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ALKALIS IN COLORADO
(INCLUDING NITRATES)

By W. P. HEADDEN



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ALKALIS IN COLORADO

(Including Nitrates)

By W. P. HEADDEN

One of the things often spoken of as characteristic of the western plains is the occurrence of alkali. I think that this used to find more frequent mention than it does now. This is perhaps easily explicable in that travelers do not now have to depend upon surface waters for drinking purposes, nor plod their way slowly through an unfamiliar country subjected to all the inconveniences of the early day travel. On the contrary, the stranger now enjoys all the comforts of modern travel, mostly through succeeding reaches of well settled and cultivated country. For all of this the question of alkali is often presented to the agriculturist as one of serious import and still unsettled.

I recall an incident that happened some years ago which illustrates how striking the appearance of our alkali-covered areas may be to those unaccustomed to them. The Colorado and Southern train was approaching the town of Loveland and such an area suddenly came into view. One of the children in an eastern family that had never been west before cried out, "Oh papa! See the snow!" This was in spite of a prevailing high temperature and of the fact that we had passed field after field of grain ready for harvest or already in shock. The impression may be largely one of surprise but the reasoning is that a thing so unusual as this must be injurious. This in the past has been not only the reasoning of the individual, but it very generally has been declared to be a fact that alkalis are injurious.

This opinion is in both the public mind and in the scientific views on this subject. I have in the outset no thesis to prove. When I began the study of the subject I participated in the prevailing public opinion on the injurious nature of these salts.

ALKALI GENERAL IN COLORADO SOILS

The occurrence of alkali in Colorado soils is practically universal. The differences in the amounts in different places may be considerable, but generally it is a question of visibility and absolute quantity and not of its presence. There are not many places where one can collect samples of soil that can be truthfully said to be free from alkali and in saying this I do not mean to use any fine distinction in regard to the amount of soluble salts remaining from those formed by the decomposition of the minerals forming the big mass of the soil. I do not even have in mind any minimum amount of soluble salts that must be present before we shall consider the soil as carrying alkalis. In the case of

most of our soils the alkali will show if a sample of wet soil be allowed to dry slowly, when perhaps the whole surface, or possibly certain prominences, will become white. This is a sufficient amount to justify one in considering the soil as carrying alkali. It is evident that this applies to "white alkali" alone; "black alkali" will betray its presence in other ways, the principal of which is the tendency of the soil to become very hard and to turn black where any drops of water may ooze out of it.

The salts present in these alkalis are the sulfate of soda, (Glauber's salt), the sulfate of lime (gypsum), and sulfate of magnesia (Epsom salts), sodic chlorid (common kitchen salt), sodic carbonate (ordinary washing soda), and possibly, also, sodic bicarbonate (baking soda). Sometimes we have still other salts, calcic, magnesian, and sodic nitrates, also calcic chlorid, etc. In some alkalis we find small amounts of potassic salts and phosphoric acid. These, together with substances that occur rarely or always in small quantities, we may neglect.

The origin of the sulfates, chlorids and carbonates can be traced directly to the minerals in the soil. So far as the sulfates are concerned we have an abundant supply of them in the minerals themselves. For instance, feldspar contains sulfuric acid, chlorin and phosphoric acid enough to supply a very great quantity of sulfates in the form of gypsum or of sodic sulfate. We do not need this source for we have a great supply of sulfate in the gypsum which is very common in Colorado, and which is very often present in the marl or hard pan that has formed in nearly all of our lands. In some places the sulfid of iron, marcasite, and pyrites may form by their oxidation sulfuric acid and sulfates which eventually give rise to the sulfates of soda, lime or magnesia.

SULFATES AND CHLORIDS CONSIDERED "WHITE ALKALI", SODIC CARBONATE "BLACK ALKALI"

Of these salts usually found in the alkalis the sulfates with the chlorids are considered as "white alkali". The salts are themselves white and the water in and on the land where they occur is only slightly if at all colored. Sodic carbonate is called "black alkali", not because the salt is black, for washing soda and baking soda are white salts, but the solutions of washing soda in the soil where there is a lot of half decomposed plant or vegetable matter dissolves this half decomposed stuff to a black solution. This salt, or its solution is, moreover, so caustic that, if it be kept, especially strong solutions of it, in contact with the stems of plants, it will eat them, that is, destroy their tissues and kill them. The vegetable matter and the solution of the salts at the same time becoming black. In this way it has come to be called "black alkali".

TERM "ALKALI" USED IN COLLOQUIAL SENSE

The term "alkali" is used in its colloquial sense whenever reference is made to such a mixture of salts as has been described. The sulfates of lime and magnesia are not alkalis in a proper sense and it is a question, how far we should consider calcic sulfate an alkali, even in this colloquial sense. The reasons why we consider its use doubtful are: First, it is in no case injurious to general crops, on the contrary it is often applied to land as a manure, something to do the land good. Second, it constitutes such a large percentage of a few soils which are often quite productive that we are justified in neglecting it among the alkalis which we consider accidental soil constituents peculiar to semi-arid regions, remaining in the soil because there has not been a sufficient rainfall to wash them into the rivers. The sulfate of lime, however, that fairly forms a zone along the eastern flank of the Rocky Mountains has not so simple a history and could not readily be removed by any conceivable rainfall. On the other hand, this salt actually forms a part of the mass of efflorescent salts to which the popular name "alkali" is applied and makes up a large percentage of these salts, sometimes almost the whole of the efflorescence. We cannot well reject such efflorescences from the group of our popularly designated alkalis. This difficulty does not attach itself to the sulfate of magnesia though, chemically, it has a close family relation to the calcic sulfate.

These salts, singly and in sufficient quantities, are injurious to vegetation. Many apple orchards in Colorado have unwisely been planted on land under-laid by gypsum (often shortened to gyp.), at shallow depths. Such orchards grow for a few years and then turn yellow, because unthrifty, and perhaps die. This is an experience altogether too common in Colorado. The yellow, unthrifty condition of such orchards, and in some cases the death of the trees, is attributed to the action of the gypsum. If this view be correct, then the calcic sulfate should be included among the injurious salts. Though this view seems well sustained by observable facts it is not so simple, for the gypsum, which is of frequent occurrence almost as a hard-pan quite near the surface in many sections, is not pure gypsum. I have found much of it quite rich in arsenic, which may in part or even wholly account for the unhealthiness of the trees.

It has been often observed that apple trees planted on gypsum lands bleed from wounds, especially during the second year after trimming. This bleeding causes the deposition of a light brown deposit, often forming pendant masses several inches long. These deposits are rich in lime and arsenic. This bleeding, with its resultant deposits is abnormal and such quantities of lime and the arsenic are not proper constituents of the sap of the apple tree. It looks as though the gypsum, with its arsenic, were the source of this trouble. This does not

make out so strong a case against lime as it appears to, for trees do well and live to an old age in limestone countries; so this effect is either peculiar to gypsum or to the arsenic which is frequently present in it.

There are difficulties introduced by retaining the calcic sulfate as a component of our alkalis, but I have consistently retained it, and that for the reasons indicated. It is seldom, however, outside of cases like the apple trees that questions of the possibly poisonous character of the calcic sulfate are raised. Sometimes shallowness of soil over a gypsiferous layer, or the impermeability of this layer may give rise to mechanical troubles which are entirely distinct from the effects alluded to above, which may also be present at the same time. I recall a very bad case of an orchard in which this was the case and both difficulties had to be contended with. But I would in no way consider myself justified in considering the case as an instance of alkali trouble.

The question regarding magnesian sulfate is not wholly unlike that of the calcic sulfate but is somewhat turned around. Experiments have shown that magnesian sulfate is quite poisonous but its presence in alkali in the soil does not actually prove so detrimental as our experiments would lead us to expect it to be. I have only made sprouting experiments in sand to which this salt had been added in as large quantities (2.5 percent of the dry sand) as we are likely to meet with in any of our soils. The germination was delayed but not prevented and the little plants grew well for the few days that we observed them. I do not think that anyone has questioned the propriety of including magnesian sulfate among the alkalis.

ORIGIN OF THE ALKALIS

There is unanimity in regard to the origin of the alkalis; briefly stated it is explained as follows: The earthy mass that we term soil is, from a mineralogical standpoint, a mass of small rock fragment in which a very large variety of minerals are represented. Among these minerals two greatly predominate, quartz and feldspars. The quartz is so good as wholly unattacked by water. It is a simple chemical compound, and if it were dissolved by water it would not give rise to the kind of new bodies that we find in the alkalis. The feldspar are comparatively complex minerals and water acts on them quite vigorously breaking them up and forming new compounds. For the present purposes we may consider the plagioclase feldspars only; these consist of alumina, lime, soda and silica, and are very abundant in our rocks. These feldspars yield readily to the action of the natural waters, all of which contain greater or less quantities of carbonic acid taken up from both air and soil, and yield sodic carbonate, calcic carbonate, soluble silicates and free silicic acid, and leave as the end product, a hydrated

silicate of alumina. This is insoluble in water while the other products are soluble. This presents the main features of this alteration process. If there be only a moderate amount of water, the decomposition may go on and the products formed remain in the soil or be only partially removed. This is the case in our semi-arid areas. These products of the alteration of the rocks remain in the soil or are removed only a little way from where they were formed only to be left, by the evaporation of the water, in some other nearby place, where they become so abundant as to form white incrustations. While this is true, it is very far from presenting all that we know about these changes, in fact, we are compelled to go further in the explanation of the facts as we find them. According to what we have said, these incrustations should be composed of sodic carbonate, calcic carbonate, some silicates and silicic acid. It is only occasionally that we find these deposits to be made up of carbonate; as a rule, we find them to be sulfates, and while the sulfates of soda and lime make up by far the larger part of our alkalis, the sulfate of magnesia and sodic chlorid are so good as always present in varying quantities. That some carbonate should be present would seem to be inevitable, for the solutions furnished by the decomposition of the feldspars are in the first place carbonates and the changes that are made in these solutions may not always be quite complete; besides, the feldspars are actually everywhere in our rocks and soils and are all the time being acted on by carbonated water. The calcic and sodic carbonates are partially or wholly changed into sulfates. These salts contain a different acid from the carbonates, which got their acid from the water which effected the decomposition of the minerals. The gypsum in the soil is the agent that most commonly brings about this change. We have also added magnesia to the list.

If we take fresh feldspar, grind it up very finely, treat it with water containing carbonic acid, say for three weeks, and examine this water, we will not only find that it contains the carbonates of lime and soda with some silica, but also both sulfates and chlorids, not so much as carbonates, but enough to show that these minerals themselves contain some sulfates and chlorids. If every rock mass of our mountains contains some chlorids and some sulfates ready formed we need scarcely puzzle ourselves in looking for the source of the chlorids and sulfates that we find so generally distributed. It won't help us any to go further back in the history of these chlorids, for our purposes, it suffices that they are present in the rocks of our mountains and in the waters that flow from them to the plains. The same is true of the sulfates, and why should we look further? Here is a source sufficient to supply as much chlorin, for instance, as we may be called on to account for. If we need more sulfuric acid, there is a source near

at hand. Concerning this easily available sulfur we need ask no questions as to where it came from, it suffices that there are large quantities of sulfides almost everywhere in our shales, especially if they have contained organic matter. The sulfides of iron, known as marcasite and pyrite, yield upon exposure to air, oxids of iron and sulfuric acid which may combine with lime and water to form gypsum or with soda to form sodic sulfate. This, under some conditions, is the easiest explanation for the presence of sodic sulfate in large quantities and it is, at least in part, the correct explanation. The occurrence of gypsum crystals in many of our shales owe their formation, in all probability, to the action of the sulfuric acid formed by the oxidation of these sulfids of iron on lime compounds. There are immense quantities of gypsum along our foothills extending both north and south of us, and under the plains. As to the source of this sulfate of lime, it suffices in this case to acknowledge that it is there in very great quantities.

Our knowledge of the source of the magnesium sulfate is not so clear. Lime is very frequently accompanied by magnesia, be it more or less in quantity. The feldspars, which furnish lime and soda by their decomposition, also furnish a little magnesia and other minerals present in the rocks, also in the soil, contain magnesia, so there is no need of looking very far to find a source of this substance. Some of our limestones are strongly magnesian. The sulfate of magnesia is very easily soluble, as is also the chlorid, so we would not expect to meet with these salts in our rocks. These salts do occur in extraordinarily large quantities in Stassfurt and elsewhere in Germany but the magnesian salts that occur in our alkalis have not the history that these Stassfurt salts have. Our salts have probably only started on their course to the ocean, while the Stassfurt salts have run this portion of their course and witnessed the passing of the ocean itself. The magnesian salts that we meet with in our rocks and minerals are silicates and carbonates; in our waters and alkalis they are the sulfates and chlorids. These salts are unquestionably formed in the soils by the interaction of the magnesian minerals and the sulfates and chlorids derived from the feldspars through the action of carbonated water. The case of some deep-seated springs in the old metamorphic rocks may be different, but, the ground-water occurring sometimes within two feet of the surface, many of our shallow springs and even artesian waters met within or above the Dakota sandstones will come under the statement made.

In regard to the chlorids in general, I believe that I shall have to avail myself of an explanation that I recall having read somewhere which referred their formation to the primordial chemistry of our globe. The incompetency of this statement to explain anything is its commendation. We find chlorids in the old metamorphic rocks when

we look for them, at least we find chlorin, in small amounts it is true, but the mass of our mountains is tremendous and that of the still undecomposed fragments of these rocks and minerals in the soil is beyond our conception. So, without appealing to the sea water and salt deposits occurring in various parts of the world, the aggregate supply of chlorids is not only exceedingly great but their distribution or occurrence is universal, our great bodies of fresh water are not free from them and the beds of our ancient fresh-water lakes contain them. The flow of the waters from the land to the sea is carrying a constantly renewed burden of these salts, especially the sodic and magnesian chlorids and the magnesian sulfate, to the sea. The reason that we have such quantities of sodic sulfate, sodic carbonate, magnesian sulfate, calcic sulfate, and the chlorids in our soils is not that they have produced more of these salts than other soils but because the water supply has not been big enough to carry away the products of its own action. The insufficiency of water is fully indicated in our term "semi-arid climate".

Enormous Quantities Contributed By Rivers

The reader for whom this bulletin is really written possibly has never thought of the different kinds of work, or the amount of it, that the streams of our mountain-sides are doing. He knows that the gaps in our hog-backs of today are places through which streams may flow, sometimes only during heavy rains or continued wet spells. He is familiar with the canyons of perhaps a score of little streams in the mountains. He may sometimes wonder how the deep gashes through the solid rocks may have been cut, but he probably never thinks of the burden of material carried by the clear, cool water that he drinks with great pleasure.

