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A PECULIAR SOIL CONDITION IN
THE SAN LUIS VALLEY

By

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A PECULIAR SOIL CONDITION IN THE SAN LUIS VALLEY

By WM. P. HEADDEN

The writer is aware of the fact that many persons consider the alkali question one of very great importance to many cultivated sections of the West, or perhaps better, of semi-arid sections. I was as fully convinced of this many years ago as these parties are now, but long and varied observations have led me to adopt a most conservative attitude toward our supposed knowledge upon this subject.

In many instances our ranchmen are confronted with very perplexing results brought about by conditions either illy or wholly unknown to them or to anyone else. In such cases the cause of these unexpected results is naturally attributed to any observable and unusual factor in the case, whether it is in any way responsible for the results or not. This is not simply a case of human nature attributing, in ignorance, results to certain causes, but is often an attitude assumed by well-informed persons who do not doubt the correctness of their observations and do not endeavor to ascertain whether they have observed all the facts or whether their interpretations are really legitimate or even rational. I know of the expenditure of years of labor to demonstrate that certain things were facts which had already been demonstrated to be wholly fallacious, though in conformity with popular ideas and preconceived notions.

I am not prepared to state that there are no conditions under which our "white alkalis" may do harm, but I have as yet seen no reason for changing my opinion already often published, that under our ordinary Colorado conditions, they do but little or no harm. No one, I think, has been disappointed more often than I have by results in the garden or field different from those that one would expect, due to great abundance of alkalis. This has been the case, too, when there was an excess of water.

We understand by "white alkali" a mixture of the sulfates of soda, magnesia and lime, associated with some sodic carbonate and sodic chlorid. The sulfates of soda and lime are usually predominant, but the sulfate of magnesia is frequently quite abundant.

The case that I wish to present in this bulletin is involved because of the presence of sodic carbonate within the area considered, which is really my justification for discussing the case. Of the presence of sodic carbonate in detrimental quantities within the area, there can be no question.

The soil in some cases becomes very hard to a depth of four inches, or perhaps more, so hard that one has to use a mattock

to start a hole. We know that sodic carbonate is present in the well-waters and that there are many places in the section rendered unproductive by the presence of this salt. The application of sodic nitrate, to some soils, at least, causes them to become hard, due to the formation of sodic carbonate. This is the explanation given and it is probably correct.

In a series of experiments I applied sodic nitrate at the rate of 250 pounds to the acre. This would correspond to 156 pounds of sodic carbonate, provided it were wholly converted into this salt. The nitrate was applied to the surface and harrowed in. The hardening of the soil took place to a depth of about four inches. The ground broke up in cakes on plowing. If we consider it to have been exactly four inches, the 156 pounds of sodic carbonate had hardened one-third of an acre-foot of soil to this extent. I do not know how small an amount of sodic carbonate might produce this effect but, in this case, we have 117 pounds per million of soil, and I doubt whether a much smaller amount would have shown any effect. Knowing

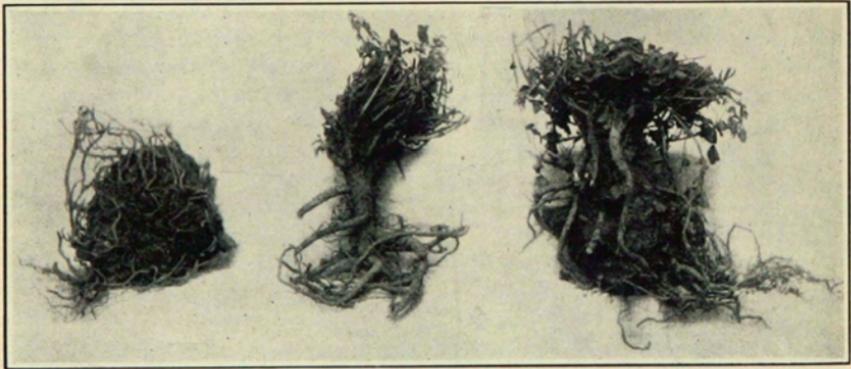


Plate I—Abnormal Alfalfa Roots

these facts, it seemed a reasonable inference that the hardening of the soil in this other case was due to the sodic carbonate.

