1-1913

Bulletin No. 121 - The Soil of the Southern Utah Experiment Station

John A. Widtsoe

Robert Stewart

Utah Agricultural College

EXPERIMENT STATION

BULLETIN No. 121

The Soil of the Southern Utah Experiment Station

BY

JOHN A. WIDTSOE and ROBERT STEWART

Logan, Utah, January, 1913

PRESS OF
Tribune-Reporter Printing Co.
Salt Lake City, Utah

Utah Agricultural Experiment Station

EXPERIMENT STATION STAFF.

J. A. WIDTSOE, Ph., D., President of the College.

E. D. BALL, Ph. D	Director and Entomologist
H. J. FREDERICK, D. V. M.	Veterinarian
ROBERT STEWART, Ph. D.	Assistant Director and Chemist
E. G. TITUS, Sc. D.	Entomologist
L. D. BATCHELOR, Ph. D.	Horticulturist
F. S. HARRIS, Ph. D.	Agronomist
F. L. WEST, Ph. D.	Meteorologist
C. N. JENSEN, Ph D	Plant Pathologist
J. E. GREAVES, Ph. D.	Bacteriologist
W. E. CARROLL, M. S.	Animal Husbandman
JOHN STEWART, B. S.	Associate Chemist
BYRON ALDER	Poultryman
C. T. HIRST, B. S.	Assistant Chemist
A. B. BALLANTYNE, B. S.	Assistant Horticulturist
A. E. BOWMAN, B. S.	Assistant Agronomist
L. M. WINSOR, B. S.	Assistant Irrigation Engineer
M. A. NELSON, B. S.	Assistant Entomologist
W. L. QUAYLE, B. S.	Assistant Chemist
JOHN WILSON, B. S.	Assistant Animal Husbandman
H. J. WEBB, B. S.	Assistant Entomologist
HOWARD SCHWEITZER, B. S.	Assistant Horticulturist
A. D. ELLISON, B. S.	Foreman Nephi Arid Farm
C. L. MERRILL, B. S.	Assistant Agronomist
H. E. McNATT, B. S. A.	Assistant Animal Husbandman
WILLARD GARDNER, B. S.	Clerk and Librarian

IN CHARGE OF CO-OPERATIVE INVESTIGATIONS
With U. S. Department of Agriculture.

W. W. McLAUGHLIN, B. S.	Irrigation Engineer
P. V. CARDON, B. S.	Agronomist
R. A. HART, B. A.	Drainage Engineer

The Soil of the Southern Utah Experiment Station

BY

John A. Widtsoe and Robert Stewart

A. INTRODUCTION.

The soil of the Southern Utah Experiment Farm is a very interesting type: it is highly charged with gypsum and thereby presents a condition unique in reported studies of the soils of America. Gypsiferous soils are characteristic of a large portion of Southern Utah; many of them are derived from shale, others from sandstone, impregnated with gypsum.

1. Geological Derivation of Soil.

The Virgin River drains the western portion of the terraces of the High Plateau country. The High Plateau area is bounded on the north by the rim of the Great Basin, on the west by the Hurricane fault and extends south into Arizona and east into Colorado. The western portion of the Terraces of the High Plateau is cut by the two forks of the Virgin River. Both branches head at the base of the Pink Cliffs and when united form the Virgin River. The Pink Cliffs are located in the southeastern part of Iron County, almost directly east of Kanarra. The Virgin River, therefore, drains all of Washington County and a small portion of Iron County. Both the branches and their many filaments cut through the deposits of the Cretaceous, Jurassic and Triassic, until at St. George the Virgin is cutting through the Permian. The Southern Utah Experiment Farm lies in the Valley of the Virgin near St. George, and the soil has been formed from the weathering of the Terrace country and deposited in its present position by the Virgin River.