The Cache la Poudre

The Cache la Poudre River, which flows through the mountains of Northern Colorado, is a comparatively small stream. Its flow averages about 600 second feet. The average fall of the river for the first 50 miles of its course, is 80 feet to the mile. In many places it is a mass of foaming water just as some other mountain streams are. This impresses us with its ability to wear the rocks which are already worn smooth and the rock walls bear witness, by their polished faces, to the action of this process in the past. We do not wonder that the boulders are worn and that the fine sand has in so large a degree been carried away. But that this same limpid water carries an unseen burden and is doing a continued work in changing the very substance of the rocks and carrying them away does not impress itself on the mind of many of us, and yet this little river with an average flow of 600 second feet, whose waters carry approximately 3 grains of total

solids to the imperial gallon, is carrying more than 50 tons of matter through its canyon every day. This mass of material, mostly carbonates of lime and soda with small quantities of sodic chlorid and some magnesia, has been dissolved out of the rocks and means the breaking down of hundreds of cubic feet of solid rock every day. Estimated roughly the amount of material mentioned here is about equal to 650 cubic feet of rock which is $2\frac{1}{2}$ times heavier than water. To make still plainer the magnitude of this action of water, we will take another example. We have stated that sodic carbonate constitutes what we call "black alkali", and also that this carbonate is one of the products of the action of water on plagioclase, a felspar, which occurs in schists and granites as well as in igneous rocks. The watershed from which the water drains into some of our mountain valleys is several thousands of square miles in area, and even though the rainfall may be only 15 or 20 inches per annum the water that flows into the valley may be millions of acre-feet. In a concrete example that I have recently had occasion to study, the amount of water removed by evaporation was 1,500,000 acre-feet. This water was supplied by the mountain streams flowing into the valley, and, on the supposition that each 10 pounds of water carried $2\frac{1}{2}$ grains of sodic carbonate, which is about what the water actually carried, the amount of this salt brought into the valley every year amounted to 145,500,000 pounds. This has been going on for many centuries and, if none of it has been washed out of the valley, the amount present at this time must be so great that we can form no adequate notion of it, and such are the facts, so far as we can make them out. These processes by which these alkalis are formed are not peculiar to our soils or our mountains. They are active everywhere but, in regions of heavier rainfall, the salts that remain in our soils and are known to us under the name of "alkalis" are washed out and carried, eventually, to the ocean, possibly not in the form in which they were dissolved out of the rocks, for they may change when they come in contact with other salts.

I have not mentioned these sources of our alkalis as necessarily the immediate source of every patch of them, but in some cases it seems to be true as in the case of the carbonate cited in our last example.

NITRATES FORMED IN THE SOIL AN IMPORTANT FACTOR

There are other salts found in our alkalis which are not always understood as being included under our term "alkalis". I refer to the nitrates and in some instances excessive quantities of calcic chlorid. The nitrates are being formed now just as the other alkali salts are being produced, by the decomposition of the minerals in the soil, but

by different agents. Nitrates in very small quantities are often present in well-waters, seldom present in river-waters and are not components of ordinary minerals. They have long been known to be present in small quantities in the surface portions of rocks and have been considered as factors in their weathering or the changes taking place in them. They have also been found in caves, but wherever they have been found they have been considered as the products of living organisms. It is only within recent years that these salts have been noticed in the soil in sufficient quantities to become detrimental. Their presence in some California alkalis was noticed by Hilgard and their origin attributed to the oxidation of the nitrogen found in organic matter. This is without doubt correct, but Prof. Hilgard did not account for the organic matter. I do not recall his making any definite statement concerning the organic matter from which these nitrates are supposed to have been formed. The nearest to a definite statement pertaining to this subject is made on Page 68 of "Soil", where he states: "In the plains of the San Joaquin Valley, spots strongly impregnated with niter are found, especially under the shadows of isolated oak trees, where cattle have been in the habit of congregating for a long time".

The conversion of organic nitrogen, such as exists in the excreta or in the bodies of animals and in the tissues of plants, into nitric acid or nitrates is well established and has been accepted for about 30 years. I think that Prof. Hilgard considers such to be the source of the nitric nitrogen referred to in a preceding sentence, in which he states that the nitrates form at times as much as one-fifth and even more, of the entire mass of alkali salts. "In one case the total amount in the soil has been found to reach two tons per acre with an average of twelve hundred pounds over ten acres". This, though it is a large quantity, is not big compared with the quantities of these salts that we have found in some of our Colorado soils. This is enough to say on this phase of the subject in this place.

The nitrates found may be either the nitrate of lime, of magnesia or of soda. It is a matter of accident, apparently, which one of the three occurs. There is a question whether these belong to the alkalis. I think that they should be included. They constitute an important part of the soluble salts in many of our lands, and more than this, we can trace very serious damage to them. Considered from the standpoint of their source, including them with the alkalis seems scarcely justifiable, on the other hand their presence in very notable quantities, their solubility and their deleterious action on vegetation are in my opinion sufficient reasons for considering them in this connection.

Calcic chlorid is occasionally met with in large quantities and is probably formed by the interaction of other "alkali" salts.

Injure Vegetation If Present In Large Quantities

These salts, included under the general term "alkali" are all injurious to vegetation when present in large enough quantities, which of course, vary for different plants and for the different salts. Our information relative to the amount of these individual salts which may be required to do damage to the crops is not very satisfactory and this is not surprising, as we cannot imitate, or even determine, all of the conditions which may be met with in our fields. I think that it can be safely stated that the most dangerous salts that we have mentioned are the nitrates. I do not know that there is any distinction to be made between the different nitrates that we have mentioned, calcic, magnesian, and sodic nitrates. They are all very soluble and all poisonous when present in large quantities. How they act upon the plant I do not know, but the results that they produce are very marked and they cause the death of the plants very quickly. The plants that I experimented with were 4-year-old apple trees. I know how much nitrate of soda I put on the ground and to how large an area I applied it, but I don't know how strong the solution was that reached the feeding roots nor do I know what proportion of the feeding roots of the trees were reached. My object in the experiment was to see what the effects of the nitrates were upon apple trees and not to determine the points that have just been mentioned. Further, I don't know how the effects were produced, whether by absorption, the prevention of osmosis, or whether the solution to all intents and purposes simply killed the root hairs. This much I do know, i.e., the leaves burned and the trees died, or were badly injured. One of these trees was dead in four days after the application of the nitrate. It was left standing for two years but it never recovered. I have seen old trees with perfect foliage and a full crop of half-grown fruit burn and die in a few days and I have never seen an instance of recovery in trees injured in this way. Sometimes only a part of a tree may be injured and this injured part dies. I have dug up such trees and followed the roots for as much as 27 feet from the trunk in an endeavor to find how the nitrates killed the tree. I have never been able to determine this. In the four-year-old trees experimented with I was unable to find any nitric-nitrogen in the leaves in more than traces although I had firmly expected to find it. Some plants, heliotropes, from the greenhouse treated with saltpetre were placed at my disposal; in these cases there was no trouble in finding nitrates in the leaves, for the nitrate crystallized out on their surfaces. We are not sure that the two cases are parallel but the important end results were the same—the plants were killed. I am inclined to think that the action of the nitrate in these two cases was different in character. In the case of the apple trees I think that the burning of the leaves was due to drying out caused by

the cutting off of the water furnished by the root hairs. This view is further strengthened by the deportment of vigorously growing trees located in ground rich in nitrates. I have seen the foliage wilt and the trees die without tip burning. I took this to be caused by the sudden cutting off of the water supply. The solution in this case contained large amounts of nitrates. May a sufficiently strong solution of other salts possibly act in a similar manner? I tried this with ordinary kitchen salt of which I put 25 pounds around a four-year-old apple tree and threw up a little dike around the area and turned in the ditch water. No injury resulted. This experiment served its purpose very well, but in this connection it only shows that 25 pounds of salt did not furnish a sufficiently strong solution to do any damage.

SODIC CARBONATE ESPECIALLY HARMFUL

The next most injurious compound in these alkalis is sodic carbonate. When this salt is present and is brought into solution it acts like caustic soda or a weak solution of lye. It attacks the tissues of the little plants and sometimes big ones and kills them. Another thing it does is to cause the soil to become hard, so hard indeed that one may be surprised that plants can grow at all. I recall such a crust, from 4 to 6 inches thick, so hard that we used a mattock to cut through it. Under this crust the soil was open, even sandy. The presence of this compound is very general, as we would expect it to be, for it is one of the first products of the breaking down of the feldspars which occur in every fragment of granite, schist, or igneous rock and also in many sandstones. It is from such rocks that our soils have been derived, at least in far the greater part, and these feldspars occur practically everywhere, so we have good reason to expect more or less of this carbonate everywhere and we find it very generally in drain-water and in our alkalis in small quantity.

The magnesian sulfate and chlorid in pure solutions are more detrimental to vegetation than the carbonate of soda, but they don't occur in the form of pure solutions, nor are they bottled up in separate corners of the soil. Even the soil itself very often has a great deal to do in determining what the compounds will do.

The most abundant constituent of our alkalis is the sulfate of soda, commonly known as Glauber's salt. This salt is fortunately not very injurious, even in pure solutions. It is scarcely corrosive at all, as many ranchmen in Colorado have had ample opportunity to observe, for the white coatings that in many places covers the surface of the land, in some sections for many square miles in one continuous body, consist very largely of this substance.

Sodic chlorid, ordinary kitchen salt, does not occur in any large quantities in our alkalis. The areas in which I have found much salt

are both few and small. Large quantities of this salt, or brine, of course will kill most kinds of vegetation. These big quantities which would make it a serious thing for us are not found in our alkalis. I recall one place where it is very abundant in what we would designate alkalis, but to insist on considering this would be foolish, because it is only in a comparatively small area and its source is evidently from a salt spring at the head of the stream along which this salt is found. In early days they boiled salt at this point. While it does not occur in injurious quantities, it occurs everywhere.

Calcic sulfate is very abundant in our soils and, as it is soluble in water, it comes to the surface with the other salts in solution and crystallizes out, forming a part of our alkalis. Sometimes it forms a very large part of them. This compound in very large quantities is dangerous as I have pointed out in the case of apple trees, but ordinarily it can be neglected unless it forms a hard-pan, when it is very objectionable, both because it forms a hard-pan and because it may become injurious.

As I may not come back to this point, I shall digress to state that the most regrettable results that I have seen in this connection are its effects on orchards. The trees may do quite well for eight or ten years, but at about this period several difficulties show themselves. The trees cease to grow and often turn yellow. In such cases it will generally be found that the root system has been prevented from developing and is inadequate to properly nourish the trees and the food that these roots furnish to the growing parts of the trees may be and probably is an improper food, i.e., is poisonous, not necessarily in a virulent degree but so much so that the trees become unthrifty.

Calcic chlorid is not very injurious and does not often occur in our alkalis in any considerable proportion. There are a few places, however, where it may be said to be very abundant. These occurrences have no significance from an agricultural standpoint, for the places where I have found it most abundant would be unproductive if it were absent, due to other conditions. I have no idea at all how much of this substance it would require to make a soil unfriendly to vegetation. I recall an orchard in fairly good condition in which the soil contained enough of this substance to keep the surface wet enough to make it so dark in color that one could easily pick out these spots. I do not know what effect this condition had upon the orchard. At the time I visited it there was no marked difference in the size and vigor of the trees in these spots and in the condition of those growing outside them. As the condition of the whole orchard was only fair and I made no further study of it than the examination of a single set of samples of soil that I took on this visit, I cannot state that this calcic

chlorid had done no harm whatever. I only wish to state that the trees in these spots where there was enough of it present to keep the surface so moist that it was actually darker in color than the rest of the surface, were neither better nor worse than the rest of the orchard.

HOW SALTS AFFECT PLANTS

I have tried to make the preceding statements clear, but there are some things that badly need explanation and even then will remain unsatisfactory. A solution may enter the plant and travel through every part of it and kill it. Just how this is done is for the plant physiologist to tell us but we know that, if we allow a solution of sodic arsenite to come in contact with the feeding roots of one side of an apple tree for instance, this sodic arsenite travels very quickly even to the ends of the branches, and wherever it goes, it kills. We can follow this sodic arsenite up the roots, through the trunk of the tree and into the individual branches, and we find dead tissues wherever it goes and live tissue wherever it did not go. We can also recover arsenic from this dead tissue. The solution need not be very strong. It enters the tree with the water that the roots take up. A similar solution of sodic chlorid (kitchen salt) would have been taken up too, perhaps. A very much stronger solution was taken up in a case in which I put 25 pounds of salt about a four-year-old tree, but it did not kill the tree. The sodic arsenite is a poison and it kills every living cell that it meets in its course up the roots, trunk and limbs of the tree. This is one way in which a poison may act.

Destroy Root Hairs

We are thinking of a poison as anything that will kill the plant. If we could take all of the little hairs off of the roots of a tree so that it could not get water to keep it fresh and moist it would dry up and die. We can cause it to do this by bringing strong solutions of certain salts into contact with these little hairs, when they will refuse to take up any water. The result is that the sun, the wind and the dry air take the moisture out of the leaves and none can take its place because these hairs on the roots which have been supplying the water to the leaves and limbs have stopped functioning, the leaves burn, and the plants may even die. Salts which will not ordinarily kill the plants, like the sodic arsenite, may be made into solutions strong enough to kill in this way and then you may not find them in the leaves or in the trunks for the root hairs refused to take them up. I do not know how strong a solution of any salt may have to be before it will do this, but I believe that nitrates do act in this way, in many instances, and I think that ordinary alkali salts, may act in this way too. In this case it amounts to killing the root hairs which is worse for the tree than

killing the leaves, for if the leaves alone are killed the tree may put out others and go on living, if we don't take off the leaves too often, but if we kill or injure the root hairs so that the tree cannot get either food or water enough its leaves burn, perhaps wilt if the action on the root hairs is sudden enough and it dies. I have seen the leaves burn on very many trees, thousands in this case is no figure of speech, and I have also seen the still green, full-sized leaves just wilt and hang limp. These trees all died. There are difficulties in making the different things that we have learned about these matters agree or consistently apply, but it may be that a nitrate solution of a certain strength may kill the root hair by poisoning just as the sodic arsenite killed the leaves and the living part of the limbs, trunk and root, whereas it did not act on the root hairs in such a way as to prevent its being taken up. If a nitrate solution will act in such a manner as to stop the taking up of water, whether it acts by poisoning or purely in a physical manner, the result is the same.

