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SOILS AND ALKALI.

FERTILITY, IRRIGATION, Etc.

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The Agricultural Experiment Station.

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SOILS.

BY D. O'BRINE,
Chemist.

Soils are formed by the natural disintegration of rocks, to which is added the black mould caused by the decay of animal and vegetable matter. This disintegration is assisted by the atmosphere. The oxygen of the atmosphere is capable of uniting with some of the constituents of rocks, by which their cohesion is weakened or destroyed. This is the cause of the rapid disintegration of some varieties of granite. The iron is oxidized, its volume is increased, and portions of the rock are separated from the mass. When granite or limestone contains sulphuret of iron, the oxygen of the atmosphere, in the presence of moisture, combines with the sulphur and forms sulphuric acid, that decomposes limestone and the feldspar of granite. The carbonic acid of the atmosphere is another decomposing agent. Water charged with this gas is capable of decomposing calcareous rocks; it is, for this reason, that caves occur in limestone formations. The moisture of the atmosphere has a decomposing action. Rocks which are exposed to frequent alternations of dryness and moisture soon crumble into fragments; in this connection, the mechanical action of the falling rain must not be forgotten. Variations of temperature, especially above and below the freezing point, have great influence in the destruction of rocks. When a rock is saturated with water and the water freezes, it expands, and this expansion tends to enlarge the interstices and in time to separate particles of the rock. It is an observed fact that in the region of perpetual snow the surface of the mountain masses is covered with rocks in a disintegrated state, in greater abundance than below the snow line. Chemical action plays an important part in soil formation. It manifests itself on a large scale in the formation of various mineral species. Some of the older rocks cleave freely in planes not parallel with the stratification, and possibly mineral veins may be due to the same cause. By the instrumentality of organic agency—aqueous, aqueo-glacial and igneous action—extending down through the ages, the rocks have been transformed into soil. The operation is to-day practically illustrated by the transformation of solidified lava from recent volcanic eruption into a plant-supporting soil. Geology teaches that the earth was once a molten mass, that it has cooled by the radiation of heat and become igneous rock. Through the agencies of the causes before mentioned, it begins to disintegrate: and soon the simplest forms of microscopic vegetable life appear, that find all they require upon their rocky home and the atmosphere; these, when they have served their purpose, finally die. The remains of these organisms accumulate upon the inhospitable home where the plants flourished. This is continued for generations, until the accumulated organic matter has covered the rock mass and transformed it into soil. The quantity of organic matter absolutely necessary as a constituent of soils for the production of plants is very small. Peat may contain 70 per cent. of organic matter, prairie and gardens 25 per cent. The Mississippi bottoms have about 10 per cent.; the average of good land is not over 6 per cent. Most crops are produced upon soils containing far less.

Oats, rye and buckwheat thrive with the lowest amount of organic matter, requiring from 1 to 2 per cent. Wheat and tobacco seem to require most among the common agricultural products, and do their best upon soils containing from 5 to 8 per cent. of organic matter. This organic matter is sometimes termed *humus*. The plants decay and add organic matter or *humus* to the soil, and the roots of plants have the power to decompose the rocks themselves, and there is a constant accession of mineral matter or soil. From the putrefaction or decay of organic matter, the elements form new combinations; the carbon combines with the oxygen to form carbonic acid; the nitrogen combines with the hydrogen to form ammonia; this ammonia undergoes a further decomposition called *nitrification*, resulting, like the original putrefaction, from the action of oxidizing *microbes*, and changes the ammonia into nitric acid. Plants are capable of receiving food, either in the form of gas through the instrumentality of their leaves, or in solution by their roots. Of the total weight of the plants, about 5 per cent. is of soil or mineral origin; the remaining 95 per cent. is wholly of atmospheric origin; most of which becomes added to the soil mass on the death and decomposition of the plants. The following elements are found in plants: Carbon, hydrogen, nitrogen, oxygen, sulphur, phosphorus, chlorine, silicon, potassium, sodium, calcium, magnesium, iron, manganese, and in rare cases a few others that may be called accidental. Of these, the carbon, hydrogen, nitrogen, oxygen, sulphur and phosphorus are grouped together to form the various organic compounds furnished by plants. The remaining elements are generally arranged in the following forms: Chlorides and silicates of potassium and sodium, calcium sulphate, phosphates of iron, calcium, magnesium and ammonium (and possibly manganese), salts of potassium, sodium and calcium, with vegetable acids. When plants are burned, the mineral elements remain as the ash. The amount of the different elements may vary. For instance, Sachs showed that the amount of silicic acid in the ash of Indian corn could be reduced from 18 per cent. to .7 per cent., without injurious effect upon the plant. The virgin soil is generally productive, but when in time it comes under tillage, the crops raised upon it are consumed by animals and removed to a distance, so that the mineral food contained in the soil is by degrees exhausted, and unless it is restored the soil becomes barren. The object of manuring is to restore the fertility of the soil, which consists in adding to the soil some substance which shall itself serve directly as food for the plant, or shall so modify, by chemical action, some material already present in the soil, as to convert it into a state in which the plant may take advantage of it. The length of time before fertilizers must or should be used, depends upon the character and amount of the soil. The character of the soil is caused by the different geological formations disintegrated, the rule being that primitive and igneous rocks yield soils rich in potash, while the fossiliferous rocks yield soils rich in phosphoric acid.

