1) Colorado

3) ~~Bulletin~~ 4) ~~65.~~ September, 1901

2) The Agricultural Experiment Station

OF THE

Agricultural College of Colorado.

A SOIL STUDY.

PART III.

THE SOIL.

—BY—

WILLIAM P. HEADDEN.

PUBLISHED BY THE EXPERIMENT STATION
Fort Collins, Colorado.
1901.

The Agricultural Experiment Station,

FORT COLLINS, COLORADO.

THE STATE BOARD OF AGRICULTURE.

		Term Expires
Hon. B. F. ROCKAFELLOW,	Canon City,	1903
Mrs. ELIZA F. ROUTT,	Denver,	1903
Hon. P. F. SHARP, *President*,	Denver,	1905
Hon. JESSE HARRIS,	Fort Collins,	1905
Hon. HARLAN THOMAS,	Denver,	1907
Hon. W. R. THOMAS,	Denver,	1907
Hon. JAMES L. CHATFIELD,	Gypsum,	1909
Hon. B. U. DYE,	Rockyford,	1909

Governor JAMES B. ORMAN,
President BARTON O. AYLESWORTH, } *ex-officio*.

EXECUTIVE COMMITTEE IN CHARGE.

P. F. SHARP, *Chairman*.

B. F. ROCKAFELLOW. JESSE HARRIS.

STATION STAFF.

L. G. CARPENTER, M. S., *Director*,	Irrigation Engineer
C. P. GILLETTE, M. S.,	Entomologist
W. P. HEADDEN, A. M., Ph. D.,	Chemist
B. C. BUFFUM, M. S.,	Agriculturist
WENDELL PADDOCK, M. S.,	Horticulturist
R. E. TRIMBLE, B. S.,	Assistant Irrigation Engineer
LOUIS A. TEST, B. M. E., A. C.,	Assistant Chemist
E. D. BALL, M. S.,	Assistant Entomologist
A. H. DANIELSON, B. S.,	Assistant Agriculturist and Photographer
F. M. ROLFS, B. S.,	Assistant Horticulturist
F. C. ALFORD, B. S.,	Assistant Chemist
EARL DOUGLASS, B. S.,	Assistant Chemist
H. H. GRIFFIN, B. S.,	Field Agent, Rockyford
J. E. PAYNE, M. S.,	Field Agent, Cheyenne Wells

OFFICERS.

President BARTON O. AYLESWORTH, A. M., LL. D.

L. G. CARPENTER, M. S.,	Director
A. M. HAWLEY,	Secretary
W. R. HEADDEN, B. S.,	Stenographer and Clerk

A SOIL STUDY:

Part III. THE SOIL.

BY WILLIAM P. HEADDEN, A. M., PH. D.

[For convenience of reference the principal paragraphs are numbered, and a table of contents placed at the end of the bulletin.]

§ 1. Bulletins 46 and 58 contain the results of our observations upon the effects of the mechanical condition, the "alkalis" contained in, and the general properties of this soil upon the crops grown on it. This bulletin forms the continuation of our study, and will treat of the soil itself. The preceding bulletins have treated of the crops; this will have nothing to do with them.

The crops grown were, with one exception, sugar beets. This soil, judged by the crops it has yielded, is abundantly rich in plant food. The crops obtained are more conclusive in regard to this point than the indications of the chemical analyses. In this case, however, the two methods of judging lead to the same conclusion, *i. e.*, that any failure of plants to grow is not due to a lack of fertility.

REASONS FOR CHOOSING THIS PLOT OF GROUND.

§ 2. The choice of this particular piece of ground for study was determined by the fact that it was considered to be the most strongly alkalized plot to be found on the College Farm. It had been cultivated previously, but no crop was obtained. It was next set to forest trees, but the most of them died, only a very few surviving the first season, and the surviving plants were unhealthy. The roots of the young trees which were set out in the spring of 1896 were blackened by the soil, and did not seem to have grown at all. There is no reason to doubt but that this was due to the soil conditions, for the mortality among the plants varied with the soil in which they were set. In portions of this forestry plot, which included the plot made the subject of this study, the young trees lived well, whether they made trees or not. The soil and its condition, however, was quite different. This fact eliminates several questions, such as the condition and vitality of the young trees at the time of setting, the manner of setting and their subsequent treatment. The failure of the forestry experiment in this portion of the plantation was quite certainly due to the soil. To be more specific, it was due either to the salts present in the soil, to the soil being so wet as to prevent a sufficiently free access of the atmosphere, or to some other unfavorable condition. The presumption was that such large quantities of salts as were evidently present were quite sufficient to prevent, by their direct action, the development of the plants without considering their effect upon the soil.

OUR ORIGINAL OBJECT EXTENDED.

§ 3. The primary object of the study was to determine, if possible, the effects of these salts upon certain crops, to see if their accumulation could be prevented or hindered by cropping, or even removed by cropping to sugar beets after they had accumulated to the extent of producing a decided alkalization of the soil. As we stated in Bulletin 46, the beet crop did not remove more soda salts from the soil under these conditions than under ordinary conditions, and it became necessary to extend our study in order to obtain an answer to our inquiry as to how we could ameliorate such conditions. The question assumed such shape that we found ourselves almost compelled to address ourselves to the study of the soil itself.

THE APPLICATION OF GYPSUM NOT ADVANTAGEOUS.

§ 4. There is a general impression entertained by some that the application of gypsum to our alkalized soils would mitigate the bad effects of these salts. This opinion has found some support from the results of its use in California. The cases are entirely different. We have not the conditions that the Californians have, and the benefits obtained by the application of gypsum in their case, will not appear in ours. The character of our " alkali " is such that we cannot expect any benefit from the use of gypsum. In our particular case its addition would be a waste of material and a loss of labor, the soil being already so full of this salt that it can easily be recognized as crystalline aggregates disseminated through the soil, often giving it a mottled appearance. The addition of more gypsum under such conditions would be utterly useless.

THE CHARACTER OF THE SOIL.

§ 5. The soil itself, as was stated in Bulletin 46, varies in its character from a loamy soil with a calcareous, clayey subsoil, to a fine alluvium resting upon a stratum of gravel, separated from it by a rather compact clay, but with no proper hard pan. The whole soil is very retentive of moisture, and it is difficult to determine whether there is any direct draining of the water from the alluvial soil above into the gravel stratum below or not. The configuration of the surface would justify the assumption that there is no hydrostatic pressure upon the water in the gravel stratum; at most it can scarcely be enough to force the water through the clay into the soil above. This would lead us to the surmise that the water in the gravel may be entirely different from the water in the overlying soil. Analyses made in the early part of our work corroborated this view.

DRAINAGE.

§ 6. The drainage of the area, of which the plot under observation forms a part, is into the Cache a la Poudre river, at a point about one and three quarters miles below the town of Fort Collins. There is at present an open ditch running through this swale for a considerable distance, and the College management has laid tile drains for a long distance, serving to extend the drainage system almost to the line of the College property. The lateral drains are laid with four inch tiles; the main drains with six, eight and ten inch tiles. On the lower portion of the property there are two drains, laid with eight and ten inch tiles. These drains are parallel for a portion of their length and in part divergent.

§ 7. A study of the country shows that this swale was formerly the bed of a considerable stream formed by the union of streams issuing from the foothills through Spring, Dixon, Soldier and probably what is now the Poudre canon. This fact accounts for the strata of gravel and sand encountered in and along the margins of the swale.

The foundation of the Chemical Laboratory, situated on the north side of the swale, had to be put down to a depth of 20 feet on account of quicksands. At this depth, however, the workmen encountered a stratum of course gravel.

The fall from the plot of ground under observation to the Poudre river is about 150 feet, more rather than less. This old water course is now filled up. Ten or twelve years ago this plot of ground was very wet and boggy, the principal vegetation being cat-tails. This condition was undoubtedly due to the character of the soil, which, as I have stated, is very retentive of water.

ORIGIN OF THE SOIL.

§ 8. The source of this soil is evident and will not account for the alkali salts or its physical properties. The gravel, where there is any at all, is clearly granitic, and can not be the residue from the breaking down of the younger formations of the foothills and plains. The mechanical analysis of the soil shows that even the finest sand is granitic and has been derived from the mountains within the foothills, carried and deposited by the waters which at one time had this swale for their bed. The only evidence that any of the soil material is of different origin is the occurrence, now and then, of a fragment of an impure limestone, which lies just out side the first hogback and belongs to the Fort Benton group or of sandstone belonging to the Juratrias. These fragments are quite rare and are the only definite proof that I have discovered that any portion of the soil has been derived from any other source than the granitic area of the mountains proper. The abundance of mica and red orthoclase in the coarser portions of the soil, and even in the silt, leaves no doubt but that this is the source of the material.

Some of the material may be the residue of strata belonging to formations of later or post cretaceous times, whose removal by waters, now represented by the Poudre river, has left some of this material. This is undoubtedly true of much of the plains soil, but probably only to a very limited extent of the soils of these old water courses.

SOURCE OF THE ALKALIES.

§ 9. The alkalies are not so easily traced. The explanation offered for the presence of alkalies 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 Colorado 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.

GENERAL COMPOSITION OF THE ALKALIES.

§ 10. 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 alkalies 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	per cent.
Magnesic sulfate	19.798	per cent.
Sodic sulfate	41.748	per cent.

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

Calcic sulfate	35.648	per cent.
Magnesic sulfate	28.750	per cent.
Sodic sulfate	11.393	per cent.

A surface well, 28 feet deep, yielded water giving a large residue, of which these salts formed 74 per cent., as follows:

Calcic sulfate	15.206 per cent.
Magnesic sulfate	29.059 per cent.
Sodic sulfate	29.865 per cent.

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 per cent. consisted of these salts, as follows:

Calcic sulfate	12.036 per cent.
Magnesic sulfate	10.473 per cent
Sodic sulfate	60.758 per cent.

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 immediate source of the salts included under the general term alkali. They are so abundantly present in the rocks and waters, even in waters from considerable depths, that there is no need to seek further for their supply. The questions relative to their 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 conditions will appear as an incrustation. This does not take place unless the water plane is at a less distance from the surface than that through which capillarity can raise the water in the particular soil. This was the case in the soil in question, the incrustations accumulating to a maximum thickness of upwards of one half inch. The incrustations being most marked in early summer, but also during the winter when the condition of the weather was favorable.

Relative to the origin of such quantities of sulfates in these rocks and soils, the possible supply is abundant, for throughout the mountain masses we find sulfids disseminated everywhere and we have an almost inexhaustible source of sulfuric acid for the formation of alkali in the gypsum which is so abundant in our Jurassic and other formations.

THIS STUDY LARGELY A MINERALOGICAL ONE.

§ 11. It is to be understood that throughout this bulletin the term soil is used sometimes to mean all of the factors conducing to make up the unit which is expressed by this term; at others in a much narrower sense, meaning to include only a part of the same.

Most of our analyses, for instance, have to do with only one phase of the subject and that almost exclusively a mineralogical one which may practically be designated as a somewhat indefinite study of the decomposition products of feldspar, principally a red orthoclase. It may be a little humiliating at this juncture to make so uncomplimentary a statement concerning this part of our work, but it is scarcely more. This is very plainly suggested by the results of the mechanical analysis which, as already stated, shows this mineral to be the principal one from which the potash can be derived. The small amount of mica in the soil would, even if the mica were easily attacked and altered, contribute but a very small amount of potash or lime, it being very subordinate in quantity. The analyses of the separate parts of the soil as obtained in the mechanical analysis will be shown to suggest the same fact so forcibly that it amounts almost to absolute proof that in our samples we have to do with an altered feldspar.

THE EXPERIMENTS COVER TOO SHORT A PERIOD.

What the effect of growing three crops on this soil may have been is scarcely shown by so short a series of experiments; that is, the results are not large enough to be measured by the means at our command. Even if we should confine the effect to the clay this would still be true. This, however, cannot, as we will show, be justly done, for the feldspar certainly yields fresh quantities of potash to the soil. This mineral is so finely divided, or enough of it is, that even the rain water can and undoubtedly does take a perceptible quantity of this compound into solution.

POTASH IN FELDSPAR AVAILABLE.

§ 12. We shall show by direct experiment that the oat plant, for instance, can appropriate potash from this mineral when it is finely powdered, even in cases in which the mineral is perfectly fresh and the whole work of decomposition has to be done during the period of growth of the plant, perhaps by the roots of the plant itself. The theory of the formation of zeolitic minerals, to serve as the conveyors of the potash, etc., from the more stable minerals to the plant, cannot very well be appealed to, at least as necessary. My experiments do not show that zeolitic compounds are not formed, but they do show that if they are formed, their formation takes place so rapidly that perfectly fresh, but finely pulverized, feldspar becomes an available source of potash in the short period required for the growth of the oat plant. I do not mean to say that finely powdered feldspar will yield potash so rapidly that it will furnish a supply adequate to the production of a crop, but that it will furnish in the aggregate a very considerable quantity of this element. It is a well known fact that this mineral yields potash to water and it was to be expected that growing plants might obtain some potash from this source, but my experiments show that this plant may perfect its growth, obtaining all of its potash from the pulverized feldspar.

§ 13. This fact is of great importance to our Western agriculture, especially to the agriculture of the eastern slope of the Rocky Mountains and eastward to the State line, as the irrigable lands are composed largely of granitic materials and consequently contain a more or less considerable quantity of feldspar, whose decomposition yields, slowly it may be, but a continuous supply of this very important compound. The partially altered mineral possibly presents a greater degree of resistance to further decomposition than the fresh mimeral does to the first attack, but this will affect only the rate of the supply, for we know that this mineral eventually suffers complete decomposition. These soils, or mixtures of minerals, quartz, feldspar and mica, are well preserved because our climatic conditions have not been favorable to their decomposition, either directly or through the decay of organic matter. The rate of change under more favorable conditions, those of irrigation with an increase of vegetable matter, may be more rapid, but it will still be comparatively slow; not too slow, however, to make its results a factor in the supply of potash for our cereal crops.

§ 14. A question arises in this connection relative to the course which the decomposition of the feldspar takes, and whether an experiment with powdered feldspar is comparable with the conditions which prevail in the soil. There is no question but that they are not wholly so. The decomposition may go on either more rapidly or less rapidly in the soil than in the experiment with a mixture of sand and feldspar in boxes. Still the results are, in a measure, comparable. The soil contained from 16 to 28 per cent. of dust, the particles of which have a diameter of less than 0.01 millimeter, and while, as previously intimated, the original feldspar present may have already been so changed that its further decomposition may be somewhat slower than at some previous stage of its history, it has not been removed from all further action of the solutions in the soil, the plant roots and other agents.

In experimenting with the feldspar, the whole of it was reduced to powder, whose largest grains were less than one millimeter in diameter, and of which rather more than 33 per cent., by weight, consisted of particles of less than one quarter of a millimeter in diameter. The feldspar was pulverized to render it more readily attacked, and to reduce its particles to a size comparable with the size of the finer soil grains.

FELDSPAR A SOURCE OF HYDROUS SILICATES.