Another peculiar fact that we observed in this immediate section of country was the very peculiar development of some alfalfa roots. Ordinarily the alfalfa plant develops a very long tap root and a rather meagre system of branching, fibrous roots. The length of this tap-root system will vary with soil conditions and I have never seen it extend very much below the permanent ground-water level. I have seen them penetrate as much as a foot below this level, and in running water I have seen a great development of fibrous roots. I have dug up both alfalfa seedlings and old plants in this section and found nothing unusual except that the roots were short; otherwise they were typical alfalfa roots. In this particular case they were abnor-

mal in that they had gone down seven inches and then flattened out as though they had grown against an iron plate, but had only a very slight lateral development.

The development of these roots presents the question of soil conditions so forcefully that we give some illustrations and shall devote a paragraph or two to their discussion.

Plate I represents four-year-old plants. The stand was good and the yield of hay was good. The depth to the water plane was not ascertained, but in this section the usual depth is three feet or a little more. The subsoil was a coarse sand.

Plate II represents two-year-old plants from another field belonging to the same party, and Plate III represents the same variety of alfalfa grown at Fort Collins. One of the plants in



Plate II—Development of Alfalfa Roots in Better Ground

this plate will be observed to be somewhat branching but to have a strong tap-root, and we did not attempt to follow it further than is shown in the illustration, 3 feet 10 inches. In other instances we have followed such roots to a depth of from 9 to 12 feet.

A bottom view of the root system is given in Plate I to show how sharply the soil conditions terminated the downward development of this root system only seven inches from the surface. In this case there was scarcely a root that penetrated any deeper than this. In Plate II we have a very abnormal development for alfalfa, but it is much better than in Plate I. What may be the cause of these differences is difficult to determine.

In spite of the fact that I had seen alfalfa grown in strongly alkalized land and in very wet land in this same section of country, my surmise was that the roots shown in Plate 1 had encountered a zone so rich in sodic carbonate that they simply curled around themselves, producing the forms shown in the



Plate III—Normal development for same variety of alfalfa

plate. I was satisfied that it was not due to water and the soil is soft and open; besides I have seen alfalfa push its way through a hard conglomerate for more than eleven feet. I have not ascertained the real cause of this deformation. It is certainly not due to excessive water, for water may shorten but does not give rise to such distortion as this; it is not due to sodic carbonate for alfalfa develops normally shaped roots in

other land containing sodic carbonate, and it is not due to the presence of any hard pan, for the subsoil is open and soft.

The hardening of the soil previously referred to and the development of these roots, together with the fact that this sandy subsoil, when placed in a sack where it can dry out well, also became hard, suggested that there might be a relation between the two series of facts. We proceeded upon the assumption that there was a relation, and despite the fact that we had no good reason for supposing that sodic carbonate had produced the deformation of the alfalfa roots, we thought that it did cause the hardening of the soil, so we applied gypsum to the soil in sufficient quantity, as we thought, to ameliorate the condition. It was a complete failure. It produced no result whatever. The ground was just as hard where we applied the gypsum as where we did not, and the alfalfa was no better. This was decidedly an unexpected result.

The soil experimented with was not analyzed, but the subsoil from the alfalfa field became hard on drying. We obtained fresh samples and found that it contained 0.0172 percent sodic carbonate. The best data that I possess on the toxicity of this salt indicates that the limit of the amount necessary to produce injurious effects on vegetation lies between 0.04 and 0.05 percent of the soil, but this may not be the lower limit necessary to produce hardening of the soil. The only data that I have on this point are those already given in the case of our own soil in which 0.012 percent produced a noticeable effect, but it was very much less than that observed in the case of the soil under discussion; besides, the failure of the gypsum to ameliorate conditions suggests some other cause unless we failed to add a sufficient quantity of it, which we did not do, as we added at least five times the amount necessary according to theory. We are willing to concede that it would have been more convincing if we had added twice as much as we did, but as it was the cost of the gypsum applied exceeded the price of some of the neighboring land per acre, and we were attempting to find a practical solution of making this land give profitable returns without excessive cost.

The amount of sodic carbonate in this subsoil was only moderate, much below the tolerance of seedling plants, but probably enough to cause some degree of hardening in a few instances, but the negative results obtained on the application of gypsum, at least, suggests that too much stress should not be laid upon the part played by the sodic carbonate in the case.