The amount of soil that covers the rocks will depend upon the slope of the ground, and the activity of those natural agencies that cause the disintegration. The soil may be so thin as barely to cover the rocks, or in other cases very thick, as in the drift material; the former are called soils of disintegration, the latter soils of transportation. A soil is commonly named from the preponderance of one of its constituents—as, if composed of sand, it is called sandy soil. Soils rest upon a sub-soil, which is tougher, more compact, and contains rubbly and stony debris. Soils differ not only in chemical composition, but also in physical characteristics, as coarse or fine, its power to absorb or retain the volatile and soluble parts of manure, etc.

PHYSICAL PROPERTIES.

The physical properties of the soil have a great deal to do with the growth and nutrition of the plants.

Schubler gives the weight in pounds of one cubic foot of dry soil:

Sand,	110
Sand and clay,	96
Common arable soil,	80 to 90
Heavy clay,	75
Vegetable mould,	78
Peat,	30 to 50

Ordinary soils, under cultivation, have an average specific gravity of 1.2; when free from air, specific gravity about 2.5.

The color of the soil depends exclusively on its composition; humus forming a nearly black soil, while sand gives a light yellow, and iron oxide produces a red color. The darker soils, other things being equal, have the highest absorptive power toward solar heat; this is shown when muck is applied to the surface of snow in the spring.

The porosity of the soil is of the greatest importance in influencing the results of cultivation. It is a fully accepted fact that, other things being equal, soil is *invariably* most fertile which exists in the finest state of division, whose particles are the smallest The finer the particles, the greater the surface exposed to the action of the dissolving medium. As plants assimilate food only from solutions, the importance of this statement can be estimated. A too fine state of division may cause the soil to become impacted. The structure of the soil should be such as to allow self-drainage. The water capacity of different soils has been very carefully determined by Meister. By water capacity is meant the ability to retain a definite quantity of water by absorption, without losing it or becoming super-saturated.

As soils are rarely *saturated* with water, as there is in most cases an outlet at the bottom, Mayer has shown that the ordinary water capacity is much less than the saturated capacity :

		Quartz.	Clay.	Saw-dust.	Heavy Spar.
Saturated, . .	per cent.,	49	46	76.4	39.2
Water capacity,	" "	13.7	24.5	45.6	11.7

During dry weather plants require a soil which is retentive and absorptive of atmospheric moisture. The amount of this retention is generally in direct ratio to two factors, viz., the amount of organic matter and its state of division. The capillary water of the soil is very closely related to its percolating power, since all waters in the soil are governed in their movements by what is known as capillary force. Liebenberg has shown that this movement may be either upwards or downwards, according as the atmosphere is dry or supplies soil-saturating rain. The water absorbed by the roots passes into the plant circulation, and the greater part is evaporated from the leaves. Where the supply of water is insufficient, the plant wilts, and if the evaporation long continues in excess of the supply obtained from the soil, the plant must die. The experiments of Hellriegel have shown that any soil can supply plants with all the water they need, and as fast as they need it, so long as the moisture within the soil is not reduced below one-third of the whole amount that it can hold. The quantity of water required and evaporated by different agricultural plants during the period of growth has been found to be as follows :

One	acre	of	wheat	exhales	409,832	lbs	of	water.
"	"	"	clover	"	1,096,234	"	"	"
"	"	"	sunflowers	"	12,585,994	"	"	"
"	"	"	cabbage	"	5,049,194	"	"	"
"	"	"	grape-vines	"	730,733	"	"	"
"	"	"	hops	"	4,445,021	"	"	"

Dietrich estimates the amount of water exhaled by the foliage of plants to be from 250 to 400 times the weight of dry organic matter formed during the same time.