§ 15. The water in the soil also shows that such changes are going on continuously, for they are constantly removing salts in solution, the supply of which is, in part at least, maintained by the decomposition of the constituent minerals of the soil. If there were no such supply of these salts, they ought to have diminished in quantity to a very small fraction of that which we now find. The formation and continuous presence of highly reactive, hydrous silicates within the soil may be accepted as established, but back of this, as well as of that of clay, whether kaolinitic or colloidal, are the decompositions of which these compounds are themselves but products. In the case of the soils in question, the original minerals whose changes have furnished the materials for these zeolitic compounds are preeminently the feldspars of the granites of the front range. Traces of igneous rocks are found, but their part in the formation of these soils is so subordinate that they may be neglected. That the ground waters, already rich in salts, participate in producing these changes is very probable. The uniform presence of potash salts in the ground water is presumably due in part to this fact. The elimination of potash from the soil in the form of nitre, potassic nitrate, will account for the presence of some, but not for the whole, of the potash present in the ground water. The presence of silicic acid in all of the water, amounting in some instances to about 2 per cent. of the total solids, is likewise suggestive of the decomposition of silicates, yielding, among other products, new silicates soluble in water. The silicic acid present in the water analyses, which will subsequently be given, was in solution either as hydrated silicic acid or in the form of soluble silicates.

A very striking instance of the presence of silicic acid in water came under my notice a few years ago. The water was a very excellent spring water, free from sediment, limpid, and had a temperature of 53° F. The silicic acid present amounted to 25 per cent. of the total solids held in solution. I do not know whence this silicic acid was derived, but most probably from the decomposition of some feldspar, as potash and soda were the next most abundant constituents of the residue obtained from the water. The chemical changes producing such a solution as this in a spring water are quite sufficient, even though they may be modified in many ways, to account for the silicic acid found in the residues obtained from ground waters.

SOME SALTS ARE FORMED IN THE SOIL.

§ 16. We cannot distinguish between the salts which have been dissolved out of adjacent localities and brought by the flowing waters into the area where it is found, and those which have been formed in the latter soil. In the former case they may contribute to bring about new changes, in the latter they will be products of the changes ordinarily going on in that soil, and aid in giving distinctive properties to it. These would remain if the others should be eliminated.

§ 17. The relative amount of magnesic salts which are present in the ground waters before and after the soil has been cultivated, also before and after the application of manure, indicate that there is a series of reactions taking place which result in eliminating these salts as end products. The growing of crops, the cultivation and irrigation of the soil, also the application of manure, accelerate these changes. The readiness with which these reactions take place, especially if they be beneficial to the crop, must, to a considerable extent, be a measure of the soil's fertility.

THE BIOLOGY OF THE SOIL NOT STUDIED.

§ 18. The soil is not only the theater of a wide range of chemical reactions, some dependent upon and some independent of the living organisms present, but it is also the home of an abundant microscopic life, constituting a veritable world of itself.

§ 19. The biological conditions of the soil ought, in this study, to have been taken up with thoroughness, but it has been impossible. We will present the results obtained by such study as we have been able to devote to the soil in the following pages.

§ 20. The purely agricultural features of this study have already been given in Bulletins 46 and 58. These bulletins have treated exclusively of the crops grown on the soil, especially of the effects of the alkali on the growth and ripening of the plant, on the amount of ash constituents taken up, etc. In this bulletin we shall treat of the soil, and in a subsequent one of the ground waters, the irrigation water and its changes.

THE PHYSICAL CHARACTER OF THE SOIL.

§ 21. Beginning at the west end of the plot the soil is a light loam. This passes into a paludal soil rich in alkali, succeeded by a gravelly, clayey soil, which has resisted treatment to a greater extent than any other portion of the plot. The most eastern section of the plot is the lowest, the wettest, and, judging by the abundance of the salts which effloresce, the most strongly alkalized one. The extreme western section is the only one in which there is a subsoil within six feet of the surface. The character of the eastern most section was that of a very tenacious, alkalized clay, which, when moulded to a form and dried, became exceedingly hard. It was a most unpromising soil to attempt to do anything with. The plot has a slope to the eastward of about four feet in 600. There is a stratum of coarse sand and gravel underlying the whole of the plot at a depth of about six feet. The surface is fairly even, with a slight depression running diagonally from near the southwest corner to the north side, a little west of the centre.

PREPARATION OF THE SAMPLES.

§ 22. Six samples of this soil were taken in the spring of 1897, before it was plowed for the planting. These samples were taken with care to obtain samples representing the soil. Sections 8″×8″×10″ were cut out and prepared for analysis. These sections were dried, all lumps being broken by hand from day to day as they became dry enough to be rubbed to pieces in this manner. When drier, and too hard to be so manipulated, they were rubbed in an iron mortar, the mortar being filled so full that pulverization did not take place. In order to be able to study the rock fragments still remaining in the samples, they were passed through sieves from one quarter inch to one twenty-fifth inch mesh. All that passed through the one twenty-fifth inch or one millimeter mesh, was preserved as the sample of fine earth. The coarser portions, six in number, were thoroughly washed and their weight and character determined. The samples were designated by the letters A, B, C, D, E and F. The successive parts are designated by the subscript figures 1, 2, 3, etc.

SAMPLE A.

§ 23. This sample was taken from the east end of the plot, 40 feet east of well A, the worst section of the plot. The sample was divided into the following parts:

Parts.	*Meshes to the Square Inch.*	*Character of the Fragments.*	*Per Cent.*
A_1	4	Quartz, granite, mica, limestone, feldspar	0.68
A_2	9	Quartz, granite, brown sandstone, limestone, feldspar	1.17
A_3	36	Quartz, granite, mica, oxid of iron, limestone, feldspar	2.19
A_4	144	Quartz, granite, iron oxid, limestone, feldspar	4.35
A_5	196	Quartz, mica, feldspar	1.92
A_6	625	Quartz, mica, iron oxid and feldspar	6.31
		Fine earth	83.38

SAMPLE B.

§ 24. This sample was taken 50 feet west and two feet north of well A. This sample is from the edge of the gravelly, clay knoll, on the north side of the plot, and east of the centre:

Parts.	*Meshes to the Square Inch.*	*Character of the Fragments.*	*Per Cent.*
B_1	4	Quartz, brown sandstone, mica, feldspar	4.54
B_2	9	Quartz, brown and red sandstone, mica, feldspar	3.40
B_3	36	Quartz, brown and red sandstone, iron oxid, feldspar	6.39
B_4	144	Quartz, brown and red sandstone, iron oxid, mica, feldspar	6.83
B_5	196	Quartz, mica and feldspar	3.14
B_6	625	Quartz, mica, feldspar	11.95
		Fine earth	63.75

SAMPLE C.

§ 25. This sample was taken 45 feet west and three feet north of well B. This sample is from the eastern edge of the depression running diagonally across the plot and western edge of gravelly knoll.

Parts.	*Meshes to the Square Inch.*	*Character of the Fragments.*	*Per Cent.*
C_1	4	Quartz, granite, feldspar	13.77
C_2	9	Quartz, granite, limestone, iron oxid, feldspar, red and brown sandstone, mica	6.63
C_3	36	Quartz, granite, limestone, sandstone, mica, feldspar	9.78
C_4	144	Quartz, mica, limestone, sandstone, feldspar	7.53
C_5	196	Quartz, mica, limestone, feldspar	2.63
C_6	625	Quartz, mica, feldspar	9.08
		Fine earth	50.58

SAMPLE D.

§ 26. Sample taken 25 feet west and three feet north of well C. This sample represents the low portion of the west half of the plot. It is quite wet and strongly alkalized.

Parts.	*Meshes to the Square Inch.*	*Character of the Fragments.*	*Per Cent.*
D_1	4	Quartz, granite, feldspar	1.50
D_2	9	Quartz, red and brown sandstone, limestone, feldspar	0.67
D_3	36	Quartz, granite, sandstone, limestone, feldspar	1.86
D_4	144	Quartz, sandstone, limestone, iron oxid, feldspar	2.80
D_5	196	Quartz, limestone, mica, feldspar	2.08
D_6	625	Quartz, mica, feldspar	8.81
		Fine earth	82.27

SAMPLE E.

§ 27. Sample taken three feet west and three feet north of well D. This sample represents the western end of the plot.

Parts.	*Meshes to the Square Inch.*	*Character of the Fragments.*	*Per Cent.*
E_1	4	Quartz, granite, feldspar	0.71
E_2	9	Quartz, granite, feldspar	0.29
E_3	36	Quartz, granite, limestone, sandstone, iron oxid, feldspar	1.25
E_4	144	Quartz, mica, limestone, iron oxid, feldspar	3.38
E_5	196	Quartz, mica, limestone, feldspar	2.99
E_6	625	Quartz, mica, feldspar	11.37
		Fine earth	80.01

SAMPLE F.

§ 28. This sample is the subsoil corresponding to sample E.

Parts.	*Meshes to the Square Inch.*	*Character of the Fragments.*	*Per Cent.*
F_1	4		0.00
F_2	9		0.00
F_3	36	Quartz, limestone, feldspar	0.03
F_4	144	Quartz, limestone, feldspar	1.58
F_5	196	Quartz, limestone, feldspar	1.84
F_6	625	Quartz, limestone, feldspar	9.34
		Fine earth	87.21

MECHANICAL ANALYSIS OF THE "FINE EARTH."

§ 29. The beaker elutriation of the fine earth gave the following results:

TABLE I.—MECHANICAL ANALYSIS OF THE FINE EARTH.

SAMPLE.	Hygroscopic Moisture.	Temperature of Absorption.	Water Capacity.	Coarse Sand. 1.0 to 0.5 mm.	Medium Sand. 0.5 to 0.25 mm.	Fine Sand. 0.25 to 0.05 mm.	Silt. 0.05 to 0.01 mm.	Dust. Less than 0.001 mm.	Clay by Difference.	Ignition.
Soil A.............. ..	6.40	15°	51.05	4.459	5.392	26.078	19.527	27.878	8.314	8.351
Soil B................	4.50	15°	36.50	8.114	10.147	35.593	12.386	23.653	4.582	5.543
Soil C................	4.20	15°	44.22	7.318	6.940	20.518	20.828	27.633	7.876	8.887
Soil D...........	5.90	15°	40.54	6.254	7.197	25.894	24.748	21.704	6.013	8.190
Soil E................	3.40	15°	36.84	7.070	9.227	29.947	25.573	16.642	3.534	8.007
Soil F................	3.50	15°	42.34	6.380	7.409	23.736	30.604	19.488	5.552	7.673
Loess Soil. Weld Co..	......	.....	.... ..	1.172	3.737	45.707	27.721	10.565	5.217	5.881
Loess Soil. Larimer Co.	......	.....	......	0.965	2.073	24.451	49.714	11.797	4.567	6.433
Red Soil. Clay Soil. Red Beds.	......	.....	....	4.411	11.872	27.943	31.592	13.793	4.600	5.789

THE MINERALOGICAL CHARACTER AND SOURCE OF THE SOIL PARTICLES.

§ 30. The sand grains in the different samples consisted of quartz, feldspar and some flakes of mica. The quartz grains show plainly the deposition of oxid of iron upon their surfaces, in checks and depressions in the grains. The deportment of the sand, and more particularly the still coarser portions, warns us that we cannot conclude that the sand particles owe their origin to the red beds, because of their color after ignition, for there is enough organic matter coating the grains to cause blackening upon heating, and this may account for the presence of the iron oxid which becomes evident upon igniting the sands. There is nothing distinctive enough, so far as I have observed, about the sand grains to justify one in asserting that they did or did not come from the juratrias, or Dakota sandstones, or are directly due to the breaking up of the granites. The presence of so large an amount of feldspar and mica, neither of which is present in the sandstones of these formations in such quantity, is strong proof that practically the whole mass is derived directly from the rock masses of the mountains which lie immediately west of us, and consists of granites, gneisses and mica schists.

§ 31. While I believe myself justified in making the statement that the most of the rock material of this soil came directly from the mountain masses in geologically recent times, I am fully aware that the disintegration of the red sandstones, and to a less extent the conglomerates of the red beds, could give rise to a very similar mixture of rock fragments. The following facts show this plainly. A sandstone belonging to the upper part of the Upper Wyoming, of loose texture and easily disintegrated by soaking and judicious rubbing, without any grinding up of its particles, gave me the following mechanical analysis:

Sand grains having a diameter greater than two millimeters, 1.40 per cent.; greater than one millimeter, 26.80 per cent.; less than one millimeter, 62.70 per cent.; cementing material, oxid of iron, calcic carbonate, etc., 9.10 per cent. The sand grains were principally quartz, but there were some grains of feldspar and a few flakes of mica. In regard to the fineness of the particles, it will be noticed that practically 63 per cent. of the mass of the sandstone was as fine as that division of the soil designated "fine earth," and that this percentage is as great or greater than that of the fine earth in two of our soil samples. The alkalies in this sandstone were determined and found to amount to 1.30 per cent. of the sandstone; potash constituting 1 per cent., and soda three tenths of 1 per cent. The cementing material, mostly calcic carbonate and oxid of iron, contained a small amount of these constituents, potash 0.025 per cent., soda 0.053 per cent., calculated on the sandstone, not on the weight of the cementing matter. The alkalies were also determined in a sandstone from the Lower Wyoming, and found to equal 2.563 per cent. of the sandstone; potash 0.924 per cent., soda 1.639 per cent. The potash in each of these cases amounts to about 1 per cent., and is contained almost wholly in the sand grains, among which, especially among the larger ones, feldspar grains are easily recognizable. These sandstones do give rise to a soil whose elutriation would yield a mixture of sand grains somewhat similar to that with which we have to do in this study. The characteristics of the soil formed by the disintegration of these sandstones are so markedly different from those of the one we are considering, that they are not even suggested as the possible source of the material, except by the most thorough washing of the soil formed from them.

§ 32. The statements relative to the mineralogical character of the different classes of soil particles are applicable to all of the soils which I have analyzed or examined with care, whether close to the mountains or as far east as the State line, excepting the soils of the valley lying between the hogback formed by the Dakota sandstone and the mountains proper. This area, corresponding to the outcrop of the red beds, is not wholly covered by this granitic soil. There are doubtlessly some sections where the surface soil is derived from younger formations, the particles of which have not been transported from the mountains by the streams or waters which have given the country its present contour, but are disintegration products of formations composed of material similar to that brought from the mountains by the streams of later times.

The particles of more than 0.5 millimeters diameter are for the most part rounded, but this is not the case with those less than .25 millimeters, nearly all of which are sharply angular.

§ 33. It may appear to many, especially to such as have an acquaintance with the occurrences of loess and other formations of the plains, the mineralogical constituents of which are often identical with those given for these soils, that the latter, like the former, may be the product of other disintegrations than that of the granites of the Colorado range. There is nothing in their composition to preclude their having been derived from some other source. Their geographical distribution makes it probable that material similar to this composing our soils has been derived from other mountains than those lying near to us. It seems reasonable, however, to assume that the near and very extended range has furnished essentially all of the material going to make up these soils. There may be a doubt entertained that the quartz, feldspar and mica given in the preceding table were derived from the present mountains, but there can be no question regarding the source of the fragments of red and brown sandstones, or of the impure limestone; these are the products of the disintegration of the red beds and of the Fort Benton limestone.

SOIL COMPARED WITH LOESSIAL SOIL.

§ 34. There is given in the table of mechanical analyses, one of a loessial soil from Weld county. This soil, according to the mechanical analysis, has a very different composition from the soils given above. It is characterized by a high percentage of fine sand and low percentages of dust and clay, but mineralogically the sand and coarser parts are the same as in the other soils, *i. e.*, quartz, feldspar and mica. The mica, though still subordinate in quantity, is more abundant in the loessial soil than in the others. It seems to be a general rule that the farther back from the river we get, or higher up on the plains, the greater is the percentage of fine sand present in the soil.