We may learn much regarding the nature of the soil of the Southern Utah Experiment Farm by studying the nature of the deposits* of the Cretaceous, Jurassic, Triassic and Permian ages in this vicinity. The deposits of the Cretaceous Age consist largely of light-colored sandstones and clay shales. The Jurassic consists of deposits of almost pure white sandstone over a thousand feet thick, surmounted by deposits of shale containing fossiliferous limestone and some gypsum. The deposits of the Triassic Age consist of highly colored sandstone separated by shaly layers and "not infrequently by bands of almost pure gypsum." Bands of limestone or calcite are not found in this series at all.

The Deposits of the Permian consist of chocolate-colored sandstone and shale, but here the cementing material in addition to gypsum consists of sandy limestone.

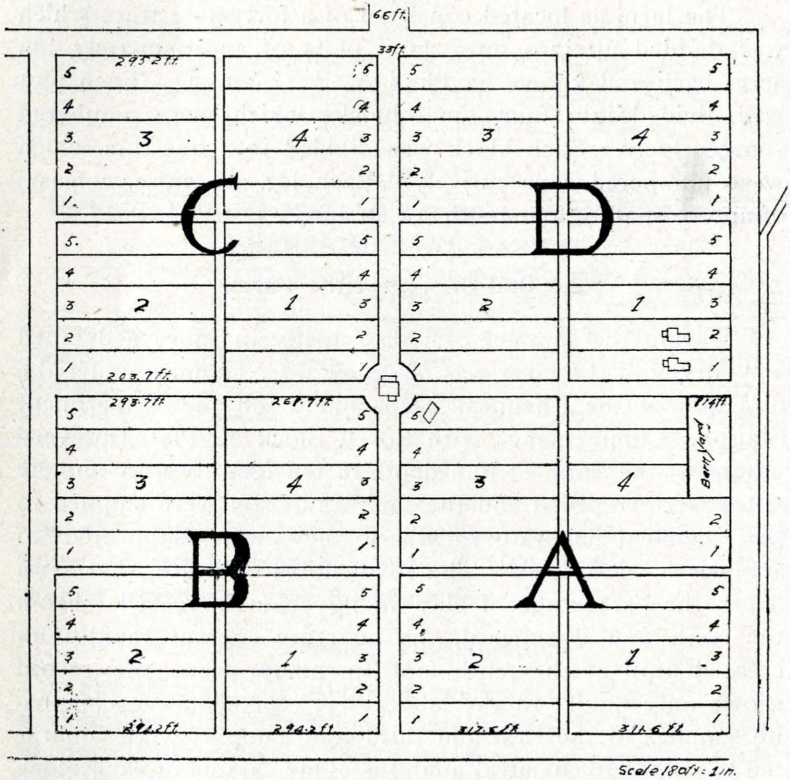
It is from the decomposition materials of these several geological deposits that the soil of the Southern Utah Experimental Farm has been made. Therefore, we would expect to find a sandy soil containing limestone and heavily charged with gypsum.

2. Location and Cultivation of the Farm.

The farm was located by a commission which was appointed for that purpose by authority of an act of the Legislature approved March 21st, 1899. It was accepted (†) by the State Board of Horticulture in December, 1899, and Hon. Thomas Judd was appointed custodian. The farm was located on the Washington field about six and a half miles southeast of St. George. When located, the land was in the virgin state. The custodian in his report to the State Board of Horticulture says: "The condition of the land was such as to necessitate a great amount of work in order to put the property in proper shape. The ground has been cleared of

*U. S. Geological Survey, Vol. II (1885).
†Biennial Report of Utah State Board of Horticulture, 1899-1900.

Plate 1



sagebrush, (‡) ploughed and mostly leveled, the latter operation requiring an unusual amount of work because of the fact that when water is applied to the soil the land sinks in spots, the depression being from six inches to three feet. After having been thoroughly soaked once and settled, there is no danger of further settling." Since the farm was to be devoted to horticultural purposes, it was planted to grapes, peaches, prunes and other horticultural products and especially to those indigenous to a warm climate.