ONE SALT MAY MODIFY ACTION OF ANOTHER

The different salts act differently, some may under no conditions act as a direct, poison but simply in a physical manner by their osmotic pressure. Further, the presence of one may modify the action of another. Magnesium sulfate, for instance, in pure solutions, has been found to be very poisonous, pretty nearly the most poisonous salt, but this don't seem to hold in the field. Experiment shows that seedling roots can just live in a solution containing 7 parts of magnesium sulfate in 100,000 parts of water, but I found the roots of four-year-old alfalfa plants which were more than 12 feet long and extended 1 foot below the level of the ground-water, which was bitter to the taste and carried 852.5 parts of mineral matter in each 100,000 parts of the water. One-tenth, or 85 parts of this mineral matter was magnesium sulfate. We have in this ground-water twelve times as much of this salt in 100,000 parts as the experiments given showed to be the limit that plants could tolerate and yet these roots were living and the plants were thrifty. This field yielded between 4 and 5 tons of hay per acre the year that this sample of water was taken, and continued to do so for years afterward. This difference between the results of laboratory experiments and the facts of the field is well known and the explanation offered is that pure solutions of these salts act differently from solutions of mixtures. In the case of the ground-water just mentioned carrying twelve times more magnesium sulfate than would be necessary in a solution of this salt alone to limit growth, there were also other salts making up nine-tenths of the whole and the presence of these other salts, sodium sulfate, calcium sulfate, calcium carbonate, magnesium chloride and carbonate, kept the strong solution of magnesium sulfate from doing

any harm. In solutions containing only magnesian sulfate, this salt is the most poisonous of all the compounds that we usually speak of as alkalis. In the field it seems to be harmless in the quantities that are present in our soils. It may be true of other salts as well as of magnesian sulfate, that their action on vegetation is modified by the presence of other salts, perhaps even by the soil particles, but we must not attempt to carry this principle too far; for instance, I do not think that we can argue from the manner in which this mixture of alkalis effects the action of magnesian sulfate what its effect would be on the action of sodic nitrate. In this case both parts of these salts are different and the two salts named have no part in common, but I do not think that this makes any difference in the statement made. I think that I can say of magnesian nitrate, just what I have said of sodic nitrate. There is, too, another side to the influence of other salts upon the action of a given salt. In the case of magnesian sulfate, the presence of calcic sulfate and other salts has the effect of lessening the action of the magnesian sulfate. There may be other combinations which might make it greater. We know a great many instances in which even a small amount of salt may greatly intensify the action which may be going on. The reader will recall the statement that the presence of calcic sulfate, sodic sulfate, etc., lessens the action of magnesian sulfate. This is mentioned to explain a contradiction between the results produced in the laboratory and in the field. One experiment is made in glass and the other in the soil. This is a difference, but the bigger difference is that in the one case only magnesian sulfate was present and in the other case a great mass of other salts was present to which we attribute the lessening of the bad effects of the magnesian sulfate. The reader must not think too little of this conclusion because we have chosen the more plausible of two possible causes for the difference; further, he must not find fault with the explanation, because we have not even attempted to tell him that this action is due to this or that individual salt. Our statement represents soil conditions as giving different results from our laboratory experiments and all of these salts are in the soil.

Sodic sulfate is by far the most abundant of our alkalis. Even in pure solutions, it is far less poisonous than the magnesium sulfate and its poisonous action is lessened by the presence of other salts, even calcic carbonate which we might expect to increase its poisonous action actually makes it less by four-fifths, so that it is only one-fifth as bad in the presence of calcic carbonate as in its absence. Calcic carbonate is usually, so far as I know is always, abundant in our soils, so that we would expect to find in our field observations that the

presence of sodic sulfate in our soils, in the quantities in which we find it, is scarcely objectionable at all.

Sodic chlorid is much less injurious than sodic sulfate and its action is lessened by the presence of other salts, notably so by calcic carbonate. The presence of calcic carbonate reduces the action of sodic chlorid to one-third of the action it shows when calcic carbonate is absent.

NITRATES AND CARBONATE OF SODA DO GREATEST DAMAGE

The two salts that we meet with in the alkalis in Colorado which have done us serious damage are the nitrates (calcic, magnesian, and sodic) and the carbonate of soda.

EFFECTS OF SODIC CARBONATE

It is difficult to tell which of these two classes, the nitrates or the soluble carbonate, especially sodic carbonate, has done us the greater damage, but probably the nitrates, for these have a very wide distribution and are very poisonous even in comparatively small quantities, but how small these quantities may be I do not know. The sodic carbonate is likewise injurious in quite small quantities but in this case we have a pretty definite idea of how much may be present in the soil before it becomes dangerous to the plants. The amount in the soil that will injure wheat plants amounts to 0.04 percent of the soil, while beet plants will endure it up to 0.05 percent. It is, however, doubtful whether beet plants will live and produce beets with so much as 0.05 percent of sodic carbonate or "black alkali", in the soil. These two figures probably represent the largest amounts that may be present without injury to the plants. These percentages mean, when put into pounds, for instance, that 100,000 pounds of soil may contain from 40 to 50, or 1,000,000 pounds of soil may contain from 400 to 500 pounds of sodic carbonate before it will actually kill the plants. A smaller quantity may cause the ground to bake very badly and in this way interfere with the growing of a crop. The figures given above amount to from 1,600 to 2,000 pounds of sodic carbonate to the acre-foot of soil, but a much smaller quantity than 1,600 pounds to the acre-foot may be sufficient to do damage if it be concentrated in the upper part of the soil. I suppose that, as a rule, we plant our small seed, wheat for instance, from 2 to 2½ inches deep. If the sodic carbonate in the top 3 inches of the soil, or at any point in the top 3 inches of this soil, equals or exceeds 0.04 percent of the soil, it is apt to kill the young plants. This statement leaves out the danger of the baking of the soil which may be caused by a much smaller amount of this salt. I don't know how small an amount of sodic carbonate it takes to cause the soil to bake on drying, but a sample of a sandy soil which I gathered for the purpose of determining the sodic carbonate

in it had become so firm a mass by the time it reached the laboratory that one could not break it, with one's fingers. No seedling plant could possibly have broken its way through such a mass. The sodic carbonate contained in this sample was 0.017 percent, or 680 pounds to the acre-foot. We do not, at the present time, know of any other cause why this soil becomes so hard.

The reader probably recalls the statement previously made that sodic carbonate is one of the first products of the decomposition of rocks by the action of water. This is why the waters in our mountain streams all contain some sodic carbonate. He may further ask, Why, then, is not this salt everywhere? The answer is that it is practically everywhere in Colorado but not in injurious quantities, for the simple reason that this salt, when it comes in contact with solutions of other salts in the soil, calcic or magnesian sulfate, for instance, it makes a trade with them, exchanging its carbonate acid for their sulfuric acid, and the sodic carbonate becomes sodic sulfate and the calcic or magnesian sulfate becomes calcic or magnesian carbonate. In this manner the very poisonous sodic carbonate is transformed into the slightly poisonous sodic sulfate and at the same time forms calcic carbonate, which makes the sodic sulfate still less poisonous. There is usually a little sodic carbonate left; besides, there is a little being formed all the time in the soil. The conditions are such in some places that the sodic carbonate is not changed and has already become so abundant, and is so nearly the only salt present, that it has become injurious, and there are great stores of it in the water beneath the land. The conditions in most parts of Colorado do not permit of the concentration of this sodic carbonate, even where these mountain waters are used for irrigating the land, for they are largely changed into the sulfate and the small remnant is carried off in the drainage water, for the soil particles seem to have less power to hold this salt back than any other, unless it be the nitrate, which facts we infer from the readiness with which these two salts pass into drain-waters. So, if there be any drain-waters, they tend to wash it out of the soil. There are really two carbonates of soda which are not quite alike, the one is more poisonous than the other. The more poisonous one is our washing soda and the less poisonous one is our baking soda. I have said nothing about the latter salt and will satisfy myself with the statement that the one is more poisonous than the other.

ORIGIN AND EFFECT OF THE NITRATES

We have seen where the carbonates, one of our really troublesome alkalis, come from, but we have not yet attempted to tell where the nitrates come from. Rocks, except near the surface, do not contain these salts, and when they occur in well- or river-water, except in

very small quantities, we consider the water polluted. It is said that natural waters can obtain from sources other than animal matter only from one-tenth to two-tenths of a grain per imperial gallon, which is 10 pounds. Taking the higher figure, this would be a little less than 50 pounds of sodic nitrate in an acre-foot of water. This amount is so good as without influence, but it must come from somewhere. It is not stated where it does come from, but it seems to be taken for granted that it is formed from the vegetable matter that is decomposed on the surface or near the surface of the rocks and soil. If there are any more nitrates than this, students of the subject consider that the nitrogen in the nitrates originally came from animal excrements. Water from deep wells contains at the very most 30 parts per million of nitrates and nitrite together. This would make 81 pounds to an acre-foot. This amount would do good and not harm to any crop to which it might be applied if it had any effect at all. We have never found in any sample of irrigating water more than one-tenth of this amount and the largest amount that we have found in return waters was in one taken from the Arkansas river at Rocky Ford which was one-fifth of the amount here given for deep wells. In the case of these deep wells, the nitrates are supposed to have their origin near the surface. Nitrates in general are supposed to come from one of three sources: They may be washed out of the atmosphere where they are formed by electric discharges, or they may be formed as the end product of the decomposition of vegetable or animal matter containing nitrogen. The very big quantities of sodic nitrate found in Chile and Peru are thought by some to have been formed by the decomposition of immense masses of sea weeds, which would give them a vegetable origin: others have claimed that they were formed by the decomposition of dung. This, of course, would give them an animal origin. These are the principal suggestions that have been made to account for their formation.

NITRATES NECESSARY TO GROWTH OF PLANTS

These nitrates constitute the most expensive fertilizers that we have and are necessary to the growth of most plants. It is possible that plants that grow in stagnant water, for instance, may take up their nitrogen in the form of ammonia compounds, but most plants get their nitrogen from the nitrates of the soil. While nitrogen is an absolute necessity to the growth of plants without any exception, and these nitrates are the most important source of their nitrogen, too much of these nitrates will kill the plants. Ordinarily the amount of these nitrates in the soil is very small, less than 48 parts per million, or less than 200 pounds in the top acre-foot at any one time. The crop, as it grows, uses this up, but it is being constantly replaced, not so fast, however, as the crop uses it, so that at harvest time the amount

of nitrates in a wheat or oat field may be very small indeed—one-fifth or even one-eighth of the amount just given. The important question in this connection is, Where does the nitrogen in the nitrates come from. If we have the nitrogen given in decaying nitrogenous matter the processes by which it may be changed into this form, the one best fitted for the use of the plant, are known. The students of this subject have to deal with very small quantities compared with the mass of the soil or in comparison with the quantities in which some of the other important constituent are usually present. In a cropped field, for instance, it is not uncommon for us to find so little as 24 pounds, or even less, in an acre-foot of soil, and the plants, too, deal with very small quantities of these nitrates. I added 250 pounds of nitrate of soda to the acre and injured my wheat crop. These 250 pounds of nitrate of soda contained only about 40 pounds of nitrogen. Perhaps the average reader will appreciate this more fully if we state this another way, i. e., that I spoiled my crop by adding 10 pounds of nitrogen for each 1,000,000 pounds in the top foot of soil. The quantities of nitrogen, then, that we have to deal with are not big like the quantities of sulfate or carbonate of soda, and still smaller in comparison with the water-soluble portion of the soil. The soil of my wheat field contained a little over 3,800 pounds of soluble salts in each million pounds of soil and yet the addition of only 10 pounds of nitrogen as sodic nitrate injured my crop. It did not kill the plants, but they fell down and did not ripen as they should and the crop was short. I have done this now some fifty times, always with the same result.

Too Much Nitrate Is Injurious

These results show us that while the nitrates are necessary for the plant's growth and fruiting, it is easy to get too much for the production of good, strong, healthy and productive plants, in fact, it is easy to get enough to kill the plants outright.

Nitrates Cause of "Brown Spots"

It is a fact, on the other hand, that we find areas, some of them very small and others very large, where these nitrates are very abundant, equivalent in some extreme cases to 56,820 pounds in a million pounds of the soil. Some of these areas are very sharply defined with only two things to show them to be different from the rest of the land. These two things are; First the fact that there is nothing growing on them, and second that they are almost always brown. They sometimes look as though they were wet and have a slight crust on the top. Under this crust they are often mealy and if there is no crust the surface may be so mealy that it is puffed up.

We find two very striking things in regard to the nitrogen in these areas. The first is that there is much more of it than in the land just outside of the area; the second one is that a very large percentage of it is in the form of nitrates. Further, it sometimes happens that the difference between the total nitrogen and that present in the nitrates is bigger than the amount found in the soil just outside of the area. I have examined vertical sections of such areas and have found but one instance in which the second or third foot of soil contained more nitrates than the first foot; in all other cases the top foot contained much more nitrate than any succeeding foot. The top 3 inches of the soil contains much more nitrogen and also much more as nitrates than the succeeding portions. The top 3 inches usually contains more than the succeeding 2 feet and sometimes more than the succeeding 5 feet. This is especially apt to be the case if there is much nitric nitrogen in the surface sample.

We thought that the nitrates might come from the waters below the surface and in this way come from some other place, but we could not prove this. On the contrary, we found a piece of land on which nitrates were so abundant in spots that the owner failed to get anything to grow on them. This piece of land lay between some seeped land which was badly alkali'd, and the river. The water that flowed from this seeped land to the river had to flow under this nitrate land. I examined four different samples of this water, three taken from the seeped ground and one from an under-drain at the north edge of the land in question, i. e., farthest from the river. Three of these waters contained no nitrates and the other contained only one-tenth part per million. The alkalis on this bad land also contained no nitrates, consequently the nitrates found in the lower land along the river could not have come from this source, for they were not present in either the alkalis, the soil or the water which flowed from under it. A further fact in this case was that the owner had previously tried to wash this soil in order to get things to grow, but it did no permanent good. As all nitrates are very easily soluble in water, and are perhaps the very easiest to wash out of the soil, it was remarkable how they persisted in these spots. Their ready solubility in water should prevent their accumulating in any spot and especially on the surface, if there were water enough to wash them down, and if they were in the rocks, the water coming out of these rocks ought to hold them in solution. Of course, if there be nitrates in the soil or in the rock through which the water runs, we will find them in the water. For this reason we do find them present in some waters which flow over the surface of some of our lands or run down through the soil of some of our mesas and seep out along their edges. But the water that comes from the rocks themselves does not contain nitrates. The following

case will make plain the meaning and force of this statement. There is a piece of land near Canon City which had been planted to fruit, apples, plums, currants, etc., but after growing well for about 13 years, a very large portion of the trees and bushes died in a single season. The cause of this trouble was attributed to excessive water. We could not well hold to this explanation for, after study and a great deal of work, we came to the conviction that the surface waters collected at a depth of about 6 feet. The surface of the ground was everywhere very rich in nitrates and in places changed from its ordinary color, for the most part that of a reddish loam, to a dark brown. A slight moistening brought about this change in a remarkable manner. This soil was, when not wet, soft and mealy. This land passed into the hands of another party, who was convinced that the main trouble was too much water. This man had an extensive system of drains put in. I saw upwards of 7,000 feet of trenches open at one time to a depth of $3\frac{1}{2}$ or 4 feet and they were not gathering enough water to yield a flow. I saw many hundreds of feet that did not draw any water at all. There was water at about 6 feet below the surface. This was very bad water and rich in nitrates. In this case we had nitrates on the surface of the land in large quantities and nitrates in the water in the ground. Had the nitrates from the water below come to the top or had they gone down from the top with the water? I wanted to know the answer to this question and that very badly, for, if they were coming from below, it would have an important bearing on our investigations. There was no question about their being in the water at a depth of 6 feet but this was very bad water; it held from 14,250 to 17,500 parts of mineral matter in a million parts; of this mineral matter, from 425 to nearly 800 parts were nitrates. We knew from conditions found in digging a cellar and in making other excavations that this water was probably only surface water that had been applied in irrigating, so a well was bored at my request to ascertain more fully what the facts really were. In boring this well we found that there was no water after we got a little below 6 feet till we got down to 19 feet, when we struck permanent water. This proved to be even richer in dissolved minerals than that we struck at 6 feet; it carried 22,100 parts of total solids to the million of water, but it carried no nitrates. The bottom of this well was several feet in the shales which underlie this section. As this water from the 19-foot well contained no nitrates it could not furnish any to the water or the surface of the land above it and as it came right out of the shales, the shales themselves certainly contained no nitrates. This is not the only instance of this kind with which I have met. A few years ago a man came to see me about some of his cattle that had died, seventeen of them within a few days. He wanted to know whether I thought the

