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THE NITRATE QUESTION IN COLORADO

A REVIEW FOR THE FARMER

BY WM. P. HEADDEN



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THE NITRATE QUESTION IN COLORADO — A REVIEW FOR THE FARMER

BY WM. P. HEADDEN

In 1910 the chemical section of this Station put out two bulletins, No. 155 and No. 160, on the subject of the occurrence of excessive nitrates in our soils. The latter of these was intended for general distribution, or gave only the general facts as we then saw them. No such general statement has been made since that time.

The accumulation of these nitrates was attributed to the activity of micro-organisms that use atmospheric nitrogen in building up their bodies. Ordinary plants and animals cannot use the nitrogen of the air in this way. Plants ordinarily have to have their nitrogen furnished to them in combination almost exclusively in the form of nitrates, but animals have to have it built up into proteid substances. These are the reasons why the fertilizer-man talks of nitrates and the cattle-feeder of proteids. These micro-organisms use atmospheric nitrogen.

This gives us the source of the nitrogen out of which these nitrates are formed; otherwise it would be a very difficult matter to give any reasonable source for the nitrates. This amounts to saying that these nitrates are formed where we find them. At first we thought, as others still think, that they came from somewhere. We could see but two ways for them to get there. The first was that animals had died, their rotting carcasses causing the brown spots. However, some of the spots were too small and some too big, and some of them appeared where we knew no carcass had decayed. Further than this, they became larger, sometimes smaller, year by year, or month by month. New ones appeared and old ones went away. Next we thought that they were brought by water, either from below or from some other place. This was a difficult proposition and did not seem reasonable as we could not explain why the same water, for instance irrigating water, would make a nitre spot in one place and not in another, or everywhere in general. We studied the irrigation water but it contained no more nitrates than river waters in general contain. Next, we tried the ground waters that had to flow under these spots on their way from some other place to the river, but such ground waters did not carry nitrates until after they had flowed under these spots. Then we dug holes in the spots to see if the nitrates were coming up from below, and we could find none from below. "The next question was, will the nitrates actually grow or increase in the soil if we put it in a glass dish and let nothing but air and pure water get to it?" This we found to be the case. We tried this a great many times, till we proved that these spots could really grow where we found them.

These were extreme cases; that is, there was a great deal of nitre in these places. The first complaints about these spots stated that they were brown and nothing would grow on them. This was true; one could see that they changed color from time to time, becoming darker till they were very brown. This was due to certain micro-

organisms which sometimes produce this color. Only some of them act thus; others are always colorless.

This brown color made a great many people think that these were spots of black alkali, but they were not. One can tell a black alkali spot almost certainly by treating a little of the black surface soil with water; a very dark brown to black solution results. These brown spots give only a slightly brownish-yellow, or even a colorless solution. The brown color due to black alkali is easily soluble in water, but the brown color made by these micro-organisms is only slightly soluble in water, even when there is a good deal of sodic sulfate or white alkali present. The brown color is, moreover, not the same as the much darker color due to black alkali.

The amount of nitrates in these spots was sometimes quite high, from 2 to 6 or more percent of the surface soil, becoming less and less as depth increased, so the richest portion was right at the surface. The nitrate content was around one thousand times as rich as in the soil outside the spot where wheat and other plants grew very well indeed. This was the only difference between the spots and the rest of the land. The water and the soil were the same, but these spots were brown, had nitre in them, and would support no plant life.

At first these spots were small, specific areas 2 to 10, or it may be 12 feet in diameter, usually round and sharply defined: they afterwards became more numerous, larger, and less precisely defined, till at last this condition involved many acres in a continuous tract.

These spots occur to some extent in all parts of the state that I am familiar with, without regard to altitude; the strongest one that I recall having seen occurred at an altitude of 7,800 feet. They require moisture but are not peculiar to wet places—not nearly so much so as is white alkali. A very common place for them is on the outside of a ditch bank, especially of an irrigating canal, along side of or in a road bed; also in tilled ground, particularly in orchards with clean cultivation. I have seen them very strongly developed on hillsides and in a great variety of soils. A light loam seems to be about the best location for spots, but they occur also in heavy adobe soils.

The first instance of the fatal action of these nitrates was noticed in a clean-cultivated apple orchard on a sandy-loam soil. The usual questions about alkalis and the water plane were made, but brought out no explanatory information. The water plane, in this instance, was more than $5\frac{1}{2}$ feet below the surface of the ground, and the roots of the apple trees did not penetrate to a depth greater than $2\frac{1}{2}$ feet. There were forty acres in this orchard. The trees that we went to see had died within the preceding ten days. There had been no warning of the trouble. Other trees were dying. The prospects for the orchard were bad. We did not know at that time that nitre would kill mature, bearing trees in that way. The ground had become very rich in nitrates, and these salts were seemingly the only cause that could possibly account for the trouble. It was a simple matter to try and see whether nitre, table salt, or sodic sulfate would kill trees in this fashion. We tried these salts and nitre on different

young apple trees. The nitre injured every tree to which we applied it, and killed one outright in four days; the other salts did no harm. This was the answer to our question: Nitre will burn and kill trees in the same way and as quickly as the orchard trees were killed. The other salts will not do this. The 40-acre orchard was finally wholly destroyed, and it was only one of very many orchards that have been killed in this way. I have seen many sad cases like this in which the results of many years of hard work on the part of both man and family were completely destroyed in one or two seasons, at a time in their lives when they had a right to expect relief from labor and financial anxiety.

A very great number of trees, more than simply whole orchards, have been killed in this manner. The trouble has not been confined to a single portion of the state, but has occurred in most sections where orcharding constituted an industry. I know of none where it has not appeared. The trouble has not been wholly confined to apple trees, for many trees of other kinds have been killed. Even the cottonwood has not wholly escaped. I have seen many of them die from this cause.

Perhaps the apple orchards present the saddest evidence of the effects of these salts, but I do not think that the loss of the apple tree constitutes the most serious injury suffered. This loss is a very evident, direct effect. There are others which, though not clearly direct, are, I fear, even more serious.

The conditions to which we have alluded have all been of the most intense sort, in which many tons of nitrates have occurred in the surface portions of the land, and we have noted only fatal results. In these same sections we have also seen cultural results; that is, results on cultivated crops which varied from the extermination of the plants to excessive stimulation and abnormal development of the crop. I have seen beets grown on the college farm whose tops weighed three or four times as much as the roots which were ill-shaped and low in sugar. I have seen the same thing in other sections. I have also seen the plants destroyed. I have at times wondered how men and women had the courage to attempt to wring a livelihood out of some land, especially such as has gone back from a state of productiveness to one much worse than its primitive state, because of nitre. There is indeed some such land to be found.

In this connection the question arises as to the permanency of these conditions. As they did not originally exist in anything like the measure that they afterward attained, we have constantly indulged the hope that they might abate or wholly disappear. I have watched them for about twenty years, and while they have varied some, they have not ceased to be a most serious factor in our agriculture. If they should disappear for a time I think that there will always be danger of their returning, unless this can be avoided by a system of rotation which will accomplish this purpose in very many instances, perhaps in the majority of cases. I do not believe that there is an infallible remedy. Our conditions are too varied.