The hydrological conditions of the valley are unusual and the soil conditions vary exceedingly within short distances. In a study of the water used in irrigating our lands, especially in the Poudre Valley, we found the amount of change very great and the character of the changes very definite indeed. The water used for irrigating is, in many cases, mountain water; that is, water taken directly from mountain streams. In other

cases, especially during the latter part of the season, it may have been stored in reservoirs. This makes a great difference in the character of the water used. All the water used in irrigating the land in question is mountain water of an exceedingly acid type, as much as forty-three percent of the total solids being silicic acid, more than half of which is in excess of available bases to combine with it.

One of the marked changes in the irrigating waters is the removal of the greater part of this silicic acid and a still larger portion during storage. In what form it may be removed will undoubtedly be influenced by the soil constituents but most probably as silicates of lime, alumina and iron, provided these bases are available, but we know also that it may be removed as silica in cases where it serves as cementing material or builds quartz grains. The waters of the Rio Grande, which are used in irrigating this land, are very rich in silicic acid and the soil itself differs little from the rocks of the mountains whence the waters come. The change in the conditions consists principally in the fact that this acid water is subjected to evaporation from the surface of this soil.

The ground-waters and the well-waters of this section are alkaline, carrying sodic carbonate as their principal mineral constituent. This is true to such an extent that the drain-waters and shallow well-waters differ from one another much less than would be expected. An illustration of this may be found in a water from a fifteen-foot well compared with one taken from a drainage ditch. The well-water carried, of total solids, 302, and of sodic carbonate 67 p.p.m. That from the drainage ditch carried, of total solids, 373, and of sodic carbonate, 68 p.p.m. The water from the drainage ditch where it tailed out over uncultivated land carried 94 p.p.m. of sodic carbonate. In the different content of sodic carbonate in the ditch water, and in the same where it tailed out over the land, we have a rough measure of the amount of evaporation that had taken place. This factor should be taken into account when comparing the ditch-water and the well-water. My information is that this drainage ditch is twelve miles long.

The whole section is an artesian area and the water is all alkaline; the deeper the wells, the richer is the water in sodic carbonate, which in some instances constitutes 90 percent of the total salts held in solution. The range is from 20 percent up to the amount just given.

The history of this water may be of first importance in this connection. There is a vast amount of evidence that water carrying silicic acid in solution has been the agent that converted many sandstones into quartzites and built many sand grains out into crystals. A more generally observed and popularly appreciated fact is the occurrence of silicified tree trunks, stumps and other fragments of vegetation found in great abundance in some sections.

The artesian waters of this section are alkaline and not acid. There is another section of this same valley which is also an artesian area in which the artesian waters are acid, even when coming from depths as great as from 700 to 900 feet. I have not found any of this peculiar hardening of the surface soil in this section.

There are two questions that will undoubtedly suggest themselves, viz., is the soil of the same origin and character? It is of the same origin and essentially of the same character, but there are variations, no more, however, in the one than in the other area.

The second question is: Is the water supply from the same source? The answer is yes, from the mountains surrounding the valley, the rocks of which are gneisses, granites and igneous rocks. There is no difference between the two sections in these respects.

There is a difference in the drainage of these sections, and this on a very large scale. It has persisted since the formation of the valley. Both sections of the valley are full of water, the fact that artesian flows are opened in the floor of the valley at depths as shallow as 75 or even 65 feet attest this fact; also, areas near the margins of the valley where springs issue from the floor of the valley can scarcely be other than artesian waters.

The waters, river, spring, or artesian, in this section are of the same character, i. e. colorless, acid waters holding the same mineral constituents in essentially the same quantities, but they are wholly different from those of the other sections. These waters may be distinguished as brown and white waters; this is a convenient designation but is not a very sharp one, for some of the alkaline waters are not brown, but most of them are.

The question in mind is: Are these facts related to our soil conditions, and how? It may be difficult to give a satisfactory answer to this question even though they are related, and that intimately.

