12-1911

Bulletin No. 114 - The Movement of Nitric Nitrogen in Soil and its Relation to "Nitrogen Fixation"

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The Movement of Nitric Nitrogen in Soil
AND ITS RELATION TO
"Nitrogen Fixation"

BY
ROBERT STEWART and J. E. GREAVES
Logan, Utah, Dec., 1911.
Utah Agricultural Experiment Station

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The Movement of Nitric Nitrogen in Soil

AND ITS RELATION TO

"Nitrogen Fixation."

BY ROBERT STEWART AND J. E. GREAVES

In the spring of 1903, we commenced at the Utah Experiment Station a series of experiments, the purpose of which was to study the development and movement of nitrates in irrigated soil. The work was so outlined that it should give some very definite results, both as to the influence of water and the plant, upon the nitric nitrogen content of the soil. Briefly stated, the outline of the work is as follows:

The field was divided into plots of 1-26 of an acre and each plot was provided with laterals and necessary devices for distributing and measuring the water applied. The field was divided into five equal sets of plots: the first set was left fallow, the second planted to alfalfa, the third to corn, the fourth to potatoes, and the fifth to oats. Each of these sets was further divided so that one plot in each set received a maximum, one a medium, one a minimum irrigation, and one was not irrigated. The plots were sampled in the spring, and then before and after each irrigation during the summer, and again in the fall; the samples being analyzed for nitric nitrogen and moisture. The irrigation and sampling were so arranged that the results from the cropped irrigated plots could be compared with the non-irrigated plot of the same series and also with the fallow plots receiving a corresponding amount of irrigation water.

1 Read before the Society of American Bacteriologists at Washington, D. C., Dec. 27, 1911.
The soil on which the investigations are being conducted is of a sedimentary nature, being derived from the weathering of limestone rocks of the nearby mountain range, and is rich in both calcium and magnesium carbonates. The latter is present in sufficient amounts, according to the older standards, to indicate a non-productive soil. Nevertheless, the soil is extremely fertile. The humus content, as is characteristic of arid soils, is low; but otherwise the soil is ideally adapted to support rapid bacterial action.

At first it was planned to take samples to a depth of four feet, as had been done by previous workers, but it was soon found that it would be necessary to sample to a greater depth, for both the spring rains and irrigation water carried the nitric nitrogen to a greater depth than four feet.

On taking samples to a depth of ten feet, it was found that the winter and spring rains had carried the nitric nitrogen of the surface soil to a depth of seven or even eight, where it accumulated in what may be designated as "nitrate belts." These nitrate belts in the unirrigated plots could be plainly followed in their upward movement from early spring to about the first of July, when the nitric nitrogen had mainly accumulated in the surface foot of soil, where it remained until taken up by the growing crop or was carried down by the autumn rains. There were, however, exceptions to this, for at times it was found, in the case of the fallow soil, that instead of the nitric nitrogen content remaining high in the surface soil, it would suddenly decrease; and since there had been no rains to carry it to lower depths, it may be that some of the bacterial flora of the soil had changed the nitric nitrogen into insoluble proteins.

With the irrigated plots, these nitrate belts were also found in spring at a depth of 7 or 8 feet, and gradually rose until irrigation water was applied, after which they became rather indefinite and could not be followed as in the case of non-irrigated soil.

The nitric nitrogen content of the alfalfa land was low throughout the year as compared with the soil of plots growing other
crops, being slightly higher in the spring than at any other period. On the application of irrigation water there was a slight decrease in the first and sometimes in the second foot sections of the alfalfa plots, but considering it to a depth of ten feet, it usually showed a slight gain in total nitric nitrogen. This was greatest where the medium (15 inches) of water was applied, which was probably due to the nearer approach to ideal moisture conditions for nitrification. It could not be due to the nitric nitrogen content of the irrigation water, for analysis of the same showed that one application of 10 inches of water per acre would deposit less than two pounds of nitric nitrogen. The amount of nitric nitrogen in the soil of the alfalfa plots receiving most water was on an average throughout the year slightly higher than where a smaller amount of water was applied, in spite of the fact that the crop on the former was greater than on the latter. In the case of the potato land, the nitric nitrogen content was high in the spring with a slight increase during the summer months, and no appreciable change during the fall. On applying irrigation water to the potatoes, with the maximum and medium applications, there was found to be an increase in the total nitric nitrogen, both in the surface foot and the total ten feet. In the case of the plot receiving a minimum amount of water, there was an increase in the surface foot, but a decrease when the total ten feet are considered. Exactly the same phenomenon was shown in the case of corn, except that the total amount of nitric nitrogen was higher in corn land than in potato land. Oat land, on the other hand, seems to show no such regularity as was brought out in the case of corn and potatoes.