§ 35. I have not attempted to determine the ratio between the grains of feldspar and quartz in these soils, but others have determined this ratio in the loess, for which the approximate determination is given as: Quartz, 40 per cent.; feldspar, 50 per cent.; other constituents, 10 per cent.* The minerals making up the other 10 per cent. were, in the case of the Weld county loessial soil,

---

* Emmons' Geology of the Denver Basin in Colorado, p. 262.

mica, magnetic oxid of iron, etc. I have not determined, by actual count, the grains of quartz and feidspar, but my judgment is that there is more quartz in the sands that I have separated from these soils than is indicated by the percentage given in the analysis quoted, viz., 40 per cent. It is to be expected that the mechanical composition of soils will vary from place to place, and yet the table shows a greater agreement than we would expect; the sample of loessial soil from Weld county and of loess from Larimer county being the only ones which show wide deviations in the percentage of any class of soil particles. Not only the mineralogical, but also the chemical examination of these soils, indicate a rather uniform composition, though the samples were taken from widely separated localities. By chemical analysis is here meant the analysis of the whole mass, a mass analysis, and not a soil analysis as it is made for agricultural purposes.

§ 36. Dr. S. F. Emmons, writing of the loess in the "Geology of the Denver Basin in Colorado," says that it contains in all cases a large proportion of sand, separable by washing, whose grains are usually under a millimeter, but rarely less than a tenth of a millimeter in diameter. The mechanical analyses of the loessial soils show 43 and 64 per cent. of the mass to have a diameter of less than five one hundredths of a millimeter. The mechanical analysis of this soil shows 47.40 per cent. of material, the clay not included, whose grains have a diameter of less than one tenth of a millimeter, and which differ from the coarser portions only in the degree of their comminution. The loessial soils given agree in having high percentages of fine sand and silt, and lower percentages of dust and clay than ordinary soils; but our results do not agree with Dr. Emmons' observation that the grains of sand in loess are rarely less than one tenth of a millimeter in diameter.

SIMILARITY OF THE PARTICLES AND COMPOSITION OF SOILS.

§ 37. The fine sands are, in every case, much more angular than the coarser, due to the manner in which the water has effected their transportation, the larger having been rounded by rolling or by attrition while in suspension. The loessial soils show this characteristic as markedly as the other soils examined. There is so great a similarity in the mineralogical composition of our soils, though they vary in appearance, that it is a matter of some surprise that they should differ so extremely in properties. The chemical analysis of the soils, mass analysis, does not change this phase of the matter at all. The following analyses of samples taken from rather widely separated localities, may serve to illustrate this:

TABLE II.—MASS ANALYSES OF SOME SOILS.

	Prairie Soil, South of Agricultural Hall. Surface.	Soil A. Taken 10" deep.	Loessial Soil. Weld County. 21½" deep.	Loessial Soil. Larimer County. 6 ft. from top.	Loess. Cheyenne, Wyo.*
Silicic Acid	69.356	64.745	72.550	67.836	67.100
Sulfuric Acid	0.041	0.827	0.023	0.025	....
Carbonic Acid	0.016	1.208	0.368	0.888	3.670
Chlorin	0.006	0.014	Trace.	0.022	....
Phosphoric Acid	0.466	0.112	0.331	0.411	0.110
Potash	2.248	2.295	2.479	2.497	2.680
Soda	1.215	1.184	1.498	1.311	1.420
Lime	1.645	2.789	1.075	2.481	5.880
Magnesia	1.412	1.819	1.245	1.740	1.240
Ferrous Oxid	....	....	....	....	0.310
Ferric Oxid	5.424	4.475	4.420	5.255	2.520
Aluminic Oxid	11.338	11.717	10.754	11.418	10.260
Manganic Oxid (br)	0.160	0.200	0.239	0.109	....
Moisture at 110° C	2.981	3.296	2.595	3.569	....
Ignition	4.044	5.402	2.311	2.287	5.090
Sum	100.352	100.080	99.888	99.849	100.280
Oxygen Equivalent to Chlorin	0.001	0.003	....	0.005	....
Total	100.351	100.077	99.888	99.844	100.280

* Analysis by Eakin's Geology of the Denver Basin in Colorado, p. 263.

I have chosen the sample of loess from Cheyenne because this is probably more nearly comparable to mine than any other at my disposal, and the locality is nearer by thirty miles than that from which the next nearest sample was taken. The sample marked loess from Larimer county was taken at a point about seven miles from the place where the sample soil A was taken. The most marked variations in the composition of these samples are, the sulfuric acid of the soil A, the carbonic acid and lime of the loess from Cheyenne. The sulfuric acid in the soil was probably present as calcic sulfate or sodic sulfate, forming a part of the "alkali" present in the soil. The carbonic acid and lime in the Cheyenne loess was doubtlessly present as calcic carbonate. This is of common occurrence in this formation; is very variable, and is not essential. With these exceptions, the causes of which are usually discernible without the aid of chemical analysis, or even a magnifying glass, these soils agree as closely as samples taken within a few feet of one another might agree, and suggest a common origin for wide areas of our surface soils.

The alkalies are lower than one would expect, judging from the number of feldspar particles which are present, and the ratio of the soda to the potash is high, as the feldspar recognizable is very predominantly orthoclase. The silicic acid is lower than the apparently large number of quartz grains present would suggest. The orthoclase contains, in round numbers, 66 per cent. of silicic acid, while the average percentage of this acid in these soils is 68.6 per cent., which seems lower than the macroscopic examination suggests.

PORTIONS OF FINE EARTH EXAMINED.

§ 38. The loess from Cheyenne was not examined further, nor was the loessial soil from this county, but the soil A was. The fine sand, with particles from 0.25 to 0.05 millimeter in diameter, the silt, the dust and the clay were each analyzed with the following results:

TABLE III.—ANALYSES OF PORTIONS OF "FINE EARTH" OF SOIL A. SAMPLE TAKEN TEN INCHES DEEP.

	Fine Sand.	*Silt.*	*Dust.*	*Clay.*
Silicic Acid	82.024	69.247	58.204	40.389
Sulfuric Acid	0.017	0.014	0.100	7.060
Potassic Oxid	1.914	2.711	3.166	3.000
Sodic Oxid	1.926	1.851	1.323	3.134
Ferric Oxid	3.383	5.425	9.109	7.113
Aluminic Oxid	6.737	13.018	19.078	14.607
Calcic Oxid	1.746	1.488	1.480	6.059
Magnesic Oxid	0.777	1.519	2.648	3.982
Manganic Oxid (brown)	0.150	0.250	0.190	0.168
Moisture and Organic Matter	0.750	4.118	3.980	14.668
Total	99.424	99.631	99.278	100.180

The coarser parts of the soil were not analyzed, for the reasons that they are comparatively small in quantity and, on account of the large size of their particles, are not subject to those actions which liberate plant food to any considerable extent. It might have been better for a favorable presentation of results had we analyzed them, but there was so little to be gained that we did not deem it worth the work. This table shows a very decided difference in the composition of the parts separated by washing the soil. We have no basis of comparison with the loess and other soils. The series stands alone, but the results that it exhibits are so pronounced and so similar to what we would expect that we have little hesitancy in accepting it as proven that there is an accumulation of the potash in the finer portions of the soil, and a diminution of the silicic acid.

PROBABLE COURSE OF CHEMICAL CHANGES IN SOIL MASS.

§ 39. We have here probably a rough presentation of the course of the chemical changes which take place in the transformation of a mass of rock fragments into true soil. The decomposable minerals, feldspar and mica, very subordinate in this case, are so acted upon that new minerals, having less silica but more alumina and possibly alkaline earths, are formed. The high percentage of lime in the analysis of the clay is almost certainly due to an admixture of gypsum. It is scarcely possible, owing to the manner of preparation, that the higher percentage of magnesic oxid can be attributed to a similar cause. In regard to the potash, which is even higher in the dust than in the clay, though the experienced analyst will be inclined to consider them the same, there may be a question as to the manner in which it is present. This arises from the knowledge of facts obtained from other experiments and not from the analyses. The testimony of the latter is, and it is in perfect harmony with what we know of the deportment of soil masses, that in the extremely small particles of the soil there is a tendency toward enrichment in potash. The indications of the analyses, contrary to the impressions of the writer, indicate that the maximum of this concentration is reached in the portion designated as dust, a portion whose individual particles have a diameter of less than 0.01 millimeter, or less than one twenty-five hundredths of an inch, and which constitutes 27.87 per cent. of this soil. The clay, which is still very much finer, contains, in this case, essentially the same percentage of potash, but constitutes only 8.31 per cent. of the soil. In this instance the dust and not the clay is the potash carrying silt-constituent of the soil.

§ 40. The fine particles of the dust and clay are probably not wholly composed of fine residual parts of the minerals originally composing the soil mass, but are to a greater or less extent made up of newly formed particles of precipitates, or at least of newly formed minerals, which may adhere tenaciously to the fine residual grains or form independent little aggregates which, being disintegrated by the washing of the soil, are obtained in the form of clay.

ANALYSES OF PARTS OF FINE EARTH SHOW NO DEFINITE RATIOS.

§ 41. Little can be said in regard to the ratios existing between the various chemical constituents as shown in the preceding analyses. There is, for instance, no clear and definite relation between the potash and soda, iron oxid and alumina, alkalies and alkaline earths. The iron is, taken roughly, equal to one half of the alumina. This holds true for soil A, the parts of the soil separated by washing, and of the Larimer county loess. I am inclined to think that this is an accident, in spite of its occurring in each of these six instances. It is not the case in the Cheyenne loess, and extraction with hydrochloric acid shows it to be almost wholly soluble in this agent. Macroscopic observation, especially after ignition, shows the sand grains to be coated to a greater or less extent with this substance, oxid of iron. It does not appear as red oxid of iron on the grains before ignition, but becomes evident after. This is well seen in the color of the mass before and after ignition. This suggests the existence of hydrates of iron or organic compounds, but the loss on ignition is so small and irregular, bearing in its quantity no relation to that of the iron, that the organic compounds, if any, are very small in amount. There seems to be, as we shall see later, but a small amount of iron present in the form of a silicate insoluble in hydrochloric acid, certainly not more than may be present in a perfectly fresh feldspar. This would still be the case if the quartz sand were all deducted or considered as carrying no iron whatever. The portion soluble in hydrochloric acid, on the other hand, is rich in iron. The total loss on ignition is not unusually large, and a portion of this is water retained at the temperature of 110° C, probably in the form of hydrated oxid of iron.

SOLVENT ACTION OF HYDROCHLORIC ACID ON THE SOIL.

§ 42. The portion of these soils dissolved or decomposed by hydrochloric acid, sp. gr. 1.115, upon digestion for five days, varied from 30 to 50 per cent. The amount dissolved certainly depends upon the character of the substances present in the samples, but in this respect our samples are very uniform, containing essentially the same mineralogical components. The variation in the amount dissolved depends upon other conditions, principally upon the fineness of the soil particles, and the particular degree of their decomposition. The former condition is the more important, as the latter one is largely dependent upon it. This is quite clearly seen upon a comparison of the mechanical analyses of these samples, taking the particles having a diameter greater than 0.05 millimeter as one group, and those of less diameter as another group. The amount dissolved under the convential conditions, HCl., sp. gr. 1.115, and five days digestion on water bath, varies, but not closely, with the ratio of these two groups, into which every soil can be divided. In other words, it is the very fine particles of the soil which yield to the hydrochloric acid the elements of plant food found in the solution. This is unquestionably the case in the soil, as well as in the analysis. The decomposition of the minute particles of the minerals will take palce more slowly in the soil solutions than in the hydrochloric acid, but the order in which they will be attacked is the same, the finest first.

RESULTS OF CHEMICAL ANALYSES NOT COMPETENT CRITERIA.

§ 43. The chemical analysis does not give us a good criterion by which to judge of the virtues of a soil. It may not follow the same course of decomposition that takes place in the soil, and it certainly extends too far, that is, we can not say how long it would take to effect the same amount of change by the soil agents, as is effected by an acid solution and heat during the five days digestion, or by strong acid in ten hours.

THE SAMPLES ANALYZED.

§ 44. The samples and the manner in which they were taken have already been described. Two sets of samples were taken, one on May 13, and another on October 20, 1897. These samples were taken from the same parts of the plot, in order to make them agree as nearly as we could. We hoped that the earlier samples would enable us to ascertain the composition of the soil, the later ones to determine, if possible, the effects of cultivating, irrigating, and cropping it. The crop grown was sugar beets. The work done on the crop, both in the field and laboratory, is recorded in Bulletin 46. The whole crop, both roots and tops, had been removed before we took the samples in October.

WATER RECEIVED.

§ 45. The rainfall was about 9 inches. The amount of irrigation water used in the two irrigations given was not measured, but was estimated by an experienced man to be about 8 inches, or approximately 17 inches in all. The drainage of this plot of ground is not good, and we now know that it receives water from the west as sub-irrigation. This we did not know at the beginning of our experiment, or rather we supposed that we were protected from this interference by a ditch and a drain. The water plane during this season was higher than during the succeeding season of 1898, but this, I think, was due in part to greater rainfall and more frequent irrigation. Two factors enter here which are wholly undetermined, the upward movement of the water-soluble salts in the soil, due to evaporation from the surface, and the salts removed by drainage. The former was made as low as our conditions would permit, by keeping the surface soil well stirred by frequent cultivations, and by the luxuriant growth made by the beet tops. I do not know how much either of these agencies accomplished during the season, nor do I know that any attempt has been made to determine the amount of evaporation from the surface of the soil at this place under any conditions. The amount of drainage from this plot was sufficient to lower the water table, after it had been raised by irrigating the plot, two feet in eleven days. In this case, the adjoining land had received no irrigation, and the rise in the water plane was purely local.

§ 46. The draining out of the water may have been due as much to a spreading of the water over a larger area, as to draining out. Under such conditions as the early summer season presented, the fall of the water plane in this plot took place at the rate of one foot in thirty days. I would have assumed this to be the rate of drainage out of this area, had we not demonstrated, much against our will at the time, that there is a flow of water from the west into our plot, and the fall of one foot in thirty days is simply the excess of the drainage out of the area over that into it.

DEPORTMENT OF SOIL WITH WATER SHRINKAGE INCLUDED.

§ 47. I have stated twice that one characteristic of this soil is its retentiveness of moisture. I do not mean by this statement that it will refuse to give up a larger percentage of moisture than other soils, when exposed to drying out in the air or subjected to drought, but that excessive water is given up slowly, and also that when it dries it shrinks and becomes very hard, which is true of many soils in this State.

§ 48. I made two experiments to determine the rate at which this soil dries after being saturated with water, and also to determine the loss of volume due to shrinkage.

These samples deported themselves very differently. The sample of soil A, placed in a cylindrical box, showed moisture on the surface in seven minutes after the perforated bottom of the box was placed in water, but the soil had not become saturated at the expiration of four and one-quarter hours, and was permitted to stand in contact with the water over night. The sample of soil D, on the other hand, did not show moisture on the surface until forty-five minutes after it was placed in contact with the water, but was saturated in one and one-quarter hours. Soil A required for saturation 18.18 grams of water, and lost in eleven days 17.78 grams; D required 16.62 grams for saturation, and gave up 16.20 grams in eleven days. The shrinkage was the same in both cases, 28 per cent. of the original volume. The cylinders were filled and shaken down to make the soil compact. The loss for each twenty-four hours, up to the end of the seventh day, is given in the following table, together with that for pulverized feldspar, which was used for the sake of comparison. The feldspar had been pulverized so that its particles approached those of the soil as nearly as possible in size. The volumes were the same. It will be born in mind that the soil contains humus, clay, salts, etc., while the feldspar does not. The feldspar showed moisture in one minute after being placed in the water. One sample was saturated in ten and the other in twenty minutes. This is a very pronounced difference, the soils requiring 75 and upwards of 255 minutes for their saturation. The feldspars required for saturation 8.94 and 7.39 grams of water respectively, the soils, 18.18 and 16.60 grams.