Our people will have to learn to fit their notions to the facts in their individual cases. They have been very slow, up to the present time, in learning that they have an unusual problem; and many of them do not yet believe that the problem exists, even though big failures are abundant, some of which could certainly have been avoided.

I am aware that there is always a question in regard to the cost of success: Whether or not it will leave any profit in the present, or provide one for the future. The renter will certainly consider only the immediate profit and not plan and work for the future benefit of the owner or some succeeding lessee. Experience alone will demonstrate the relation of cost to profit, but success in the former line of their agriculture has, in many cases, passed beyond hope for this generation, and perhaps longer. We may succeed in combating the general effects of these conditions on cultivated crops, but not the acute ones such as we had ten or twelve years ago, and which still exist in our orchards.

The crops that we have studied in detail are the sugar beets, wheat, and potatoes. These are our most important crops. The questions concerning the action of nitrates on these have two general divisions: The yield and the quality, both of which may be affected directly—that is, in some way in which we see no intermediary agent to account for the result. They may also be affected indirectly by rendering them more readily attacked by diseases.

These crops were studied in the order that they have been named, and we had a specific reason in each case for taking up the work.

In the case of the beet crop, our greatest interest was in the quality. The fact was that from 1893 to 1905 the beets grown in the Arkansas Valley were excellent in quality. The record of our college work shows that they have averaged, in round numbers, 17.5 percent sugar from 1893 to 1900, the year in which the factory at Rocky Ford was built. The sugar content began to fall about 1905 and continued to do so year after year, with some fluctuations, till it dropped as low as 13.5 percent for the year's average. This low point was reached after I had quit the beet work in the valley. The lowest average that I actually had personal knowledge of was 14.2 percent. The period during which these low percentages prevailed extended from 1905 to 1924, when, for some reason, the sugar content went back to a high average, possibly because of the very excessive rainfall of the preceding year.

I had been interested in the sugar beet crop of the valley since 1894, and was aware of the fact that this deterioration of the beets was taking place. About 1904 I became acquainted with the occurrences of nitrates in spots. At that time I was interested in the study of our so-called alkali questions, and was concerned about the Arkansas Valley.

The brown spots had been taken by the ranchmen to be black alkali (alkalis in general were considered as bad), and I had pre-

viously studied their effects on sugar beets on the college farm which was well supplied with alkalis. Thus, this was a home question. The results of four years' experimentation with beets on land very rich in alkalis and with a high water-plane had led me to the conclusion that alkalis were by far less injurious than had been thought, or would appear from the general teachings on the subject.

There is no question but that we shall always have seepage problems in some places. This is not avoidable so long as we have some high and some low lands, and have irrigating ditches; but the farmers themselves are ordinarily fully capable of taking care of these cases.

I was quite prepared to question the ordinary explanations offered for the falling sugar content of the beets, i. e., alkalis and seepage. It was evident on the face of conditions that these were not the cause of this, for it was not true that any great percentage of the land was passing into these conditions. But the average crop was steadily losing its quality. The manager of one of the factories put the question this way: "What is the matter? Our beets used to run 18.0 percent sugar by the carload; now they run scarcely more than 13 percent, and rot before we can get them cut."

The beet did suffer from a variety of diseases, and while the decline was attributed to these by some, I could not find any great justification for the claim by examining diseased and healthy beets, or better by examining a great many diseased beets and comparing them with the general average. Very badly diseased beets were often as rich in sugar as others which were only very slightly diseased. There remained but one way to prove what was the matter: to take the very best land that we could get and see if we could grow some good beets and poor beets, just as we wished; and this we did. The ground was all good ground. This means that if we put nothing on it but simply planted it to beets, we could get a good yield of good beets. This was the history of the land.

The factories found that the beets were decreasing in sugar each year, and that they were making more and more molasses for each ton of beets worked. This means a great deal: The beets had at that time fallen from an average of 17.5 percent to one of 14.2 percent. Some of them were making 9.5 percent of molasses, whereas 5.5 percent would be high enough for the percentage of molasses from good beets.

I had examined both the beets and the molasses for nitrates. They were present in too large quantities. Though there should have been none present, there was a great deal of them.

As I saw the question, it was like this: This is the same country that used to produce good beets; it now produces poor beets. There is no reason to think that the land has changed in its composition in so short a time. Analyses gave no indication that this had taken place; further, we had not relied upon analyses for information on this subject. We had also fertilized the soil to see if adding these things would produce bigger and better crops. We did

not have any success. Although we tried a great many different combinations, and tried them many times, we never got enough benefit to pay our expenses. This country is not all alkali and it is not all too wet. We concluded that the trouble must be something else.

The beets did not ripen well. Nitrates will cause this. The beets and the molasses contain large quantities of nitrates; therefore, I proposed that we find out by direct experiment whether the application of nitrates to the good ground, which we knew produced good beets, would change the harvest into poor beets. In this we had complete success. We produced top-shaped beets. We reduced the yield, and we reduced the percentage of sugar from 16 to 11 percent. The juices in the factory proved all that we wanted them to prove. The details of the study were very interesting; but the big results which are the principal things, I have just given; namely, we grew poor beets and good beets alongside of each other on good ground by simply adding nitre enough (500 to 750 pounds per acre) to the growing crop.

The object of this experiment was to see if we could, by adding enough nitre, grow beets in imitation of the average crop then grown for the factory. The question was how much may we add without doing damage. It was to answer this question that we used land as nearly free from any fault as possible, and which we knew produced large crops of high-quality beets. The application of 250 pounds of sodic nitrate at the time of planting produced favorable results on this land, but the application of 500 pounds per acre produced bad results. It lowered the yield by one ton and the sugar by about one percent. Seven hundred and fifty pounds per acre lowered the yield by two tons and the sugar three and one-half percent. The greatest injury was done by 1000 pounds per acre, which reduced the tonnage by two tons and the sugar content by five and one-half percent. The coefficient of purity was lowered in each case.

These amounts, 250, 500, 750, 1000 and 1250 pounds per acre seem very big, but they are very moderate compared with the amounts that we actually find in a great many instances. We have repeatedly found the equivalent of 1000 pounds of sodic nitrate in the top two inches of soil in cropped and cultivated land. Two beet fields were systematically sampled to the depth of one foot. In one there was only an ordinary amount for our lands, 672 pounds per acre to the depth of one foot. This was in July, but it fell to 144 pounds by the 25th of August. In the other field the nitrates were high thruout the season, and on the 25th of August amounted to 4728.0 pounds per acre. The beets in the former field on 18th of September carried 16.2 percent sugar, in the latter 12.6 percent. The amount of sodic nitrate given above, 4728 pounds per acre taken to a depth of one foot, was in a field in cultivation to beets. We have found in other beet fields—bad ones, of course—as much as 13 tons per acre, in the top three inches of soil. In beets that were cultivated with the expectation of obtaining a crop, more than 2400 pounds of nitrates occurred in the top four inches of soil.

While it is not usual to apply 500 or 750 pounds of nitrates as a fertilizer, they are very moderate amounts compared with those that frequently develop per acre in some of our cultivated land.