water from a new well that he had just dug might have killed them. On learning how the animals had acted, I suspected that nitrates in the water might have been the cause of their dying. The owner had brought in some of the water and it responded strongly to a test for the presence of nitrates just as he had taken it from the well. This man said: "I have to drive my cattle several miles to water and I want a home supply", and asked what I thought about driving a well. I had tested deep-well waters from this section and knew that they were unfit for any household use unless one were absolutely forced to use them, but I did not think that they would kill cattle. He put down a well 280 feet and obtained water. It was just such water as I had received from other wells and his cattle got along all right, but it physicked the men who drank it. Later he came to see me again and as the locality was a new one for the occurrence of these nitrates, I went to see the place. My assistant who went with me remarked before we got within three-quarters of a mile of the place that the whole country looked to him like an area in which we should find nitrates in great abundance. Anyone could recognize the characteristics. We found the well which had killed his cattle. It was in the middle of his corral and so shallow that I would not do any work on such water. We returned on another occasion prepared to obtain a sample of water to represent this well. We did not get it out of the corral nor very near to it. The water in the old well in the corral had risen to within 3 feet or so of the surface. We dug a hole in the edge of a beet field, perhaps 250 yards south of this well, and the water came into this hole at a point about 3 feet from the surface. Below this there was but little or no water to the depth that we dug, about 5 feet. We waited till about 10 gallons of water had run in, which required about an hour. The well that he drilled was just outside of his corral and was 280 feet deep, most of the way in shales. This well is cased. We took a sample of this water, for here we had as fair conditions as we could possibly get to show us whether these nitrates might come up from the shales below. The results were that the water from the 5-foot hole contained some 3,000 parts of nitrates and 6,900 parts of other salts to a million parts of the water, while the water that came from the shales 280 feet from the surface contained no nitrates, though it carried 5,328 parts of other salts for each million of water. The surface soil at this place, taken to a depth of 4 inches, contained 7.46 percent water-soluble salts of which 54.5 percent, or more than half, were nitrates. This means that 4.0 percent of this surface soil was nitrates, or 40,000 pounds per acre in the top three inches of this area where I took the sample. This condition was scattered over at least a square mile. Other portions of it were quite as bad as this, so this does not represent just a little, sought-out spot to give us a high

result. We have these facts: The surface soil is extremely rich in nitrates; the ground-water is also very rich, while the water from the shales carries none at all. The shales then cannot be the source of the nitrates that we find on the surface of the land, nor in the ground-waters. Evidently the nitrates in the ground-waters came from the surface soil.

We have the following facts to help us answer the question Where do the nitrates come from? The mass of the mountains does not contain them, they are not brought to the lands by irrigating waters; they do not come out of the shales even when these are present. In this connection I will call attention to the fact, that, in discussing this point in Bulletin No. 155, the first one this station published on the occurrence of nitrates in soils in injurious quantities, and I believe the first one ever published on this subject, I said: "This, (Referring to a suggestion that I had previously made to the effect that these nitrates might, in some cases at least, be derived from the shales), can all be answered very easily by stating the following facts: The mesas above these shales are cultivated and bad nitre spots occur on top of them, in one case 80 feet above the level at which the water was taken; second, that nitre spots occur in entirely different geological formations where these shales do not occur, in alluvial deposits and under ordinary prairie conditions, in other words, the shales, considered as a source of the nitre, would not be adequate for the explanation of the greater number of occurrences and, independent of any other reason, than their insufficiency, we must seek for a more general source, or a cause sufficient to account for all of the occurrences, assuming that they have a common cause, which is reasonable, at least, until we are sure that they have different causes."

The nitrogen in these nitrates never forms a component of the rocks in the sense that soda or potash or phosphorus does and there is no great store of this nitrogen laid up anywhere to be changed into these nitrates. The only stored-up nitrogen that we have is in coal, a vegetable residue, or in these nitrates themselves, which are final products in the oxidation of organic or ammoniac nitrogen. On the other hand, we find nitrogen and nitrates in all soils. This nitrogen is of vegetable or animal origin, we think mostly of vegetable origin, and the nitrates are found in the soil mostly at the surface. If we find them below the surface, say at 3 or 4 or perhaps 9 feet, they have been washed down there, in all probability, by downward moving water, for they are easily soluble and the soil particles do not hold the nitrates back as they do some other salts. These brown spots contain nitrogen and nitrates too in much larger amounts than the soil just outside of them. These spots are sometimes only a foot or two across

and as round as a circle. Inside this circle there is more nitrogen and more nitrates than outside of it. These spots are not always small; they may cover a whole section of land or several sections. In such cases the nitrates are, of course, not evenly distributed forming one continuous bed of nitrates, still last year, 1916, I saw a section of land that had been planted to peas in which the nitrates were abundant enough to kill practically all of them. As said in the quotation given above, from our Bulletin No. 155, these spots and larger areas are not confined to one particular geological formation, nor so related to any given one that we can say that the formation has anything to do with them. Shales occur in great quantities within our State and some of our valleys are both bordered and underlaid by them, so it is quite proper to speak of shales in this connection, but I have met with these nitre spots, both above and below the shales and where there are no shales at all, so we could not, without leaving out part of the facts, say that they come from the shales, even if we had some good reason for believing that they really are present in the shales. I pointed out in Bulletin No. 155 that some shales carry nitrates and explained how these nitrates could have got there; in fact, they ought to be there, and we would have to explain how it happened if they were not. These nitrates occur in the surface portions of some sandstones, also of limestones and volcanic rocks. Some ammoniac compounds have been found in the gases which accompany volcanic eruptions and these may later be converted into nitrates by certain living organisms, but the properties of these nitrates forbid their being an original part of a molten rock, especially if the rock is acid or contains quartz. If we find nitrates in such rocks, as well as in sandstones or in limestones, they do not belong to the rock proper and they are not in the deeper portions of the rock, but only in the surface portions.

We know that the small amounts of nitrates found in soils are formed there. It has been worked out that if we put animal matter, fish, or dried blood, for instance, containing nitrogen, on the soil, the nitrogen contained in it is broken out, converted into new forms and, while some of it may go off into the atmosphere as nitrogen gas, most of it is oxidized or burned to nitric acid. If we added enough fish or blood or other nitrogen-carrying matter, and kept our soil conditions favorable, we could make the soil carry several percent of nitrates.

The question is not how the nitrates may be formed in the soil but Where does the nitrogen contained in them come from? This is the question that bothers us.

I have stated in the preceding some reasons why I do not believe that the nitrates come from the rocks or from the waters. In fact, it would

be pretty hard to explain how the nitrates, if they came from any such source, could collect in a spot, perhaps not more than 2 feet in diameter, in the middle of a field, or right at the edge of a river bank. I have stated that the nitrogen is present in the spots in greater quantities than in the soil just outside of them, also that the water that flows under them from outside land does not contain them.

Micro-organisms Fix Atmosphere Nitrogen

After I had studied a great many spots and tried to find some source for this nitrogen and could find none, the atmosphere forced itself on me as the only source from which the nitrogen could come. In short, it is well known that there are micro-organisms that in growing, take their nitrogen directly from the air and do not have to have some other plant to help them grow. The organisms that make the warty bunches on the roots of pea-vines, tubercles, in some way make the atmospheric nitrogen available to the pea, but these organisms cannot grow without the pea and the pea cannot use the atmospheric nitrogen without the organisms; nevertheless, they are said to fix the nitrogen, though they have to have help. There are other organisms, really plants, so small that we have to magnify them a great many times before we can see them, which can use the nitrogen of the air to build up their bodies. If we grow these in a soil fitted for them, these organisms add nitrogen to it even when there is no nitrogen in it to begin with, because in growing they take nitrogen from the air. We say that they fix it and call the process fixation. This process is going on in our arid soils much more freely than in most soils and in these "brown spots" these organisms have been very active and gathered a great deal of nitrogen.

These organisms die like other plants and, when dead, their nitrogen travels the same way that all other organic nitrogen travels. It is made the prey of changes that result in the formation of nitrates and when these nitrates get strong enough they kill out the nitrogen-fixing organisms themselves. We have found these organisms very abundant in some spots and have grown them and had them fix nitrogen rapidly, and in others we found them nearly all dead, at least, we judged them to be dead for they would not fix nitrogen, while their living neighbors from the outside of the spot fixed it very vigorously. We may say, then, that the nitrates are formed in these spots where we find them. The only really new thing in this explanation is the claim that these organisms carry on these processes on a big enough scale to produce these conditions that we find. We have shown that they can fix, under favorable conditions, enough nitrogen in 1 acre foot of soil to form $16\frac{1}{2}$ tons of sodic nitrate if it were all converted into this form. This result is far beyond anything that we have found in our fields, so these organisms, *Azotobacter*, are not called upon to maintain this record all

of the time in order to account for the conditions that we find. This explains how the spots grow and also why they become brown. Prof. Sackett has found that these organisms grow without producing any color when there is no nitrate present; at least, if they are grown for a few generations without any nitrates, they cease to produce any color, but if a certain amount of nitrate be added, they produce a dark-brown color. This is what happens in these "brown spots" and explains why we find the brown-colored spots rich in nitrates. The brown color tells us beforehand that there is an excess of nitrates present. These organisms taken directly from the soil may produce this brown color for a few generations without the addition of nitrates.

"BROWN SPOTS" FREQUENTLY CONFUSED WITH "BLACK ALKALI"

These "brown spots" have been confused with "black alkali" sodium carbonate, but the two things are entirely different in their nature and also differ in their color; the "black alkali" produces a dark almost black color on the surface of the soil. The hue of this is entirely different from that of the brown of the nitre spots. Of course, we meet with many brown places which do not owe their color to the brown coloring matter of these organisms, or yet to "black alkali". We have no more reason to say that every brown spot owes its color to *Azotobacter* pigments than we have to say that all men are white. These *Azotobacter* may be present without producing this color. They make this color most readily when the nitrates have accumulated somewhat. The "black alkali" makes no color unless there are organic substances, particularly humus, present for it to dissolve. "Black alkali" may be present in injurious, perhaps fatal quantities, without being black at all. This is sometimes the case in Colorado because there is not humus enough present to show this characteristic of "black alkali". Humus or humus-like substances may cause the soil to be dark, or even black, or go into solution and make the water brown. These are all well known facts. We even have a name for these humus-like substances *matiere noire*, or black matter, but this does not look like the brown spots, or the black of "black alkali". These distinctions are easily recognized in the field, more so than in the books. The presence of calcic chlorid in a soil may also make dark spots in the soil, but these do not necessarily have anything to do with either the "brown spots", "black alkali" or the humus; these spots are just what they look like, wet spots, for the calcic chlorid takes up so much water that it becomes wet, even goes into solution, of its own accord.

The "black alkali" in the soil up to quantities ten times greater than is necessary to kill ordinary crops will not prevent the formation of these nitrates; on the contrary, up to this amount, it favors the development of these nitrogen-fixing organisms, so these two may be,

and often are, found in the same soil. They are independent of one another in their origin and are not always associated.

We have given the views held in regard to the poisonous properties of the important members of our alkalis and it has been fairly stated that the results of laboratory experiments made with solutions of these salts do not agree with the results found by observations made in the field, also that the explanation offered is that this difference is made by the presence of other salts in the soil solutions or in the soil which modify the action of these salts. It is an important fact that these alkalis are really much less harmful in the soil than we would expect, judging from their action taken singly in laboratory experiments.

While some investigators have spent much time and effort to ascertain the amount of these alkalis at different depths in the soil, it is agreed that only that alkali that gathers at or near the surface ever does any harm. As these alkalis get to the surface largely by being brought up from the lower portions of the soil, investigators have examined the soils to a depth of 4 feet, which is a fair height for water to be lifted through the soil, and it is also a fair depth for the plant roots even of apple trees, for instance, to go down.

TWO DISTINCT GROUPS OF ALKALIS

It is necessary to separate the alkalis into two groups, one which does but little injury, and the other which does more, even great injury.

To the less injurious group belong the calcic magnesian and sodic sulfates, and the chlorids of these elements. To the decidedly injurious group belong sodic carbonate and the nitrates. Fortunately for us the less injurious alkalis constitute practically all of our ordinarily visible alkalis.

"WHITE ALKALIS" NOT INJURIOUS

These alkalis, "white alkalis" as we designate them, which form so striking a feature of some sections of our State, especially in the spring-time after a light snow or rain, are very gentle indeed in their action. So gentle that I have not seen any bad effects which were clearly attributable to these salts. If, by chance, I have seen instances in which these salts really damaged plants I have failed to recognize them. I have seen, on the other hand, so many instances of their presence, in such quantities that one would expect them to kill the plants, and they apparently did no harm, that I feel justified in making the general statement that in Colorado these alkalis constitute only an unimportant factor in our agriculture. I recall a case in illustration of my last statement. There was a piece of land planted to corn. It was, of course, deeply creased and was watered profusely. The sides of the creases just above the water had a band of white efflorescent salts, alkalis, between 2 and 3 inches wide, while the crowns between the

creases showed an abundance of these salts. The corn was good. I wondered why the corn was alive. I took a sample of the surface soil at a spot where the corn was not as thrifty as most of it was. This sample of soil carried more than 4.5 percent of salts which were soluble in water. These salts consisted, for the most part, of calcic, magnesian and sodic sulfates with more sodic chlorid than usual, but no carbonates. Practically 70.0 percent of this soluble portion was made up of these sulfates, with only a moderate amount of calcic sulfate, 16.6 percent of the total soluble matter. I mention this in particular because this calcic sulfate is very common in our soils and alkalis, often making up a big part of the white coating on the ground, further, because it is not very poisonous, but the lime salts do seem to be poisonous under some conditions. This case was even more interesting than the statements so far made suggest. The land was not only at that time full of alkali, a little more than 4.5 percent of the soil being soluble in water, but the owner was irrigating it freely with seepage water, that carried 16,414 pounds of salts in each acre-foot of water. A good, open, loamy soil will take an acre-foot if it is dry enough to really need irrigation, and the soil is able to hold back a great many salts when such water sinks through it; besides, from 20 to 30 inches of water will evaporate from the surface of the soil and leave the salts that it held in solution. I do not know how much corn the man got to the acre, but it promised to give a fair crop. This land was planted to wheat the next season and again irrigated with this seepage water. I saw it just before harvest and it was far above the average. I subsequently learned that the yield was about 60 bushels to the acre.