TABLE IV.—RATES AT WHICH THE SOILS GAVE UP WATER.

	Soil A. *Grams.*	*Soil D.* *Grams.*	*Feldspar.* *Grams.*	*Feldspar.* *Grams.*
Water given up in first 24 hrs	3.58	3.10	2.06	2.00
Water given up in second 24 hrs	2.45	3.00	2.52	2.42
Water given up in third 24 hrs	2.47	2.45	1.99	1.95
Water given up in fourth 24 hrs	2.33	2.40	1.85	0.97
Water given up in fifth 24 hrs	2.40	2.40	0.06	0.01
Water given up in sixth 24 hrs	2.10	1.60	....	....
Water given up in seventh 24 hrs	1.20	0.35	....	....

The experiment with the soils was continued for four days longer, but the loss was comparatively slow. The feldspar showed no shrinkage. The temperatures at which these experiments were made were 15°–16° C. for the soil samples, and 16°–17° for the feldspars.

ANALYSES OF HYDROCHLORIC ACID SOLUTIONS OF THE SOILS.

§ 49. The description of these samples has been given in a preceding paragraph, and the method of analysis was a conventional one, digestion with hydrochloric acid, sp. gr. 1.115, on a water bath for five days.

TABLE V.—ANALYSES OF SOILS. GENERAL SAMPLES.

	A. May 13, 1897.	B. May 13, 1897.	C. May 13, 1897.	D. May 13, 1897.	E. May 13, 1897.	F. May 13, 1897.	A. Oct. 20, 1897.	B. Oct. 20, 1897.	C. Oct. 20, 1897.	D. Oct. 20, 1897.	E. Oct. 20, 1897.	F. Oct. 20, 1897.
Insoluble	53.470	70.065	58.951	53.617	62.572	54.262	50.228	70.756	51.047	56.092	61.871	53.572
Silicic Acid, Soluble	17.875	11.379	17.449	18.662	12.918	12.126	21.346	11.587	20.287	17.926	13.552	10.671
Sulfuric Acid	0.827	0.488	0.508	0.921	0.517	0.529	1.433	0.486	0.354	0.927	0.817	0.237
Carbonic Acid	1.208	Trace.	0.652	1.267	2.251	6.934	0.419	Trace.	0.949	0.785	1.991	8.025
Chlorin	0.014	0.014	0.031	0.008	0.033	0.019	0.034	0.019	0.004	0.007	0.007	0.016
Phosphoric Acid	0.112	0.064	0.081	0.061	0.070	0.054	0.086	0.128	0.115	0.099	0.138	0.122
Potash	1.495	1.003	1.443	1.443	0.876	0.854	1.528	0.978	1.457	1.372	0.936	0.750
Soda	0.624	0.521	0.589	0.778	0.610	0.600	0.722	0.540	0.618	0.546	0.535	0.614
Lime	2.479	0.778	1.029	2.751	3.698	9.141	1.944	0.840	1.602	1.777	3.129	10.537
Magnesia	1.649	1.007	1.429	1.446	1.081	1.254	1.697	0.860	1.737	1.353	1.198	1.465
Ferric Oxid	4.075	3.575	4.185	4.225	4.025	3.630	4.320	3.385	4.960	4.170	3.795	3.600
Aluminic Oxid	7.387	4.484	5.587	6.733	4.853	5.190	7.410	4.264	7.281	6.492	4.499	3.756
Manganic Oxid (br)	0.200	0.120	0.140	0.190	0.075	0.065	0.245	0.130	0.290	0.095	0.085	0.190
Moisture at 100° C	3.296	1.765	2.004	2.214	2.020	1.642	2.990	1.526	2.853	2.721	2.109	1.850
Ignition	5.402	3.976	5.581	4.417	5.095	4.103	5.361	4.017	6.035	5.470	5.898	5.223
Sum	100.113	99.246	99.659	99.734	100.694	100.403	99.763	99.516	99.489	99.831	100.460	100.678
Oxygen Equivalent to Chlorin.	0.003	0.003	0.007	0.002	0.008	0.004	0.008	0.004	0.001	0.001	0.002	0.004
Total	100.110	99.243	99.652	99.732	100.686	100.399	99.755	99.512	99.488	99.830	100.458	100.674
Nitrogen	0.0937	0.0882	0.0882	0.0959	0.1295	0.1040	0.0938	0.1022	0.1015	0.1083	0.1191	0.0996
Humus	0.8150	0.9450	0.7360	0.6600	0.8080	0.5740	0.7120	0.9100	0.7400	0.8460	1.0300	0.5020
Phosphoric Acid in Humus.	0.0384	0.0205	0.0296	0.0288	0.0486	0.0384	0.0333	0.0345	0.0396	0.0294	0.0537	0.0334

CONSIDERATION OF ANALYTICAL RESULTS.

§ 50. There is no division of soil into surface and subsoil, except in the case of samples E and F, where E is the soil and F the subsoil. The mechanical and chemical analyses both show that there are marked differences.

The subsoil disappears entirely a few feet east of this point, and is entirely wanting at the point where sample D, the next on the east, was taken. The subsoil contains less decomposable silicates, corresponding to the soluble silicic acid, a considerable quantity of carbonate of lime, and a different mechanical composition.

The surface soils vary more than would be expected, and not in the manner that a knowledge of their physical appearance and deportment under cultivation would lead one to anticipate. Soil A becomes heavily incrusted with alkalies, the incrustation reaching a thickness, at times, of one half inch, while soil E does not at any time show an incrustation and would not be considered as containing any alkali, except for the marked amount of sulfuric acid appearing in the analysis. The carbonic acid in both samples appears to be in combination with calcium to the extent of about 50 per cent. in the case of A, and probably a still greater extent in the case of E. This is the case if the water-soluble portion of the sample represents the salts present in the soil, and no changes are induced by the long treatment with water necessary to remove all the soluble salts. We notice that the sulfuric acid in the samples of A and E, taken in October, is higher than in the samples taken in May. This may be due to a transference of the sulfates from the subsoil to the soil, but taking the two series of samples, we see that only two samples indicate any loss of sulfates, *i. e.*, samples C and F; and as already suggested, the loss in F may account, in part, for the gain in E.

§ 51. The carbonic acid does not give us any strong indication that the season's cropping and cultivation has eliminated much if any alkali from the soil, while the total soda present tends to show that the apparent diminution in the carbonic acid present is to be explained otherwise than by attributing it to any variation of the quantity of alkali. Samples E and D are from contiguous sections. E shows no alkali on the surface, while D shows an abundance of it. If, for the sake of simplicity, we calculate the sulfuric acid as corresponding to sodic sulfate in the soil, we observe that in May it ranges from 0.87 to 1.63 per cent., whereas in October it ranges from 0.63 to 2.54 per cent., one sample only, C, showing a decrease from 0.90 to 0.63 per cent. In the case of the subsoil F, we have a decrease from 0.94 to 0.42 per cent, but in the surface soil E, corresponding to it, we have an increase from 0.92 to 1.45 per cent.

§ 52. This soil E is in excellent condition and would ordinarily be considered free from alkali, but if we calculate the amount of sodic sulfate corresponding to the sulfuric acid in an acre of such soil taken to the depth of one foot, we find in round numbers 16 tons in May, and 25 tons in October. In the subsoil, sample F, we find in May 16 tons and in October 7 tons. It appears that 9 tons of this salt, or its equivalent, has been transferred from the subsoil to the soil by surface evaporation and capillarity, but no incrustation was produced. In the case of sample A, we find a little larger increase in the surface layers, but there is at times a heavy incrustation covering almost the whole of this section. This was not the case at the time the sample was taken. We have a marked change in the other direction in sample C, as we find that about four tons per acre of this salt has passed below the depth to which our sample was taken. It is possible that this salt was washed out or flooded off of this section of the plot at the rate of four tons per acre during the season. I would like to believe this, but I see no reason why I should. The ground here is about one foot higher than at B or D, and the irrigation water flowed towards these points, but there was no increase in the alkali at either B or D. In the case of F there is a patent explanation, in the case of C there is not. The sulfuric acid determinations were done in duplicate in both cases, and agreed within four one hundredths of one per cent. The crop as previously shown did not remove a large amount of sulfuric acid, and I have no explanation for the disappearance of the alkali from this section, unless it was simply carried into the soil by the irrigation and was not brought back by the capillary movement of the water within the reach of our sample. The differences in the percentages of the potash are so small, and the samples not being identical, there is not even the same small object in trying to draw any inferences from them, that there is discussing the effect of the season's work on the "alkali," basing it upon the total amount of sulfuric acid present in the different samples.

One could scarcely expect one season's study and work to produce a change of sufficient magnitude to show a decided difference in the results of such anaylses, nor does the matter stand in a much more favorable relation at the end of three or four years. After three crops had been taken off of the plot, a sample from E showed the presence of 0.849 per cent. of potash, and before any crop had been taken off it showed 0.876 per cent. The plowing, cultivation, irrigation and cropping of three seasons gave us as their total effect this uncertain difference of 0.027 per cent. There were other samples taken, but these are the only two that coincide in the point at which they were taken. Others, however, show the same thing; sample B, for instance, at the beginning showed 1.003 per cent. of potash; after three crops had been taken, we obtained 0.999 per cent. This shows nothing, because the samples were not taken from points near enough together. The samples of the third season were not taken for the purposes of such a comparison, and merely chance to serve even in this measure. The fact that the nitrogen content in the October samples was higher than in the May samples, has but little if any dependence upon the beet crop, but was possibly very dependent upon the cultivation and irrigation. It is, we may say, a distinct crop, which increases with favorable conditions of season and soil; and our analyses simply show that there was more in the soil on October 20 than on May 13, regardless of what had been removed by the crop or dissolved out by water.

§ 53. The effect upon the organic matter in the soil did not seem to be very decided, but at the end of three seasons there was a gain, not so large, however, as I expected, the tops of two crops of beets and a heavy coating of manure having been added to one half, on alternate sections, of the plot.

§ 54. The analyses, as we ought to expect, do not show us the changes which have really taken place. This plot, for instance, has improved most wonderfully in its quality, and the analyses do not and cannot measure these improvements. It is not a question of composition, but one of conditions.

SOME RESULTS DUE TO THE PRESENCE OF FELDSPAR.

§ 55. The consideration of the mineralogical constituents of the soil renders it evident that in our case we have to deal with the mineral feldspar, and indefinite decomposition products of this mineral, mixed with decaying organic matter. The agricultural analysis of the soil will yield results which will vary with the fineness of the feldspar particles the character of the decomposition products present, with slight variations in manipulation, and with other conditions which one cannot foresee. The minor variations, for instance in the percentages of potash found, as in case of sample A, 1.495 and 1.528, or in B, 1.003 and 0.978, may arise from such causes, and not depend in any way upon cropping or cultivation.

§ 56. As the solubility of feldspar in dilute acids is a well recognized property of this whole class of minerals, the results of the mineralogical study of these samples was somewhat disconcerting, not in regard to the value of such analyses in general, but of my analyses in particular. The abundance of this mineral present, the abundance of potash soluble in dilute acid, and the impossibility of washing out all the lime, soluble in dilute hydrochloric acid in any reasonable time, led me to experiment with orthoclase, powered so fine that the whole mass would pass through a sieve with one millimeter mesh, because this is the conventional size of the particles of fine earth. Thirty-three per cent. of this was less than one quarter of a millimeter in diameter. The mechanical analyses of the soils show that 60 per cent. of the soil particles are smaller than one fourth of a millimeter in diameter. This feldspar used had been washed out of the soil and was treated just as the soil was, and the results were as follows: Potash dissolved out of the feldspar by digesting with hydrochloric acid, sp. gr. 1.115, for five days, was 0.845 per cent.; soda, 0.816 per cent.; silicic acid set free, 4.31 per cent. This simple experiment is so decisive of the fact that five days digestion with dilute hydrochloric acid, sp. gr. 1.115, will extract potash from finely divided orthoclase in considerable quantities, that further questions arise as to whether plants can use the potash present in this form, or is our analysis of such a soil wholly misleading? The following questions are also suggested, viz: To what extent does water alone act on this mineral, for that water extracts potash from it is already an established fact, and how much does carbonic acid increase its solvent action?

ACTION OF WATER AND CARBONIC ACID ON FELDSPAR.

§ 57. The perfectly fresh, finely pulverized feldspar was suspended in water, 10 grams in 300 c. c., and allowed to stand five days with frequent shaking. One hundred c. c. of this solution was filtered off, evaporated to dryness, and the residue weighed. Another portion of feldspar was treated in the same manner, except that the water was saturated with carbonic oxid.

§ 58. A like quantity of water was placed beside these and carried through as a control.

§ 59. The water dissolved from the feldspar 0.0081 gram, after deducting the amount contained in the distilled water.

§ 60. The water charged with carbonic oxid dissolved 0.0723 gram. The residue obtained in this case gave a heavy precipitate for potash with platinic chlorid, as did the water solution of the feldspar. The residue from the distilled water did not react for potash.

EXPERIMENTS WITH OATS.

§ 61. This question was carried still further, and we endeavored to determine whether the feldspar could furnish potash to plants. For this purpose the perfectly fresh mineral was used, pulverized as already described in imitation of the soil, *i. e.*, the particles varied from one millimeter in diameter to an impalpable powder. This was mixed with pure quartz sand. Bone ash was used to supply lime and phosphoric acid. The sample used contained no potash. Nitrate of lime furnished the nitrogen. Chlorin was furnished by a minute quantity of calcic chloride. Distilled water was used throughout the experiment.

The plants grew healthily in this mixture until the floors of the building were oiled and the room in which the plants were growing was shut up and became too warm; these two things together gave them a decided set back, and later a thrips, *Thrips striata*, according to Prof. Gillette, attacked the plants and did them much damage. Some of the plants, however, seeded. They were harvested, though in bad condition and very uneven in the degree of their development. The root system was well developed, the sand being filled with the roots. The weight of the tops as harvested was 198.5 grams; that of the roots as washed out was 40 grams. The tops and roots were incenerated together and yielded 5.795 per cent. of soluble and 9.803 per cent. of insoluble ash, a total of 15.598 per cent.

§ 62. Examination of the feldspar used showed the presence of 11.993 per cent. of potash, and 2.988 per cent. of soda. Phosphoric and sulfuric acids were present in very small quantities, the former equalled 0.041 per cent. and the latter 0.003 per cent. of the feldspar.

§ 63. The nitrogen in the oat hay, roots included, was 3.2543 per cent.

The ash gave the following analysis:

TABLE VI.—ANALYSIS OF OAT ASH GROWN WITH FELDSPAR.

	Per Cent
Carbon	0.172
Sand	8.135
Silicic Acid	15.737
Sulfuric Acid	4.411
Phosphoric Acid	3.982
Carbonic Acid	15.356
Chlorin	2.732
Potassic Oxid	15.959
Sodic Oxid	4.622
Calcic Oxid	21.709
Magnesic Oxid	3.906
Ferric Oxid	0.696
Aluminic Oxid	0.314
Manganic Oxid	0.163
Ignition	2.611
Sum	100.505
Oxygen Equivalent to Chlorin	0.615
Total	99.890

RESULTS SHOWN BY EXPERIMENT WITH FELDSPAR.

§ 64. This ash is very anomalous in its composition as well as in the quantity present in the plants. The plants were not evenly mature at the time of gathering and were in bad condition. The question we endeavored to investigate, however, is perfectly answered by the results, *i. e.*, the oat plant can use the finely divided feldspar as a source from which to obtain potash; for in this experiment, made under very adverse conditions, we find that the oat plants took from the feldspar 1.4417 grams of potash. The potash added in the seed has been deducted. The silicic acid appropriated by the plant indicates the decomposition of the silicate. The partially decomposed, finely comminuted feldspar is actually a part of the soil. Its deportment toward water, especially when charged with carbonic oxid, is also strongly suggestive of this conclusion.