Cultivation conserves soil moisture. It must be remembered that this water contains soil ingredients in solution. Hoffman has estimated that the quantity of matter dissolved from the soil by water varied from .242 to .0205 per cent. of the dry earth. The experiments of Humphrey and Abbot have shown that about one-sixth of the total sediment of the Mississippi river is *soluble in water*. Another important fact is the relation between the soil and heat. The heat comes from three sources: Solar heat, as the sun's rays; heat of chemical decomposition within the soil, and the original heat of the earth's interior. The latter cannot be of any value to plants; the heat of chemical decomposition is not of any value, except in a few special cases. The sun, therefore, remains the only source of heat of practical importance in relation to the production of crops from the soil. Dark-colored soils, absorbing most and radiating the fewest rays, must attain the highest temperature. Schubler's classical researches on soil temperature, show that there is a difference of over 7° C. between white and black soils, all other conditions being alike. The ease with which a soil receives and retains solar heat is largely due to the specific heat of the soil. The specific heat of a body is expressed by a number which shows the amount of heat necessary to raise a given weight of the body one degree (0° to 1° C.) of temperature, as compared with the amount necessary to raise the same weight of water one degree. The specific heat of the soil is usually between .20° and .25°; while that of water is taken as the standard, or 1°, or four or five times as high. It must follow that the *moisture* of the soil possesses great influence on the soil temperature—so much so, that a dry, light-colored soil may attain a greater degree of warmth than a moist, dark-colored one. The action of water in reducing soil temperature is easily explained. In our latitude, we see the water in all its forms—solid, liquid and gaseous—and we know that these forms are the direct result of temperature. The changing of water from the solid to the liquid or gaseous form, is performed at the expense of heat; the more water evaporated from the soil, the more heat must be extracted from the soil for the evaporation. Therefore, the more water contained in the soil, the lower must be its temperature, because of the greater evaporation and consequent exhaustion of heat. The experiments of Liebenberg, Pattner, Schubler and Dickenson have practically settled all the questions of soil temperatures. The radiation of heat from the soil, and the consequent cooling propensity of the latter, are directly proportional to the absorptive power of the soil. Two soils of like absorptive power towards heat possess equal radiating power. But it does not follow that soils most rapidly warmed are likewise most rapidly cooled again; because the sun's rays are of two kinds, illuminating rays and heating rays, and substances absorbing or radiating one kind of ray may be inactive toward the other.

In a general way, it can be said the greater the heating capacity and conductivity of a soil, the more readily and rapidly does it give off its heat and become cooled, clay being the most slowly affected and sand the most readily influenced. There are many modifying circumstances, as the properties of the atmosphere and protective covering of various kinds—snow, vegetation and the clouds. In this connection, the explanation of the formation of dew upon the plants has been radically changed. The old theory presupposed the coldness of the soil and the warmth of the atmosphere. Now, the *facts* in the case show that the soil at the place dew is deposited is *generally warmer* than the surrounding vapor-containing atmosphere. The temperature of the soil is modified by many circumstances, as the vegetation, condition of the atmosphere, clear or cloudy, the angle of contact between the sun's rays and the soil surface. Even the electrical condition of the soil must not be overlooked, for Fischer has shown that the electrical current possesses the property of acting upon the soil constituents, rendering the insoluble ingredients more soluble; besides, it is the most active ozone former in nature, and shows its invigorating effects upon vegetable and animal life in every recurring thunder-shower.

CHEMICAL PROPERTIES.

Only very general statements can be made in regard to the kinds of plant food required by the different crops. Cereal crops feed on silicates, and contain a less amount of nitrogen than either root or leguminous crops, but they are improved by nitrogenous manure. The phosphoric acid is concentrated in the grain, and is the most constant of all the constituents of the crop. Root crops contain a large amount of potash, and are very exhausting to the soil; they take up more nitrogen than the cereals, besides other ash constituents, as phosphoric acid. The leguminous crops contain twice as much nitrogen as do the cereals, and potash and lime in large quantities, while silica is nearly absent. They respond readily to potash manures.

Chemical analysis of the ash of plants reveals the character of the mineral matters which they absorb from water and soil; the office of each constituent is ascertained by what is known as water culture. The plan of the operation is quite simple. The seeds are germinated upon some clean support, as a sponge or piece of cotton; they are placed in clean glass vessels and the vessels filled with pure water, so as to cover the roots. It has been found that if the water is pure, only a certain development will be produced; but if, now, certain salts of the elements are added, the plant commences to thrive; for instance, potash has been found necessary to the formation of starch, and the chloride of potash gave the best results. Calcium (lime) has been thought to serve as a vehicle for sulphuric and phosphoric acid and in fixing the oxalic acid, which is poisonous to the plant, and rendering it harmless. Phosphorus has been thought to assist in the transfer of soluble albuminoids. Iron is necessary to develop the chlorophyll granules and give the plant its green color. The nitrogen in combination is always present in active cells. Protoplasmic matters in plants contain about 15 per cent. of nitrogen in combination. At different stages in the life of a cell, its protoplasmic matters may pass through considerable changes of form and structure, as indicated in an examination of a ripening seed; but under all these varying conditions, nitrogen in combination is never absent from the living substance of the plant. For the formation of new protoplasmic matters in the plant, supplies of nitrogen in an available form must be furnished; for healthful growth, these supplies must be adequate in amount, hence the importance of a fertilizer containing nitrogen, either as ammonia or nitric acid. Having seen that the soil, the principal medium in which roots extend, possesses the power of absorbing and retaining water, saline matters and gases, we must direct our attention to the conditions upon which the root hairs (fibrous roots) can abstract from it the matters requisite for the plant. These conditions are (1) presence of free oxygen, (2) certain temperature, (3) the presence of saline matters in an available form in the soil.