Some of our facts cannot be proved directly and on a small scale, either of means or in time. We cannot prove directly that the one section has been drained in some measure, at least, since the formation of the valley, and that this measure has been sufficient to maintain the present character of the underground-waters of the one section and has had no influence on that of the other section. Unless we have some rather evident facts to indicate that one part does not communicate directly with the other, it is difficult to believe that drainage from one end of a closed valley for very many years, more years perhaps than we can appreciate when expressed in numbers, would not affect the further end when the floor dips but a few feet and that toward the eastern and north-central part of the valley.

The only fact I know that indicates that there is a direct drainage out of the valley other than the Rio Grande is that

more water flows out of the Embudo Canyon than enters it at its upper end. Where this excess outflow comes from is, after all, a matter of inference. The only apparent and probable source of this excess is the San Luis Valley. The adequacy of this outflow now and in the past, to maintain the character of the water in the southern end of the valley, is also a matter of inference based on the great similiarity between the artesian waters of this area and the mountain-waters that maintain the supply. However great the difficulties in the question, there is no question about the existence of two artesian areas, one characterized by colorless, acid, artesian waters and another by artesian waters which are mostly brown and all characterized by an excess of sodic carbonate. A line approximately parallel with the Rio Grande and only a little way north of it is the boundary between these areas.

This is the only river that flows out of the valley and has unquestionably always been the big river of the section, even when there was no valley—only a big lake. This river built its fan across the lake and divided the lake, as it now divides the valley, into two sections, one north of the fan and one south and west of its present course. On the south side this fan limits the southward drainage and has always cut off drainage from the north side. If these views be correct, as we think they are, the north side has been different from the south side so long as the valley floor has existed and has had a set of water conditions peculiar to itself, whose characteristics have become more and more emphasized as the valley has grown older, until they are now wholly different.

The water supplied to the valley by the Rio Grande and other streams is probably identical in character with that which flowed into the old lake. The character of this water is determined by that of the rocks of its drainage area. These have not changed and the water flowing into the valley is accordingly identical in character with that which first filled the lake. This is a highly characteristic mountain water carrying only a comparatively small amount of mineral matter in solution, and this mineral matter is such as water with a little carbonic acid dissolves out of the soda-lime felspars. This latter fact was established by direct experiment using carbonated water and pulverized felspar, an experiment discussed in former publications. The characteristics of these mountain waters are fairly uniform for Colorado, whether the water be from the Poudre or the Rio Grande. An analysis of the Rio Grande will serve our present purpose well, for it represents the actual water supply of the valley.

The amount of mineral matter held in solution was 5.39 grains in each imperial gallon, or 10 pounds of water.

Analysis of Mineral Matter Contained in Rio Grande Water.

	Percent
Carbon	1.685
Silicic acid	43.395
Sulfuric acid	6.096
Carbonic acid	13.352
Phosphoric acid	0.229
Chlorin	0.907
Calcic oxid (lime).....	19.845
Magnesian oxid	3.791
Potassic oxid	2.886
Sodic oxid	6.759
Ferric oxid	0.610
Manganic oxid (br)	0.657
	<hr/>
	100.212
Oxygen equivalent to chlorin.....	0.212
	<hr/>
Total	100.000

Analysis of a White Artesian Water, Depth of Well 923 Feet. Mineral Matter Held in Solution, 14.07 Grains per Imperial Gallon.

	Percent
Silicic acid	50.202
Sulfuric acid	3.345
Carbonic acid	14.346
Chlorin	0.485
Calcic oxid	2.877
Potassic oxid	1.903
Sodic oxid	23.267
Ferric and aluminic oxid.....	0.260
Ignition	3.081
	<hr/>
Oxygen equivalent to chlorin.....	99.766
	0.110
	<hr/>
	99.656

This well is located quite close to the Rio Grande and on the north side of the river. The river water at this point in its course carries 8.12 grains mineral matter per gallon.