In this work there has also been discovered a marked seasonal influence, some years all the plots ranging much higher in nitric nitrogen and showing much greater variation in some foot sections than was shown in others.

When calculations are made showing the concentration in nitric nitrogen of the soil solution, it is found that there is a marked variation in the concentration of the soil solution, ranging from 5 p. p. m. to 158 p. p. m., the lowest concentration being found in the alfalfa land and the highest in the corn land.
From the chemical and bacteriological point of view, the soil is ideally adapted to support rapid bacterial action, and the water applied to these plots has varied from no irrigation water to 69 inches per year, yet the maximum amount of nitric nitrogen has not exceeded three hundred pounds per acre foot to a depth of ten feet.

Since in this soil, so favorably adapted to bacterial action, we do not find great accumulations of nitric nitrogen, while in other western soils, no better adapted to bacterial action, we do find great accumulations, which in some cases have been attributed to the fixation in place of the atmospheric nitrogen, it is interesting in this connection to consider some of these cases. The accumulation of nitric nitrogen in arid soils was first observed by Hilgard as early as 1892, and more recently cases have been studied at the Utah and at the Colorado Experiment Stations. Hilgard\(^1\) observed that in some cases of the alkali accumulations of the California soils, the nitrate consisted of 20 per cent of the total water soluble salts.

At this laboratory, deposits of nitrates have been studied, one of which contained 12.79 per cent of nitric nitrogen and 35.06 per cent potassium. This deposit,\(^2\) which occurs in a cave in red sandstone, was examined by one of us. The position of the deposit and the nature of the surrounding country indicated that the nitrate had been carried through the sandstone by percolating water. The position of the deposit, high up in a mountainous country, far above any irrigating system, precludes the possibility of its recent formation by bacterial action under the influence of irrigation water. Deposits of nitrates have been observed elsewhere in Western America.\(^3\) We have received samples from the southwestern part of this state, also from Idaho, which show a high content of nitric nitrogen, and it has been recently discovered by Headden of Colorado\(^4\) that nitrates are present in enormous quantities in many of the alkali soils of Colorado. The

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1 Soils, p. 448.
presence of these excessive quantities of nitrates has been attributed by him to fixation of atmospheric nitrogen by bacterial action at the present time. Our work indicates quite clearly that we have no such accumulations of nitric nitrogen in irrigated soil, notwithstanding the fact that the soil upon which the experiments have been conducted is exceedingly rich in calcium carbonate, and the optimum amount of water has been supplied by irrigation and the soil supports an abundant bacterial flora, including the azotobacter. The fact that in widely distributed areas in the arid West deposits of nitrates are found which do owe their origin to leaching from the country rock, supports the theory that the excessive quantities of nitrates found in the soils of Colorado owe their origin to the same source as do the other water soluble salts.

While an examination of the results as reported by Dr. Headden indicates that the nitric nitrogen does not necessarily vary in the same ratio as the water soluble salts, a close examination of the results as reported by him indicates that the nitric nitrogen does vary in the same ratio as the chlorine; that is, wherever we have an excessive quantity of nitrates we find an excessive quantity of chlorine. This relationship is very obscure in the results as they are reported by Dr. Headden. We have recalculated all of the results reported by him to the element basis, and have tabulated the results, showing the amount of nitric nitrogen and chlorine actually present in the soil, expressed as pounds per acre. Wherever we have been able to make a direct comparison of the nitric nitrogen content of the soils in earlier years with the content of this same soil in later years, we have done so. In some cases such a comparison has been made upon the basis of pounds per acre of the surface two inches of soil, while in other cases it has been reported as pounds per acre foot of soil, depending upon the depth to which the samples which were analyzed had actually been taken. The results obtained are reported in Tables 1 and 2.
TABLE 1—NITRIC NITROGEN, CHLORINE AND TOTAL SALTS.
Results recorded as pounds per acre two inches of soil.

