to be stated that the green, succulent clover and alfalfa were rapidly destroyed by the soil population. To what extent this population multiplied we have no means of telling nor do we know anything of its history, how long it persisted nor how it compared with that of the fallow at any given time. This was a study belonging in another province of investigation but we continued our study of the amount of carbon dioxid in the soil air. The observations reduced to normal conditions, 0°C. and 7.60 mm. pressure, are given in the tables and reproduced in the form of graphs. The whole of the crops, tops and roots, was available for whatever changes it might be subjected to.

The alfalfa root sometimes persists a long time in the soil and for a time at least respires carbon dioxid freely as do also clover roots, even after they have been treated with mercuric-chlorid solution to sterilize them. This respired carbon dioxid comes from the breaking down of carbohydrates within the roots. That which we obtained was probably due to vital changes going on in the root cells. This would account for a large quantity of carbon dioxid if it continued for any considerable time. The amount of the carbon dioxid found in this ground that had been in alfalfa or clover for 2 years, the crops plowed under, and cultivated fallow the third season, greatly strengthens the view that this substance is the key to the benefits accruing to the soil due to this rotation. The carbon dioxid in this fallow shows the same course as when it was in crop.

We shall confine these detailed statements to alfalfa and the 18-inch lysimeter. It has its minimum in March or April and its maximum from the end of July till after the middle of September. The amounts are lower than when the crop was living, 160 against 290 as maxima and 44 against 43 for the minima. Further, the curves are parallel throughout the years but the cropped is always higher than that for the fallow. If the curves given in this bulletin be compared, it will be observed that those for the alfalfa are the highest, those for the clover next and those for the fallow are lowest. They are very uniform and differ but little from those for the preceding years. These data correlate with the crops and the treatment of the land, showing that they are respectively the causes of the differences.

During the first 2 years the plants were living, during the third year there was nothing except their remains in the soil. These maintained not the same, but similar differences between these soils and the fallow following their courses even in their maxima and minima. Just how this may be brought about is not evident. One would suppose that the decay of the roots when once established would go on at an approximately uniform rate.

CARBON DIOXID IN FALLOW GROUND VARIES WITH TEMPERATURE

We observed that under our conditions there is a close relation between the temperature and the amount of carbon dioxid in the soil air in fallow ground, and very little or none between the moisture and the carbon dioxid. The period of minimum carbon dioxid in the cropped soil is in March or April and is a consequence of the dormant conditions of the plant, supposedly influenced by the cold of the winter season and just prior to its period of new growth. The maximum is in July and August but there is no such maximum in the fallow after fallow and it is not strongly marked in fallow after corn but it is as high relative to its minimum as the alfalfa. In these cases the carbon dioxid must be mainly produced by the destruction of the plant remains by lower organisms, though this may not explain the parallelism of the curves shown by the growing crops. While the crops are growing there is comparatively little dead matter in the soil to be destroyed and the living processes of the plants produce the carbon dioxid, but after the crops have been plowed under and the land cultivated fallow there are no ordinary plants to produce it, only dead roots which may furnish some by respiration and the micro-population to which the dead organic matter falls a prey.

For 1 year at least the alfalfa and clover supplied a large amount of carbon dioxid to the soil air and even the corn maintained approximately twice as much in the soil air as was present in the fallow after fallow.

A small portion of one set of plots was planted to wheat in 1928. The results are given in a previous bulletin which should be consulted as it presents an entirely different class of facts from those given in this one. Both classes of results have presented some unexpected features but we have been content to accept them just as they have presented themselves. Measured by the crop obtained, the fallow was more effective than the cropping. The yield exceeded that after alfalfa by 18 bushels per acre and by 12 bushels per acre that after clover. The protein content of the grain after alfalfa was 19.13 percent, after clover 17.55, and after fallow 17.26. After corn, which gave the second highest yield, 52.5 bushels per acre, the protein was 12.69 percent.

SUMMARY

This study was undertaken to ascertain, if possible, how legumes, alfalfa and red clover in particular, produce the beneficial effects observed in a rotation. For this purpose we have studied the changes in two series of plots for three seasons. The crops were plowed under at the end of the second season and the plots cultivated fallow with irrigation the third season, except a small portion of one series which was planted to wheat.

A similar series of observations extending over 3 years had been made previous to this, making 6 years of observation in all.

The following features of the problem have been presented:

The relation of the crop to the carbon dioxid in the soil, mostly to depths of 6, 18 and 30 inches but also to other depths up to 11 feet.

The action of carbon dioxid and water upon felspar, the principal reactive mineral in our soils, and also upon the soils.

The relation of the crops to the total, also to the nitric nitrogen in the soil, both while growing and after the crops had been plowed under. This feature was extended to older plantations of alfalfa than those established on our experimental plots.

The changes effected in the composition of the soil, especially in regard to its exchange values.