The fertility of the soil depends upon many conditions, as temperature, rainfall, elevation above the sea level, etc., as well as its chemical composition. The experiments of Messrs. Laws and Gilbert have shown that most soils have a natural fertility and can raise the same crop for a number of years with but little diminution in the crop.

There are two kinds of soil analysis: Mechanical and chemical. Great stress was formerly laid upon the mechanical analysis of soil. The principle is quite simple. Water is commonly made use of to separate the soil into coarse and fine particles, or the same thing can be accomplished by metal sieves ranging from 10 to 100 meshes to the square inch, a weighed quantity of the soil being taken, and the portion remaining on each sieve being collected and weighed. The chemical analysis is quite long and tedious, and the *selection* of the soil is one of the most *important* operations to be performed. It is almost impossible to select a single sample of soil that will fairly represent a field; when to this is added the small quantity taken for analysis, as compared with, say even one acre, the difficulties are increased.

The soil of an acre of land taken to the depth of one foot will weigh about 4,000,000 pounds. About 1-10 of one per cent. is the usual limit of chemical analysis in this kind of work. One thousand pounds of guano would contain about 150 pounds of nitrogen, 150 pounds of phosphoric acid and 30 pounds of potash, making 330 pounds of fertilizing ingredients; then we have $\frac{330}{4,000,000} = \frac{1}{12,100}$ or within the limits of chemical analysis. It is possible that the droppings of a bird flying over it, if it happens to be in the sample analyzed, would make an unfair statement of the chemical analysis. If it were the place to discuss it, there are many questions that the chemical analysis of a soil cannot answer.

The following samples of soil were analyzed. The method of analysis is described in Bulletin No. 10, Division of Chemistry, of the Department of Agriculture:

No. 1—Arkansas Valley Experiment Station, from the orchard—sandy soil.

No. 2—Arkansas Valley Experiment Station, from nursery—clay loam.

No. 3—Arkansas Valley Experiment Station, from farm—adobe.

No. 4—Yuma, Colorado—adobe land.

No. 5—College farm, average of two places.

No. 6—College garden, average of two places—beets grown on soil, not manured.

No. 7—College garden—tobacco land.

No. 8—College garden—beets grown, manured.

No. 9—San Luis Experiment Station—sandy, gravelly loam.

No. 10—San Luis Experiment Station—sandy, gravelly loam.

No. 11—San Luis Experiment Station—sandy, gravelly loam.

SOIL ANALYSES.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.	No. 10.	No. 11.
Moisture	3.15	3.47	3.39	2.77	2.40	3.43	2.78	2.66	1.66	1.72	2.31
Insoluble Silica	79.19	82.24	74.17	84.52	74.21	78.58	82.71	82.40	83.24	83.09	82.20
Hydrated Silica	7.56	4.53	6.66	5.82	3.36	4.79	7.07	5.12	4.12	5.02	5.46
Soluble Silica	.08	.06	.04	.04	.08	.07	.04	.04	1.00	1.20	.07
Iron (Fe_2O_3)	3.30	3.05	3.42	2.16	3.16	3.47	3.37	2.99	4.78	4.17	6.22
Alumina (Al_2O_3)	4.53	5.23	4.23	3.98	5.59	5.07	4.29	3.59	5.59	6.45	6.02
Phosphoric Acid (P_2O_5)	.23	.22	.21	.14	.16	.15	.21	.29	.23	.23	.14
Calcium (Ca O)	2.80	1.28	3.69	1.46	3.58	2.17	.70	.91	.67	.81	.68
Magnesia (Mg O)	.97	.97	1.61	.69	.73	1.00	.85	.69	.54	.56	.67
Potash (K_2O)	.23	.27	.59	.39	.56	.62	.41	.66	.41	.27	.14
Soda (Na_2O)	.41	.21	.88	.29	.66	.71	.71	1.04	.69	.39	.30
Sulphuric acid (SO_3)	.08	.05	.08	.05	.09	.07	.08	.11	.04	.05	.03
Chlorine (C l)	.008	.01	.012	.008	.008	.004	.012	.007	.004	.008	.005
Carbonic acid (CO_2)	4.97	3.68	5.41	4.40	5.47	5.38	2.79	2.95	2.13	2.13	2.66
Volatile and organic matter	3.39	3.05	5.45	2.01	5.01	3.73	4.53	5.03	1.39	1.39	1.59
	100.20	100.33	99.81	100.17	99.77	100.10	100.73	100.72	100.74	100.77	100.24
Nitrogen	.04	.02	.03	.01	.01	.02	.02	.03	.01	.01	.02
Coarse Gravel	10.30	12.41	19.25	16.39	36.36	34.32	34.72	24.39	30.00	24.26	36.95
Fine Material	89.70	87.59	80.75	83.61	63.64	65.68	65.28	75.61	70.00	75.74	63.05