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Lab. No.</th>
<th>Date</th>
<th>Total water soluble salts</th>
<th>Chlorine nitrogen</th>
<th>Ratio N:Cl</th>
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<td>7316</td>
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<td>947a</td>
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<td>1013</td>
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<tr>
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<td>Nov., 1909</td>
<td>39400</td>
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<tr>
<td></td>
<td>959</td>
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<td>22666</td>
<td>4874</td>
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<tr>
<td>6</td>
<td>1069</td>
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<tr>
<td></td>
<td>784</td>
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<td>31200</td>
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<td>819</td>
<td>May, 1909</td>
<td>55443</td>
<td>5522</td>
<td>231</td>
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<tr>
<td></td>
<td>818</td>
<td>May, 1909</td>
<td>51200</td>
<td>5211</td>
<td>205</td>
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<tr>
<td></td>
<td>816</td>
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<td>1075</td>
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<td>57266</td>
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<td>June 3, 1909</td>
<td>6566</td>
<td>744</td>
<td>220</td>
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<td>1061</td>
<td>March, 1911</td>
<td>9780</td>
<td>421</td>
<td>210</td>
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<td>19</td>
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<td>Oct., 1907</td>
<td>222230</td>
<td>30460</td>
<td>1055</td>
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<td>981</td>
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<td>68667</td>
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<td>680</td>
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<td>Oct., 1910</td>
<td>151400</td>
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<td>1002</td>
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<td>1029</td>
<td>Oct., 1910</td>
<td>76467</td>
<td>3808</td>
<td>765</td>
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<td></td>
<td>1028</td>
<td>Oct., 1910</td>
<td>29733</td>
<td>3948</td>
<td>730</td>
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<tr>
<td></td>
<td>1046</td>
<td>Feb., 1911</td>
<td>8600</td>
<td>1499</td>
<td>378</td>
</tr>
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</table>

TABLE 2—NITRIC NITROGEN, CHLORINE AND TOTAL SALTS.
Results recorded as pounds per acre foot of soil.

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Lab. No.</th>
<th>Date</th>
<th>Total water soluble salts</th>
<th>Chlorine nitrogen</th>
<th>Ratio N:Cl</th>
</tr>
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<td></td>
<td>736</td>
<td>May, 1909</td>
<td>83600</td>
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<tr>
<td></td>
<td>785</td>
<td>May, 1909</td>
<td>74400</td>
<td>10866</td>
<td>87</td>
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<tr>
<td>7</td>
<td>1071</td>
<td>May, 1911</td>
<td>251040</td>
<td>112750</td>
<td>1937</td>
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<tr>
<td></td>
<td>1014</td>
<td>Sept., 1910</td>
<td>118960</td>
<td>55190</td>
<td>279</td>
</tr>
<tr>
<td></td>
<td>May, 1939</td>
<td>7480</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1076</td>
<td>March, 1911</td>
<td>395280</td>
<td>192650</td>
<td>2197</td>
</tr>
<tr>
<td></td>
<td>1367</td>
<td>May, 1911</td>
<td>326600</td>
<td>157200</td>
<td>2048</td>
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<td></td>
<td>1070</td>
<td>May, 2, 1911</td>
<td>727040</td>
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<td>9</td>
<td>1067</td>
<td>May, 1911</td>
<td>326600</td>
<td>157200</td>
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<td></td>
<td>989</td>
<td>July, 1910</td>
<td>115360</td>
<td>52100</td>
<td>576</td>
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An examination of this table will bring out some very interesting results. In case 5, we have the positive statement by Dr. Headden that there is no ground water within a reasonable distance of the surface. This case is given by Dr. Headden to show that, although we may have excessive quantities of nitric nitrogen in different parts of the same field, there is a variation in the nitric nitrogen content. An examination of Table 1 shows quite conclusively that wherever we have a variation in nitric nitrogen content there is also a variation in the chlorine content in the same direction, and that the ratio of nitric nitrogen to the chlorine varies only slightly in the different samples obtained in this field, and at different seasons, which would seem to indicate clearly a common origin of these two elements. It is evident that the same influences which are working to cause the variation in composition of the water soluble salts is working to cause a similar change in the chlorine content. There is apparently no other explanation possible. Since the nitric nitrogen content rises and falls in the same general order as the chlorine, may not the same influences be at work here also? The noted increase in the chlorine must come from the ground water, and why may not the nitric nitrogen also, which varies in the same general order? This variation cannot be due to the irrigation water, since it has been eliminated as a factor by Dr. Headden.¹