In another instance, a beet field, I measured the incrustation between the rows, practically beneath the leaves, for they almost covered the ground. This incrustation was three-sixteenths of an inch thick. This case was much worse than the preceding for the land had been irrigated with seepage water and the ground-water was within 18 inches of the surface. The incrustation as gathered contained 51 percent of water-soluble material which was made up of magnesian and sodic sulfates, together 80.0 percent with 10.0 percent of sodic chlorid. There was very little calcic sulfate in this incrustation. The water-soluble in the upper portion of the soil, but not including the incrustation, was 3.6 percent; 44 percent of which was calcic sulfate, 21 percent magnesian sulfate and 20.5 percent sodic sulfate. There were less than 1.0 percent of carbonates and 4.2 percent of sodic chlorid. There was, in the top 6 inches of this soil, after scraping off the incrustation, 70,000 pounds of soluble salts to the acre. This land was in a river bottom and parts of it are sometimes flooded to such an extent as to drown out the crops. This land was planted to beets three years in succession. I got the record of the production for the second and third years. It was 9 and 10 tons respectively with a sugar content of 16.0

and 16.5 percent. Subsequent inquiry regarding the production and quality of beets grown on other portions of this piece of land showed that they were even better than those grown on the part where I took the samples that I have mentioned. The water used to irrigate this land was seepage and carried 10,930 pounds of solid matter in solution in an acre-foot. The statement of the man who was renting this place was that he could raise all manner of garden truck in abundance.

Another instance is that of a truck garden owned by an Italian. This garden was located at the base of the first bench back from the river. The north end of the piece of land was covered with water and was not more than 3 feet lower than the highest portion of the land. The portion of this land which was not cultivated was used as a cow pasture and I have seen crystals of sodic sulfate in the cow-tracks $1\frac{1}{2}$ inches long by 1 inch wide. The Italian manured the ground heavily and cultivated all kinds of truck successfully. He and his numerous family were well clothed and evidently well fed and the living was made off this 5-acre garden tract. I dug a hole in a part of this garden planted to carrots and found the ground-water at a depth of 22 inches. The surface was exceedingly rich in alkali, so rich that every bit of straw or dead weed that stuck up out of the ground became covered with a mass of sulfate of soda crystals. The ground-water carried 484 grains to the imperial gallon, or 14,300 pounds of salts in the acre-foot of water. The analysis of this water residue showed 23.3 percent of calcic sulfate, 27.2 percent of magnesian sulfate, 27.0 percent of sodic sulfate, 4.7 percent sodic carbonate and 11.2 percent of sodic chlorid. The alkali gathered from the surface of the wet land carried 94.0 percent of sodic sulfate.

Such observations, combined with my own experience in growing sugar beets on land the top 4 inches of which carried 3.16 percent of water-soluble, one-half of which was made up of magnesian and sodic sulfate with only small amounts of sodic chlorid and carbonate, leads me to the conclusion that the ordinary "white alkali" as it occurs in our Colorado soils, does not do us much if any damage. If the few examples cited were the only instance of successful cultivation of strongly alkali soils that I have seen, I would not feel willing to unhesitatingly make the assertion that I have just made. This fact, however, can be observed in large sections where the alkali, is everywhere very abundant, and in many places, we would judge, in excessive quantities.

I can see no object in giving a number of analyses all showing the same thing, i.e., that our "white alkalis", especially the effloresced masses which whiten the surface of the land by the square mile in some sections of the state, are made up essentially of the sulfates of soda, magnesia, and lime mixed with some sodic carbonate and some sodic chlorid. In a few cases it is practically all sodic sulfate, in a few others

it is largely magnesian sulfate; in one I received from New Mexico it was wholly magnesian sulfate, but the rule is that these salts are mixed.

In three of the instances that I have cited the water plane was high, in the fourth it was not high. In all of the cases the crops were good, both in quantity and quality. In the case of my own sugar beets, the best crop I gathered from the very strongly alkali ground was 19 tons of beets to the acre with 18 percent, of sugar, an unusually good crop.

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I have explained so fully the primary origin of our alkalis that no reader ought to be surprised at the presence of some sodic carbonate in almost every sample of alkali and also of the ground-water. The same is true of sodic chlorid. The sodic carbonate is "black alkali", it is true, but the presence of a little sodic carbonate does not change "white" into "black" alkali. While it is true that we may be mistaken about the carbonate present being sodic carbonate, I do not believe that we are, and think, that the carbonate in solution is really sodic carbonate. The presence of soluble carbonates probably indicates that the process of alkali formation is now going on just as it has been ever since there have been rocks and moisture to act upon them. So the almost universal presence of more or less sodic carbonate in "white alkali" should not cause any surprise, for it is perfectly natural that some of it should be present, but it is highly injurious if too much of it be present. Under the conditions that we find in most parts of this state there is no danger of its accumulating, for it will be changed more or less quickly into the sulfate by the abundance of calcic sulfate in our soils, or it will pass into the drainage of the country, where there is any drainage. There is no doubt but that this "white alkali" is being formed in all parts of the State. There may be one considerable exception to this statement and reservation should be made on this account.

ALKALIS CONSTANTLY BEING FORMED

While some of our alkalis may be comparatively old, geologically speaking, others of them, exactly the same salts, occurring very abundantly too, may be comparatively young. It is, further, by no means necessary that, in dealing with two different samples of alkali, exactly the same in character, we are dealing with products from the same immediate source. Mr. Geo. Eldridge called attention to the fact some 30 years ago that the Cretaceous shales in this section of Colorado, particularly about Boulder, seem to be heavily impregnated with alkali. Sixteen years ago the following statements were published in Bulletin No. 65 of this station: "The alkalis are not so easily traced. The explanation offered for the presence of alkalis in the soils of arid regions is as true here as elsewhere, but these general facts are not applicable in the explanation of the particular cases with which we meet in agriculture. It is

a well known fact, one long since recognized, that the shales of several of the Cretaceous groups contain a remarkable amount of these salts, designated by the general term "alkali", including sodium, calcium and magnesium as sulfates, carbonates, and chlorids.

"Analyses of incrustations from various parts of the State, and of waters from both ordinary and artesian wells, show the very general distribution of these salts. They also corroborate the observation of their presence in the shales and other rocks which, whatever may have been the origin of the salts, serve at the present time to furnish the alkalis to the waters percolating through them.

"The following figures, representing the general composition of the alkali, will serve to illustrate the general application of the assertion. An incrustation from the college farm showed:

Calcic sulfate	25.451 percent
Magnesian sulfate	19.798 percent
Sodic sulfate	41.748 percent

The ground water from about 5 feet below the surface yielded an abundant residue, composed of

Calcic sulfate	35.648 percent
Magnesian sulfate	28.754 percent
Sodic sulfate	11.393 percent

A surface well 28 feet deep yielded a large residue of which these salts formed 74 percent, as follows:

Calcic sulfate	15.206 percent
Magnesian sulfate	29.059 percent
Sodic sulfate	29.865 percent

An artesian well, supposed to tap a water bearing Dakota sandstone and having a depth of 845 feet, furnished a water carrying 79 grains of total solids in each imperial gallon, of which 83 percent consisted of these salts as follows:

Calcic sulfate	12.036 percent
Magnesian sulfate	10.473 percent
Sodic sulfate	60.758 percent

It is evident, not only from observation, but as is also indicated by such figures as these, that it is not at all necessary for the agriculturist to question in regard to the primary source of the salts included under the general term "alkali". They are so abundantly present in the rocks and water, even in waters from considerable depths, that there is no need to seek further the source. The questions relative to another more remote origin and how it happens that the shales and even the sandstones are impregnated with these salts can be left to the geologist without serious inconvenience in studying the questions with which our agriculture has to deal. They are here, and in cases where the drainage of any larger area accumulates in a small basin, alkali salts will be brought together and, under proper con-

ditions, will appear as an incrustation. This does not take place unless the water plane is at less distance from the surface than that through which capillarity can raise the water in the particular soil".

This is all true, but does not preclude the continuance of the formation of these salts at the present time at a sufficiently rapid rate to produce all of the salt with which we have to deal. It is simply a question of judging from the conditions which is the more probable source of these particular alkalis. If we have a heavily irrigated, high country, such as many of our mesas, underlaid by shales rich in alkali, and we find the lower-lying adjacent land wet and strongly alkaliied, we are justified in speaking of the shale as the source of the alkali without reference to the manner, place, or time of its original formation. The facts that we find, rightly interpreted, indicate that alkali is of recent origin. The wet land, with its abundance of alkali, shows that the shales let the water run through them and carry out the alkali. In short, it is washing them out. The long time and the water necessary to cut these mesas into their present shape would have done just what the irrigating waters are now doing. It is just as possible that the artesian water mentioned above carried the sodic sulfate into the sandstone with it as that it dissolved it out of the sandstone. If we had no districts abounding in alkali, except within the Cretaceous shales, we might be justified in leaving the impression that our alkali questions are intimately connected with the occurrence of these shales and that otherwise we have no alkali questions. This is not true, for these shales have nothing to do with our most serious alkali questions, for the very simple reason that there are none of these shales in the country where these questions arise, and yet we have square miles of this country whitened by these alkalis. Furthermore, we know the character of the water that is discharged into this country and it does not contain these alkalis. The alkalis that I refer to as whitening the country for many square miles at some seasons of the year are not confined to cultivated land; the most of it has never been irrigated since it was laid down. These alkalis are identical in every way with those referred to as coming from the shales. They consist of the same sulfates and other compounds and have without doubt been formed where we find them. While there has been moisture enough to bring about their formation there has not been enough to wash them out of the soil, not even to wash them so deep into the soil as to remove them permanently from the surface, but they are at times washed into the soil only to come to the surface again. This is the accepted explanation, and what I have said regarding the shales does not in any way contradict it. In the region referred to we are dealing with a primary source and in the case of the shales with a mediate or secondary source. The salts present in the shales may have been in part formed within the shales and in part

found their way from the surface into them. In order to have alkalis present in our soils it is not necessary to have a Cretaceous or any other shale formation present. We have them without these.

It is true that a very large percentage of irrigated Colorado land lies within the Cretaceous formation but there is land of Pleistocene age completely separated from the Cretaceous areas and we have an abundance of alkalis in such lands. These alkalis are not all of the same character, but, so far as the "white alkalis" are concerned, they are composed of the same salts that we find in the Cretaceous areas. I repeat what I have already said that there is no ratio between the amounts of these salts, but they may range from pure sodic sulfate to pure calcic or magnesian sulfate. In "white alkali" the sodic carbonate and sodic chlorid never become predominant. We have conditions under which sodic carbonate is predominant and present in injurious quantities. The geological evidence in this case is strongly in favor of a very recent origin, in fact of its production at the present time.

"WHITE" AND "BLACK" ALKALIS ON ADJACENT TRACTS

A very interesting fact in this case is that we have the "white" and "black" alkalis in adjacent territories. While it is beyond the scope that I set for this bulletin, it may be permissible to give some details in this connection. Even though I am not able to designate a section line as the dividing one between the two areas, The actual division between them, however, is very sharp, considered from the standpoint of productiveness. In the area of "white alkalis" we have such mixtures as the following:

	Percent
Calcic sulfate	0.874
Magnesian sulfate	0.033
Potassic sulfate	3.217
Sodic sulfate	79.557
Sodic chlorid	7.373
Sodic carbonate	3.472
Sodic silicate	0.748
Ferris Aluminic oxids	0.130
Excessive Silicic acid	0.684
Ignition	3.912

The water-soluble in this sample as collected was 80 percent. Another alkali collected from the surface of this land consisted of calcic sulfate 10.0 percent and sodic sulfate, including a little magnesian and potassic sulfates, 84 percent. This sample contained no carbonates. Still another sample contained 90.6 percent sodic sulfate, and another 80 percent of sulfates with 14 percent sodic chlorid. Of those having 80 percent of sulfates, 60 percent was sodic sulfate, and still another from the same ranch carried 78 percent mixed sulfates, 64 percent of which was sodic sulfate. This last sample carried 15 percent sodic

chlorid. These represent the soluble portions of efflorescences as they were removed from the surface of the soil.

The soil and subsoil were sampled at the point where the first alkali sample was taken and analyzed with the following results:

ANALYSES OF SOILS NOS. 580 AND 581

	No. 581	No. 580
	Surface Soil	Subsoil
	Percent	Percent
Sand	56.271	51.285
Silica	17.531	11.662
Sulfuric Acid	0.255	0.123
Chlorin	0.462	0.184
Carbonic Acid	3.956	10.207
Phosphoric Acid	0.651	0.019
Lime	6.900	14.318
Magnesia	1.619	1.444
Sodic oxid	1.464	0.679
Potassic oxid	1.047	1.183
Aluminic oxid	3.383	2.868
Ferric oxid	4.420	3.567
Manganic oxid (br)	0.192	0.161
Ignition	1.867	3.085
Sum	100.017	100.790
Oxygen equal to chlorin.....	0.104	0.042
Total	99.913	100.748

This was virgin soil and about 400 feet from a large drainage ditch. The ground-water at this time was 5 feet from the surface in a stratum of sand, beneath which was a yellow, marly clay. The presence of marl in the subsoil was apparent by its color and manner of distribution. Its presence shows plainly in the analysis, being indicated by the 10.2 percent of carbonic acid against 3.9 for the soil, and 14.3 percent of lime against 6.9 in the soil.

The mineral constituents of this soil indicate the neighboring mountains as the source from which they came. The geological formation is designated as the Alamosa and consists of an alternation of sands and clays. The sands are very uniform in their mineralogical components, being those of the schists, granites, and igneous rocks which everywhere flank the valley. This alternation continues to a depth of more than 1,000 feet. I am informed that there is no change in this respect as far as any of the borings have penetrated, which I understand is 1,800 feet, of this figure I am, however, not certain.

An analysis of the ground-water from this stratum of sand is added to complete the record of our examination of this particular place. The water carried 98.9 grains of total solids in the imperial gallon. Loss on ignition 16.9 grains.

ANALYSIS OF GROUND-WATER NO. 490

	Percent
Calcic sulfate	55.647
Calcic carbonate	15.081
Magnesian carbonate	0.577
Magnesian chlorid	11.809
Magnesian silicate	3.233
Potassic silicate	0.377
Sodic silicate	8.441
Aluminic and ferric oxids.....	0.075
Ignition	(4.760)
Total	100.00

We have a number of other analyses of alkalis from this section and they are all of this type with few exceptions. These exceptions belong to the chlorid type. But to undertake to discuss types of alkalis in this place would lead us away from our purpose and tend to confusion rather than to clarity. The reader should remember, however, that the particular form of alkali with which he has to deal may be produced in his particular district by the interaction of the common salts occurring in the soil of the section. Sometimes these sections or areas are quite small.

SODIC SULFATE PREVAILING ALKALI IN ONE AREA OF 1,000 SQUARE MILES

The statements made in the preceding apply to an area of probably more than 1,000 square miles of which it is perfectly safe to state that the prevailing alkali is sodic sulfate associated with more or less calcic and magnesian sulfate. I have a number of analyses of alkalis from this section that contain from 90 to 96 percent of sodic sulfate. This type of alkali does not contain much sodic chlorid. I think I have given about the highest that we have found, i.e., 15 percent of the soluble salts.