The vital question for the farmer is, What are the important elements of plant food that the soil contains, and in what proportion? This is best shown by a comparison of the analysis of average barnyard manure with the analysis of the soil. The average barnyard manure (Ville) contains:

Water	80.00	(1)
Carbon	6.80	(2)
Hydrogen	.82	(2)
Oxygen	5.67	(2)
Silica	4.42	(3)
Chloride	.04	(3)
Sulphuric acid	.13	(3)
Oxide of iron	.40	(3)
Soda	--	(3)
Magnesia	.24	(3)
Lime	.56	(3)
Phosphoric acid	.18	(4)
Potassa	.49	(4)
Nitrogen	.41	(4)
	100.00	

In the above classes, the elements found in Nos. 1, 2 and 3 are in great abundance in the atmosphere, and in most soils, and therefore form elements of little value as manures; but the elements in the 4th class, as you will see by examining the analysis, the soil contains in very limited quantities, and for this reason the return of them becomes necessary, as they are the most *essential elements* of plant food. Soils containing these elements in large quantities, other things being equal, must be the most productive. In the above analyses the nitrogen ranges from .01 to .03; the phosphoric acid from .14 to .29, the potash from .14 to .66. In many of the States *trade values* are agreed upon for nitrogen, phosphoric acid and potash in the fertilizers bought and sold, the nitrogen being worth about 18 cents a pound, the phosphoric acid 9 cents, and the potash 7 cents, these elements being the "trinity of excellence" in any soil. A glance at the table will show that soil No. 8 contains the elements of plant food in the greatest proportion, and the notes accompanying it show that it is a rich garden soil that had been manured for experiments with sugar beets. Another important fact in connection with soils and fertilizers is that this plant food must be in a *soluble* or *available* form to do any *immediate* good to the crops.

ALKALI SOILS OF COLORADO.

The name *alkali soils* is applied, in the arid region, to all soils containing a large amount of mineral matter, usually occurring as a white powder or crust upon the surface. The first rain dissolves it and carries it into the watercourses and back into the soil, to rise again at the recurrence of dry weather. The rain that falls upon the soil may be divided into three parts: One part that rushes immediately off the surface, and causes the floods of rivers and small streams; another part that sinks into the earth and, after doing its chemical work of soil-making, reappears as springs, and forms the supply of streams and rivers, and a last portion that reaches the sea by subterranean channels. The amount of the rainfall that is carried off by the rivers has been estimated by Humphrey and Abbott, in the cases of the Mississippi and Ohio rivers, to be about one-fourth of that furnished by the rains; for the Missouri, 15-100. It is not far from the truth to say that about one-fourth the rainfall is carried off by the rivers. The other three-fourths goes off by evaporation and as subterranean water. A well is nothing but a hole in the ground a little below where the ground is *saturated* with water. Engineers call the upper surface of this ground water the "water-table," and they are familiar with the fact that it lies at very different depths in different soils and places and at different seasons of the year. Sometimes the water-table is at the very surface of the ground, or at a depth of no more than a few inches or a few feet, while in other situations it may lie, perhaps, hundreds of feet below the surface of the land. Much depends on whether the soil is porous or compact, whether or not the upper soil is underlaid by impermeable strata, and whether or not there is ready opportunity for the water to flow out sidewise and so escape from the soil.

The height of the ground water, that is to say its distance from the surface of the earth, varies greatly at different times in any given soil, according to the permeability of the soil and the time which has elapsed since heavy rains. When people speak of wells and springs as being "full" or "low," they mean the ground water is up or down. The proper height at which ground water should stand in order best to conduce to the prosperity of the growing plant, is an important question in some localities. The rice, cranberry and ribbon grass flourish with their roots actually wet. There are two kinds of movements of water in the soil: First, the movement of percolation of the ground water towards the sea, which is, on the whole, a downward movement; and secondly, a movement by force of capillarity, which is, or may be, a movement in any direction. A great amount of valuable work has been done in this line by Pettenkofer at Munich, also by the lamented W. R. Nichols in his book on "Water Supply."

When rain or snow falls upon the earth, it is speedily subjected to the influence of capillarity and dragged downward. The capillary power of soils has been worked out in great detail by Zenger. It takes a heavy shower for the rain to penetrate as such to the depth of an inch. The water in passing through the soil dissolves it, and when this water is again brought to the surface, it carrries with it the saline matters—in our case the alkali; and as it is evaporated from the surface, leaves this alkali as a white crust or coating on the soil. The alkali is not peculiar to Colorado or this arid region, but is found in many countries—Greece, Patagonia, India, California and other places.