The effects upon the tonnage of the crop, the sugar content, and the coefficient of purity were as stated above. These are the principal factors in which the grower is interested, but there were many points of interest found in the quality of the beets of monetary concern to the factory people and also of interest to the student of plant composition. We found that the total nitrogen was increased, the phosphoric acid depressed, and the alkalis, potash plus the soda, exclusive of the chlorid, were increased.

We tried to grow good beets by the application of fertilizers, but met with indifferent results. Sometimes we had a small favorable result, but more often no result, or an unfavorable one. These attempts were repeated so often that it became apparent that no definite expectation could be based on this practice, at least on the different soils with which we experimented. This did not end our endeavor to grow better beets; by this we mean beets with a good sugar content and higher coefficient of purity.

We tried plowing under a green crop with very encouraging results. We had difficulties of various kinds in these endeavors. This story might amuse some, but we are not going to tell it. The results were favorable; we harvested about 9 tons of beets to the acre, with about 16 percent sugar and 84 purity. We shall come back to this under another subject.

IMPORTANCE OF SOIL'S DEPARTMENT

The second crop that we experimented with was wheat. Many contradictory things had been said about our wheat: some that it was too hard and some that it was too soft. It was claimed that our dry air and sunshine made it hard, and that our irrigation made it soft. It was further claimed, without the assignment of any cause, that hard seed wheat produced soft wheat when imported into Colorado. Colorado conditions were accordingly at fault for the softness of our wheat.

Colorado flour had an excellent reputation as a biscuit and pastry flour but it was agreed that it was a poor bread-making flour. Minnesota and Kansas flour would make, so it was claimed, from 30 to 40 loaves more bread per barrel than Colorado flour.

That the climate accounted for all of the characteristics in our wheat was the favorite theory. It was really claimed that the soil has not very much to do with the character of wheat, but that the climate is the important factor. This subject had been canvassed apparently from every viewpoint and the matter settled.

After having studied the varied and important changes affected by the nitrates in the soil, it appeared to me probable that the soil factors might have a great deal to do with the character of the wheat in Colorado after all. At any rate, our wheat was ranked as soft and we have rather a plenty of first-class climate and ought to have

first-class wheat, but soft wheat does not belong to this class unless it is for pastry. While pie is good, bread is the staff of life, even in commerce.

We had these facts to start with: Our wheat was supposed to be soft; we knew our climate, our practice of irrigation, and our soil factors. The soil factors, conventionally considered, aside from mechanical properties, are phosphoric acid, potash, and nitrogen content.

Until within recent years it was quite common to plant wheat after wheat or other grain, except in dryland culture where it was wheat after fallow. There were many factors in our case which were unknown or were not considered in the theories stated, but which will appear as commonplace to the average wheat grower of Colorado. In the same section of country, for instance, under the same practice of irrigation, the same lot of seed wheat often produces crops of both hard and soft wheat. This, in short, does away with the climate and irrigation theories and also with the influence of the seed wheat as a determining factor, and we have left only the questions pertaining to the soil. Then, why should one field in a section of country almost immediately beside other fields produce soft wheat while its neighbor produces hard wheat? There is a general impression that dryland wheat is hard wheat. This is often the case, but it is just as uncertain as is the crop of two neighboring fields. If wheat be grown after wheat on dryland, it may be just as soft as any other wheat. The fact that it is dryland wheat is no assurance that it is going to be hard wheat.

In studying the beet crop, I learned that the soil factors were, in fact, the controlling ones in determining the character of the crop, disease and accidents excepted. In examining the soils of beet fields, even samples taken in November, December and January, when their nitrate content had fallen very considerably, it was not uncommon to find the equivalent of 100 to 1900 pounds and over of nitrates in the top six inches of soil. The beet crop is one that is carefully cultivated and consists of individual plants approximately eight inches in the row, with rows eighteen to twenty-two inches apart. In no case are there more than 43,000 plants per acre. While these may tend to keep the amounts of nitrates developed somewhat in control, they are not very efficient plants for this purpose. We have found over three and a half tons of nitrates per acre in land planted to beets. These beets were low in sugar, being of about 12 percent content.

The wheat crop is a very different one. The land is not cultivated after planting to this crop as in the case of the beet or potato, and instead of 43,000 plants at most, to the acre, we probably have 500,000 of them. When we sow 75 pounds of wheat (1 $\frac{1}{4}$ bushel) to the acre, we plant not less than 750,000 seeds to the acre. The roots of these plants possess the land completely and the sunshine is effectively precluded from the soil for all of the spring and summer period. To whatever it may be due, the wheat plant, also the oat and other

grasses, interferes very materially with the biological processes that would otherwise go on in the soil, suppressing the nitrates.

We had in the wheat then, a new problem. Still we felt positive that the soil factors were the important ones in determining the character of the wheat produced. We realized fully that this problem differed from the beet problem, in that we had to deal with the mature seed, whereas in the beet we had to deal with a different portion of the plant. The spring wheat runs its whole life course in a few months, about 120 days. The beet would take two seasons to do this, and we studied it at the midway point in its development. Notwithstanding these differences in the problem, we believed that we should find the secret of our soft wheat in our soil.

As already stated, the same season and the same district produced both hard and soft wheat. Though the general practice of a community is the same, individual farmers differ in the manner of doing their work, and they often use irrigating water out of the same canal and plant the same lot of seed. I believed, when I undertook this study, that the secret lay in the part played by those organisms that are concerned in the formation of nitrates. I did not know how the difference was brought about. This was what I wanted to find out.

The first question that I tried to answer was, 'How does nitre, phosphorus, or potassium affect wheat?' The second one was, 'How much nitre does the wheat ordinarily have at its disposal during its growing season?'

In order to answer the first question we applied nitre, phosphorus and potassium to different plots in different quantities, some of them very much more than we thought necessary to produce the desired results. We used the very best land, which was provided with a good water supply, that we could get.

The soil presented no serious problems; it was sufficiently well supplied with phosphorus and potassium to grow good crops on the check plots. The history of the land showed this, and we knew from previous studies that under both fallow and cultivated conditions it would furnish a good supply of nitrates. We did not know what it would do when cropped to wheat in regard to the development of nitrates. We had examined soils that had been in oats and wheat and found that the nitrates were very low—lower than our virgin soils in prairie grasses. We assumed at that time that this was due to the exhaustion of these salts from the soil by the crop.

The results obtained were surprising. We had 36 plots, among them 12 check plots, 12 to which nitre had been added, which with the guard areas made over four acres. One could easily recognize, even to the drill row, where the nitre had been applied. We continued this work for five seasons, using the same land. This difference in the plots was at all times very apparent.

We followed the nitrates in fallow plots and in the wheat plots that had received no nitrates. The fallow plots contained on 4 August the equivalent of 284 pounds of sodic nitrate in the top four feet; the wheat plots contained 43 pounds in the same depth. Sixty-six dif-

ferent series of samples were taken with similar results. The wheat crop had not used such an amount of nitrogen; therefore, the difference was not due to appropriation of nitrates by the plants, and the wastage in the different plots was probably the same. From this it appears that the wheat crop suppressed the formation of nitrates as well as appropriated what the plants needed. This, we shall see later, may be an important factor.