ARTESIAN WATERS IDENTICAL WITH THOSE OF STREAMS

The deeper waters of this section are of the very finest quality. The artesian and spring-waters that I have examined carry from 5 to 16 grains of total solids to the imperial gallon, from 20 to 50 percent of which is silicic acid. The principal salt in these waters is sodic carbonate. This is essentially the composition of the waters of the mountain streams, almost without any change. This is what we would expect, provided our theory of artesian waters is correct. I have stated that the sands through which these artesian waters must flow are mineralogically identical with the rocks of the mountains. These artesian waters are not so far below the surface as to absolutely preclude their having an influence upon the character of the alkalis, as they actually came to the surface, in the form of permanent springs. One, of which I have knowledge, has a flow of 20 second feet. Flowing wells are

also struck at depths so shallow as 65 to 75 feet. The character of these waters, even if they carried many times as much matter in solution as they do, preclude them as the primary source of such alkalis as we have been describing.

Without any change in the geological formation or surrounding conditions, we pass to an area in which the alkali relations are entirely different, and here we find a coincidence in the character of the salts in the water contained in the strata, the salts in the soil, and the alkalis, which, on the surface, are becoming more and more serious, in that they seem to be changing in their character, i.e., becoming richer in carbonates.

The waters of the artesian wells probably present these facts more plainly and simply than do the alkalis themselves though the differences show very plainly in these. It is useless in this connection to multiply examples, so I will choose only two waters, and some alkalis. The two waters that I shall give are about 6 miles apart, located on a north and south line. There is less than 20 feet difference in level between the two places and they are in the same geological formation, while the whole area is surrounded by high mountains of metamorphic and igneous rocks.

The well at the southern end of this line yields a flow of 1 cubic foot per second of good water, carrying 15.9 grains of total solids in the imperial gallon, of which 50 percent is silicic acid and 34 percent is sodic carbonates. The well at the north end of the six-mile line carried 103.6 grains of total solids, of which only $\frac{3}{10}$ of 1 percent was silicic acid and 89 percent was sodic carbonate. The former well is 923 feet deep, while the latter was 500 feet deep, but it has been closed for a number of years. Deeper wells still further north of this point, are even richer in total solids and carbonates, though the increase is not great. There are only very small amounts of either sulfates or chlorids in either of these waters. To state the differences of these waters in other words, the one contains only a small amount of material in solution and the other contains seven times as much; the one contains relatively much silicic acid, the other very little. The total solids from the one at the southern end of the line contain 34 percent. those from the one at the northern end, 90 percent of sodic carbonate. There are only small quantities of sulfates and chlorids present in either water.

I have said enough about the alkalis of the southern section; namely, that they are essentially sodic sulfate, containing quite frequently upwards of 90 percent of this salt and, excepting a few in which chlorids are very abundant, always consisting of sodic, calcic, and magnesian sulfates. The ground-waters are very similar.

In the northern section the effloresced salts contain some carbonates varying from a very little up to 40 percent. We have in this section some deposits of pure sodic carbonate. The soil extracts contain 25 percent sodic carbonate, and upwards, while the ground-waters are even richer in carbonate than the corresponding soil extracts. We would expect this, as the soil retains the sodic carbonate but feebly, or not at all, and consequently permits it to pass into the ground-water, also into the drain-waters. It is for this reason, too, that the nitrates, when present in the soil, are easily washed out by water that runs through it.

An alkali gathered from uncultivated soil contained 8 percent of sodic carbonate. The aqueous extract from the soil below this contained more than 25 percent, and a ground-water taken in the same neighborhood gave a residue on being evaporated to dryness that contained 29 percent of soluble carbonates. These results represent a large area which has now become practically unproductive. Two efflorescences gathered about 17 miles southeast of this contained 20 and 40 percent of sodic carbonate respectively. The well-waters in this whole section, about 800 square miles in area, are alkaline. Shallow wells dug for household purposes contain, according to their depth, from 22 grains of total solids upward, 75 or more percent of which is sodic carbonate. The water from a large drainage ditch which runs through this section from west to east is essentially the same in character as the water from shallow wells. The deeper the wells after they attain a depth of 200 feet, the richer is the water in total solids and the more sodic carbonate they contain. The total solids from the deep wells contain about 90 percent of sodic carbonate.

These conditions are different from those described for the southern section, where we had calcic, magnesian, and sodic sulfates in the effloresced alkalis and essentially the same in the ground- and drain-waters, while the artesian water and that of the big springs in the southeastern portion of the section, contain only small amounts of total solids and these are poor in sulfates and chlorids but are fairly rich in carbonates, and are characterized by the presence of much silicic acid. In this northern part we have sodic sulfate as the principal salt in the effloresced alkalis with some carbonate. The ground-waters contained less sulfates and more carbonates, while shallow wells contain much carbonate and very little sulfates. The amount of salts and the percentage of carbonates increase with depth. They also increase in a line from west to east across this section; for instance, at the west side of the area, where conditions are still good, the first flow of artesian water contains 10.6 grains of total solids to the imperial gallon with 2.2 grains of sodic carbonate; 16 miles east of this the first flow, pre-

sumably the same as the preceding, contains 29 grains to the gallon and 9.3 grains of sodic carbonate, whereas at 750 feet the water in the eastern part of this area carries 104.3 grains, of which 99 grains or 94 percent is sodic carbonate. The calcic and magnesian sulfates are almost wanting in the effloresced alkalis of this section, and also in the soils. I do not recall a single section of soil in which I have found the usual layer of marl consisting of a mixture of calcic carbonate and sulfate. If we find any, it is the carbonate. The analysis of the soil made by extracting it with strong hydrochloric acid, shows that there can be but little sulfate of lime even if all the sulfuric acid present were combined with lime. It is improbable that any of it is so combined, owing to the presence of sodic carbonate. An analysis of one of these soils, taken in a very strongly alkaliied section, shows only 0.363 percent of sulfuric acid, which would form but enough calcic sulfate to make a scant 0.6 percent of the soil. The analysis shows that there is carbonic acid enough present to combine with more than three-fourths of all the lime present, leaving 15 percent of soluble silicic acid to satisfy about 13 percent of bases which the hydrochloric acid took into solution. At the same time we are quite certain that some of these bases were present in still other forms, ferric hydrate, for instance.

Judging from the above sample of soil taken from as strongly an alkaliied area as there is in the section, the total amount of calcic sulfate which may possibly have existed in an acre-foot of this soil is about 12 tons, but which we do not think was there at all, is not large compared with the amount existing as gypsum, which we can see in the soils from other parts of Colorado. There are some sections where we find layers of calcic sulfate 3 or more inches thick. A sample of subsoil from another part of the State taken to represent 2 feet of the subsoil, carried 120 tons of calcic sulfate to the acre-foot.

The composition of the alkalis varies locally but it is usually quite persistent in its character, for instance, in some sections the calcic and magnesian sulfates make up as much as 50 percent of the effloresced mass while sodic sulfate, chlorid, and carbonate make up the rest, of these the sodic sulfate usually predominates sometimes, however, the chlorid predominates, but this occurs rarely with us.

This whole section of approximately 5,000 square miles is characterized by the absence of calcic and magnesian sulfates in the efflorescences found on the surface of the soil, the predominant salt being sodic sulfate. This statement also applies to the 800 square miles of the northern section of which we have spoken in the preceding paragraph. In this section the sulfate is associated with the carbonate, which is not only present with it but even becomes abundant enough to be injurious. The following analysis of an effloresced alkali taken

in an uncultivated section of this area, may be permitted in illustration of this statement even though a previous statement that we found 40 percent of sodic carbonate in an alkali taken from a desert claim has been made.

ANALYSIS OF AN EFFLORESCED ALKALI, UNCULTIVATED LAND

Calcic sulfate	0.710
Magnesian sulfate	0.710
Potassic sulfate	2.539
Sodic sulfate	21.929
Sodic carbonate	54.162
Sodic chlorid	16.959
Sodic phosphate	1.368
Sodic silicate	0.314
Ferrie oxid	0.001
Aluminic oxid	0.161
Manganic oxid (br)	0.222
Silicic acid uncombined.....	1.057
Total	100.000

We have followed the same order in calculating this analysis as we have in all of this work. The sodic carbonate is evidently very abundant. This efflorescence contained, as I gathered it, 36.95 percent of material soluble in water.

This sodic carbonate is present throughout this section and its occurrence is independent of the sulfate.

ALKALIS ORIGINATE FROM FELSPARS

I have elsewhere called attention to the fact that the felspar common in our granites contains both sulfates and chlorids and these are consequently present in our mountain waters. These waters may have run their cycle of changes from rain-water to rain-water again many times but we are interested in only a short portion of their course, i.e., that they fall on our mountains as rain or snow and flow off as mountain streams upon whose waters we look as pure, but which, as in the case of the Poudre, carry their burden of rock constituents from the mountains to the plains. This burden sums up a surprisingly large amount, even in a single 24 hours of their average flow. The Poudre, with its average flow of 600 second-feet through its canyon is carrying material in solution equal to 650 cubic-feet of rock material to its lower levels every 24 hours. These materials consist of calcic, magnesian, sodic, and some potassic carbonate with sulfates and chlorids. The sulfuric acid and chlorin forming the sulfates and chlorids may be combined with calcium or magnesium, but it is more probable that they are combined with sodium and form sodic sulfate and chlorid.

This is the solution that I believe we should start with in accounting for the origin of our alkalis, for this is the solution formed by the action of rain- and snow-water upon the surface rocks of the drainage areas of the water courses coming down from the mountains,

also of all soft waters on the feldspars, especially the plagioclase feldspars, present in the soil. In our case these feldspars are very abundant, as this soil is composed of a mixture of sands derived from granites, schists, and quite a range of igneous rocks. In the neighborhood of Fort Collins and very generally eastward from this place the soil owes its origin largely to the rocks of the Front Range. There are some soils derived from the shales and sandstones, but the latter contain much feldspathic sand. In the San Luis Valley there are no shales and the soil is derived from the rocks of the surrounding mountains. Among these rocks is included a variety of igneous rocks. The sands brought up in sinking artesian wells are of the same general character as those near the surface. This statement is true for a depth of at least 800 feet. Through this extended region we have the action of water on these feldspars and these are practically our soda-yielding minerals. They may also yield lime and magnesia but there are other minerals that might yield these elements so their presence is not such direct evidence that the feldspars are the source of our alkalis as are the sodic salts. It is, however, easily susceptible of demonstration that both calcic and magnesian salts are actually derived from these feldspars. This process of alkali formation is actually going on everywhere at the present time just as has been explained by writers on the characteristics of arid soils and they are present due to the fact that there has not been water enough to wash away the compounds built up by the action of water and carbonic acid. This process is not confined to the rocky watersheds of the mountain streams but is going on perhaps even more vigorously within the mass of the soil itself. While these changes may go on within the soil in the same measure as on the mountain slopes, we have not the same opportunity to study them, as they are certainly modified by more complex conditions. Our mountains are not thickly covered by an old accumulation of any sort, in fact they are only thinly covered by the fragments of rocks of the same kind or perhaps not covered at all and the products of the changes which they are suffering are constantly being carried away in the waters of the streams flowing out of them. For these reasons these mountain waters present the simplest and best conditions for the study of these changes.

A STUDY OF MOUNTAIN WATERS

It may now be interesting to see what we find in these mountain waters and to inquire whether the waters and the alkalis that we have tried to present bear any evident and natural relation to them. I am, of course, convinced that they do and that we have, in this area where we find the carbonates in the soil and waters even to the depth of approximately 800 feet, the simplest case for study that we have yet found and we shall see that the case may be quite easily explained.

That the waters of our mountain streams are as pure natural waters as can be obtained, spring waters which may come from deep-

seated sources or may issue from an open, shallow mineralized veins are not included in this statement. The waters, for instance, of a stream in South Park whose very head is a brine that in early times was boiled as a source of salt, could not be included, even though these waters, later in their flow, appear as mountain waters, nor a spring which was struck in the bed of Clear Creek, Gilpin County, which was rich in the sulfates of iron, manganese, and zinc associated with calcic sulfate. Such springs may discharge their waters into mountain streams, and if their volume is sufficiently big, may modify the character of the water of that stream in a lower part of its course. It really seems unnecessary to state such evident exceptions as these but they are of actual occurrence, and there are many such within the State. I know of a small spring which is discharging an almost pure solution of aluminic sulfate into one of our rivers. This spring is at an altitude of approximately 5,000 feet, but we would scarcely consider the river at this point a mountain stream, though it is a branch of the Gunnison River. Such a water would of course be changed quickly on mingling with any ordinary water.

By mountain waters is meant such as run off of the mountain areas or issue from springs fed by such waters which have been in contact with metamorphic or igneous rock in which felspathic constituents are abundant. The presence of carbonic acid is assumed, as it is present in the atmosphere, in all surface waters, and in the soil.

I will give the analysis of a residue obtained by evaporating about 40 gallons of water to dryness. This water was taken from the Poudre River above the mouth of the North Fork before it receives any other than mountain water.

ANALYSIS OF POUDRE RIVER WATER

	Percent
Calcic sulfate	11.782
Calcic carbonate	24.781
Magnesian carbonate	9.063
Potassic carbonate	4.325
Sodic carbonate	9.146
Sodic Chlorid	5.899
Sodic silicate	8.772
Iron and aluminic oxids.....	0.388
Manganic oxid (br).....	0.063
Silicic acid uncombined.....	16.546
Ignition	(9.235)

 100.000

SANITARY ANALYSIS

	Parts per Million
Total solids	41.4286
Chlorin	1.9804
Nitrogen as nitrates	Trace
Nitrogen as nitrites	None
Saline ammonia	0.0350
Albuminoidal ammonia	0.0900
Oxygen consumed	2.5500

The waters of our mountain streams, as they flow in their mountain sections, are quite similar in composition and carry the following salts in solution: Some sulfate, usually calculated as calcic sulfate; calcic, magnesian, potassic, and sodic carbonates; some chlorid, usually calculated as sodic chlorid, and a relatively large amount of silicic acid.

The amount of sodic silicate present in such a residue will undoubtedly depend upon the amount of aeration to which the water may be subjected. If the fall of the stream is heavy and the water has to flow over falls and large boulders we will find sodic carbonate instead of sodic silicate and the silicic acid will be free or absent, as it may have been deposited. If, on the other hand, the water flows over a more even bed and the aeration is slight, the sodic silicate may not be broken up. We find this to be largely the case in the Rio Grande waters, which flow for many miles with an almost unbroken surface over material of essentially the same character as the naked rocks of the mountains themselves.