Analysis of Brown Artesian Water: Depth of Well 750 Feet. Mineral Matter Held in Solution 104.3 Grains per Imperial Gallon

	Percent
Silicic acid	5.167
Sulfuric acid	0.196
Carbonic acid	36.923
Chlorin	0.434
Calcic oxid	0.563
Magnesian oxid	0.179
Potassic oxid	0.456
Sodic oxid	51.766
Ferric and alum. oxid.....	0.170
Manganic oxid (br)	0.146
Ignition	4.267
	<hr/>
	100.276
Oxygen equivalent to chlorin.....	0.098
	<hr/>
Total	100.178

These analyses have been published before with many others. They serve, however, just as well as any others, to show the characters of these three waters, the original water supplied to the valley, the white acid artesian waters that occur along the Rio Grande on the north side and south and west of the river, and the alkaline, usually brown water, north of the Rio Grande. These differences are evident even on a casual examination of these statements. In the river and white artesian waters there is a decided preponderance of acids, with lime and magnesia abundant in the mineral matter of the river water. These two bases recede in the white artesian water but the preponderance of acids remains pronounced, while in the alkaline or brown artesian waters these two bases and the silicic acid have disappeared to a very large extent, whereas sodium and carbonic acid have become almost the exclusive constituents.

We have intimated, though we have not formally expressed the view, that the white acid artesian water is really the mountain or river water, protected from deep-seated changes by the drainage from the southern end of the valley, which is no more than sufficient to regulate the water level in that section of the valley. It has also been stated that there are large springs and springy areas from which water of this same character is constantly flowing. In this section we have ground-waters of the usual character for a country whose soil is an "alkali" one; i. e. waters whose mineral contents consist essentially of sulfates of lime, magnesia and soda. These conditions are not the prevailing ones in the section north of the Rio Grande, where we have seen from the analyses of water that there is a radical change, both in the relative and absolute quantities of the salts present, and a most radical change in their character. A natural inference would be that the writer may have, for the purposes of his thesis, put favorable contrasts to the front while the facts presented in a fuller series might not show such to be the case. This is not true; the intermediate facts in the series are in perfect harmony with the extremes. To meet the misgivings that the facts may be considered by many to justify, I will add an analysis of an alkali collected on a desert-claim in this northern section. I do not think it possible to find such an alkali in the southern section, where we find the so-called white alkalis only, sometimes with an inexplicably large amount of calcic chlorid.

Analysis of Alkali from Desert-Claim, Northern Section of Valley

	Percent
Calcic sulfate	1.489
Magnesian sulfate	0.367
Potassic sulfate	2.874
Sodic sulfate	26.162
Sodic carbonate	40.368
Sodic chlorid	20.928
Sodic phosphate	0.959
Sodic silicate	4.271
Ferric and Alum. oxids.....	0.082
Manganic oxid	0.202
Excess sodic oxid.....	2.288
	100.000

This is without doubt the result of the evaporation of an artesian water and the reactions with the soil salts during the process.

Drain-waters and those from shallow wells show the same characteristics. A drain-water and that from a well only 15 feet deep show about 20 percent of the total solids to be sodic carbonate.

We have now stated that we offer the drainage of the southern section of the valley as the explanation for the maintenance of the similarity between the composition of the artesian and the river or mountain waters. We now propose the lack of drainage and concentration by evaporation with the concurrent reactions between the soil and the mineral constituents of the water as the factors that determine the composition of the alkaline waters. In the southern section only small changes have taken place for the simple reason that the water is in motion through sands or soil particles identical in composition with the rocks of its drainage surface, and the concentration of the solution remains approximately the same. In the northern section these factors are reversed; there is no general drainage out of the area, and the concentration of the solution has not remained the same. The reactions between the mineral contents of the water and the rock particles are very different. The sulfates and chlorids, together with the silicic acid, are removed. The calcic, magnesian and potassic salts are removed by precipitation or absorption, while the sodic carbonate remains in solution even when the concentration has increased its relative quantity perhaps 125-fold, as the analysis of the brown water roughly indicates. This statement of the case is nothing more than one of facts observed in ordinary soils. The sulfates and chlorids are retained quite largely while the carbonates go very freely into the drain-waters.

The mineral matters held in solution by the river waters flowing into the valley consist of silicic acid up to more than 40 percent of their total weight. In the case of the Poudre water, this silicic acid is probably largely removed as a calcic silicate. I have met with marls underlying our soils so rich in soluble

silicates that it would gelatinize on treatment with hydrochloric acid. The conditions in the San Luis Valley are different and the probability is that the silicic acid is removed as such by deposition on the soil particles in a manner similar to the cementing silica between the sand grains in the formation of quartzite, or in the formation of agatized wood. These waters are evaporated at the rate of from 30 to 36 inches per annum from the surface of these lands, or would be, provided they were constantly supplied with the necessary water; the sodic carbonate would remain in solution, the other constituents would be very largely or wholly thrown out of solution. These are the conditions indicated by the drain-waters and well-waters of this section, whether deep or shallow.