NITRATES AFFECT BOTH GROWTH AND CHARACTER

The effects of the nitrates on the wheat were surprising, not only on the growth of the plants but upon the amount and character of the crop. The land had been in oats the year before we began our experiments, so we had grain after grain to start on; and our check plots would have been influenced by this fact, had not this condition been common to all of them. The yield was in no case increased sufficiently to pay for the costs of application. The wheat ripened abnormally; it remained green in the middle portion of the plants with very heavy leaves, so that in some cases the middle of the sheaves burned; they did not quite rot. The plants lodged badly and were very susceptible to rust. In most cases the yield was less than on the other plots, the grain was shrunken, and not so plump and round as that of the other plots, even in case where there was no lodging. The grain was flinty and high in protein. The effect on the straw was softening. The effect on the soil was to make it hard, and when plowed, it broke up in cakes. There was no perceptible difference in the deportment of the plots toward irrigation.

LATE IRRIGATION OF NO BENEFIT

It was found that an irrigation when the wheat was in half boot or early head produced the best results, provided the plants had grown continuously up to this time; and that later irrigations were of no benefit.

Wheat grown with three feet of irrigating water had the same composition and the same characteristics as wheat grown with one foot of water. The amount of water added as irrigating water made no differences in these respects and the amount of grain produced was only slightly increased by the heavier irrigations.

The action of rain or continued heavy dews on the wheat plant is different from the action of irrigating water, and may affect the composition of the grain and of the plant also.

The phosphorus that we added produced no effect upon the growth of the crop or yield of grain. The potassium added, perceptibly softened the grain. The nitrates depressed the amount of phosphorus in the grain. This is the same result that is produced in the case of the beet. It also increased the potash in the plant, and tended to increase it slightly in the grain.

The effects of the nitrate as given above applied also to the flour made from the wheat. The hard wheat makes the better

flour for bread-making. The serious effect of nitrates on the wheat crop was usually a depression in the yield of grain, which was of big, leafy, weak plants that lodged badly and did not ripen normally. They turned yellow at the top and bottom, while they were green in the middle. The effect never increased the crop to a remunerative extent. The plants rusted badly. The grain produced was hard but almost always shrunken; it was never as plump as the wheat grown on the other plots. Its only good quality was the production of hard wheat.

THE REAL CAUSES OF VARIATION IN HARDNESS

The relative amounts of nitrates and potassium available determine the hardness or softness of the wheat. This is best seen in the condition known as yellow-berry.

The experiments with wheat were made to include other features, but we have here given those to which the nitrates are related.

RELATION OF NITRATES TO POTATO PRODUCTION

The third crop that we shall present in this connection is that of the potato. I do not know that any relation between the nitrates in the soil and the prevalence of disease in the beet plant has been established. There was no question about the prevalence of rust in the wheat, or the tendency of the wheat to lodge, indicating a decided weakness in the straw.

From 1911 to 1914 the potato growers in the Greeley district suffered seriously from the loss of crops. The potato grown in this district had an excellent repute years ago, and deserved it; but things have changed and the quality of the potato produced is often inferior.

This problem was studied by our potato experts in 1911 and subsequent years, and it was thought that the troubles were due to the relations of heat and moisture to the crop. But the studies based on this theory did not satisfactorily solve the problems which have been studied from that time until the present, not by the Colorado Experiment Station at Fort Collins, but by the Potato Experiment Station established at Greeley. The writer examined some samples of soil taken by himself at Greeley in 1911 and found that the crests of the ridges were richer than normal in nitrates. The vines for the most part were well enough grown, but were often diseased. It seemed, even at that date, that the feeding of the plants might have something to do with the trouble—that they had too much nitrogen.

The solution of the problem has presented many difficulties and has not yet been satisfactorily effected. In 1920, with the consent of the Bureau of Plant Industry at Washington and the Station at Fort Collins, I undertook to make a study of the problem similar to the study that I had made of the beet crop, and to ascertain the effects of the nitrates on the crop, including both vines and tubers. Only part of the results obtained have, as yet, been published. A bulletin,

however, completing the account of the results will be published as soon as they have been worked into proper shape.

We hoped by applying nitrates, as in the beet study, to find out their effects on the composition of the vines and tubers and the properties of the latter, and, further, to observe the growth and deportment of the plants toward disease.

IMPORTANCE OF SOILS DEPARTMENT

In order to interpret any results that we might obtain, it was requisite that we should know the deportment of the soil and its composition. These were not very difficult to establish, so far as the composition was concerned, and in regard to the deportment we could, at best, not go beyond the big aggregate results of simple tests. It has been known for some years that soils kept under proper conditions show an increase in their nitrogen content; but all soils do not increase their nitrogen to the same extent. We tested this soil to see how much it would increase in a given time, 40 days. In this time we found a great increase, 75 to 625 pounds of proteid matter per million pounds of soil. As a layer of soil three inches deep covering an acre weighs about one million pounds, this means that each three inches of soil might increase this much, especially the top three inches. The 625 pounds of proteid matter corresponds to more sodic nitrate than we found changed our wheat crop, and, in some cases, ruined it.

But proteid matter is not taken up by plants in this form; it must be changed into nitrates before it can be taken up. This proteid matter is transformed in the soil to nitrates and so becomes available to the plants, but it must be changed rapidly if it plays any part in this problem. In our experiments we found that the amount of nitrogen corresponding to nitrates increased rapidly, as much as four times in 40 days in some cases. It became necessary for us to follow this particular change in the soil thruout the growing season that we might be able to compare our potatoes grown on plots to which we had added nitrates at the rate of 200, 400, 600, and 800 pounds per acre, with those grown on plots to which we had added no nitrates; for if the nitrates were being formed in this soil all the time, we would have to find out how much nitrate was formed in it from time to time. It is evident that the plants would take up this nitrate as readily as they would take up that which we had added. Besides, these nitrates were being supplied continuously, whereas our application was made just after planting and almost anything might happen to it—heavy rains might wash it away, or micro-organisms might destroy it. Though the latter case was possible, I do not believe it occurred.

This was not the case with nitrates that were being formed meanwhile in our check plots, so we had to know from time to time how much there was of these. I suppose that they were also being formed in the plots where we had added nitrates. We thought that they would be, but from our experience with the beets and wheat we thought that the quantities added would be more than enough to show their effects on the crop.

In our experiments with both the beets and the wheat it was clearly shown that a certain amount of nitrates produced almost as big a result as much more would do. This was most plainly shown in the wheat experiments, in which the application of nitrates at the rate of 250 pounds at the time of planting produced nearly the same results as 750 pounds applied in portions of 250 pounds each at intervals of about four weeks. The effects of the larger amount were greater, but not proportional to the amount. The same was found in the case of beets. The soil, the season, and the crop, in the latter case, were different, and yet the application of 500 pounds of nitrates per acre sufficed to show a decided prejudicial influence on the yield and quality of the crop.

That there is also a time of application that will produce a maximum effect is more than probable, although I do not know at what period this is true. This fact, however, does not refute the claim that a large application of nitrates at any time during the growing period of the plant may influence the character of the crop.