The following analysis will make the difference plain:

ANALYSIS OF RIO GRANDE WATER

	Percent
Carbon	1.661
Calcic sulfate	10.203
Calcic carbonate	27.620
Magnesian chlorid	1.218
Magnesian carbonate	2.730
Magnesian phosphate	0.351
Magnesian silicate	5.220
Potassic silicate	4.705
Sodic silicate	10.000
Ferric oxid	0.645
Manganic oxid	0.609
Silicic acid uncombined	35.037
Total	100.000

SANITARY ANALYSIS

	Parts per Million
Total solids	77.00000
Chlorin	0.00014
Nitrogen as nitrates	None
Nitrogen as nitrites	0.000070
Saline ammonia	0.000001
Albuminoidal ammonia	0.000002

This residue was obtained by evaporating the necessary amount of water in the field and this is the reason why there is no determination of the dissolved carbonic acid. The appearance of carbon in the analysis is due to the fact that we had to destroy some organic matter and we preferred to heat no higher than was necessary to accomplish

this purpose as we knew that there was an excess of silicic acid present sufficient to expel all of the other acids.

When such waters as these pass into the soil which differs from the rocks and sands with which they previously have been in contact, changes take place which vary with the character of the soil. In the case of the Poudre water these changes, in their rougher features, are that the silicic acid is almost completely removed, and the calcic, magnesian and sodic carbonates are exchanged for sulfates, the sodic carbonate less completely than the others. Potassic salts are, as a rule, completely removed. Other changes may also take place and give rise to special forms or types of alkalis. These changes are often complex and their course not self evident.

The waters previously referred to are collected from the same general watershed as those of the Rio Grande, though they do not find their way into it but are delivered into the valley by other smaller streams. I have stated that the strata, even the soil of the valley, are made up of the same minerals that form the rock masses surrounding the valley. The principal differences between its condition as the water of mountain streams and when spread out in the strata of the valley is the change from a flowing mass to a resting one spread over many times the area, with changing conditions of pressure and concentration. The effect of these differences is to permit the calcic and magnesian compounds to be removed probably as carbonates and the silicic acid also either as such or as newly formed silicates, leaving in solution the sodic salts as sulfates, chlorid and carbonate. If a solution containing these salts, sulfate, chlorid and carbonate, be allowed to run through the soil, the carbonate is permitted to pass most readily while the sulfate and chlorid are retained to a very much larger degree. The evaporation of the water and consequent concentration of the salts held in solution is a matter of fact and of great importance. I hold that this, in a rough way, is the manner in which we have to account for the difference in the character of the alkalis in the two sections which I have presented. The process of formation of the alkalis in the two sections is essentially the same and the source of the alkalis is the same. The fundamental cause of the difference is that the one section has always enjoyed drainage enough to keep the underground, the artesian water constantly removed from the surface, and evaporation has played a very minor part. Whereas in the other section the supply of fresh mountain water has, in fact, been less abundant and there has been no drainage, or one wholly insufficient to cause the renewal of the water frequently enough to prevent accumulation of the sodic carbonate. In this case the discharge of water into the area is not enough to replace more than one-half of the water that would evaporate from a free water surface and scarcely more than enough to re-

place that which evaporates annually from the land surface, if it be kept ordinarily moist. Under these conditions the silicic acid, calcic and magnesian salts pass out of solution, leaving the sodic salts. Any calcic sulfate that may be formed, together with the sodic sulfate, will be retained near the surface and will be brought up and deposited as efflorescences or disappear into the soil again, according to the supply of surface-water or the weather, while the sodic carbonate in excess of what may be necessary to form calcic and magnesian carbonates will remain in solution and in effect be concentrated therein by each annual increment. This may seem too simple an explanation of the condition which we find in this northern section but I believe that it is the correct one.

The ground- and drain-waters in this section are quite similar in character, both carrying very significant quantities of carbonates. The ground-waters within 4 feet of the surface may carry sulfates principally but at a depth of 15 or more feet these give place to sodic carbonate, and at considerable depths, though the total amount of salts in solution may exceed 100 grains to the imperial gallon, there is so good as no sulfates, while the sodic carbonate amounts to 90 or even more grains to the gallon.

The chief difficulty in this explanation lies in our ideas of artesian waters, i.e., that they are waters confined between impervious strata so curved that they form a series of basins one inside of the other and that the water between a pair of these impervious strata is under pressure enough to force the water above the surface in the case of a flowing well. The wells referred to in this bulletin are all flowing wells. The water that flows into the valley is all mountain water and contains sodic carbonate especially in such quantities as we find in the deeper wells only after it has been changed quite radically. The only way that the sodic carbonate can accumulate in the lower strata of these waters is apparently by passing through the strata into the water from above. I have mentioned the fact that there are in one locality small beds of sodic carbonate on the surface, but borings have failed to show other deposits of this salt.

LACK OF DRAINAGE CAUSES EXCESS OF ALKALI

The only difference between the two areas is that the one is fairly well drained while the other is not, owing to the form in which the strata of the valley were laid down while this whole area was occupied by a fresh-water lake across which the Rio Grande built a bar, or fan.

The water supplied to the valley has always been the same, i.e., the waters of the streams coming down from the surrounding mountains, some of which are never entirely free from snow, and yet the artesian waters from the two sections are wholly different.

We have in this valley a series of strata of common origin, attaining a very considerable thickness, which formed the bed of a fresh-water lake. These strata abut against the metamorphic or igneous rocks which surrounded the lake and now surround the valley. The valley abounds in alkalis of two kinds, the "white" and "black" alkali. The "white alkali" is very generally present but is probably nowhere a serious detriment. The "black alkali" is everywhere present, as would follow from our previous explanation, and is now being formed as one of the first products of the action of rain- and snow-water on the felspathic constituents of our rocks and soils, but, owing to its easy solubility and the inability of the soil to retain it, and also to the readiness with which it can be transformed into the sulfate, it has not accumulated in deleterious quantities except under special conditions. These special conditions in the case discussed are; First; that the sands and soils of the valley are identical in their mineralogical features with the rocks of the mountains; Second; that these conditions have been the same throughout the history of the valley; Third, that this portion of the valley has no sufficient drainage, owing to an old river fan or bar which divides the valley into two sections; Fourth, that there has been an approximate equilibrium between the water supply and the rate of evaporation during a very long period of time, just so long as this valley has existed. The result being that we have in the one section a comparatively simple phase of the alkali question in which the products resulting from the action of rain-, snow- and phreatic waters on the felspathic constituents of our rocks have been partly removed and those remaining only partially modified. For the sake of simplicity we can consider these products to be silicic acid, calcic, magnesian, and sodic carbonate with a little sodic sulfate and chlorid. Considering these to be the products of this action does no violence to the facts, as a reference to the analysis of the residue obtained from the Poudre River water will show. If anyone wishes to consider the results given in the analysis of the Rio Grande water as more typical, I call attention to the fact already pointed out that the difference is only a matter of aeration, and would support this by the results obtained by the examination of the water of the Arkansas, taken above Canon City, which is just below the entrance to the Royal Gorge.

The silicic acid would be removed from such a mixture by flowing through a soil containing soluble salts with which it might combine, or even by sand grains themselves. The calcic and magnesian carbonates can be precipitated by the simple removal of carbonic acid which holds them in solution. We find the most positive evidence of this deposition nearly everywhere in the soils of our State. This is the origin of the white, marly layer of soil encountered in the upper portion of our subsoil, sometimes as a veritable hard-pan. The soil par-

ticles possess the power to retain the sulfates and chlorids as such, but they have little or no power to retain the carbonates. The sulfates and chlorids are retained near the surface and the sulfates in particular are first carried into the soil by descending waters, are there seized upon by the soil particles and later may be brought to the surface again by ascending capillary currents to be left as efflorescences on the evaporation of the solvent water. When there are no salts present in the soil to affect a transformation of the sodic carbonate, and no outflowing water to carry it away, it must become more and more abundant until it becomes strong enough to prohibit vegetation. This is what has happened in the northern section of this valley. This I believe, to be the simple history of the 800 square miles of land included in this section. This is the reason why the artesian waters to a depth of 880 feet at least are, for all practical purposes, a simple solution of sodic carbonate. It will be noticed that these waters carry but little silicic acid and still less of sulfates and chlorids.

“WHITE” ALKALI REMAINS NEAR SURFACE—“BLACK” ALKALI GOES TO DEEPER STRATA

The “white” and “black” alkalis, then, are formed simultaneously as primary products of the action of waters containing carbonic acid. There is a tendency for the “white alkali” to be retained near the surface and for the “black alkali” to pass into the deeper-seated waters. If there be a deep under-ground movement of these waters out of the region, the “black alkali” goes out with them, if not, it must accumulate within the area. We have the former case in the one section and the latter in the other of the two sections that we have discussed.

There are other ways that “white alkali” is formed. I have already cited the production of sulfates by the oxidation of the sulfur in marcasite or other sulfids, principally of iron. While this is a widely distributed action it is not comparable in importance to the action of carbonated waters.

CHANGES WITHIN THE SOIL DEPEND UPON SALTS PRESENT

The changes that may take place in ordinary soils when solutions produced as above described, enter them will depend upon the salts in the soil and these changes will determine the character of the alkali of the locality. With us the general character is that of the sulfates. We have already seen that some sulfates are already present in the mountain waters, further that sulfates may be formed from the sulfur in the sulfids of iron which are widely distributed and also from other sulfids. Besides these sources there are already formed deposits of gypsum in certain geological horizons. This compound though not very soluble in water is a common constituent of our ground-waters. The manner in which this may act with sodic carbonate to form sodic

sulfate is easily explained. If the two salts be brought together in solution they simply exchange the acids, forming a more difficulty soluble salt and an easily soluble one, the sodic carbonate becomes sodic sulfate and calcic sulfate becomes calcic carbonate. Another change which may take place is the result of the action of salt, sodic chlorid, on calcic sulfate, in which the sodic chlorid becomes sodic sulfate and the calcic sulfate becomes calcic chlorid. There are many other changes of this sort that are possible and which undoubtedly take place in certain localities. It seems that we are compelled to apply this principle of exchange which we are quite sure takes place in some instances to other cases in which we are not so certain that the conditions are the same. We can feel quite satisfied that calcic chlorid has been formed from calcic sulfate and sodic chlorid if both of these salts are abundantly present in the soil, but if one of them is present in small quantities only, and we still find the calcic chlorid present, especially in spots, and that sometimes in improbable looking places, this explanation may fail to be entirely satisfactory. We find some such cases in Colorado. We find some magnesian sulfate and occasionally chlorid in some alkalis and I may say always in the ground- and many spring-waters. The fact that these magnesian salts are very easily soluble accounts for their presence in the waters and their formation may take place in a manner similar to the formation of calcic salts. If magnesian carbonate and sodic chlorid act upon one another, both products, sodic carbonate and magnesian chlorid, are soluble. Magnesian sulfate may be formed in a similar manner, and if magnesian sulfate and calcic chlorid chance to mingle, there will be a change resulting in the formation of calcic sulfate and magnesian chlorid. The magnesian salt occurring most frequently in our waters and alkalis is the sulfate. These salts sometimes make up as much as 35 percent of our ordinary alkali and occasionally they are even more abundant than this.

These sulfates, which constitute the so-called "white alkalis," while poisonous to plants, some of them in comparatively small quantities, are so modified in their action, when in the soil and mixed with one another that extremely large quantities fail to produce seriously injurious results. The calcic sulfate in some instances, as I have elsewhere mentioned, may, when very abundant, produce a yellowing of the leaves on apple trees, and lime salts may be the primary cause for the bleeding described in a previous paragraph, but ordinarily we do not observe any ill effect from the presence of very large quantities of these salts in the soil. The poisonous action of the magnesian salts is so greatly reduced by the presence of other salts in the soil that in all ordinary cases we may neglect it altogether. I have cited four cases in illustration of the fact that the amount of alkalis which may be present in the surface

portions of a soil without doing damage is so big that, unless there be other bad conditions, we need scarcely have any fear of them. This result of my observation is in keeping with the experience of large sections of our State.

"WHITE ALKALI" QUESTION PURELY ONE OF DRAINAGE

Water in the soil very frequently involves the question of alkali. As a general statement, we will all agree that our cultivated crops require a soil comparatively free from water and well aerated. The practice of sub-irrigation and the results obtained, even on strongly alkali land, make one decidedly cautious in making very positive assertions. In this practice it seems never to be desired that the water-plane should fall lower than 24 inches below the surface; it is very generally maintained at from 22 to 18 inches of the surface, and in some cases, with good results, too, as high as within 12 inches of the surface. I scarcely believed this last statement and inquired regarding the reliability of the man making it. The man's reputation for veracity was good and the party of whom I made inquiry stated that he had himself seen the man's team mired in his potato field. These are peculiar conditions, but I am convinced that we must modify our views somewhat in regard to the height at which the water plane becomes dangerous to plants. In spite of such facts it remains entirely correct that, in large sections of the State, there is no considerable accumulation of alkali except in depressions which receive the run-off and seepage waters from higher lands. Drainage of such areas is necessary to remove the water and to prevent the accumulation of the alkalis. The chief deleterious effects of these conditions with us are upon the condition of the soil which, of course, may ruin the crop. In all such cases, and they are by far the majority of our cases, the alkali question resolves itself into one of drainage, a statement that I made 15 years ago or longer.

"BLACK ALKALI" RESULT OF PERMANENT GEOLOGICAL CONDITIONS

This is not the case with the "black alkali" or sodic carbonate. I believe that the geological conditions which have made the accumulation of this salt possible to be as permanent as the region itself and to be so serious that it is only by constant effort that we can in any successful measure ward off the practical destruction of the area as a productive farming section. A meagre agriculture will undoubtedly continue for years to come but unless a more rational system of irrigation be followed and continual remedial applications be made the final result can scarcely remain in doubt.

I have stated the original source of our alkalis and while the accumulations on the surface may be very heavy and may even impregnate the underlying strata to considerable depths, for more than 880

feet in the case of the sodic carbonate, their production has been the result of the action of carbonated waters on the minerals of the surface rocks, and the time of the production of the alkalis with which we have to do in the present period. The alkalis are in no probability older than the artesian waters containing them but are possibly in part younger, as they are now being formed. The mode of their formation can be imitated in the laboratory and is universal in its application.

NITRATES SOMETIMES MISTAKEN FOR "BLACK ALKALI"

I have previously made mention of the occurrence of nitrates, not in the sense in which these substances are usually mentioned as occurring in the soil, but in much larger quantities such as are sufficient to be very injurious. In the previous mention I suggested a doubt as to the propriety of including them among the alkalis. The only reason that would seem to justify our doing so is the fact that they have been mistaken very frequently for "black alkali". Some nitrates do occur in the area described in this bulletin as actually suffering from the presence of "black alkali", sodic carbonate, but they are not confined to this condition, though their formation may be facilitated by it, provided it is not too bad.

I have deemed the statement, relative to the composition of our river- and other surface-waters, especially as they show the absence of these salts, sufficient to show that their origin is not the same as that of our alkalis. These are formed by the action of meteoric waters on the rocks containing felspar, and particularly soda-lime felspars. These rocks do not contain nitrates nor yet any elements from which the necessary nitric acid can be formed. I have further pointed out that the alkalis that we find are of recent origin, are confined to relatively shallow depths and are to be looked upon as having penetrated the soils and rocks, in some cases, from the surface. We find in many places that under favorable conditions various kinds of rocks contain in their superficial parts some nitrates but these do not penetrate very far and owe their formation to processes that are going on at the present time at the surface of these rocks. Of course these processes have been going on in the recent past just as they are today.