In case 6, we have two samples of surface soil which are comparable. We find that wherever the chlorine content is increasing, it is in the same general ratio as the nitrogen content. If the increase in nitrogen of 561 pounds, which has occurred in this soil during the two years from 1909 to 1911, cannot be accounted for by deposition from the soil water by evaporation, how can we account for the increase of 10,430 pounds, or over five tons, of chlorine? It seems that the inevitable conclusion is that there must be an upward movement of the water soluble salts. There is no other way of accounting for the marked increase of chlorine. Why may not the nitric nitrogen be accounted for in the same way?

In the first foot of soil underlying these surface samples, there

¹ Colorado Exp. Sta. Bul. 178, p. 82.
are 87 pounds of nitrogen per acre, which is equal to 21.75 parts per million of nitric nitrogen. What would be the concentration of the soil water in contact with this much nitric nitrogen? It is evident that it would all be in solution. The concentration of the soil water may be determined by making a simple calculation, assuming the optimum\(^1\) amount of water, 18 per cent, to be present. This calculation shows the concentration to be 120.8 p. p. m. of soil solution. An acre foot of water weighs 2,722,500 pounds. Therefore, an acre foot of water having the concentration this soil water must have, would contain 329 pounds of nitrogen. That is, to deposit the amount of nitrogen actually deposited, 561 pounds, would require the evaporation of 1.23 acre feet of water. There would be required, therefore, only one-half year of maximum evaporation to deposit the amount of nitrogen actually deposited in two years, instead of the seventy years as calculated by Dr. Headden. The value of this calculation depends upon a supply of nitric nitrogen. This supply is clearly indicated in the second (736) and third foot (787) and in the shale. The water issuing from the shale\(^2\) contains 78.3 p. p. m. of nitric nitrogen, that is, an acre foot of water would contain 213 pounds of nitric nitrogen and the evaporation of 2.6 acre feet would deposit the amount actually deposited. Less than one year would be required to deposit the amount of nitrogen which was actually deposited in two years. At the same time, the chlorine must be accounted for. The increase of chlorine is 10,430 pounds. The drainage water from the shale contains 495.5 p. p. m. of chlorine. An acre foot of this water would therefore contain 1,346 pounds of chlorine, or the evaporation of 7.8 acre feet of water would be required to deposit the amount of chlorine actually deposited, i.e., the time required would be 2.3 years, while this amount of chlorine was actually deposited in two years. Furthermore, we have fortunately the chlorine content of the ground water uncontaminated

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with the nitric nitrogen. Since this uncontaminated water does not contain any nitrates, Dr. Headden feels certain that the nitric nitrogen observed in the surface soil cannot be accounted for by the evaporation of the ground water. The evaporation of this ground water cannot account for the presence of the chlorine. This water contains 74.48 p. p. m. of chlorine. The evaporation of an acre foot of this water would deposit only 202.8 pounds of chlorine. Therefore, to deposit the 10,430 pounds of chlorine actually deposited in two years, it would necessitate the evaporation of 51.4 acre feet of water, which would require 15.1 years, assuming the maximum possible evaporation of water under Colorado conditions, but the deposition of chlorine was made in two years. It would appear that the inevitable conclusion must be that the ground water does have a greater concentration in chlorine and nitrogen than assumed. We are now in a dilemma: we must conclude either that the water which evaporates from the soil has a different concentration in chlorine and nitrogen than this ground water, or else that both nitrogen fixation and chlorine fixation have taken place.

In case 7, as indicated in Table, 2 there is a distinct upward movement of water soluble salts. The amount of chlorine in the soil in May, 1911, is nearly equal to the total amount of water soluble salts present a year before. The chlorine must come from the ground water, and may not the nitric nitrogen also? Dr. Headden states that case 8 is interesting because “This is one of the places referred to in bulletin 155, as especially rich, so rich in chlorine that the salt, sodic chloride, present may possibly be injurious to vegetation.” Comparing No. 632 with No. 1070, we note some very interesting results. In 1907 (632), there were only traces of nitrates in the soil, while four years (1070) later there were 621 pounds of nitric nitrogen in the soil, formed, according to Dr. Headden, in place by bacterial action. The increase of nitrogen, 621 pounds, is accompanied by an increase in chlorine of 236,883 pounds, or over 118 tons. If we cannot account for the presence of the 621 pounds of nitric nitrogen by