It has been shown that the beet takes up about two-thirds of its total nitrogen during the months of June and July, but experiment has shown that 500 to 750 pounds of nitrates applied in August and September will influence the quality of the crop prejudicially. It is, then, important to follow the nitrates thru the growing season of the crop. We did this in the experiments with the potatoes. The largest amount of sodic nitrate, 800 pounds per acre, was applied immediately after planting, and made in one application. Our study of the check plots showed that the nitrates increased steadily until August, when the average of our check plots showed the presence of 400 pounds per acre in the top three inches of soil. In September we found a maximum of 1,100 pounds. Under these conditions we could not expect decisive results. Our trial plots and our check plots were so nearly alike that the results would be uncertain.

The only thing that we could hope for was that the general result obtained with 800 pounds per acre would be so uniformly better or worse than the checks would enable us to tell which it was. This proved to be the case, but during the four seasons that we continued these experiments, we had to satisfy ourselves with this very unsatisfactory condition.

Had we not had one rather favorable year, the work would have been very discouraging. At the time we did not appreciate the reason for this, but the results promised eventual success. Unfortunately, the results of this year were lost by fire, but they had served a purpose which we later came to appreciate; we then regretted our loss of the record all the more. This year we used the same land that we had used the preceding year, and that caused our rotation to be potatoes after potatoes. This is what we would have had had we had our choice, but we had to follow another rotation, potatoes after alfalfa. This latter procedure was not the best for the purpose of our study; it was very good practice in the culture of potatoes, but it tended to defeat our purpose. It was a practice that we had already advocated to prevent

the accumulation of these nitrates in the soil, or rather to correct their effects. It did make our results uncertain, but in the end we shall see it served us very well in another way and did not wholly defeat us in our purpose, so far as the chemical features of the problem were concerned.

The net results are interesting, even though all of our potatoes were grown with an excessive supply of nitrates in spite of the alfalfa rotation. The composition of the vines showed an increase of nitrogen where we increased the supply of nitrogen. Of the ash constituent, phosphoric acid (P_2O_5) and potassium (K) stand out prominently, so far as we can judge; but we practically have only our own analyses by which to be guided, as data on the ash constituents of potato vines seem to be very scarce or non-existent. The two striking instances are the amounts of phosphoric acid and the potassium; the former is extremely low and the latter is very high. We found the same thing in the wheat plant, and in addition we found the ratio of lime or calcic oxid disturbed.

The only figures that I have found for the composition of the ash of the potato vine indicate the presence of about 8 percent of phosphoric acid, 30.0 of lime, 15 to 20 of magnesia and 20 of potash in ripe vines. We have from 2.0 to 5.0 percent phosphoric acid, about 20 for lime, 9 to 11 for magnesia, and from 45 to 50 for the potash. (These results are not yet published.)

The effects of the nitrates upon the composition of the tuber were to increase the total nitrogen, and also the total ash. There is only a very little lime in the ash of the tuber and not much magnesia, but more of the latter than of lime. The ash constituents, affected in a marked manner by the nitrates, were again the phosphoric acid and the potash. The average potato-tuber ash carries 17.33 percent of phosphoric acid and 60 of potash; ours carries about 13.7 phosphoric acid and 67 of potash. The nitrogen is high and the starch is low. The average nitrogen is 0.342 to 0.37; ours about 0.42; the average starch about 17.37. The highest average for any year found for our Greeley potato was 15, and the lowest was 10.8 percent. In five seasons we have found only two samples above the average in starch, and we have examined about 70 samples of tubers from all parts of the state. The potato, whether grown to serve as a food or for the production of alcohol, owes its claim to consideration to its starch content, and one low in starch may be taken as one that is below par. A good potato should cook white and mealy—at least opaque, and not glassy and transparent or soggy. It should have only a slight odor or none, and have no strong, pronounced taste. This odor and taste are due to something in the potato besides starch. Potatoes grown with the application of nitrates fail in some, or all, of these requirements. Ours were yellow, soggy, and strong. They were poor in quality as well as low in starch, but the checks were better than the trial plots. We used only those grown with the addition of nitrates at the rate of 800 pounds to the acre.

We tried a number of samples, mountain-grown and others, in order to have a standard for comparison. We found none wholly satis-

factory. The best was probably a sample of the Burbank Russet, and this was one of the few samples that approached the average in starch. This contained a little over 16 percent starch.

The keeping qualities of our potatoes were not high. This test was made with our samples by putting them in storage at 34 deg. F., and not in a potato cellar. In some samples the starch decreased very perceptibly during the storage, which varied in duration.

The effect of nitrates on the yield was to decrease it. These were the results obtained in four years of experimentation, three of which were after a rotation of two years in alfalfa, a most important factor, as the sequel will show.

It seemed at the end of four years that we would have to finish up our work, however unsatisfactory and inconclusive it might appear to us. It was not due to our own planning nor to that of any party concerned in our previous work on this subject, that we continued our observations for another season. But an opportunity presented itself in the most auspicious manner, and we were very glad to continue our study on a subject that articulated so well with the work that we had been doing. We could not have wished for a better series of facts than actually presented themselves the following year.

Two fields of potatoes presented three conditions: Potatoes grown after potatoes and other cultivated crops, potatoes grown after a rotation of two years in grain, and potatoes grown after a rotation of two years in alfalfa. In addition to this, the experiment was conducted on land that the writer had been familiar with for more than 25 years, and that he knows better than the soil at Greeley. In this way it was really fortunate for us that we were not experimenting at Greeley and were free to address ourselves to this. The soil is really a better potato soil than that at Greeley, and possessed but one complicating condition which, however, we had studied some 12 or 15 years before. The situation was very favorable for us; there was only one feature that we might have wished different. There were none of the diseases present whose relation to the soil conditions we should like to have had studied.

Both of these pieces of land lay on the river bottom. One of them lay immediately under a mesa and really abutted against the escarpment where the mesa breaks down to the bottom land; the other piece lay immediately along the river bank. The drainage is excellent in both cases. The farm land under the mesa was formerly rich in alkalis, not particularly the land on which the potatoes were planted, but other nearby parts of the farm. The land along the river was not rich in alkalis. Both farms are supplied with river water for irrigation, but river water has not always been the only water used on the ranch under the mesa. I do not know about recent practice, but formerly I have seen them using seepage water that issued from the mesa. There is a large acreage of cultivated and irrigated land on the mesa and this is where the seepage water comes from. I do not know whether any of this water was used on the potatoes or not; neither am I sure that it has been used on the land of late years. The land by the river has, so far as I know, no available seepage water to use, but the whole of this

bottom land is alkaline to some extent. Nitre spots have existed in this neighborhood for a long time. I cannot recall when I first saw them to recognize them. We had in these two pieces of land a fair example of the soil problems that we usually meet, except the question of drainage. This was eliminated. Each field was uniform in its general character and exhibited two conditions. One part of each had been in potatoes or other cultivated crop for two preceding years, and the other part in grain, in one case, and alfalfa in the other. In both cases the potatoes after potatoes were practically failures, but after grain or alfalfa the crops were so much better that one would call them good.

An examination of the ground revealed, by its physical features, the general condition of affairs—the crests of the ridges in the parts planted after potatoes were mealy to a strong degree, while those in the other sections appeared like normal soil. These soils were not only physically different, they were different in their composition. This meanness of the soil is a very common indication of the presence of nitrates, and was in this case. The surface soil, top two or three inches, carried in both cases the equivalent of 13,782 pounds of nitre to the acre; the same depth of soil after the alfalfa carried 1620, or one-ninth as much. Taken six inches deep after potatoes, the soil carried 4,692 pounds; and after alfalfa, 324 pounds. There was nearly three times as much in the top six inches of soil after potatoes as in the very surface soil after alfalfa.