The effect of the crops upon the water-soluble potassium in the soil in consequence of the carbon dioxid given off.

The effects of the different plots, alfalfa, clover, corn and fallow upon a wheat crop the season after the crops had been plowed under, in the fall at the end of the second season.

The effects upon the total and nitric nitrogen during the first season after the crops had been plowed under and all of the plots cultivated fallow.

The carbon dioxid in the soil air of these plots during this fallow after cropping to the same depths and manner as when the crops were growing.

Field and incubation tests to establish the deportment of these plots toward the nitrogen questions during this third season.

Determinations of the water-soluble potassium to ascertain the persistency of these changes.

Some incidental remarks on the sanitary condition of the soil.

Such is the scope of the work.

CONCLUSIONS

The conclusions arrived at are as follows:

The carbon dioxid in the soil air is derived from two sources, principally from the alfalfa, clover, corn or wheat that is growing upon the land, very subordinately from the micro-population inhabiting the soil. Under alfalfa, clover and wheat the carbon dioxid of the soil air may reach from 170 to 290 p. p. 10,000. In our fallow land it may under favorable conditions exceed 70 p. p. 10,000 but is usually less than 50 parts.

The carbon dioxid under growing crops is dependent upon the growing of the aerial parts. When these are removed or the growth impeded, as by drought, the carbon dioxid in the soil air falls. The carbon dioxid increases again upon the resumption of growth whether this is caused by a second growth or by the application of water to revive the plants. If the drought is too long continued the plants will not recuperate. The plants may be in great distress, which will be shown by a falling off of the carbon dioxid, but if this critical point has not been passed and water is applied, the carbon dioxid increases promptly with the resumption of growth.

Alfalfa and clover roots after thorough sterilization respire carbon dioxid very freely. They may not act in the same way while attached to the unmutilated plant; they probably do not or we could scarcely expect the prompt falling of the carbon dioxid when the tops are removed, especially if the plants are very immature.

When, for instance, a wheat crop matures, the carbon dioxid does not fall immediately but falls gradually from the time it ceases growing till it reaches the level of the fallow ground about 1 month later. This is a different problem, one involving the decay of the roots.

The action of this carbon dioxid and water upon felspar is very largely to eliminate potassium. It attacks coarsely ground felspar slowly compared with its action when the felspar is finely ground. One part of felspar treated with 20 parts of water saturated with carbon dioxid yields potassium equal to 270 p.p.m.

in 4 days. The potassium dissolved out of felspar equals from 40 to 50 percent of the total dissolved out of the mineral. This action is increased and not lessened by the presence of other salts.

The variations in the amount of water-soluble potassium in the soil are not synchronous with the variations of the carbon dioxid in the soil air.

The water-soluble potassium correlates with the different crops. Alfalfa maintains the largest amount of carbon dioxid in the soil air and though it is itself a heavy feeder on potassium, the soil under it carries approximately twice as much soluble potassium as the fallow land. Clover stands next in order in this respect. The amount of water-soluble potassium involved is considerable, its excess over the original soil in two seasons taken to a depth of 2 feet was equal to a dressing of 1600 pounds of potassic sulfate.

The carbon dioxid in our soils leads to the formation of calcic carbonate which forms aggregates, even entering into the mechanical portion designated clay of which it may form better than 30 percent. It also forms incrustations on the soil particles which includes some clayey matter. These aggregates and incrustations play the most important part in retaining the potassium, and possibly the phosphoric acid, in a readily available form for the plants. That this is the case in regard to the potassium is made probable by the large amount of potassium that goes into solution when the soil is treated with dilute acetic acid in only a slight excess over that necessary to bring the calcic carbonate into solution which amount has been ascertained by a previous determination.

When this soil is treated with a 10 percent solution of hydrochloric acid for a few minutes, 3 to 5 minutes, better than 30 percent of the total phosphoric acid goes into solution, and 50 percent in 10 minutes. This was one of the important points brought out in our study of the changes produced in the deportment of the soil. Even acetic acid dissolves up to 42 p.p.m. Calculated on the air-dried soil, an amount of phosphoric acid greatly in excess of the minimum said to suffice for the growth of the plants. Carbonated water takes 30 to 40 p.p.m. into solution and holds it even in the presence of large quantities of calcic carbonate.

The changes that we found in the soil so far as the soil complex was affected were as follows. There is a complex whose hydrogen replacement is equal to thirteen units. This complex remained unchanged throughout the season that we studied it.

We found it most convenient to remove the simple soil aggregates, consisting very largely of calcic carbonate, with dilute acetic acid which apparently did not disturb this complex and then treat the residue from the acetic acid extraction with a normal ammonium chlorid solution. This treatment divided the potassium into two portions, one soluble in the acetate solution and the other replaceable by the NH_4 group. This latter portion did not seem to be affected by the cropping. Only the water-soluble present in the simple aggregates seemed to be affected, i. e., decidedly increased by both the clover and alfalfa. This was the most important feature brought out by our study. The ammonium taken up by the soil was not affected by the treatment with acetic acid.