1 Colo. Bul, 178. p. 64, Sample No. 1041.
2 Loc. cit., p. 20.
deposition from the ground water, how can we account for the increased deposit of 118 tons of chlorine? The evaporation of one acre foot of ground water (1041), obtained at low depth, from which contamination from nitric nitrogen from surface soil is impossible, would deposit only 202.8 pounds of chlorine, or it would require the evaporation of 1,172 acre feet of water, or 343 years would be required to deposit this amount of chlorine. Since "This is one of the places referred to in bulletin 155 as especially rich, so rich in chlorine that the sodic chloride may possibly be injurious to vegetation," and at the same time there was only ten tons of chlorine, while four years later the concentration of chlorine was 128 tons per acre foot, it would seem unnecessary to assume the fixation of nitric nitrogen to account for the observed increase in nitrogen.

In case 8, there are still two more interesting samples. Dr. Headden says, with respect to these two samples: "The samples 1067 and 1076 are alike in location, so that they are perfectly comparable in every respect, except that the land represented by 1076 has been well drained for four years." The implied conclusion is that since 1076 represents a well drained land, and there is an increase in the nitric nitrogen content, it cannot have come from deposition from the water, but must have been fixed by bacterial action. The excess of 149 pounds of nitrogen in the well drained soil is accompanied by an excess of 35,450 pounds of chlorine. If the nitrogen cannot come from the ground water, owing to the well drained character of the soil, where does the excess of chlorine come from?

In case 9, it is stated that sample 891 represents a considerable area and is to be compared with 1067. "The localities are probably as much as two miles apart, but the soils are similar in location and character." The increase of nitric nitrogen is accompanied by an increase in chlorine. Dr. Headden says: "I know of no more intensive instance of this trouble than presented in case 9." In this connection it is interesting to make a comparison with case 5. In case 9, all of the trees were dead, while

1 Colorado Exp. Sta. Bul. 178, p. 64.
2 Colorado Exp. Sta. Bul. 178, p. 27.
in case 5 the trees were in a dying condition. Comparing the chlorine and nitrogen content in the two cases, we find that in case 9 there is nearly the same nitrogen content in the surface foot as in the surface two inches of case 5, while there is eight times as much chlorine, which would seem to show that it is the chlorine that is doing the main damage, because, with a greater concentration of chlorine in case 9 and less nitrogen, the trees have been killed.

In cases 13 and 14, Dr. Headden states:¹ "There are portions of this area through which the drain passes and which one should think would receive the full benefit of the drainage, which, though not wetter than other portions, are unproductive." He recognizes three conditions, first a crust on the surface as represented by 819, the portion under the crust as represented by 818, and the soil one foot deep as represented by 816. The results obtained, when calculated upon the element basis, show a remarkable agreement in the variation of the nitric nitrogen content with that of chlorine, while the ratio is an exceedingly close one in every case.

Samples 815, 1061 and 1075 have been taken from the higher sandy portions of the orchard, and therefore apparently from the well drained portion, in which the nitric nitrogen content could not, according to Dr. Headden, be accounted for by deposition from the soil water. It is noted, in studying the results of these samples, reported in Table 1, that there is a remarkably close agreement in the variation of the nitric nitrogen content with the chlorine content, while the ratio of nitrogen to chlorine is an exceedingly close one, indicating a common origin of these two elements.

In case 19, samples 590 and 595 were taken in 1907. In one spot in 1907 (590), there was only 2,248 pounds of chlorine and traces of nitric nitrogen. In another spot (595) there was a measurable quantity of nitrogen, 1055 pounds, but it may be noticed that in the latter case there was fourteen times as much chlorine, showing a greater deposit of salts from below and fully accounting for the observed increase of nitrogen. That is, at least fourteen times as much chlorine has come from below in

¹ Colorado Experiment Station Bul. 178, p. 36.
this spot, and why not fourteen times as much nitrogen? In sample 981, there is an increase of nitric nitrogen, while the chlorine diminishes, the only exception to the rule that wherever the nitric nitrogen increases the chlorine also increases, and generally in the same order; but this noted increase in this sample cannot be due to the action of azotobacter, because Dr. Headden, in discussing this sample, states:1 "Prof. Sackett tells me that the soil extract made from the surface sample which he took failed to develope azotobacter in his culture media. They had probably been killed, as well as the other plants, due to the concentration of the salts." In a study of the other two samples of this case, 826 and 822, as noted in Table I, there is nearly twice as much total salts in sample 822 as in 826, while both the nitric nitrogen and the chlorine content is less, the decrease being in practically the same ratio, indicating quite clearly a common origin.