---

‡True sage brush (*Artemesia tridentata*) does not occur in this locality. Two-thirds or more of the original "Brush" in this section of Washington field was Giant Salt Brush (*Atriplex canescens*). Small amounts of Rabbit Brush (*Bigelovia sp*), Greasewood (*Sarcobatus Baileyii*), Sea Blite (*Suaeda Moquinii*), and scattering specimens of *Atriplex lentiformas Artemesia filifolia* and *Hymenocles fasciculata* occurred throughout this area.

3. Plan of the Farm.

The farm as located consisted of a forty-acre tract which was divided up into four equal plots of approximately ten acres each and known as Plots A, B, C, and D. Each plot was divided into four equal blocks which were numbered consecutively. Each block was divided into five lots which were numbered consecutively. Each lot, therefore, consists of approximately four-tenths of an acre.

4. Soil Survey of the Farm.

During the summer of 1905 (chiefly in June) a detailed soil survey of the farm was made by J. C. Thomas, under the direction of the Chemical Department of the Experiment Station. Commencing with Lot 1, Block 1, Plat D, every other lot was sampled to a depth of ten feet. Very complete notes were recorded and the samples of soil were shipped to the chemical laboratory, where they were submitted to analysis as described. The field notes indicate that with depth the percentage of clay and gypsum increased. From the sixth foot downward, the moisture content rapidly increased until at the tenth foot in many cases the record shows only mud. In the laboratory, representative composite samples of the first and third foot samples were submitted to complete chemical analysis. One sample of each block which in turn was a composite of one-half the lots on the block, was submitted to analysis. Thus, four samples of the surface foot and four of the third foot of each plot, which in turn were composites of ten separate borings, were analyzed. Three composite samples of the first, second and fifth feet were submitted to physical analysis to determine the percentages of sand, silt and clay. All of the original samples from the first, second, third, fifth, and tenth feet were analyzed for alkali.

B. EXPERIMENTAL PART.

This part naturally falls into three studies: (1) the physical composition; (2) the fertility; (3) the alkali content of the soil.

1. The Physical Composition.

In Table 1 will be found the results obtained from a physical analysis of the soil as determined by the method described in Bulletin 89 of the Utah Station. These results clearly show that the soil is distinctly of a sandy nature.

TABLE I.

PHYSICAL COMPOSITION OF SOIL FROM SOUTHERN EXPERIMENTAL FARM.*

	First Foot.	Second Foot.	Fifth Foot.
Coarse Sand	37.48	38.96	37.31
Fine Sand	23.16	18.62	24.10
Coarse Silt	16.11	12.75	10.88
Medium Silt	8.36	9.47	7.61
Fine Silt	4.91	4.35	3.98
Clay, Water and Loss	9.99	15.85	16.12

The soil would be classified as a sand or sandy loam. The notes of the surveying party of 1905 indicate that the ground water was near the tenth foot.

2. Chemical Investigations.

The chemical investigations were of two kinds: the determination of the plant food content, and the determination of the alkali content. The plant food content was determined by the methods of the Association of Official Agricultural Chemists.

(a). FERTILITY IN SOIL.

Since the fertility content was determined by the methods of the Association of Official Agricultural Chemists, the results are also reported by their method, i. e., as the oxides of the elements instead of as the elements themselves. There has been considerable agitation of recent years to report such results on the element basis, but since the results obtained by the method followed do not represent the total amount present in the soil, the method of reporting as used by the association has been followed.

*All results in this bulletin are reported as per cent of dry soil. Each result in this table represents the average of seven determinations.

1. Composition of Plot A.

Four composite samples of the surface foot of Plot A, representing ten separate borings, and two composite samples of the third foot, representing six separate borings, were submitted to analysis. The results obtained are reported in Tables 2 and 3.