It is easily seen that the more water that is evaporated from the surface of the soil, the more alkali will be drawn to the surface within a certain limit, which is a problem for another section of the Experiment Station; a greater rainfall will bring up a larger amount of alkali, provided the rainfall is not sufficient to wash the alkali into the water-table before alluded to, and so be washed or carried off as drainage. It will be readily seen that it will make no difference in what form this water is, whether rain or irrigation, that the same result would be true. The amount of this water to accomplish one or the other of the above results will depend largely upon the soil, as clay or sand, and upon the underlying strata. There must be an *inverse* relation between the rainfall or irrigation and the prevalence of the alkali in the soil.

The alkali effects plants in two ways: First, by bringing the upper roots and crown roots of the plants grown upon the soil in contact with its corrosive action; second, by destroying the tilth of the soil Alkaline solutions render the soil like well-worked potter's clay, instead of the flocculent condition that it should be in, with innumerable openings and channels for the passage of the rootlets.

The composition of the alkali will vary with the locality from which it is obtained.

The following account is from the Department of Agriculture, 1870, p. 96: "Dr. Edward Palmer brought to the laboratory, from Western Kansas prairies, a sample of what is called 'alkali' of the Western plains. It was in the form of a dry, milk-white powder, mixed with bleached leaves and coarse grass. It did not effervesce with acids, nor did it exhibit an acid reaction to test paper. It contained:

Water	3.6
Insoluble clay	1.5
Chloride of sodium	traces
Sulphate of sodium	94 6
	99.7

"It is consequently a native sulphate of soda, which, from the small amount of water present, may be classed as anhydrous. There is no evidence to show that it is a product of volcanic action. It differs from the varieties of mirabilite of Dana in the small amount of water, which we may conjecture, has been lost during the prolonged heat of summer. It may owe its origin to the decomposition of sulphate of lime, which is so largely present in the soils at the foot of the Rocky Mountains and Sierra Nevada series, by means of carbonate of soda occurring as efflorescence on soils. The usual origin of sulphate of soda is either directly from volcanic sources, or by the delivery of springs containing the salt derived from pre-existing sedimentary beds. In a few cases it is derived from the oxidation of sulphur in bituminous strata, or in pyritiferous beds, which, reacting on common salt, produces thenardite or other forms of sodic sulphate."

The sample of alkali analyzed in the laboratory came from Mr. Black's farm, three miles north of Fort Collins, and it contained:

Water at 100° C.	53.8	per cent.
Silica (Si O2)	12.72	per cent.
Iron and alumina oxides	traces	
Lime (Ca O)	.10	"
Magnesia (Mg O)	1.16	"
Chlorine (Cl)	5.23	"
Sulphuric acid (S O3)	48.92	"
Soda (Na2 O)	31.97	"
	100.10	"

It was neutral to test paper, and did not effervesce with acids. The analyses show but little difference The sample analyzed by the Department at Washington was a sulphate of soda, while the alkali here was both a *chloride* and a *sulphate of soda.* The question that the farmer is interested in is, How can he best reclaim his land? Where the alkali is in small quantities, *deep tillage* will help it. Where deep tillage will not accomplish the purpose, as in cases where the alkali is very abundant, then resort must be had to *underdrains*, where the alkali water is carried off before it comes to the surface. The roots of the plants, where it is underdrained, will go deeper for what moisture they require, with no injury to the crop; and a small quantity of water, when applied at the proper time, will carry off the alkali from the surface soil. To my mind, the question of the drainage of the alkali has been practically settled by the experiment of Prof. Cassidy, on the College farm. Before it was drained, the ground was covered with a white incrustation of alkali, and the field looked as though it was covered with snow. Now there is not a particle of alkali to be seen. Drain tiles were laid thirty feet apart and three and one-half feet under ground, and they emptied into an open ditch.

The question has often been asked, "Is there any thing, or substance, that can be put upon the soil that will kill the alkali?" Neutral alkaline salts, like those found in the alkali, are not very injurious except when present in large quantities, and in our alkali they must be *washed out by some means.* If the composition of the alkali was mainly earthy and metallic sulphates and chlorides, such as chloride of calcium, alum, copperas and the like, the cheapest and most practical antidote would be lime. Alkaline carbonates, like those found in Southern California, are from ten to twenty times as injurious to vegetation as the same amount of neutral alkaline salts. In most cases lime or gypsum, with *deep tillage*, will be of great benefit to the land. The presence of a *carbonate* of potash or soda can be known to the farmer by the alkali effervescing with *strong* vinegar, or by the fact that it dissolves the vegetable humus of the soil, and this dissolved humus is more or less black in color, and is what is commonly called "*black alkali.*"

One of the most important considerations in the alkali question is the *water used to irrigate* the land. If this water is pure, as it is about Fort Collins, where the water comes from the melting of the snow upon the mountains, but little danger need be anticipated; but if, on the other hand, the water used, as in some parts of California, is itself a dilute solution of alkali, and in some cases not very dilute, the farmer is but adding fuel to the flame.