The simple facts in this case are these: We have areas varying greatly in size in which we find a great deal more nitrogen than in the surrounding lands, and a very large percentage of this nitrogen is in the form of nitrates.

I have already made it plain that our soils, generally speaking, contain alkalis among which sodic carbonate is usually found in small, but not injurious quantities. In this sense the nitrates are associated with the alkalis but they are not necessarily associated with the efflorescences

usually meant when we use this term. An important question in this connection is, If they do not come in with the alkalis where do they come from? These salts are characterized by the presence of nitrogen, which is necessary for their formation. Chile saltpetre or sodic nitrate is an example. It is not intended to state that this salt actually occurs in these soils though it may either be alone or associated with other nitrates. The rocks, especially the minerals from which the alkalis are formed are found practically everywhere in our soils and very abundantly in our mountains, so if our alkalis and these nitrates had the same origin they should have the same general distribution. This is not the case. We believe that we have so good as no plants which can do without nitrates and, as we have plants growing and bearing their fruit, we must accept it as proven that these nitrates are present wherever we find such plants growing. The characteristic thing in the occurrences which we are discussing is that they kill plants and, of course, nothing grows where they occur. The complaint that the ranchmen send in is almost uniformly of "brown spots" on which nothing will grow. These spots are usually in cultivated fields which are elsewhere productive and I can testify that, judging from the whitened surface of these fields when not covered with vegetation, they are at the surface, very rich in alkalis and are brown and unproductive in spots only. We find these spots rich in nitrogen and especially in nitrates. We all have the same practical method of considering these questions. Why is not this nitrogen spread out everywhere just as generally as the alkali and why are these spots richer in nitrogen than the rest of the land? There are no deposits of these salts found anywhere except near or at the surface of the land. The deep portions of the rocks contain no nitrates for they are all soluble and have been washed out or destroyed as one of the changes which are going on all the time.

We know how the nitrates that our plants use are formed in the soil. There are different kinds of little plants that grow in the soil that are able to change ammonia, step by step, into nitric acid, and if there is some alkaline substance present to take up this acid we have nitrates formed. This is no more strange than the fact with which everyone is familiar that, if we keep cider under proper conditions it turns to vinegar, or that buttermilk is sour. In the former case a plant, but a different one, has converted the alcohol of the cider into acetic acid, and still another plant has converted the milk sugar into the lactic acid of the buttermilk. There is nothing so very unusual, then, in the production of nitric acid or nitrates in the soil, if we only have the nitrogen in the right form to start with.

In these days nearly every farmer has read, heard of, and seen root tubercles. If peas, clover or alfalfa will not grow, it is because

the tubercle-producing organism is lacking in the soil and the plants do not get a sufficient supply of nitrogen. This statement is as common now as almost any other one of every-day life. These organisms are simply little plants that thrive best on the roots of peas, clover, alfalfa, vetches, etc., and have the power to help the plants to use nitrogen from the air in building up their nitrogen-containing parts. As this nitrogen, which these little plants help the peas to get, comes from the air, we say that they "fix" it. These little plants are supposed to need the help of the pea or the alfalfa to fix this nitrogen, but there are other plants growing in the soil that do not need help to use the nitrogen of the air to build up their structures, provided they have a sufficient supply of everything else. In other words, if the conditions are favorable, they will take care of themselves as far as nitrogen is concerned. These plants multiply, build up their tissues and increase the total nitrogen in the soil. These plants are usually present in all of our soils; only a few samples have been found entirely free from them. If the conditions are exceptionally favorable, they will grow very freely and the amount of nitrogen fixed in a comparatively short time may be quite large. These plants use this nitrogen from the air to build the same kind of compounds that are built by other plants from the nitrogen of the soil and when the plants die, these compounds go through the same processes of change that the similar compounds built up by other plants undergo. The end product of these changes that interests us at the present is the nitric acid, nitrates, into which this nitrogen is finally converted.

These nitrates are not colored, they are just as white as the "white alkalis" and the little plants that fix the nitrogen are also without color, but when there are nitrates enough present in the soil in which they are growing, whether it is natural or artificial, they color it eventually a deep, almost a black, brown. Matters in the natural soil are pretty well advanced when this takes place and this is the reason that samples taken from the brown spots prove to be rich in nitrates. The brown color is produced because the nitrates are present and serve as a good guide for us in judging whether the nitrates are there or not. Other things may cause the surface of the soil to become darker in some spots than others. Sodid carbonate gets its popular name of "black alkali" from the fact that it dissolves humus or eats the plant tissues and takes the products into solution with a very deep color, which leaves on the surface of the ground a black coating when it is evaporated to dryness. Calcic chlorid, one of the occasional constituents of alkali, causes the surface of the soil to be darker in spots where it chances to be because it takes water out of the air and keeps those spots more moist than the neighboring land. But humus and the calcic chlorid have nothing to do with the brown nitre spots.

One of the most difficult questions for us to answer is, Are there enough of these little plants and can they grow fast enough to build up all of the nitrogenous matter that is necessary to account for the nitrates that we find? A great many people think that we give them too big a job to do. I do not think that this is true. We have tried to find out not exactly what they may be able to do under very favorable conditions, but what they actually do in our ordinary cultivated soil, soil that we have growing wheat on and which we consider a good soil and in good condition, but not at all rich in nitrogen.

We imitated field conditions by taking 3,000 pounds of this soil from the field and made a bed of it where we could watch it, water it and keep the weeds out. We built a fence around it to keep animals off and to let the children know that we did not want them to go on it. We watered it with pure water of which we added only enough to keep the moisture in the soil around 15 percent. We protected our bed from being washed by heavy rains by fixing it so that we could cover it with canvass if it should rain, but the bed was open to the sun and air just as it would have been had we left it in the field. While we did not want to have our soil washed out by water from above we did not want any water to come up from below and bring a lot of salts up with it, so we put a tight board bottom under our bed with tight board sides to it. We added nothing to this soil but water. The plants had to get along on that soil. We even banked up the earth a little way from the bed to prevent any rain-water washing other dirt into it and to catch any blowing sand as far as possible. We analyzed the soil as we put it into the bed and every fifth day after that for 40 days. At the end of this time we found that it had more nitrogen in it than at the beginning, so much more that every million pounds of this soil had gained 36 pounds of nitrogen, which would be equivalent to 216 pounds of sodic nitrate if it were all converted into this form. Further, we found that the nitrates themselves had increased by 94.8 pounds for each million pounds of the soil. Our bed was 6 inches deep, so we had the equivalent of 198.6 pounds of sodic nitrate formed in the top 6 inches of this soil which weighs about 2,000,000 pounds per acre in 40 days. There was just about the same gain in the first and second 3 inches, and while this will be different in different cases, we may state the results for the acre-foot, which would be 397.2 pounds calculated as sodic nitrate. We did not pick a particular 40 days in which to make our experiment, so we have a fairly good right to assume that the same results would be obtained for any other 40 days of the season. The results at the end of the five-day periods may indicate whether this assumption is justified.

These results show that the increase was not uniform, but that there was sometimes a falling back, though it never got back in our experi-

ments to the original quantity, but always showed that there had been a gain over the quantity with which we started. The gain during the last period of five days was almost the same as for the first period of five days. The results of the five-day periods indicate that the various changes going on in the soil are sometimes greater in one direction and sometimes in another direction. This is probably the case in a field. Still, where no nitrogen is removed from the soil but such as may escape into the air, the results show a net gain of 36 pounds for each million pounds of soil in 40 days, and for the nitrates in the soil, a gain of 94.8 pounds, which corresponds to the changing of 15.8 pounds of nitrogen into nitrates for each million pounds of soil.

BROWN SPOTS ILLUSTRATE EFFECTS OF TOO MUCH NITRATES

The nitrates, when present in too large quantities, will kill our cultivated plants, and we find that too much will also kill out these little plants that get their nitrogen from the air. The reason that these brown spots, of which the ranchmen complain that nothing will grow on them, are actually bare, is because of the presence of too much of these salts. I am sorry that I do not know how much or rather how little of these nitrates it takes to kill vegetation and that I do not know how they kill it, but it is certain that they kill. I put some sodic nitrate, from 5 to 25 pounds around each of a number of apple trees. I injured every one and killed one in four days. This was satisfactory proof that nitrate in too large doses, even 5 pounds to a tree, is poisonous to apple trees.

IRRIGATION IS CARRYING ALKALI FROM HIGH LANDS TO LOWER LEVELS

There is a very general notion that water brings the alkalis to the surface of the ground. There is no doubt but this is so in a certain measure, but it is also very often true in Colorado that it brings them "in", that is, that they are moved from the high lands to the low lands. This, however, can not well be the case with the two sections of country that we have told about in this bulletin, for the only high lands from which the alkalis could be washed are the mountains, and I have already told in what sense the alkalis are really washed from the mountains into the soil of the valley. But this is not what we mean when we speak of the alkalis being washed from high land down on the low land. In this case we mean that there is land, perhaps hills, into which former waters have carried alkalis and left them, or perhaps the alkalis now forming have accumulated there because there has not been water enough to wash them out before this, but now that we have been watering these lands, this water is carrying the alkalis to lower lands as it flows down to them. This is really happening in a great many places

but the salts that are washed down into the low places were really formed in the high places, just as the "black alkali", told about in this bulletin was formed by the waters acting on the rocks of the mountains and has been carried down into the valley; and they would have all gone out of the valley with the water if the water itself could have gotten out. In the southern section of the San Luis valley the water has always been able to get out and the "black alkali" has gone out with it, because the soil cannot hold the "black alkali" back as it can the "white alkali". The same is true of the nitrates, the soil cannot hold them, they are easily washed out, and where the water runs out of a section it will carry both the "black alkali" and the nitrates out with it. This is the reason that we often find nitrates in waters. In our country this is true of water seeping out of the face of shale banks which have cultivated mesas or plateaus on top of them, or of water which may trickle along the surface of rocks, especially if it be the first portion that comes off, for nitrates may be forming on the surface of rocks; as well as on the surface of the land; but if these waters be sufficient to flow on they take the nitrates with them, if they evaporate on the surface, they may leave the nitrates. These have nothing to do with our brown spots, though these nitrates are formed by the same little plants as the nitrates in the brown spots. The formation of these nitrates is going on near, or at, the surface only, and they do not come up from any considerable depth, nor are they stored up in deep beds like common salt. It is unusual to find such quantities as we have except in arid climate. It is only in a few places that these salts are produced rapidly enough to accumulate in soils as they have done in some of ours and then under very different conditions. The formation of nitrates is going on in every soil and even on the surface of many rocks so their occurrence in any place where there has not been water enough to wash them out may be expected. I have found small quantities on the face of sandstones and more in the little pockets made in the sandstone by the winds. In these cases the nitrates were all on the surface. They do not penetrate in such cases to any depth. I do not know how deep they may go. I have given, on a preceding page, an instance in which the surface soil and ground-water were very rich in nitrates, rich enough to kill cattle, but the water obtained from the shales at 280 feet did not contain a trace. These salts are not usually found in any quantities in deep water. Some very deep wells may yield water containing four or even seven parts per million but this is about the limit.

In the cases that I have chosen to present the origin and character of our Colorado alkalis, we have not only the two big classes of "white" and the "black" alkalis in a large area, but we also have scattered through both areas occurrences of the nitrates in injurious quantities.

I have stated fully, without any reservations, the occurrences and composition of these alkalis, of the river-waters, of the ground-waters, of the soil, and of the well-water to a depth of 923 feet, and in none of these did we find any unusual amounts of nitrates, except in the brown spots, some of which proved to be so rich in nitrates that nothing would grow on them. The surface portions of the richest of these carried 5.6 percent of nitrates, calculated on the dry surface soil. These spots may be found anywhere in the San Luis valley, near the mountains or 20 miles away from them, but this would make no difference for there are only two things in this landscape, the mountains and the valley floor. There are no mesas, shales, or high lands from which these nitrates might come; besides, they are just in spots at first, though they may become numerous enough and grow big enough to run together and cover the better part, or the whole, of a large area of land.

I have explained how they come to be in these places, how the little plants enrich the soil in nitrogen by taking it from the atmosphere, how they, like other plants, die and their substance undergoes changes as other organic matter does. In our soils a large proportion of their nitrogen is changed into nitric acid or nitrates. So the nitrogen which is changed into nitric acid to form these nitrates does not come from the rocks, either as nitrogen or as nitrates, as the soda, lime, magnesia, chlorin and sulfuric acid, that form the white alkalis do, but is taken from the air by these plants just as truly as the carbonic acid is taken from the air by water which helps it to build up carbonates with the lime, magnesia and soda of the rocks.

SUMMARY

The alkalis that we usually meet with in Colorado are for the most part "white alkalis".

In a great many cases these are simply washed from the higher parts of the fields into lower parts, where the water gathers and, having no way to flow out, fills up the hollow and is removed by evaporation, leaving the alkalis. In this way a very bad-looking spot may grow to a considerable size. If this water could be let out by a drain this would be stopped.

When water carrying alkalis has to sink through the soil some of the alkalis are retained and the same is true of shales, so if moderate amounts of water have annually fallen on the surface where some alkali has formed, it will move it downward to leave it at a little lower level, so that together with the changing of any sulfide of iron by the action of the air, which will help to form sodic and calcic sulfate, any water that seeps out of banks of such materials may and often does carry a large amount of sulfates. Such waters should, if possible, be drawn out of a section by drains.

Our observation is that the bad effect of "white alkali" has been greatly over-estimated. There is, undoubtedly, a limit to the amount that may be present in a soil without danger to the crops, or trees grown on the land, but this limit is so high in the case of our soils that the danger line has not been observed.

We have not observed the death of any plant which we could with certainty attribute to "white alkalis", though we have seen some alkalis quite rich in magnesian sulfate.

The "black alkali", sodic carbonate, is very generally present in small quantities as a direct product of the action of carbonated waters on the rock particles, whether in the mountains or in the soils, but it passes into the drainage of the country to such an extent as to prevent its accumulation except under unusual conditions.

In one section of the State, which has been presented quite fully, unusual conditions occur and the "black alkali" has accumulated in injurious quantities. Irrigation by flooding, and the application of gypsum will probably lessen this evil but cannot be expected to wholly remedy the trouble.

The nitrates cannot properly be considered as alkalis in the sense that we use this term, but inasmuch as they are usually mistaken for "black alkali", and are injurious to crops, in the quantities that they occur in places, they have been discussed.

These nitrates are not derived from the rocks but are formed in several successive steps through the agency of small plants or micro-organisms which are present almost everywhere but which are much more active in our soils, especially in particularly favorable spots, than is usual.

"Black alkali", sodic carbonate, in small amounts, is said to favor the activities of these plants. The amount of sodic carbonate required to retard their development is greater than that which will injure the ordinary cultivated plants.