We have in these figures a measure of the effects of cultivating a crop of potatoes two years in succession, compared with the effects of two seasons in alfalfa on the amounts of nitrates in the soil. The effects of the grain were less than those of the alfalfa, but were very marked in the same direction.

There was another result that cannot, in fairness, be omitted. This was the difference in the water-soluble portions of the soil. We would ordinarily understand by this the amount of alkalis in the soil. This is not a correct designation for the water-soluble, except in a limited sense. Often the white alkalis are really so predominant that this definition of water-soluble is the most convenient one, but the water-soluble includes more than ordinary alkalis and in the present case we must so consider it. This water-soluble is 4.46 percent in the surface sample taken after potatoes and 1.08 in a similar sample taken after alfalfa. In the six-inch samples it was 0.692 after potatoes, and 0.46 after alfalfa.

The water-soluble portions were not only different in quantity but very different in composition, the principal feature of which was the much greater amounts of nitric acid corresponding to the nitrates in the samples after the potatoes. In one field after potatoes we have 3.48 percent of water-soluble with 23.72 percent of nitric acid; in the other, we have 4.46 percent water-soluble with 19.86 percent nitric acid; whereas after the alfalfa we have 1.08 percent water-soluble with 13.9 percent nitric acid in the surface samples, and a much greater difference in the water-soluble portions of the six-inch samples.

In these fields after potatoes we have 0.692 water-soluble with 15.04 percent nitric acid. After alfalfa we find 0.46 water-soluble and 4.55 percent nitric acid.

These facts relative to the water-soluble present suggest a point that often arises in this connection, 'Where does this water-soluble come from, and what is its relation to the crops planted?' The answer to the latter question will vary somewhat with the crop dealt with and the nature of the water-soluble. Ordinarily the water-soluble portions of our soils do, as stated before, consist essentially, but not wholly of our ordinary white alkalis, a mixture of calcic, magnesian and sodic sulfates, with smaller quantities of chlorids and carbonates. It is very seldom that these last are present in large enough quantities to justify special mention. White alkalis do not do much if any harm in the quantities met with in soils.

About 12 years ago the writer was surprised to see a very good crop of beets growing on the same ranch, but not on the same field, where one of these crops of potatoes was grown. The white alkali was so abundant in this beet field that I took a surface sample of the soil and tested it for the amount of water-soluble present. It was 7.1 percent. The water used on these beets was seepage water that came out of the mesa above it. This seepage water was heavily charged with salts of various kinds, 3,900 or 4,000 parts per million—just twice as much as is said to be about the limit for water considered safe for use. The beet crop was good, and my information was that the sugar content was high. This is not the only case in which I have seen beets grown in ground rich in alkalis and irrigated with seepage water with good results. I recall a case on the Uncompahgre bottom in which the soil, after the alkaline surface had been scraped off, carried about 4 percent alkalis and the water plane was within 18 inches of the surface; this land was planted to beets two years in succession to my knowledge and produced nine tons per acre one year and ten tons the next. The factory returns on these beets gave 16 percent sugar for both years. I have grown beets in soil carrying 3.9 percent alkali in the surface two inches of soil with a variable but constantly high water-plane; and I obtained a yield of 19 tons of 18 percent beets. I have seen a 60-bushel crop of wheat grown on land heavily charged with alkali, and seepage water used for irrigation. These facts are mentioned to answer any misgiving that may be entertained as to the part possibly played in the results by the soluble salts in these potato fields (by "soluble salts" we mean our ordinary alkalis). I do not think that they played any prejudicial part whatever. It will, then, make no difference whether some of the water-soluble came from the mesa or was formed in the soil if the salts were really harmless in the quantities in which they were actually present.

The fact is very suggestive that in a level field, one part of which had been in alfalfa for two years, the other in potatoes for the same time, after the alfalfa there should be less than one-fourth as much water-soluble salts as after the potatoes.

These were the conditions under which these potato crops of 1924 were grown: The cultivation was good; the physical condition of the soil was good; the crops after the potatoes were failures, but not after the grain or alfalfa. The yield in one field was, after potatoes, 20 sacks; after grain 75 sacks. In the other field after potatoes there was no crop; after the alfalfa, 140 sacks.

The potatoes grown in the first field after potatoes and wheat were exceedingly poor; in the second field after alfalfa, fair. The little potatoes gathered from the portion of this field that yielded no crop after potatoes were not usable. These contained 12 percent starch, while those that grew after the alfalfa contained 16 percent. The total nitrogen in these potatoes shows the same difference but more strongly than we found in the Greeley potatoes grown on check plots, and on plots with the addition of 800 pounds of sodic nitrate. The potatoes grown after potatoes showed 0.5269 and 0.5866 percent nitrogen, but after grain 0.49 and after alfalfa 0.378 percent.

The surface soil after potatoes carried, in one case, 12,900 pounds of nitrates, and in the other case 13,782 pounds per million of the surface soil. The alfalfa land carried 1620 pounds, and the 6-inch sample only 324 pounds.

DISCUSSION

Briefly stated, we have learned that in our soils very large amounts of nitrates may be formed, and from time to time are formed.

For many years our orchardists practiced clean cultivation. They became wedded to this practice and changed only with great reluctance, or not at all. In many of these orchards the nitrates developed with great intensity, and the orchards were ruined—in some cases almost every tree died.

With continued cultivation, the beet crop in the Arkansas Valley deteriorated from an average sugar content above 17 percent to one of 14 percent or lower. The relation here was established by the study of the results of the application of nitrates. The results were found to be identical with those which had taken place in the beets.

In the study of the wheat crop, we found an entirely different, but not less instructive relation. In following the nitrates in land planted to beets, it was shown that a nitrate development actually took place, sometimes at a rapid rate, so that the land became enriched in these salts to such an extent that the quality of the beet was reduced. The sugar content was kept down in a specific instance to 12.2 percent against 16 percent in a case where the nitrates did not develop so intensely.

With the wheat crop we found that this nitrate development either was prevented in the soil, or the crop used it up. The amount found in the crop studied, from week to week during its whole period of growth and ripening, did not justify the assumption that the nitrate had been used up; the only alternative was that it had not been formed. In samples of soil taken from beet fields after harvest, we found

large amounts of nitrates in some of them, especially in samples from turn-rows. After oats and wheat we found very small amounts of nitrates, from 1 to 5 parts per million, whereas after beets we found amounts running from a trace to 160 parts per million. In the potato rows, from crests of ridges between plants we found in samples taken three inches deep on the ninth of August an average of 66.55 parts per million for nine plots, which are equivalent to 400 pounds of sodic nitrate per acre.

The experiment with wheat in this case was not made with this specific purpose in view, but rather to seek the cause of its softening under our conditions. We found the explanation in the ratio of the available nitrogen to the potassium.