The greatest stress at the beginning of our work was laid on the effect of these crops on the amount of total nitrogen. Our observations on the amount of total nitrogen in soils that had been in alfalfa for 2 years, a common rotation period for alfalfa with us, had led us to doubt the current opinion and teaching that the benefits accruing to soils from a rotation of alfalfa were due to increase of nitrogen. This doubt was at the bottom of this whole study. It is here stated as an explanation for the very large amount of work expended upon the subject. The result of it all is that we do not believe that these crops add any nitrogen to the soil and the benefits are due to other effects. The most favorable results that we obtained supporting the view that these crops add nitrogen, make the amount added so small that it is negligible, equal to the application of 5.5 tons of manure carrying 1.5 percent nitrogen every 2 years per acre or 2.75 tons per annum.

In regard to the nitric nitrogen we found it always low in the alfalfa and clover ground compared with fallow ground. Ten parts per million in the very uppermost portion of the soil were about the maximum; from 1 to 3 parts were common. The only two really high results obtained in a whole season's sampling were 33 and 37 p.p.m. for samples scraped off the surface under the alfalfa plants, and these were mixed with still undecomposed plant debris.

Whether the small amount of nitric nitrogen found associated with alfalfa plants is due to the prohibition of its formation or to its exhaustion by the plant may be a question but there is no question about the fact that it is low from the surface to a depth of 11 feet. Whatever the facts may be regarding the exhaustion, we believe that the growing plant exerts a prohibitive influence upon the process of nitrification.

When we plowed under the crops of alfalfa and clover we changed conditions radically. For a short time there was an increase in both total and nitric nitorgen but both soon began to fall off and we suffered an almost continuous loss of total nitrogen throughout the season. The nitric nitrogen in the cropped land gained till it was much like the fallows. Then followed a series of gains and losses from sampling to sampling till they left the situation in this respect almost identical with that of 1 year previous. There was a loss of total nitrogen which cannot be accounted for by differences in sampling. These plots were all cultivated fallow with irrigation during the season of 1928; the sampling extended from 27 October, 1927, till 4 October, 1928.

The impression made by these statements may be that we intend to intimate, or even hold for proved, that this loss of total nitrogen and the frequent losses in nitric nitrogen, are to be attributed to the effects of the crops. This is not the case. We do not believe that this is the explanation. The whole series of plots, eight in all, show the same course in the nitrogen relations whether they were previously fallow or occupied by crops. We do not attempt to present any reason for this deportment but believe it to be of very great importance in explaining the variations in quality of crops from year to year.

The effects of rock super phosphate, ground rock phosphate, and gypsum, applied to small plots of this land rather increased the losses than decreased them.

The following sentences may not properly belong in this place but they are pertinent to the subject. We have losses throughout the season whereas we expected gains in both total and nitric nitrogen. It made no difference whether we had plowed in heavy crops of alfalfa or clover or whether they had been fallow. The liberal addition of the amendments named did not change the course of the changes in the nitrogen. We infer that the changes were really dependent upon some condition of which we are ignorant.

The reports reaching me relative to the sugar content of the beet crop of 1928 are to the effect that it is everywhere excellent; in the Poudre Valley 1 percent above the average, in the Arkansas Valley better than 16 percent against averages as low as 13 percent for some former years, in Wyoming the best crops and highest quality that they ever had. The condition is general. The suggested question is, may not our loss in total and nitric nitrogen and the very general high sugar content of this year's beets be related? It has been proved that the sugar content of beets is related to the supply of nitric nitrogen in the soil. An appropriate quantity is of the highest advantage, too much is very injurious. The amendments used in our experiments except the gypsum are often used in practice. In our experiments they impeded nitrification. May this be a mode of action through which they sometimes give good results whereas at others they give none?

The effect of the 2-year rotation on a wheat crop grown the season after the crops were plowed under has been given elsewhere. The plot that had been fallow gave the best yield, 58.2 bushels and excellent quality, 17.26 percent protein; after corn, second best yield, 52.5 bushels, quality ordinary, 12.69 percent protein. That after clover was third in yield, 46 bushels, quality excellent, 17.5 percent protein; and fourth, alfalfa with 40.0 bushels, and 19.13 percent protein.

The water-soluble potassium remained about the same for the first season after the crops were plowed under as when the crops were growing and the amounts stood in the same relative position, alfalfa first and fallow last.

The carbon dioxid in the soil air during this year was smaller in amount but stood in the same relative positions as when the crops occupied the ground and also showed the same seasonal variation, low in the spring and high in the fall. It is doubtful whether this is the course of simple decay. The greater depths, to 84 inches, show big amounts of carbon dioxid.