§ 65. This fact is of very general importance, as it applies to so large a portion of our soils; it also facilitates the interpretation of our analytical data, and enhances their value a little. The mass analyses show that our soils contain from 2.24 to 2.50 per cent. of potash—the latter seems to be the rule, about 2.50 per cent. The agricultural analysis of samples from all parts of the State show a range from 0.10 to 1.50 per cent. In fifty-eight analyses of samples from different counties of the State, only five fall so low as 0.15, and very few of the rest so low as 0.25 per cent. It is evident that, so far as the results of analyses are reliable, the soil with which we have been experimenting is richer in this constituent than the average soil. This is, I believe, true of all of alkali land.

ANALYSIS OF THE ACID SOLUBLE AND INSOLUBLE PORTION OF SOIL A.

§ 66. The mineralogical composition of our soil, *i. e.*, quartz and feldspar, and the decomposition products of the latter, together with the results of our experiments with feldspar, suggest the combination of the mass analysis and agricultural analysis to give us some idea of the relation of the agricultural analysis to the actual composition of the soil. We, therefore, in order to exhibit as fully as we can the chemical composition of this soil, give the agricultural analysis of soil A, together with the analysis of the residue designated as insoluble in the agricultural analysis.

TABLE VII.—ANALYSES OF THE ACID SOLUBLE AND INSOLUBLE PORTION OF SOIL A.

	Soluble in HCl., sp. gr. 1.115, 5 days digestion. Per cent.	*Insoluble in HCl., sp. gr. 1.115, 5 days digestion. Per cent.*	
Silicic Acid	17.875	46.870	
Sulfuric Acid	0.827	None	
Carbonic Acid	1.208	......	
Chlorin	0.014	......	
Phosphoric Acid	0.112	None	
Potash	1.495	0.800	
Soda	0.624	0.560	
Lime	2.479	0.310	
Magnesia	1.649	0.170	
Ferric Oxid	4.075	0.400	
Aluminic Oxid	7.387	4.330	
Manganic Oxid	0.200	Trace	
Moisture at 100° C	3.296	......	
Ignition	5.402	......	
	46.640	53.440	
Total			100.080

DISCUSSION OF ANALYSIS.

§ 67. This analysis shows that 65 per cent. of the potash, 63 per cent. of the alumina, 90 per cent. of the oxid of iron, 27.6 per cent of the silicic acid, a very high percentage of the lime and magnesia, and the whole of the sulfuric and phosphoric acids, were removed or, as in the case of the silicic acid, rendered soluble in sodic carbonate. If the silicic acid rendered soluble by this treatment be taken as the measure, then the action of the hydrochloric acid on the soil was between six and seven times as great as it was on pure feldspar, and probably not more than one sixth of the silicic acid could come from the decomposition of this mineral. The potash dissolved out of the soil is about 75 per cent. greater than was taken into solution from the pure, fresh mineral. The relative amount of soda dissolved out of the feldspar was high compared with the amount of potash dissolved, but low when compared with the percentage of soda dissolved out of the soil. A glance at the analysis shows that, taken roughly, 50 per cent. of the soda in the soil was dissolved out, but only about 25 per cent. of it went into solution in the case of the feldspar. The relatively large amount of soda dissolved out of the feldspar by digestion with the dilute hydrochloric acid, is probably due to the fact that the feldspar used was not wholly composed of the potash feldspar, orthoclase, but may have contained an admixture of oligoclase, another feldspar, rich in soda and more readily attacked by acids. When we take up the portion of the soil soluble in water we shall see that some, as much perhaps as one third, of the soda is present in a form readily soluble in this menstruum, and in this case belongs to the "alkalis" present.

THE WATER-SOLUBLE IN THE SOIL.

§ 68. When these soils are treated with fresh portions of water, so long as they yield either chlorin or sulfuric acid to the water and the amount taken into solution is determined, we find it ranging from 0.389 per cent. to 2.550 per cent. Soil A yielded the highest amount to water, 2.55 per cent., taking the sample to a depth of ten inches, and as high as 3.93 per cent. taking the first two inches of the soil.

§ 69. In stating the analyses of the portions of different samples soluble in water, I have combined the acids and bases and give the salts alongside of the direct analytical results. The order followed in combining them will be apparent to anyone upon an inspection of an analysis. I have adopted this order and have been as uniform as possible throughout. This order is convenient and probably represents the salts present in the soil as nearly as any other which might have been adopted, but it is certainly not always correct.

§ 70. The water-soluble has been determined in one set of general samples, but has been analyzed in only one case, that of sample B, taken in 1897. The analysis is not wholly satisfactory, showing too large an excess of sodic oxid, even after using all of the silicic acid present. A large quantity of organic matter in an analysis is sometimes accompanied by an excess of soda. This analysis was made on a smaller amount of material than the analyist was accustomed to, and other conditions did not contribute either to his comfort or to the accuracy of his work. The water-soluble amounted in this instance to 0.878 per cent. of the soil.

TABLE VIII.—ANALYSIS OF THE WATER-SOLUBLE IN SAMPLE B, 1897.

	Per cent.
Silicic Acid	1.516
Sulfuric Acid	50.451
Carbonic Acid	0.140
Chlorin	1.529
Sodic Oxid	14.423
Potassic Oxid	2.517
Calcic Oxid	15.091
Magnesic Oxid	7.608
Aluminic and Ferric Oxids	0.152
Manganic Oxid (br)	not det.
Ignition	6.885
Sum	100.312
Oxygen Equivalent to Chlorin	0.344
Total	99.968

Combined.	*Per cent.*
Calcic Sulfate	36.633
Magnesic Sulfate	22.824
Potassic Sulfate	4.659
Sodic Sulfate	20.513
Sodic Chlorid	2.523
Sodic Carbonate	0.337
Sodic Silicate	3.078
Aluminic and Ferric Oxids	0.152
Manganic Oxid	not det.
Ignition	6.885
Sum	97.604
Excess of Soda	2.400
Total	100.004

§ 71. Analysis shows that the whole of the sulfuric acid in these soils is soluble in water and in hydrochloric acid. The soil analysis of B, sample taken May 13, was made on the same sample that was extracted with water and the analysis of which extract is given above. The difference when the sulfuric acid is calculated into percentage of the soil is far within the limit of the analytical errors, being only 0.045 per cent. In regard to the order in which the acids and bases have been combined, it appears that there is but little choice. The water-soluble consists essentially of sulfates. The above residue was obtained by washing the soil so long as the water with which it was digested in the cold for twenty-four hours showed any trace of sulfuric acid. The water used in the particular case given, sample B, was not measured, but it was in all of the cases to be given and ranged from 18 to 45.5 litres per 1,000 grams of the soil.

THE WATER-SOLUBLE PORTION OF THE SOIL DIFFERENT FROM THE INCRUSTATION.

§ 72. It may be well to anticipate a later discussion to the extent of stating that the water-soluble in the soil is not the same, as the "alkali" that effloresces from the soil. The salts are of the same kind, sulfates, but while the predominant soluble salt in the soil is calcic sulfate, that in the alkali which effloresces from this ground is sodic sulfate, with magnesic sulfate second in quantity, while the calcic sulfates is but little greater than the sodic chlorid.

§ 73. The analysis is not unsupported in showing a large amount of calcic sulfate to be present. I caused several boxes of the soil to be gathered and planted with beet seed. These boxes were covered with glass and left standing for some days. When they were examined again there was an abundant crop of fine acicular crystals of gypsum uniformly distributed over the surface. Inspection of the soil as it was turned up by the plow also showed this substance to be present. Its abundance suggested the possibility of this soil having sometime received a heavy dressing of gypsum, in the hope of correcting the evil of the alkali, but I could not learn that such had been the case, and the presence of the gypsum in its present quantity seems to be due to accumulation of this salt from the evaporation of the ground water.

WATER-SOLUBLE PORTION OF THE SOIL DIFFERENT FROM SALTS IN GROUND WATER.

§ 74. The salts held in solution by the ground water agree more nearly with the water soluble in the soil than those which effloresce and are considered as alkali, but even the ground waters are not solutions of the water soluble portion in the soil. They differ in two essentials, in the amount of silicic acid and also in that of potash, which they contain. The water-soluble portion of the soils being richer in these constituents, sometimes containing ten times as much of one or the other of these. The water-soluble in the soil, on the other hand, is not at all uniform in its relative content of sodic sulfate, and is oftener poor in this salt than even mediumly rich. In only two cases out of the eight following analyses does it constitute any considerable fraction of the water-soluble salts, and in these cases its presence in such large quantity, 17.7 and 27.2 per cent. of the soluble salts, is probably due to its concentration at the surface and its subsequent washing back into the soil, as the samples represented the first two inches of the soil from sections where efflorescences are always formed under favorable conditions. The fact that the water-soluble salts are richer in potash than the soil water is explicable by the facts which have been demonstrated, by the action of water on the feldspar and the property of certain compounds in the soil of exchanging lime for potash brought into contact with them through the agency of solutions, the ground water being in this manner deprived of its potash, receiving lime in exchange. The analyses of the parts of the soil classified according to the size of their grains showed an increasing percentage of potash as the grains of the respective parts became finer, until it reached its maximum in the dust and clay. The continued treatment with pure water, used in small portions at a time, yet relatively large compared with that acting upon the same amount of soil in the field, may act more energetically upon the feldspar than the soil waters do, but in considering this the presence of carbonic acid in the soil is not to be neglected, as it strongly tends to increase the solvent action of water upon this mineral.

§ 75. The analyses of the water-soluble portion of these soils show, as a rule, very much more silicic acid than is present in the residues from the ground waters. This fact, together with the higher percentage of potash which the water-soluble portions uniformly contain, suggest that the reaction itself is either primarily different or that there is a subsequent reaction between the ground water solution and the soil. The known ability of soils to remove potash from solutions seems to make it probable that such secondary reaction takes place. The more exact nature of this reaction is not known. I believe, however, that such a reaction would account very largely, if not wholly, for the accumulation of the potash in the very fine portions of the soil, among which these newly formed and highly reactive compounds are included.

THE WATER-SOLUBLE PORTION OF THE SOIL.

§ 76. The following tables exhibit the composition of the water-soluble portions of the first and second two inches of the soil. They give us an idea of the differences which exist in the salts of the different layers of the soil, but no correct idea of the distribution of the alkali, for the samples were taken on different dates.

That which has already been said in regard to the order in which the acids and bases, oxids, have been combined probably needs to be emphasized. The order adopted seems to be the most convenient one for the majority of cases, and approximates the facts in these cases, but is not always correct. Phosphoric acid, when found in these residues, has been combined with magnesia. While this may be correct, it is more probable that it was in combination with lime. Its quantity, however, is so small that no great violence is done to our knowledge or to the facts.

TABLE IX.—WATER-SOLUBLE, SOIL A, FIRST TWO INCHES.

	Per cent.
Silicic Acid	0.574
Sulfuric Acid	49.411
Phosphoric Acid	None
Carbonic Acid	0.721
Chlorin	5.557
Potassic Oxid	1.223
Sodic Oxid	14.301
Calcic Oxid	16.189
Magnesic Oxid	7.635
Aluminic and Ferric Oxids	Trace
Manganic Oxid	0.297
Ignition	5.058
Sum	100.966
Oxygen Equivalent to Chlorin	1.252
Total	99.714

Combined.	*Per cent.*
Calcic Sulfate	39.289
Magnesic Sulfate	22.924
Potassic Sulfate	2.263
Sodic Sulfate	17.728
Sodic Chlorid	9.167
Sodic Carbonate	1.737
Sodic Silicate	1.165
Aluminic and Ferric Oxids	Trace
Manganic Oxid	0.297
Ignition	5.058
Sum	99.628
Excess of Sodic Oxid	0.081
Total	99.709

The percentage of water-soluble equalled 3.93.

TABLE X.—WATER-SOLUBLE, SOIL A, SECOND TWO INCHES.

	Per cent.
Silicic Acid	1.999
Sulfuric Acid	51.740
Phosphoric Acid	0.129
Carbonic Acid	3.092
Chlorin	0.939
Potassic Oxid	1.490
Sodic Oxid	4.429
Calcic Oxid	26.617
Magnesic Oxid	7.591
Aluminic and Ferric Oxids	0.161
Manganic Oxid	0.209
Ignition	2.173
Sum	100.569
Oxygen Equivalent to Chlorin	0.212
Total	100.357

Combined.	*Per cent.*
Calcic Sulfate	64.594
Magnesic Sulfate	20.642
Magnesic Phosphate	0.229
Magnesic Carbonate	1.285
Potassic Carbonate	2.185
Sodic Carbonate	4.157
Sodic Chlorid	1.549
Sodic Silicate	2.312
Aluminic and Ferric Oxids	0.161
Manganic Oxid	0.209
Ignition	2.173
Sum	99.496
Excess of Silicic Acid	0.861
Total	100.357

The percentage of water-soluble equalled 2.55.

TABLE XI.—WATER-SOLUBLE, SOIL B, FIRST TWO INCHES.

	Per cent.
Silicic Acid	1.348
Sulfuric Acid	47.649
Phosphoric Acid	None
Carbonic Acid	1.311
Chlorin	4.008
Potassic Oxid	2.048
Sodic Oxid	18.632
Calcic Oxid	13.900
Magnesic Oxid	5.365
Aluminic and Ferric Oxids	0.113
Manganic Oxid	0.266
Ignition	6.281
Sum	100.921
Oxygen Equivalent to Chlorin	0.903
Total	100.018

Combined.	*Per cent.*
Calcic Sulfate	33.733
Magnesic Sulfate	16.108
Potassic Sulfate	3.789
Sodic Sulfate	27.229
Sodic Chlorid	6.612
Sodic Carbonate	3.158
Sodic Silicate	2.714
Aluminic and Ferric Oxids	0.113
Manganic Oxid	0.266
Ignition	6.281
Sum	100.003
Excess of Silicic Acid	0.012
Total	100.015

The percentage of the water-soluble equalled 0.75,

TABLE XII.—WATER-SOLUBLE, SOIL B, SECOND TWO INCHES.

	Per cent.
Silicic Acid	6.768
Sulfuric Acid	40.378
Phosphoric Acid	0.407
Carbonic Acid	4.738
Chlorin	2.821
Potassic Oxid	2.042
Sodic Oxid	9.826
Calcic Oxid	19.165
Magnesic Oxid	6.954
Aluminic and Ferric Oxids	0.390
Manganic Oxid	0.760
Ignition	[6.387]
Sum	100.636
Oxygen Equivalent to Chlorin.	0.636
Total	100.000

Combined.	*Per cent.*
Calcic Sulfate	46.510
Magnesic Sulfate	16.939
Magnesic Phosphate	0.751
Magnesic Chlorid	2.296
Potassic Sulfate	3.778
Sodic Chlorid	1.825
Sodic Carbonate	11.414
Sodic Silicate	4.295
Aluminic and Ferric Oxids	0.390
Manganic Oxid	0.760
Ignition	[6.387]
Sum	95.345
Excess of Silicic Acid	4.654
Total	99.999

The percentage of water-soluble equalled 0.389.

TABLE XIII.—WATER-SOLUBLE, SOIL C, FIRST TWO INCHES.