It is well known that in this section in the early days we raised big crops of wheat, but these big crops gave place to very small ones. The practice of planting wheat after wheat was given up, and the land planted to alfalfa for a few years. The wheat grown in those early days was soft wheat. How much of this was to be attributed to the variety grown, the writer does not know.

Our dryland farmers still practice planting wheat after wheat, with an intervening year of fallow. Without this intervening year of fallow the dryland wheat will be soft or strongly yellow-berried. The explanation is clear from our results with wheat. Nitrogen, in the form of nitrates, is necessary to the production of hard wheat. If the amount of these nitrogen salts is too small in proportion to the potash, the wheat will be either yellow-berried or all soft. Wheat interferes with the production of nitrates in the soil (by this I mean retards or prevents their formation), and uses up what is ready formed, so that a crop of wheat immediately after wheat is likely to have too short a supply of nitric nitrogen to produce a first-class quality of wheat. The intervening year of fallow, in the case of our dryland practice, gives an opportunity for the accumulation of a sufficient quantity to produce good wheat, provided other conditions are favorable.

Our conditions in this respect are very interesting. I stated that the land assigned us for our wheat experiments had been in oats the preceding year and was very good land; in fact, we have no better, but its total content of nitrogen was only moderate—about 0.14 of one percent—and only a small amount of this was found to be present as nitrates. In this soil on which we made our experiments, the ratio of nitrates to the potash available was so nearly the best one for wheat that when we added 10 parts per million of nitric nitrogen we did more harm than good. It must be remembered that we were not trying to find out how much nitrogen to add to do the most good, but endeavoring to discover the answer to a very different question which we did not believe had been correctly answered. We found that the answer was this ratio of nitric nitrogen to potash. In prosecuting this study it was necessary to consider the reaction between the crop and the soil in regard to the formation of nitrates. The results here considered are interesting and have an especial value as applying to our conditions.

The next crop that we undertook to study was the potato. Diseases of different sorts had brought about failures for several years. The matter had been so serious that some measure, if any could possibly be found, had to be adopted to combat these conditions. At first the Experiment Station at Fort Collins assigned a man to study the trouble. The troubles that were recognized were not new ones but they were very injurious; in fact, they destroyed the crop. The question was, 'Why are these troubles, which are not new ones, so much more serious than they have been in the past?' Answers were offered and investigations made, but the results were not conclusive. As the diseases were the same ones that had been present for years, it seemed really evident that the trouble was due to either the climate or the soil, or to both. The effects of temperature and moisture were studied but the results obtained, although at first believed to be sufficient to account for the difficulties, were finally held as too doubtful. This was about 1912 or 1913. In 1914 the county and state conjointly established a Potato Experiment Station at Greeley; and the Department of Agriculture at Washington took over the prosecution of the work, as previously stated. In 1919 we planned to study the effects of nitrates upon the composition and properties of the potato, plant and tuber, and observe if opportunity presented itself, the deportment of the crop, grown with and without the application of nitrates, toward the diseases. This opportunity did not present itself. This is why we have presented the results that apply to the first feature of the investigation only.

The results of four seasons' work showed that the composition of the vines and tubers was affected by the amounts of nitrates available; further, that the composition of the ashes was also materially modified by the nitrates. At the end of the fourth season a combination of facts made it necessary that we should either change our arrangement or stop our experiments. We decided upon the latter. In 1924 two very marked instances of nitre trouble were observed. This gave an opportunity to study them and seek for the interpretation of perplexing things that we had observed.

The facts in this case were that in each of these two fields one part, approximately one-half, was a failure while the other half yielded a crop. The failures were on land that had been in potatoes for two previous seasons, and the crops were obtained on land that had been in grain or alfalfa for two seasons. The differences in these respective halves were that after potatoes the water-soluble nitrate content was high, and after the grain or alfalfa it was low. This water-soluble after potatoes amounted to 3.48 and 4.46 percent in the separate cases; after the alfalfa it amounted to only one percent. About one-third of this water-soluble was made up of nitrates. These prevented many of the seed potatoes from coming up, and killed many of the plants that did come up, so that in one instance the crop was a total failure and in the other the yield was 20 sacks of very poor potatoes to the acre. After the grain we had 75 sacks, and after the alfalfa 140 sacks of fairly good potatoes.

In these instances we have it again demonstrated that even in cropped and tilled land very excessive amounts of nitrates are sometimes developed. In connection with the orchards we asserted that in such as were kept in clean cultivation excessive quantities of nitrates were developed, often to such an extent as to kill the trees. In connection with the beets, we cited an instance in which the nitrates, developed during the growing season, depressed the sugar content to 12.2 percent against 16 percent. We further have shown that by the application of nitrates we can produce those characters in the crops that we find in those grown on land in which nitre develops abundantly.

All of our Greeley potatoes had the peculiarities of potatoes grown with too liberal a supply of nitrates. Our analyses of the soil during three of the four seasons show independently of the composition and properties of the potatoes, that large quantities of nitrates were developed in the soil.

When experimenting with beets, we sought in a preliminary way how we might improve the beet crop. We tried wheat and mustard as green manures. The theory was that by growing a crop we would use up the nitrates already formed and by plowing under the crop we would change the biological conditions of the soil. Our results were good, but we did not continue that line of experiments, as we thought that those interested could repeat the work as well as we. Our results were crops of 9 and 10 tons of beets with about 16 percent sugar, 84 purity, against 11 to 13 percent beets and low purity, in adjacent land.

The lesson of our wheat crops is even more marked. (It is understood that these are different experiments and on different land.) In the soil cropped to wheat we did not find any proof of the development of nitrates; on the contrary the nitrates in the land occupied by wheat were very low, while the same land in fallow showed a rather strong development of them. They were not lower in the wheat plots because the plants had used the nitrates, but because their formation had been prevented.

The properties of the wheat produced after a fallow and after a crop of wheat show the effects of this suppression. The wheat grown after a fallow on this land with which we were experimenting produced grain richer in protein by 3.7 percent than the same variety grown after wheat. Further, the appearance of the wheat showed the difference; it had far fewer yellow-berry kernels than that grown after the wheat. Similar observations were made on wheat grown after oats.

The preceding facts explain the crops of 1924 in which we have failure and fair success side by side in the same field. Two years in potatoes permitted the development and accumulation of large amounts of nitrates, sufficient to insure failure of the 1924 crop. Two years in grain or two years in alfalfa had prevented this so that a crop was secured. In this case the alfalfa was much more effective than the grain crop. This shows the effects of rotation of crops.

The wheat crop in the case of the beets seemed to be as effective as the mustard, but there is almost certainly a great difference in the value of crops for this purpose. It is possible that some plants may even favor the development of nitrates in the soil. It is already certain that shallow cultivation is favorable so that a cultivated crop is more favorable than one which is not so treated.

We have in all accounts of our experiments avoided discussing the fertilizer features possibly involved. There have been good reasons why we should avoid these questions. There has been no special fertilizer propaganda urged upon the people of Colorado, and if there had been the high cost of fertilizers and their failure to produce results would have, and will for years to come, keep the farmers from investing too heavily in them.

Things may change, and with some crops on some lands a profit may be made by the application of certain fertilizers, but in our own experience we have not found this to be the case.