Case 20 presents an exceedingly interesting study. It was first reported in bulletin 155. In February, 1908, the soil was in a very bad condition, and in 1910 the land was completely ruined, due, according to Dr. Headden, to the increase of nitrates by fixation. In 1908 the surface two inches of soil contained 3,151 pounds of nitrogen and 8,368 pounds of chlorine, while in September, 1909, it contained 5,138 pounds of nitrogen and 13,660 pounds of chlorine, an increase in nitrogen of 1,987 pounds, and in chlorine of 5,292 pounds. In discussing this case, Dr. Headden says:2 "The location of this land is such that we cannot account for the presence of large amounts of nitrates by supposing them to have been brought into the area by surface waters and scarcely by underground flow." How, then, can we account for the increase of chlorine, two and one-half times as great? Was it fixed in place or brought in by the water? It is also a remarkable coincidence that in this soil in 1908 the ratio of nitric nitrogen to chlorine is 1 :2.7, while in 1909, when the increase of nitrogen had taken place, the ratio of nitric nitrogen to chlorine is still 1 :2.7. What better evidence could be offered of common origin? Samples 841 and 842 represent brown spots occurring in this section,

and indicate quite clearly that the accumulation of nitric nitrogen is accompanied by an accumulation of chlorine, these elements occurring together in the same ratio in both spots.

In cases 22 and 23 we may make a comparison of four samples, 1027, 1028, 1029 and 1046. Sample 1027 is labeled “Sample of white alkali.” Samples Nos. 1029, 1046 and 1028 are samples of surface soil. Sample 1028 is labeled “No white alkali.” We are thus enabled to make a very interesting comparison. Sample 1027, which is labeled a sample of white alkali, and on which we may assume that nitrogen fixation is not taking place, owing to the excessive amount of total water soluble salts\(^1\) and to the fact that there are no indications of the brown azotobacter pigments,\(^2\) contains actually more nitric nitrogen in an acre foot of soil than do the other three nitre samples, 1029, 1028 and 1046. Furthermore, 1027 is labeled “White alkali,” while 1028 is labeled “No white alkali.” Yet both contain nearly the same amount of chlorine.

It is thus readily seen, from the study of the results reported by Dr. Headden, that wherever we have the accumulations of nitric nitrogen there are also accumulations of chlorine, and, furthermore, wherever we may make comparisons of nitric nitrogen and chlorine content of the soil at the present and in earlier years, we find an increase in nitric nitrogen and also an increase in chlorine in the same general ratio as they occur in the soil in earlier years; this clearly indicates a common origin. This origin is indicated by the deposits occurring in the country rock, such as noted in the shales of Colorado, the sandstones of Idaho, and the rocks of Southern Utah and Nevada.

In conclusion, we wish it distinctly understood that we do not maintain that nitrogen fixation may not take place to a certain extent in the Colorado soils, and in some places to an appreciable extent; but what we do maintain, and it is well borne out by the results reported in this paper and all the published results of Dr. Headden on this subject, is that whatever theory is used to account for the accumulation of chlorides in the Colo-

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2 Loc. cit., p. 54.
rado soils will also account for the greater portion of the nitrates present.

SUMMARY.

In the work which has been conducted for eight years at the Utah Experiment Station, upon the influence of irrigation water upon the production and movement of nitric nitrogen in the soil, there has been observed a variation in the nitric nitrogen content of the soil, and the concentration of the soil solution with the water applied, the crop grown, and with the season.

The soil upon which these investigations have been conducted is ideally adapted both chemically and bacteriologically to support a rapid bacterial action, yet the amount of nitric nitrogen present to a depth of ten feet does not exceed three hundred pounds per acre.

Deposits of nitrates do occur in the country rock in widely distributed areas in Western America.

The careful analytical work reported by Dr. Headden on the composition of Colorado soils indicates a close relationship between the nitric nitrogen and chlorine content of these soils, indicating clearly a common origin of these two elements.