We have stated that among the changes is the removal of the silicic acid by precipitation on the surface of the soil or rock particles, and it is possible that this is the case to such an extent that it may account for the hardening of some of these soils. If this be the case, the relation between the alkali water and the hardening of the soil is direct and intimate.

We have attempted to find out whether any facts substantiate this view; if so, it will not only help in explaining the deportment of the soil but also in supporting the view expressed in regard to the origin of these alkaline, artesian waters. Referring to the soils we have the following facts: Sodic carbonate will cause some soils, at least, to harden; gypsum counteracts this, but in our case it failed. Plants may develop short roots but not distorted ones, where the water-plane is too high for the full development of the roots. Here we have distorted roots and the soil, when removed and packed in a sack, becomes very hard. The amount of sodic carbonate found on analysis was only about one-quarter of the minimum found to be injurious to plants, but we have no definite data as to how little sodic carbonate may produce a hardening or caking of the soil. The only data that we have indicates that the addition of an amount no greater than we found in this soil may produce a considerable degree of caking. This soil, in its natural position was not caked, it was too far below the surface, but the alfalfa roots did not penetrate it so the distorted roots were caused by some other factor. These were the specific facts, pro and con, that confronted us.

In order to test the question of the presence of hydrated silicic acid which might, on exposure to air and drying, serve to cement the particles together, we treated fresh samples of the soil, some with dilute potassic hydrate, and one with water. One sample was treated with a solution of potassic hydrate of 10 grams, and one with a solution of 20 grams to the litre, while a third one was treated with twice its own weight of distilled water. The samples of soil were treated as they were removed from the ground and were not allowed to dry.

The distilled water dissolved 0.008 percent. Ten grams of

potassic hydrate to the litre dissolved 0.229 percent; twenty grams of potassic hydrate to the litre dissolved 0.432 percent. The silica was weighed as SiO_2 but it undoubtedly existed in the soil as a hydrated acid. Weak solutions of potassic hydrate were used because it is known that stronger solutions will attack, even in the cold, chalcedonic forms of silica. The fact that soluble forms of silicic acid are present stands out plainly; even distilled water took up a noticeable quantity, 0.008 percent of SiO_2 calculated on the dry soil, while the amount dissolved by the two potassic hydrate solutions was proportional to the strength of the solutions. The soil was put into the solutions in the field and the silica determinations were completed eleven days later. I am aware that objections may be made to the interpretation that this silicic acid existed as free, hydrated, silicic acid in the soil, but it is a more reasonable assumption than any other that can be made in the case. The solution of 20 grams to the litre is too weak to attack the silicates in so short a time and to such an extent.

The amount of silicic acid, H_2SiO_3 , which was removed by the stronger of the two solutions is very considerable. The sample taken represented six inches of the soil. Assuming that such a layer weighed 2,000,000 pounds per acre, we have about $5\frac{1}{2}$ tons silicic acid soluble in such a solution per acre.

Is the supply furnished by the mountain water used in irrigating and the ground-water adequate to account for this? The only answer that we can offer to this is a consideration of the rate of accumulation, based on the amount of water evaporated from the surface of this land. If the power of soils to remove silicic acid from solutions, such as the mountain waters, has been determined, it has escaped my attention; but if the water is evaporated at the temperatures prevailing at the surface of these soils, the silicic acid would certainly be left. The evaporation from a free water-surface in this section has been given to me as 61 inches annually. This is about twice as great as it is from a soil surface, so we may assume 36 inches per annum as the amount of this evaporation. On the basis of these data and the silicic acid content of the Rio Grande water, it would be possible to have this much silicic acid deposited from this source alone in just a trifle over two years. The alfalfa was four years old and the conditions had existed at least this long, provided this is really the cause of the distorted roots.

These facts strengthen the view here intimated and elsewhere expressed, that the alkaline water of this area owes its existence to the lack of drainage and its character to concentration by evaporation and the elimination of silicic acid, lime and magnesian salts.

If silicic acid be the cause of the hardening of the soil, it will explain the failure of gypsum to ameliorate the condition.