The kind of crop that will shade the soil and prevent evaporation from the surface will be best adapted to alkali soils. It may be said that an accumulation of alkali around the roots of the crops would be injurious, but it must be remembered that the solution is very *dilute* and could not injure the crop. When the ground is hoed during a dry time, the capillary pores are cut off at the surface and evaporation is prevented, or at least very much lessened; therefore, a hoed crop would be valuable on alkali soil. Owing to the expense, the question of *sub-irrigation* has not been tried in a practical way where I have had an opportunity to examine it. There are two arguments in favor of sub-irrigation, viz: It would prevent the rise of the alkali and accomplish a saving of all the water lost by evaporation. If the farmer wants to reclaim his valuable bottom land, he must provide a system of drainage by which the surplus subsoil water is carried off to the rivers and other places, or he will share the fate of the people of India and their "*reh*" (alkali) lands. It is to be hoped, some day in the near future, that the Government will build reservoirs to store the water that now escapes during the spring and fall Should that ever be consummated, another question may arise, viz: Will this water get contaminated with alkali? This is a very pertinent question.

Bulletin No. 82, of California Experiment Station, gives the total solids of Lake Tulare, in January, 1880, as 81 grains to the gallon; in June, 1888, 204 grains; in February, 1889, 303 grains, and that the fish in the lake were dying in large quantities It would seem that the lakes on the upper San Joaquin valley are being concentrated into a strong alkaline lye, too strong for animal life, as before described. In our case the water that is available for storage comes from our mountain streams, from the melting of the snow, and rivals in purity the water of the Alpine lakes of Switzerland, as is shown by the following analysis:

The sample was taken May, 1889, where the river leaves the last foothills. Found 6.4 grains solid matter to the gallon.

The *solids* contained moisture, at 100° C., 8.01 per cent.

Iron and alumina (Fe_2O_3 + Al_2O_3)	1.65	per cent.
Lime (CaO)	38.45	"
Magnesia (MgO)	16.60	"
Sulphuric acid (SO_3)	2.75	"
Carbonic acid (CO_2)	38.09	"
Chlorine (Cl)	1.20	"
Alkalies (Na_2O)	1.16	"
	99.90	"

With a view of ascertaining what changes had taken place in the river water by going down the stream, the water was analyzed about twenty miles lower down. Found 68.8 grains of solid matter to the gallon. The sample was taken July 16, 1889:

Iron and alumina (Fe_2O_3 + Al_2O_3)	1.197	per cent.
Lime (CaO)	13.200	"
Magnesia (MgO)	7.358	"
Sulphuric acid (SO_3)	45 850	"
Carbonic acid (CO_2)	15.637	"
Chlorine (Cl)	.210	"
Alkalies (Na_2O)	16.300	"
Phosphoric acid (P_2O_5)	.085	"
	99.83	"

It will be noticed that the alkali has increased over fourteen times, and the presence of phosphoric acid would be another proof of seepage. It will also be noticed that the total solids have increased over ten times. In this case the seepage water was largely diluted with the river water. A sample of seepage water was taken from the garden of the College farm, 50 feet from the Town Ditch. Found 240.4 grains of solid matter to the gallon:

Iron and alumina (Fe_2O_3 + Al_2O_3)	2.80	per cent.
Calcium (CaO)	13.50	"
Magnesia (MgO)	5.72	"
Sulphuric acid (SO_3)	50 12	"
Chlorine (Cl)	2.42	"
Carbonic acid (CO_2)	11.08	"
Alkalies (Na_2O)	14.22	"
	99.86	"

It will be noticed that there is quite an agreement between the river water and the seepage water in the proportion of sulphuric acid, carbonic acid and alkalies present, the seepage water having about four times as much solid matter to the gallon.

The condition of the well water was examined with reference to alkali. A well was selected five miles from the foothills, away from surface drainage; it was fourteen feet deep, and when the sample was analyzed (April, 1889) had eighteen inches of water. It had a slightly alkaline taste. It contained 84 grains to the gallon of solid matter:

Sulphuric acid (SO_3)	38.28	per cent.
Iron and alumina ($Fe_2O_3 + Al_2O_3$)	2.50	"
Magnesia (MgO)	7.25	"
Calcium (CaO)	13.17	"
Carbonic acid (CO_2)	19.00	"
Alkalies (Na_2O)	19.17	"
	99.90	"

The analysis shows about 38 per cent of carbonate of soda in the residue. It was contemplated in the experiment to have a field so arranged that the seepage water could be used over and over again, to see what effect it would have upon the crops, and to ascertain its *composition* and the amount of solid matter when it became useless for irrigating purposes. Such a field was not available this year. To guide the farmer as to the *least* amount that could be detected by the taste, one gallon of distilled water was taken and the alkali before analyzed added until it was manifest to the taste. As the result of three experiments, it was found that 300 grains to the gallon must be added before it could be detected. There are about Fort Collins a number of reservoirs. The water in three of these was analyzed.