	Per cent.
Silicic Acid	1.084
Sulfuric Acid	48.826
Phosphoric Acid	None
Carbonic Acid	0.385
Chlorin	4.321
Potassic Oxid	1.338
Sodic Oxid	10.190
Calcic Oxid	17.826
Magnesic Oxid	8.080
Aluminic and Ferric Oxids	———
Manganic Oxid	0.342
Ignition	8.281
Sum	100.673
Oxygen Equivalent to Chlorin.	0.973
Total	99.700

Combined.	*Per cent.*
Calcic Sulfate	43.260
Magnesic Sulfate	24.260
Potassic Sulfate	2.475
Sodic Sulfate	10.789
Sodic Chlorid	7.128
Sodic Carbonate	0.928
Sodic Silicate	2.202
Aluminic and Ferric Oxids	–
Manganic Oxid	0.342
Ignition	8.281
Sum	99.665
Excess of Sodic Oxid	0.031
Total	99.696

The percentage of water-soluble equalled 2.0544.

TABLE XIV.—WATER-SOLUBLE, SOIL C, SECOND TWO INCHES.

	Per cent.
Silicic Acid	9.095
Sulfuric Acid	34.832
Phosphoric Acid	0.522
Carbonic Acid	5.558
Chlorin	2.663
Potassic Oxid	3.252
Sodic Oxid	8.778
Calcic Oxid	20.981
Magnesic Oxid	7.131
Aluminic and Ferric Oxids	0.878
Manganic Oxid	0.245
Ignition	6.996
Sum	100.951
Oxygen Equivalent to Chlorin.	0.600
Total	100.351

Combined.	*Per cent.*
Calcic Sulfate	50.917
Magnesic Sulfate	3.197
Potassic Sulfate	6.016
Magnesic Phosphate	0.963
Magnesic Chlorid	3.565
Magnesic Carbonate	8.646
Sodic Carbonate	2.490
Sodic Silicate	14.418
Aluminic and Ferric Oxids	0.898
Manganic Oxid	0.245
Ignition	6.996
Sum	98.351
Excess of Silicic Acid	1.998
Total	100.349

The percentage of water-soluble equalled 0.813.

TABLE XV.—WATER-SOLUBLE, SOIL D, FIRST TWO INCHES.

	Per cent.
Silicic Acid	2.261
Sulfuric Acid	48.354
Phosphoric Acid	——
Carbonic Acid	0.768
Chlorin	2.670
Potassic Oxid	3.792
Sodic Oxid	5.604
Calcic Oxid	22.084
Magnesic Oxid	5.486
Aluminic and Ferric Oxids	0.011
Manganic Oxid	0.662
Ignition	8.789
Sum	100.477
Oxygen Equivalent to Chlorin	0.602
Total	99.875

Combined.	*Per cent.*
Calcic Sulfate	53.593
Magnesic Sulfate	16.473
Potassic Sulfate	7.015
Sodic Sulfate	4.682
Sodic Chlorid	4.405
Sodic Carbonate	1.841
Sodic Silicate	0.282
Aluminic and Ferric Oxids	0.011
Manganic Oxid	0.662
Ignition	8.789
Sum	97.753
Excess of Silicic Acid	2.122
Total	99.875

The percentage of water-soluble equalled 0.800.

TABLE XVI.—WATER-SOLUBLE, SOIL D, SECOND TWO INCHES.

	Per cent.
Silicic Acid	3.354
Sulfuric Acid	44.392
Phosphoric Acid	Trace
Carbonic Acid	5.738
Chlorin	0.632
Potassic Oxid	1.310
Sodic Oxid	5.594
Calcic Oxid	27.656
Magnesic Oxid	5.895
Aluminic and Ferric Oxids	0.443
Manganic Oxid	0.227
Ignition	4.919
Sum	100.160
Oxygen Equivalent to Chlorin	0.142
Total	100.018

Combined.	*Per cent.*
Calcic Sulfate	67.116
Magnesic Sulfate	7.397
Magnesic Carbonate	7.202
Potassic Carbonate	1.922
Sodic Chlorid	1.042
Sodic Carbonate	3.265
Sodic Silicate	6.164
Aluminic and Ferric Oxids	0.443
Manganic Oxid	0.227
Ignition	4.919
Sum	99.697
Excess of Silicic Acid	0.321
Total	100.018

The percentage of water-soluble equalled 0.864.

§ 77. The quantity of water used in extracting the soils ranged from 18 to 45.5 litres, and the time of extracting from 14 to 68 days. It was thought that the long time and large quantities of water used might have made some differences in the results which a quick extraction would make evident, but two experiments made on quantities of 10 and 150 grams each failed to show anything of sufficient interest to lead us to prosecute the work. The silicic acid, sulfuric acid, lime and magnesia extracted from 10 grams in from 30 to 45 minutes differed but a few hundredths of a per cent., when calculated on the soil used, from the figures obtained in the more carefully prepared extract. In the experiment with 150 grams the alkalies and magnesia with the silicic acid went into solution more readily than the last portions of lime and sulfuric acid. This is entirely in accordance with the properties of these sulfates, but tends to show that the silicic acid is present as easily soluble silicates, probably as an alkaline silicate.

THE DISTRIBUTION OF THE SALTS IN THE FIRST AND SECOND TWO INCHES OF THE SOIL.

§ 78. I regret exceedingly that these sets of samples were not taken on the same date, but the record shows them to have been taken nearly a year apart. The set representing the first two inches having been taken in June, 1899, and that representing the second two inches in May, 1900. The two series are not comparable, except in a very general way, but the members of the series are perfectly so among themselves. The larger features of their differences are probably thoroughly representative of the facts, and show that the first two inches of the soil contains a somewhat higher percentage of soluble salts than the second two inches; that the sodic and magnesic sulfates constitute a materially higher percentage of these salts than they do in the second two inches; that the first two yielded less silicic acid than the second two inches; that the potassic oxid soluble in water is very irregular, but is present in both series in significant quantities; that there is no soluble phosphoric acid in the series representing the first two inches, and is present throughout that representing the second two inches. I was at first inclined to think that this was an error, but it is not. The plots from which these samples were taken had been cultivated, but had not received any manure.

§ 79. The uniformity of the presence of phosphoric acid as well as the significant quantity in which it is present is a matter of some surprise. Phosphoric acid is sometimes present in drainage waters in appreciable quantities, but usually only in traces. I have repeatedly tested the residues obtained by evaporating the ground waters of this plot for phosphoric acid, but I have not been able to prove the presence of a trace of it.

In regard to the silicic acid, a trifling amount of it might have been derived from the glass by solution, aided by the repeated shaking of the mass in the bottles, but the solutions made quickly, using freshly distilled water, gave the same results.

THE ALKALI.

§ 80. The efflorescence which forms on the surface of the soil is popularly called alkali, and is of common occurrence in many places in all parts of the State. It is not my intention to go into this subject at present, except as it pertains to this particular soil.

§ 81. There are small areas almost everywhere, especially in irrigated sections, which at times are white with a crop of these salts. They are not sightly from the agriculturists' standpoint, but are much less injurious in themselves than the conditions which admit of their formation. We have seen that among the salts present in the soil are sodic, magnesic and calcic sulfates, and sodic chlorid. This is not the order, according to the respective quantities in which they occur in the soil, but in the incrustation formed on the top of the soil. There is an order, seemingly, in which the salts come to the surface or are brought there by capillary action, the sodic and magnesic sulfates forming some 80 per cent. of the total salts brought to the surface and deposited from the solutions in this soil. The character of these deposits, these alkalies, will vary in different localities. This variation undoubtedly depends upon the nature of the solutions in the soil, *i. e.*, the salts present in the ground water, rather than upon the nature of the water extract which we may be able to make of the soil. The salts present in the ground waters are intermediate in the order of their relative quantities between the water-soluble in the soil and the alkali incrustation, but are of the same kind. The analyses already given of the water-soluble salts, and those given in the following tables, represent the extremes for our soil.

TABLE XVII.—ANALYSIS OF ALKALI FROM SOIL A, JUNE 23, 1897.

	Per cent.
Silicic Acid	0.282
Sulfuric Acid	53.637
Carbonic Acid	0.513
Chlorin	2.103
Potassic Oxid	0.520
Sodic Oxid	28.259
Calcic Oxid	3.097
Magnesic Oxid	9.136
Aluminic and Ferric Oxids	0.090
Manganic Oxid	0.117
Ignition	3.112
Sum	100.596
Oxygen Equivalent to Chlorin	0.474
Total	100.122

Combined.	*Per cent.*
Calcic Sulfate	7.518
Magnesic Sulfate	27.408
Potassic Sulfate	0.963
Sodic Sulfate	53.682
Sodic Chlorid	3.470
Sodic Carbonate	1.237
Sodic Silicate	0.572
Aluminic and Ferric Oxids	0.090
Manganic Oxid	0.117
Ignition	3.112
Sum	98.168
Excess of Sodic Oxid	1.954
Total	100.123

TABLE XVIII.—ANALYSIS OF ALKALI FROM SOIL A, JULY 5, 1897.

	Per cent.
Silicic Acid	0.129
Sulfuric Acid	52.127
Carbonic Acid	0.488
Chlorin	5.574
Potassic Oxid	0.315
Sodic Oxid	29.785
Calcic Oxid	1.369
Magnesic Oxid	9.684
Aluminic and Ferric Oxids	0.111
Manganic Oxid	0.101
Ignition	1.571
Sum	101.254
Oxygen Equivalent to Chlorin	1.256
Total	99.998

Combined.	*Per cent.*
Calcic Sulfate	3.323
Magnesic Sulfate	29.059
Potassic Sulfate	0.580
Sodic Sulfate	54.217
Sodic Chlorid	9.198
Sodic Carbonate	1.177
Sodic Silicate	0.262
Aluminic and Ferric Oxids	0.111
Manganic Oxid	0.101
Ignition	1.571
Sum	99.601
Excess of Sodic Oxid	0.396
Total	99.997

These analyses are sufficient to show how very different the percentages of the various salts are in the alkali, and in that portion of the soil which is soluble in water. The latter contains a relatively small amount of sodic sulfate, the former a large amount. The sodic sulfate, together with the magnesic sulfate, is concentrated in the alkali.

FORMATION OF ALKALI INCRUSTATIONS EXPLAINED.

§ 82. The formation of these incrustations effects a rough separation of the markedly efflorescent salts, sodic and magnesic sulfates, from the permanent calcic sulfate. Ordinary salt, sodic chlorid, which is present, is also concentrated in the alkali, but not nearly to a like extent, as those already named. The highest figure obtained for the sodic sulfate in any sample of the water-soluble is in the first two inches of soil designated as B, in which it amounts to 27 per cent. In the alkalies it is practically 54 per cent., or twice as much. The highest percentage of magnesic sulfate in the water-soluble is 24 per cent., found in the first two inches of the soil C, while the average for the two samples of alkali is 28 per cent. The decrease of the calcic sulfate from the amount present in the water-soluble to that present in the alkali, is more marked than the increase in the sodic sulfate in the alkali given above. The minimum of the calcic salt found in the water-soluble is 34 per cent., the maximum 67 per cent., while the amount in these alkalies are 7.5 and 3.3 per cent., respectively. These relations show us the deportment of these salts when present in the soil solutions, whose surfaces are brought up and exposed to the evaporating influences of the atmosphere and sun. It is quite a different matter when the free surface of the water in lakes and ponds is presented to the same. In this case there is simply an evaporation to dryness, and the residue represents the salts held in solution by the waters, whereas, in the efflorescing alkalies we have the chemical and physical properties of these salts playing an important, if not the most important part. The sodic sulfate is predominant in the alkali, not because there is more of it in solution in the soil, but because it is separated more readily at the surface of the solution than the calcic sulfate. Magnesic sulfate also passes out of the solution more readily than the calcic sulfate, not because there is more of it in the solution, but because its chemical properties are different and its department toward the dissolving water and the soil particles is different. This subject will be discussed more fully and facts given, when we consider the soil waters. I wish, however, to emphasize the fact that the efflorescent alkalies are quite different from the residues left by evaporating bodies of water; such residues seem to be intermediate between those obtained by evaporating ground waters to dryness and the salt brought to the surface by capillarity and separated as efflorescences on the ground.

ALKALINITY OF THIS SOIL.

§ 83. Several attempts were made to estimate the alkalinity of the soil, but without satisfactory results. It was simply determined that they all reacted with cochineal and a properly prepared litmus solution, showing an alkaline reaction. This reaction was more decided when the moistened soil was placed on litmus paper and allowed to remain there for a few minutes. While the samples were all alkaline, none of them were strongly enough so to permit of its determination by a one hundredth normal acid solution. I was not at all satisfied as to the cause of the alkaline reaction, for the samples of soil which had been washed free from the sulfates still showed the reaction when placed on litmus paper.

FREE AMMONIA IN THE SOIL.

§ 84. Though aware of the unsatisfactory results obtained in endeavors to make this determination, I thought that the peculiar character of our soil and the very frequent occurrence of similar soils in Colorado, would justify me in making the attempt.

§ 85. The samples were taken in their fresh condition, magnesic oxid added, and after standing a short time, an hour or so, were subjected to distillation. Ammonia-free-water was used throughout this experiment. The disillate at first was rich in ammonia, and while it became poorer and poorer, it continued to give a decided reaction with Nessler's reagent for ten days, when the experiment was stopped. It the case of sample No. 3, the whole of the ammonia was given off in four days. Three samples, Nos. 1 and 3 from plots which had not received any manure, and No. 2 from a manured plot, were subjected to distillation. The results obtained were:

No. 1. Ammonia in dry soil......0.00962 per cent.
No. 2. Ammonia in dry soil......0.00765 per cent.
No. 3. Ammonia in dry soil......0.00367 per cent.

The persistency with which the ammonia continued to come over, showed that it was probably being formed during the distillation and was not originally present as free ammonia, or as ready formed ammonia salts. In order to obtain as much evidence as possible regarding the occurrence of free ammonia in this soil, a fresh portion of sample No. 1, was taken and subjected to distillation with the addition of ammonia-free-water alone. The distillation was, as in the previous cases, permitted to proceed very slowly until two and a half litres of distillate were collected. There were still traces of ammonia coming over. The ammonia obtained equalled 0.00211 per cent. of the dry soil. The comparatively abundant evolution of ammonia in the early stages of the distillation with magnesic oxid, and the decided quantity yielded upon distillation with pure water, prove the presence of both ammonical salts and free ammonia in this soil, and the samples show that the amount of them was not dependent upon the manure added to the soil one year previous to the time that they were taken. I interpret the formation of ammonia salts and free ammonia in this soil, as indicating unfavorable biological conditions. The sample numbered 1 in this series is from that section of the plot which I have described elsewhere as a paludal soil. Its reclamation was not at this time complete. I may be mistaken in this view, but I believe it to be the explanation, and that the larger quantity of ammonical salts and free ammonia were due to the greater resistance this soil had presented to the ameliorating effects of cultivation.

§ 86. The examinations made of the ground waters, not only strengthen but extend this view. The ground waters show not only ammonia, but large amounts of nitrites, indicating a probable reduction of nitrates in some zone of the soil. The presence of ammonia in the upper portions of the soil is probably the most suspicious of all of our facts, as it seems to indicate a slow oxidation, and brings the zone of denitrification to the very surface.

VOLATILE ACIDS IN THE SOIL.

§ 87. The conditions obtaining in this soil being such that acid fermentations might take place, an attempt was made to determine the quantity of such acids, if any were present. Two samples of soils were examined for volatile acids; one had received manure and the other had not. The sample which had received manure yielded volatile acids, other than hydrochloric, equal to 1.3 c. c. of one hundredth normal soda solution. The one which had not received manure yielded volatile acids corresponding to 10.30 c. c. of the soda solution. These are exceedingly minute quantities and their only possible value is a qualitative one, suggesting that one of the effects of the manure added was to lessen the amount of these acids in the soil by modifying the character of the changes taking place within the soil.