In regard to nitrogen, we might be misled by the analytical results as recorded in soil analyses, as these show an average below the minimum considered as indicative of a sufficient supply for an average productive soil. Our observation is that the application of nitrates should be made with great care, if made at all. It seems probable that by a proper system of fallowing and cropping much of our land will never need the application of ammonium salts or nitrates.

Up to the present time, I have not seen the case in which the application of phosphorus has proved remunerative, but under the best system of cultivation the time will come when we shall need this element. It would be folly to advocate the general use of this by this generation, for it does not pay; and the second, third, or tenth generation that comes after us will be better able to judge of its need than we.

The nitrogen question is with us and our problem is to learn to so control it that it shall serve us, instead of killing our orchards, suppressing the volume of our crops, and spoiling their quality. So far, they have done us much damage, but I am sure that when we have learned to solve our own problems for ourselves, this development of nitrates will be converted into a very great blessing.

If we act wisely, I doubt whether we shall ever have to buy nitrogen. The cost, labor, intelligence, patience, and the money thirst of the farmers themselves are, and will be, important factors in this problem.

SUMMARY

The first instances of excessive nitrates in our soils appeared as "brown spots in which nothing would grow." They are still referred to quite often as brown spots. They were taken to be spots of black alkali; but they were not, for they contained no black alkali, or sodic carbonate.

Sometimes these spots appeared in new places and people thought that the irrigation water brought them up from below. This was the first attempt to explain where they came from. This was a big question, as these spots spread over big areas, among them, apple orchards, where the trees died.

Examination of these soils showed large amounts of nitrates, but no one had seen apple trees die in this way. It was a question whether or not the nitrates had actually killed the trees. We put nitrate of soda, Chile saltpetre, about some trees. These trees all showed the same kind of injury that they showed in the orchards, and even died.

These brown-spots were becoming more numerous, and the individual spots were becoming larger. The question, 'Where are they coming from?' had to be answered. We had already shown that they would kill trees, and there was a notion that they were coming up from below. However, we could not find any below. They were all on top of the ground. The water used for irrigating the land contained only just a little nitrate, not as much as a great many river-waters contain. We examined the well-waters and the drain-waters, and considered where we could get them. These well and drain-waters contained only a little nitrate, and that only after they had flowed under these brown spots. We had holes bored in these spots; and when we got down a few feet the water did not contain any nitrates. So the spots were not coming up but were going down, and out with the drain or ground-water.

We then tried cultivating these nitrates by proper treatment of the soil; and we found that the soils would become brown, take up nitrogen from the air, and increase in nitrate content. Of course, this means that there was something living there. It was a patch of bad weeds, but they were microscopic in size and we could only see them when they turned the ground brown. We call this increase a fixation of nitrogen, and the building of the nitrates, nitrification.

This was what was going on in the soil that killed the trees. Nitrates in small quantities are good, but in large quantities they are bad. Apple trees were the first subjects that we studied, because they are big plants and are sensitive to the action of these nitrates. A great many of them, in all parts of the state where apple orchards are grown, died. The matter was a serious one.

Complaint was also made that sugar beets were becoming poorer in sugar and were yielding too much molasses. That these nitrates would kill sugar beets, as well as other plants, was not only a natural inference, but was often found to be the case in the field.

It was often the case in wheat, oat, and sugar-beet fields, that these spots on which nothing would grow were surrounded by very big, dark green plants. We often found that whole fields of beets had large green tops and poor beets. We tried to see if we could imitate this condition by adding nitrate of soda, Chile saltpetre, to the land, and we concluded that we could. We also found that we could grow just as poor beets as were then being delivered to the factory. When we found the nitrates in the soil, the beet tops were big and green, and the beets were such as we actually grew, with the addition of nitrate of soda. There was then no doubt about the cause of the poor beets. We tried also to grow good beets, but we shall tell of this later.

A great deal had been said, and a few years ago was still being said frequently, about our wheat. It was pie-bald, yellow-berried, soft wheat and was not much good for making bread. Kansas and Minnesota flour would make, so it was claimed, 30 to 40 loaves more bread to the barrel of flour than our Colorado wheat, and this seemed to be true. The bakers all told the same story. Further, it was stated that hard seed wheat would produce soft wheat when grown in Colorado. There were various explanations. Climate was said to be the principal factor in determining the properties of a wheat crop, but our climate is acknowledged to be a good one. We have lots of sunshine and have to use irrigation to grow the crop. This irrigation was claimed to be the cause of the softening of the wheat.

We studied the subject, believing that the soil did have a lot to do with the character of the crop, and we found this to be so; but we also found a marked relation between the wheat plants and the suppression of the nitrates, as others have also found. We have shown in the body of the bulletin that the hardness or softness of the wheat depends upon the amount of nitrates in the soil, and that it takes only a little too much nitrate to make the plants grow heavy leaves, weak stems, ripen abnormally, and rust worse than wheat grown without application of nitrates. On the other hand, where we have too little nitrate, we have soft wheat. We also observed that after wheat or oats, we often have yellow-berried or soft wheat. This is just the reverse effect of the application of nitrates; but we found that the relation between the wheat crop and the formation of nitrates results in a suppression of the nitrates, so that there is very much less of them formed in ground planted to grain than in ground planted to some other crops. These facts have been given to help understand the results obtained in our endeavor to grow good beets, but we will leave this subject till later when we shall try to bind these things together in a few statements.

The third crop that we tried to study in connection with the nitrates was the potato. Our object just now is to cull out the main results obtained.

We believed it possible that there might be an intimate relation between the nitrates supplied to the growing potato plants and their susceptibility to disease. We had to learn by experiment what the

effect of nitrates is upon the potato. No one before us had studied this matter, as far as we knew (we have described this part of our work in the body of the bulletin), but no diseases developed during the time that we studied this subject, so we had no good chance to see how the second half of our proposition would work out. We have had to confine our studies to the questions of composition of the plants and tubers, and to the quality of the latter. We found that the potato, like the beets, is poorer in quality when grown with too large a supply of nitrates. They cook yellow, glassy and soggy; they have a strong odor and an unpleasant taste.

We stated that we tried to grow good beets as well as poor ones. We did not try to grow good potatoes intentionally, but, in effect, we did.

In our endeavor to grow good beets, we plowed under mustard and a crop of winter wheat. This resulted in our growing good beets, 16 percent sugar against 11 to 13 percent on similar land without green manure.

In the last year of our potato work we found two places where experiments in rotation of crops were ready made to hand. There were two fields, both planted to potatoes. About one half of each field had been in potatoes for the two preceding seasons, and the other half in grain in one case, and in alfalfa in the other for the two seasons. The principal data will be given in another bulletin.

In the land that had been in potatoes, the nitrates were very high and the crops were failures; after the grain, they had 75 sacks, but the potatoes were of poor quality. After the alfalfa, the nitrates were low: the yield of potatoes was 140 sacks and the quality ran fair to good.

The winter wheat, the mustard, the grain, and the alfalfa had suppressed the nitrates and the crops following them were very greatly improved.

This is the principal reason for saying so much about the wheat in the body of the bulletin. With other grains, it is a good crop to keep the nitrates down, but apparently not so good as alfalfa. Though we have all been taught to believe something entirely different about the alfalfa, we should be ready to give up our firm beliefs when we find them false.