Reservoir No 2 is about five miles from the foothills. The water is carried from the river in an open ditch about twenty miles long. It was analyzed in May, 1889, when it was being filled. Found 52 grains of solid matter to the gallon :

Iron and alumina ($Fe_2O_3 + Al_2O_3$)	2.10	per cent.
Lime (CaO)	14.00	"
Magnesia (MgO)	42.65	"
Sulphuric acid (SO_3)	22.10	"
Carbonic acid (CO_2)	14.41	"
Chlorine (Cl)	3.54	"
Alkalies (Na_2O)	1.09	"
	99.89	"

Claymore lake, one-half a mile from the foothills, is fed by an open ditch about eight miles long. The water was taken when it was very *low*, in May, 1889. Found 69.6 grains of solid matter to the gallon :

Iron and alumina ($Fe_2O_3 + Al_2O_3$)	3.00	per cent.
Lime (CaO)	15.50	"
Magnesia (MgO)	8.55	"
Sulphuric acid (SO_3)	31.25	"
Carbonic acid (CO_2)	21.44	"
Chlorine (Cl)	10.14	"
Alkalies (Na_2O)	9.94	"
	99.82	"

Warren's lake, five miles from the foothills, is fed by an open ditch eleven miles long. The water was taken in July, 1889, when it contained a *medium* quantity of water. Found 26.4 grains to the gallon of solid matter:

Iron and alumina ($Fe_2O_3 + Al_2O_3$)	1.72	per cent.
Lime (CaO)	13.85	"
Magnesia (MgO)	7.72	"
Sulphuric acid (SO_3)	36.72	"
Carbonic acid (CO_2)	22.00	"
Chlorine (Cl)	2.96	"
Alkalies (Na_2O)	14.90	"
	99.87	"

The chemical analyses show that the reservoir waters are purer than the well water examined. This does not include the organic matter that may be present, which would be an advantage to the land irrigated. The water used to fill up the reservoirs is taken from the river, and it takes but a relatively short time to run in the ditches to its destination; while the water in the well, uncontaminated with surface drainage, must take a great deal longer time in its underground channel, and must correspondingly have more alkali dissolved in it. Suppose the well water in question is used for irrigation, what amount of alkali would accumulate near the surface? Dr. Hilgard, of California, says that ten inches of water is the usual estimate of what is required in a year to perfect a crop; if this be true, $6\frac{2}{3}$ gallons of water per square foot is equal to 10 inches depth of water. The solid contents of the well water was 84 grains to the gallon; this quantity, upon evaporation, would leave $84x6\frac{2}{3} = 560$ grains, or a little over $1\frac{1}{8}$ ounces of alkali on each square foot. It is known that in Colorado much more water is used to raise a crop than in California. It can then be readily seen that this operation could not be repeated many years without disastrous results. Sufficient experiments have not been tried to draw any very accurate conclusions as to the extreme limit of the per cent. of alkali that a soil can contain and be productive. A California soil was productive that contained over two ounces of carbonate of soda to the cubic foot, and had, possibly, three or four ounces of other ingredients, making, in all, over six ounces to the cubic foot. The alkali is caused by the yearly evaporation of enormous quantities of water, whose dilute solutions have been allowed to concentrate upon the soil. These facts should impress upon the farmers the importance of providing proper drainage for their lands, so they will not be compelled to abandon, in many cases, the most valuable and productive portions of their farms.

CONCLUSIONS.

To summarize, the analyses of Colorado soils and waters seem to justify the following conclusions:

1. That the physical properties of the soil influence its fertility.

2. That the fertility of a soil is not always thoroughly shown by chemical analysis.

3. That the fertility of a soil depends largely upon

the per cent. of phosphoric acid, potash and nitrogen present in available condition for plant food.

4. That the soils of Colorado compare favorably in fertility with productive soils everywhere.

5. That alkali soils can be reclaimed where drainage is possible.

6. That the alkaline carbonates are much more injurious to the soil and plant growth than are the neutral sulphates.

7. That water from canals and reservoirs is much better for purposes of irrigation than that from wells, as it contains less alkali.

8. That strong alkali water cannot long be used upon land without producing a soil highly charged with alkaline salts, unless drainage be employed.