NITROGEN AND NITRATES IN THE SOIL.

§ 88. Less has been done with this subject than appears desirable. My excuse is, that I have tried to study this subject in connection with the ground water, rather than with the soil, because there is no material and permanent accumulation of the nitrates in the soil, where it receives water enough, either as rainfall or as irrigation, to remove them more or less nearly at the same rate at which they are formed in the soil.

§ 89. The samples in which the total nitrogen was determined are comparable in a general way only, owing to the fact that the soil is very varying, and that the samples were not taken from the same places in the plot. This variability in the soil is shown with greatest certainty in the amounts of potash in the different samples, these amounts varying much more than can justly be attributed to analytical errors. The series of samples in which I have made such determinations may serve as a measure of the changes which the cultivation of this soil had effected in the time elapsing between the taking of the samples. The nitrogen determinations for the year 1897 have not been taken from the table of "Analyses of Soils, General Samples," but were made on special samples. The samples for 1899 are sufficiently described as manured and not manured, the manure having been applied in 1898, one year before the samples were taken.

TABLE XIX.—TOTAL NITROGEN IN THE SOIL.

1897.	*Per cent.*	*1899.*	*Per cent.*
Sample A	0.0920	No. 3, not manured	0.0935
Sample B	0.0945	No. 3, manured	1.1700
Sample C	0.0829	No. 2, not manured	0.1355
Sample D	0.0819	No. 2, manured	0.1295
Sample E	0.1382	No. 1, not manured	0.1316
Sample F*	0.1081	No. 1, manured	0.1312

§ 90. The samples have been arranged in this table so that those representing the same general sections stand as nearly opposite each other as possible, but they are not identical.

§ 91. The samples were taken in the same month of the year, and, so far as seasonal influences upon the nitrogen content are concerned, are comparable. The water received in 1899 was greater than in 1897. The general effect indicated is an increase of nitrogen for the whole plot.

§ 92. No effort was made to follow the formation of nitrates in the soil from day to day, or from week to week, but the amount of this substance eliminated in the ground water was determined weekly for the seasons of 1897-98-99 and 1900. The nitrates have been determined in but a single series of soil samples, representing the first and second two inches of the soils which had received no manure. The water-soluble, analyses of which have already been given, was determined in the same set of samples. The results are given in parts per million of the air dried soil.

---

* Sample F is the subsoil.

TABLE XX.—NITRATES IN THE SOIL.

	Water-Soluble.	*Nitrogen.*	*Nitric Acid.*	*Potassic Nitrate.*
A—First two inches....	39,314.0	7.075	31.746	50.930
B—First two inches....	7,513.0	36.062	161.814	259.598
C—First two inches....	20,544.0	12.326	55.308	88.730
D—First two inches....	8,000.0	19.200	86.152	138.214
A—Second two inches..	......	Trace	Trace	......
B—Second two inches..	3,890.0	0.389	1.745	2.800
C—Second two inches..	8,130.0	1.626	7.296	11.705
D—Second two inches..	8,640.0	2.073	9.306	14.929

§ 93. This indicates that, at the time these samples were taken, a very small percentage of the total nitrogen existed in the soil in the form of nitrates, and that the first two inches of this soil was at the time very much richer in nitrates than the second, also that different portions of the plot contained very different amounts of these salts.

DO SOIL SAMPLES ABSORB NITROGEN ON KEEPING?

§ 94. The most of the nitrogen determinations given in this bulletin were made on fresh samples, but occasionally we found it desirable to check a determination on an old sample, one that had been in the sample room for one or more years. The samples are kept with ordinary care, but not always sealed. The samples which suggested this question had been carefully stoppered and kept two years, but had not been sealed. In order to answer this question, a sample was taken and the nitrogen determined in duplicate. The remaining portion of the sample was dried as usual, bottled, corked and kept in the laboratory for fifteen months and the nitrogen redetermined in duplicate. The average of the first two determinations was 0.1058 per cent., that of the last two 0.1066 per cent. The difference is 0.0008 per cent., which is possibly to be attributed to analytical differences, rather than to the absorption of nitrogen in any form from the atmosphere of the laboratory. If, however, we accept the analytical results as correct, they show that the sample gained a quantity of nitrogen, due to increase of microorganisms, corresponding to 28 pounds per acre, taken to a depth of one foot.

HUMUS IN THE SOIL.

§ 95. The humus in this soil is not especially low, as is the rule with our soils in general. The earlier determinations being slightly under one per cent., while the later ones average about one and one tenth per cent., a gain of about three tenths of one per cent. I thought that the physical condition of the soil and the presence of so large an amount of soluble salts would probably modify the character of the humus to a sufficient extent to cause some marked changes in properties or composition sufficient to justify its analysis. This was not found to be the case. The humus is very much like other humus, and is much more like the humus of the Southern and Eastern States, as given by Hilgard, than the humus of the prairie soils of the arid regions, which are supposed to be rich in nitrogen, carrying, according to Hilgard and Jaffa, as high as 18.5 per cent.

§ 96. A quantity of soil was treated as usual for the preparation of humus, extracted with ammonia and the solution precipitated by acidulation with hydrochloric acid. The precipitated humus was washed and dried. It formed a black mass with a strong vitreous lustre and conchoidal fracture. Its reaction was acid with litmus. The precipitated humic acids alone were preserved. The portion soluble in dilute hydrochloric acid and water was neglected, as we thought to obtain the whole of the soluble humic substances by evaporating the ammoniacal soil extract to dryness and examining it, but it was found to contain so much ammonic chlorid that the results were unreliable. It seems to be a difficult matter to wholly avoid this error when handling larger quantities of soil. The results obtained indicate a very much higher percentage of ash in the ammoniacal extract than in the precipitated humus, but on the other hand a materially lower percentage of carbon.

The elementary analysis of the precipitated humus resulted as follows:

TABLE XXI.—ELEMENTARY ANALYSIS OF PRECIPITATED HUMUS.

	Per Cent.	*Per Cent.*
Carbon	41.787	45.727
Hydrogen	4.804	5.267
Nitrogen	5.536	6.051
Oxygen	39.254	42.955
Ash	8.619	......
Total	100.000	100.000

I have deducted the ash and given the carbon, hydrogen, etc., in parts per hundred to make their quantitative relation more evident, not to indicate that they form a definite compound. It is noticeable that the percentages throughout are almost identical with those given for humocienic acid obtained by precipitation as the lead salt from a solution prepared from a sample of Russian black earth.

HUMUS AS A SOLVENT.

§ 97. The ash probably forms an integral part of this precipitated humus, that is the humus carried this inorganic part in such a state of solution that it retained it when thrown down by the dilute hydrochloric acid. The total sulfur present equalled 0.44 per cent. of the precipitated humus, equal to one and one tenth per cent. of sulfuric acid (anhydrid). The potash taken into solution by the four per cent. ammonia equalled 0.385 per cent. of the humus dissolved. The ash obtained from the filtered ammoniacal solution, by evaporation and incineration, is rich in lime, that from the precipitated humus contains only a very slight trace of it. The ash from both, the ammoniacal solution of humus and the humus precipitated from it, is relatively rich in phosphoric acid.

§ 98. We made an attempt to determine the ash carried into solution by the extraction with ammonia. The results were not satisfactory. The solutions were all filtered repeatedly, but owing to the intense color of the solutions we could not feel assured that some of the variations in our results might not have been due to a turbidity in the solution. Our results indicated roughly one per cent.; this is probably too high, but it suffices to show that a very considerable portion of the whole mass of soil is soluble in this ammoniacal humus solution.

§ 99. Authors have insisted upon the value of humus as a solvent for the inorganic constituents of plant food in the soil. Free ammonia and ammonic salts are probably present in small quantities, as previously shown, and we have in the humus, dissolved out of the soil by a dilute ammonia solution, phosphoric acid, sulfuric acid, potash, lime, iron and an abundance of silicic acid, which are not only food for the cultivated plants, but also for the micro-organisms which we believe effect the change of the nitrogen in the humus into nitric acid, respectively into nitrates, rendering it also available food for the plants. This seems an important function to attribute to humus, amounting in but few instances to more than one and a half per cent. of the soil, and yet it is justified. Our method of treatment or extraction does not faithfully represent the soil conditions, and therefore exaggerates its importance. This is probably less true than it appears to be, for the acids and bases forming the salts of the soil are not in the fixed and quiescent condition in which we usually think of them. On the contrary, there are certainly as many, and possibly more, changes going on than there would be in a mixture of the same salts in simple aqueous solution, and we know that there would be many. We have seen that there is probably free ammonia and ammoniacal salts in the soil, both of which aid the humus in its action by favoring its solution. The phosphoric acid extracted with the humus was determined at the beginning of the experiment and again after three crops had been grown on the plot. The results are shown in the following tables of analyses.

SOME RESULTS OF THREE SEASONS' WORK.

§ 100. The plot had received but little cultivation before I began my experimentation with it, and was in such bad condition that a part of it was so good as useless for any agricultural purpose. That this was not due to any lack of plant food is indicated by the chemical analyses and also by its subsequent deportment under cultivation.

§ 101. The analyses of the samples taken at the beginning of the experiment may be summarized as follows:

TABLE XXII.—ANALYSES OF SOIL AT BEGINNING OF EXPERIMENT.

SOIL, SAMPLES TAKEN 1897.		Nitrogen. Per Cent.	Potash. Per Cent.	Phosphoric Acid. Per Cent.	Humus. Per Cent.	Phosphoric Acid in Humus. Calculated on Soil. Per Cent.
A....	Spring	0.0937	1.495	0.112	0.815	0.0384
	Fall	0.0938	1.528	0.086	0.712	0.0333
B....	Spring	.0.0882	1.003	0.064	0.945	0.0205
	Fall	0.1022	0.978	0.128	0.910	0.0345
C....	Spring	0.0882	1.443	0.081	0.736	0.0296
	Fall	0.1015	1.457	0.115	0.740	0.0393
D....	Spring	0.0959	1.443	0.061	0.660	0.0288
	Fall	0.1083	1.372	0.099	0.846	0.0294
E....	Spring	0.1295	0.876	0.070	0.808	0.0486
	Fall	0.1191	0.936	0.138	1.030	0.0537
F*...	Spring	0.1040	0.854	0.054	0.574	0.0384
	Fall	0.0996	0.750	0.122	0.502	0.0334

* F is a subsoil corresponding to soil E.

§ 102. The samples, "Spring" and "Fall," represented in the above table were not taken by the same person, nor were they taken so nearly from the same spot that they can be considered as duplicates, still the agreement throughout is as close as can be expected, except in the case of the phosphoric acid. The analyses were made by the same person, so that the personal equation is eliminated, but the differences in the phosphoric acid are great, varying from 60 to 126 per cent. of the lower percentage found. It is possible that this variation between the spring and fall samples may be in the sampling, either in the field or in the laboratory, but every care was exercised to get this entirely correct. Duplicate analyses were made on most of these samples and good agreement was obtained, so that after making every allowance for errors in the analytical work and in the sampling there is a difference in favor of the samples taken in the fall. That the whole of the phosphoric acid present went into solution, there can be no doubt. We have examined the insoluble residues obtained from these digestions and have been unable to find any phosphoric acid. I have no explanation to offer.

The only remnants of the crop which could have been present in the fall samples were the fine roots which we could not remove, and such leaves as might have fallen and decayed during the season, all others were removed from the field. With these explanations, we must abide by our results even if there is a difference of 126 per cent. in the amount of phosphoric acid in practically the same soil, sampled in the spring and fall of the same year.

§ 103. It is not a matter for surprise that samples taken three years later, after the refuse of several crops and a liberal amount of manure had been incorporated with the soil, should show differences, indicating an improvement in the soil. The subsoiling, deep plowings, and the continued cultivation, together with the fact that the ground was left thrown up into rather high and rough ridges during the winters, exposing the deeper portions of the soil to the effects of the winter seasons—all tend to mix and improve the soil; but there is only one thing which has added any mineral matter to the soil, that is the application of the manure, which was made to alternate sections of the plot, as has been stated elsewhere.

Samples taken in the autumn of 1899 gave the following results:

TABLE XXIII.—ANALYSES OF SAMPLES OF SOIL TAKEN IN 1899.

NUMBER OF PLOT.		Nitrogen. Per Cent.	Potash. Per Cent.	Phosphoric Acid. Per Cent.	Humus. Per Cent.	Phosphoric Acid in Humus. Calculated on Soil. Per Cent.
3	Manured	0.1152	1.1700	0.1343	1.1000	0.0767
	Not manured	0.0935	0.9990	0.1215	1.0500	0.0735
2	Manured	0.1295	1.3030	0.1567	1.0600	0.0607
	Not manured	0.1355	1.0994	0.1695	1.2550	0.0255
1	Manured	0.1312	0.9540	0.1215	1.2800	Lost
	Not manured	0.1316	0.8493	0.1727	1.0900	0.0670

These numbers, 3, 2 and 1, manured and not manured, do not correspond exactly to A, B, etc. The five sections A, B, C, D and E, were made into six sections to study the effects of manure upon the crop and soil. No. 3 manured corresponds to part of A, while No. 3 not manured corresponds partly to A and partly to B, and so on. The plot was 600 feet long, and the manured and not manured sections were each 100 feet long. The samples were taken from the middle of the respective plots at the end of the season and nine months after the application of the manure.

The results indicate an increase in the humus present, but the analyses do not show conclusively that this was due to the application of manure, though the indications are that it had a perceptible effect. The results in regard to the phosphoric acid are difficult to bring into harmony with the facts as recorded or with one another, but the general results are in the same direction as those obtained from the samples taken in the autumn of 1897, namely, an increase. The increase in the nitrogen is not very pronounced, but seemingly quite general. The most marked result, however, recorded in the last table is the increased extent to which the phosphoric acid present in the soil can be extracted with the ammoniacal solution of the humus. It is entirely out of the question to attribute this large percentage of the phosphoric acid found in the humus solution to any turbidity which, owing to the dark color of the solution, might have passed through the filter and escaped detection. I regret that I did not examine the hydrochloric acid with which the soil was washed to determine how much phosphoric acid was removed by it. An inspection of the table shows that from 14 to 60 per cent. of the total soluble phosphoric acid was found in the ammoniacal humus solution.

§ 104. If we recall the amount of nitrogen found in the precipitated humus, about 5.5 per cent., we will see that the observation made on the phosphoric acid is also applicable to the nitrogen, only in a different degree. The humus contained from 14 to 60 per cent. of the former, but 40 or more per cent. of the latter.

The manure which was applied to this soil was analyzed, the results, together with some observations on its effects, etc., are given in Bulletin 58, pp. 13, 18, 36, *et seq.*

The sulfuric acid was determined in the samples taken in 1899, giving for No. 3, manured and not manured, 1.320 per cent. and 0.350 per cent.; for No 2, 0.333 and 0.633 per cent.; for No. 1, 0.683 and 0.314 per cent. If we compute this into sodic sulfate, as we have done elsewhere, it will be seen that the sulfates have either been removed or carried down into the soil beyond the reach of our sample, and either is an improvement.

§ 105. The results of this experiment are readily recognizable in the improved condition of the soil. The figures given as representing the composition of the samples taken in the autumn of 1899, may be right or wrong, but the improvement in the soil is much more pronounced than any analytical results can indicate, and after all of our seeking after facts and explanations, we are fully satisfied that there is much in the aggregate effect, whether it has been produced by moisture, æration, frost or sunshine, that has escaped our analysis, and while it is perfectly patent, it is not subject to clear and definite formulation. The application of manure produced some effects which we have noted at some length in Bulletin 58, especially those upon the crop, and we have incidentally stated that the salts in the ground water were influenced by the same, but we have acknowledged an effect, by stating that it improved the mechanical condition of the soil, which we fail to explain, because we do not recognize in what this actually consists. There are certain bold features in this improved condition which we readily perceive, but we cannot tell to what agents this improvement is to be attributed, nor the degree in which any particular agent has participated.

ANALYSES OF SOME COLORADO SOILS.

§ 106. I append a table of hitherto unpublished analyses of some soils from this State. These analyses were made some years ago by Mr. Chas. Ryan, under the direction of Dr. D. O'Brine, my predecessor.

There is no description or data of any kind given with the analyses. The record does not even show the locality from which the samples came more specifically than somewhere within a Colorado county. As a matter of fairness, I feel it due to Dr. O'Brine to state that, according to my information, he is not at fault for this, but that, owing to a bit of mistaken economy, he was not able to take the samples as he wished to, and did not obtain the data, whose lack detracts so materially from an otherwise commendable piece of work.

§ 107. The history of some of the samples is know, but so far as the record shows, there is nothing to indicate whether the samples are of virgin or highly cultivated garden soils, whether they are samples taken from excavations in city streets, or have been scratched from between the rocks of the hills.

The presumption was, and ought still to hold, in spite of the few exceptions of which we have definite knowledge, that the samples fairly represent the virgin soils of the State. If they do not, it is to be regretted that this work has been done to such little purpose.

TABLE XXIV.—ANALYSES OF SOME COLORADO SOILS.

COUNTY.	Insoluble.	Silicic Acid, Sol.	Sulfuric Acid.	Carbonic Acid.	Chlorin.	Phosphoric Acid.	Potash.	Soda.	Lime.	Magnesia.	Ferric Oxid.	Aluminic Oxid.	Manganic Oxid.	Moisture.	Ignition.	Total.	Nitrogen.
Arapahoe	69.79	7.05	0.05	0.05	0.07	0.08	0.16	0.54	3.25	0.03	2.69	10.03	....	2.16	3.98	99.93	0.10
Archuleta	72.48	4.05	0.13	0.54	0.04	0.20	0.26	0.35	1.31	0.08	2.29	9.90	....	2.79	5.45	100.56	0.19
Baca	63.00	7.44	Tr.	1.28	0.04	0.05	0.22	0.20	2.51	0.66	2.35	7.48	....	5.00	9.25	99.48	0.16
Boulder	70.68	3.90	0.14	....	0.06	0.16	0.75	1.97	0.41	0.06	6.38	7.79	....	3.10	4.68	99.99	0.20
Boulder	67.50	10.00	0.22	0.35	....	0.14	0.45	0.95	2.25	0.85	2.04	6.96	0.09	....	8.28	100.09	0.11
Chaffee	69.01	5.06	0.39	....	0.02	0.05	0.17	0.95	2.60	1.14	1.57	10.31	....	2.33	6.33	99.95	0.26
Cheyenne	72.57	6.14	0.63	....	0.03	0.04	0.30	0.25	1.02	0.56	0.22	8.88	...	2.80	7.16	100.60	0.13
Clear Creek...	65.50	5.00	0.10	...	0.04	0.02	1.69	1.34	0.96	0.75	7.08	8.32	....	3.14	6.17	100.11	0.27
Conejos	70.24	.....	0.02	0.38	0.03	0.06	0.68	1.98	1.46	0.44	2.94	5.07	....	3.50	13.10	99.90	0.23
Costilla	78.50	1.27	0.39	0.01	0.06	0.07	0.26	2.31	1.65	0.14	1.42	8.03	....	2.17	4.57	100.85	0.18
Custer	59.85	2.33	0.63	7.55	0.02	0.02	0.49	0.37	9.39	0.83	1.24	1.58	....	1.81	12.96	99.07	0.11
Delta..........	76.77	1.56	0.11	1.45	0.05	0.01	0.45	0.18	2.03	0.83	4.50	8.40	....	1.96	1.87	100.17	0.08
Douglass......	82.04	0.08	0.20	0.02	0.07	0.03	0.37	0.51	0.24	0.28	2.54	8.34	....	1.42	3.10	99.24	0.13
Eagle	73.67	1.80	....	3.49	0.09	0.03	0.10	0.16	5.32	0.91	2.51	5.55	....	1.34	5.04	100.01	0.09
Elbert.........	86.35	0.69	1.19	0.48	0.04	0.01	0.46	0.93	0.12	0.42	1.54	3.83	....	1.34	2.66	100.06	0.12
El Paso	74.37	2.13	0.06	1.68	0.05	0.01	0.20	0.70	0.28	0.21	1.97	10.57	....	2.23	5.52	99.98	0.23
El Paso	79.35	5.35	0.42	0.31	....	0.49	0.35	0.30	0.65	0.25	1.25	4.25	0.08	....	7.09	100.15	0.20
Fremont	74.65	2.70	0.49	0.46	0.06	0.04	0.49	0.12	1.49	0.29	3.75	10.90	....	1.49	2.97	99.90	0.07
Garfield	72.68	5.20	0.44	0.21	0.06	0.14	1.38	0.63	0.71	....	2.07	8.27	....	2.82	5.32	99.93	0.16
Grand	72.01	6.09	0.53	1.00	0.05	0.05	0.37	0.22	0.70	0.16	1.06	3.88	....	3.80	11.08	100.95	0.25
Gunnison	67.00	5.51	1.46	....	0.05	0.01	0.75	0.86	2.05	0.58	2.86	10.24	....	2.30	6.21	99.98	0.13
Jefferson......	60.72	10.56	0.99	....	0.05	0.01	0.57	0.78	2.34	0.17	6.17	9.77	....	3.06	4.72	99.98	0.12
Kiowa.........	70.53	7.36	0.41	....	0.03	0.06	0.27	0.31	5.67	0.02	1.55	7.35	....	3.55	2.92	100.03	0.24
Kit Carson....	73.11	7.11	0.61	0.02	0.07	0.03	0.41	0.30	3.00	0.66	1.93	6.06	....	3.57	3.14	100.02	0.14
Las Animas...	77.72	5.32	0.45	1.01	0.04	0.90	0.25	0.11	1.55	0.11	2.93	4.70	....	1.66	3.70	100.45	0.06
La Plata......	75.74	7.15	1.14	....	0.02	0.10	0.76	0.22	0.93	0.13	2.59	4.06	....	1.48	5.66	99.98	0.16
Larimer	65.35	6.38	1.44	4.90	0.03	0.08	0.12	0.56	6.72	0.28	2.18	5.96	....	1.80	4.10	99.90	0.08
Larimer	81.50	5.67	0.31	0.40	....	0.28	0.42	0.36	1.15	0.35	2.17	4.10	0.03	....	3.25	99.99	0.10
Larimer	67.47	7.88	....	1.96	0.09	0.09	0.15	0.35	3.43	0.56	2.01	7.30	....	2.88	5.75	99.92	....
Lincoln	78.43	10.74	0.36	....	0.03	0.15	0.24	0.71	0.48	0.50	1.79	3.90	....	1.17	2.00	100.50	0.12
Logan.........	78.08	8.30	0.05	....	0.05	0.03	0.70	0.46	1.36	0.18	1.76	6.19	....	1.57	2.02	100.12	0.11
Mesa	72.49	10.41	1.66	1.65	0.03	0.11	0.11	0.50	3.43	0.70	2.45	3.36	....	1.00	2.11	100.01	0.01
Montrose	66.00	1.75	1.23	5.32	0.06	0.04	0.78	0.87	6.81	0.08	2.68	6.25	....	2.45	5.76	100.04	0.05
Montezuma ...	77.60	2.98	1.35	....	0.06	0.05	1.29	0.55	0.38	1.49	2.13	6.56	....	2.64	2.93	99.99	0.09
Morgan	84.94	2.04	0.39	0.06	0.05	0.04	0.56	0.86	0.19	0.05	0.99	5.53	....	1.33	2.67	99.60	0.16

TABLE XXIV.—ANALYSES OF SOME COLORADO SOILS—(Continued).

COUNTY.	Insoluble.	Silicic Acid, Sol.	Sulfuric Acid.	Carbonic Acid.	Chlorin.	Phosphoric Acid.	Potash.	Soda.	Lime.	Magnesia.	Ferric Oxid.	Aluminic Oxid.	Manganic Oxid.	Moisture.	Ignition.	Total.	Nitrogen.
Ouray	55.12	6.55	0.97	6.54	0.05	0.19	1.95	0.48	8.16	0.27	1.86	10.85	....	1.48	5.69	100.16	0.13
Otero	80.23	3.03	0.50	1.15	0.09	0.14	0.91	1.52	1.76	0.16	2.38	4.45	....	1.55	3.25	100.12	0.12
Park	79.55	2.67	0.54	....	0.05	0.07	0.65	0.45	2.33	0 55	0.95	2.10	....	2.04	7.90	99.85	0.32
Pitkin..........	70.50	3.95	0.85	3.16	0.03	0.08	0.46	0.81	2.27	0.28	2.89	4.60	....	2.54	7.62	100.04	0.26
Phillips	73.43	4.00	1.86	1.98	0.04	0.25	0.15	0.75	1.45	1.89	2.31	5.68	....	2.96	3.78	100.53	0.08
Prowers.......	69.90	8.10	0 60	....	0.03	0.09	1.69	0.54	1.44	0.79	2.78	5.94	....	2.65	5.79	100.36	0.13
Pueblo	75.84	5.11	0.10	0.36	0.04	0.08	0.22	0.16	1.02	0.54	3.71	5.66	....	2.19	4.75	99.36	0.13
Rio Blanco....	69.88	4.35	1.12	1.95	0.04	0.18	0.78	0.27	1.45	0.43	2.75	7.13	....	2.56	6.64	99.55	0.24
Rio Grande ...	76.03	4.64	0.67	....	0.09	0.09	0.90	0.77	1.55	0.95	5.40	5.09	....	1.48	3.00	100.66	0.09
Routt	67.04	6.14	0.66	....	0.04	0.20	0.69	0.57	1.21	0.53	3.33	6.73	....	3.56	9.20	99.90	0.24
Saguache	65.59	9.46	1.10	....	0.09	0.11	0.26	0.99	1.64	0.63	3.60	5.33	....	3.97	7.41	100.18	0.24
San Miguel ...	69.61	5.28	0.47	1.19	0.04	0.06	0.11	0.44	2.10	0.67	3.38	6.08	....	3.60	7.30	100.33	0.31
Sedgwick	69.43	5.87	1.20	2.47	0.03	0 30	0.33	0.84	3.46	0.32	2.21	5.40	....	2.33	6.34	100.58	0.11
Washington ..	73.33	6.80	0.41	1.02	0.02	0.05	0.56	0.16	1.04	0.28	2.01	5.56	....	3.56	4.75	99.53	0.12
Weld	79.76	6.36	1.13	....	0.05	0.11	0.54	0.16	1.38	0.42	2.43	3.52	....	1.48	2.52	99.86	0.07
Weld	78.17	7.75	0.26	0.28	0.05	0.31	0.38	0.30	0.97	0.40	3.01	3.96	0.04	....	4.42	100.26	0.13
Yuma	67.90	5.31	1.03	0.11	0.02	0.29	1.53	0.84	3.43	1.15	4.88	7.55	....	1.43	4.83	100.30	0.07
*Otero†.......	74.27	10.50	0.05	0.68	0.02	0.04	0.41	0.78	1.38	0.71	4.34	2.43	0.17	1.44	3.54	100.76	0.08
Otero‡	84.06	5.88	0.04	0.31	0.01	0.04	0.26	0.33	0.60	0.22	3.38	1.66	0.22	0.74	2.42	99.98	0.05
Otero§	78.22	9.87	0.06	0.27	0.02	0.02	**0.01	0.70	1.05	0.46	4.24	1.36	0.22	0.89	2.55	99.94	0.06

* Analyses of melon soils from Fowler, taken Jan. 27, 1899, analyst F. C. Alford. Digestion with acid sp. gr. 1.115 for 10 hours.

† Humus 0.14. ‡ Humus 0.08. § Humus 0.10.

** Examination of this sample shows very little feldspar in it.

SUMMARY.

§ 108. The "alkali" salts in the soils and waters of Colorado are essentially mixtures of the sulfates of lime, magnesia and soda.

§ 109. The soils of the eastern slope of the Rocky Mountains and of the plains lying to the east in Colorado, have in general a very similar composition, as shown by the composition of the soil mass.

The mineralogical composition of these soils is very similar, the principal variation being in the ratio of the quantities of the minerals present.

§ 110. The surface soils of this section of Colorado probably owe their mineral constituents to a common source, the schists and granites of the Colorado range.

§ 111. The feldspar, orthoclase, an almost universal constituent of our soils, serves as a source of potash and also of hydrous silicates under ordinary cultural conditions.

§ 112. The readiness with which the chemical reactions take place and their character, as indicated by the salts present in the ground waters, probably have a direct and important bearing upon the fertility of the soil. The loessial soils of the plains agree with the ordinary prairie soils in the chemical composition of their mass and in the general results of the agricultural analysis, but not in the mechanical analysis.

§ 113. The analyses of the whole soil mass and of the different portions of the fine earth, suggest important differences between the unchanged rock particles in the soil and the finer portions which have suffered change or are the products of alteration.

§ 114. The aggregate amount of soluble salts per acre whose movement is effected by the water falling on or supplied to the surface, or by its evaporation from the surface, is large; we make it nine tons in one instance. The application of water, irrigation, may carry the soluble salts so deep into the soil that a long time may be required for them to come near to the surface again.

§ 115. The chemical analyses give us no hint of the very great improvement which was effected in this soil by three, really four, years experimentation with it. Our question was one of conditions and not of composition, so far as its purely agricultural features were concerned.

§ 116. The water-soluble in the soil and the incrustations formed upon the soil are very different in composition.

§ 117. The incrustations are formed by the evaporation of water from the surface of the soil, which, owing to the deportment of the solutions of these salts toward capillary action, and the chemical instability of the hydrated salts themselves, effects their separation from the soil solutions.

§ 118. The water-soluble in the soil is not identical with ground water solutions, probably due to reactions dependent upon the relative masses, which react upon each other within the soil and during the extraction.

§ 119. The reactions near the surface of the soil are quite different from those more remote. This is indicated by the solutions yielded by samples taken to depths of two and four inches.

§ 120. There is, in the samples of soil examined, both free ammonia and ammoniacal salts, which we interpret as indicating unfavorable biological conditions, which view is materially strengthened by the nitrates in the ground waters.

§ 121. There is a significant gain in the total soil nitrogen during the time of the experiment, which may have been favored by, but was not dependent upon, the application of manure.

§ 122. The nitrates in the first two inches of this soil are from nine times to two hundred times as great as in the second two inches, corrobative of the suggested reduction in certain zones of the soil.

§ 123. Air dried soil samples can be kept for a year or more with ordinary precautions, without material change in their nitrogen content.

§ 124. The humus in this soil is nearly as abundant as in average Eastern soils, and we were unable to find anything about it markedly different from ordinary humus. It is unlike the humus of arid soils, in that it is not so rich in nitrogen as they have been found to be.

§ 125. The solutions of the humus carried relatively very large amounts of silicic acid, phosphoric acid, potash and lime. The precipitated humus did not carry much lime.

§ 126. The effect of the cultivation, manuring, etc., for three seasons, may be summed up by stating that the store of plant food in the surface soil, taken to a depth of ten inches, was actually increased. This, however, was the lesser part of the improvement, the greater part lay in the betterment of the general conditions, whose best features cannot be shown by chemical analysis, or expressed in any formula.

TABLE OF CONTENTS.

LIST OF TABLES.