A study of Table 2 indicates some very interesting and important results. The amount of insoluble residue clearly confirmed and the results of the physical analysis of the soil. i. e., that the soil is of a sandy nature. The amount of potash present is normal for arid sandy soils, while the amount of soda present is not high for an arid soil. The amount of calcium present is high and when taken in connection with the percentage of carbon dioxide indicates that a large part is present in the form of the carbonate. The high percentage of sulphuric acid and the low content of soda indicates that part of the calcium is present as the sulphate. The magnesia content is high, and when the reported toxic action of magnesia is taken into consideration, is very important.

TABLE II.

FERTILITY IN SOIL OF FIRST FOOT OF PLOT A.

Block No.	1	2	3	4	
Lot Nos.	1, 3, 5	2, 4	1, 3, 5	2, 4	Average
Lab. No.	45041	45042	45043	45044	
Insoluble Residue	83.55	76.09	82.32	82.23	81.05
Potash, K_2O	0.63	0.85	0.50	0.54	0.63
Soda, Na_2O	0.76	0.84	0.77	0.84	0.80
Lime, CaO	3.63	5.70	4.67	4.93	4.73
Magnesia, MgO	1.36	3.29	2.33	2.32	2.32
Sulphuric Acid, SO_3	0.13	0.68	0.35	0.24	0.35
Oxide of Iron, Fe_2O_3	2.05	2.76	2.40	2.31	2.38
Alumina, Al_2O_3	3.42	3.74	2.72	1.98	2.96
Phosphoric Acid, P_2O_5	0.064	0.09	0.099	0.11	0.09
Carbon Dioxide, CO_2	3.25	5.57	2.49	3.21	3.63
Difference	1.16	0.39	1.35	1.29	1.05
Total	100.00	100.00	100.00	100.00	100.00
Humus	0.79	0.83	0.64	0.68	0.73
Nitrogen	0.033	0.040	0.0283	0.035	0.034

Loew maintains that the ratio between the lime and magnesia is a very important factor in crop production. Using the average results obtained on Plot A, if we regard the "lime" as all of the calcium present as carbonate, silicate and sulphate, the ratio of magnesia to lime is 1:2.04. If we assume that all of the sulphuric acid exists as calcium sulphate and we subtract the theoretical amount of calcium in this form (.25%) from the total, the ratio of magnesia to lime is 1:1.93.

The amount of phosphoric acid is very low and indicates a deficiency of this material. The humus is very low, even for arid America, and the nitrogen content is also remarkably low, indicating a deficiency in these two important substances.

In the third foot (see table 3) there is a lower content of potash, soda, nitrogen and humus, while the phosphoric acid is slightly higher in subsoil than in the surface soil. In the third foot, the magnesia-calcium ratios are 1:2.29 and 1:1.5.

TABLE III.

FERTILITY IN THE SOILS OF THIRD FOOT OF PLOT A.

Block No.	1	3	
Lots Nos.	1, 3, 5	1, 3, 5	Average
Lab. No.	45057	45058	
Insoluble Residue	82.78	79.17	80.97
Potash, K_2O	0.21	0.14	0.18
Soda, Na_2O	0.11	0.11	0.11
Lime, CaO	4.40	5.36	4.88
Magnesia, MgO	1.89	2.36	2.13
Sulphuric Acid, SO_3	2.24	2.56	2.40
Oxide of Iron, Fe_2O_3	2.47	1.79	2.13
Alumina, Al_2O_3	1.40	2.63	2.01
Phosphoric Acid, P_2O_5	0.12	0.14	0.13
Carbon Dioxide, CO_2	2.69	3.65	3.17
Difference	1.69	2.09	1.89
Total	100.00	100.00	100.00
Humus	0.31	0.31	0.31
Nitrogen	0.023	0.028	0.0255

2. Composition of Soil of Plot B.

Tables 4 and 5 show that the results for the insoluble residue in Plot B are somewhat lower than for Plot A, but in general the results indicate a sandy soil. The result for Lab. No. 45048 is lower than any of the other three but when taken in connection with the exceptionally high calcium and sulphuric acid content, indicates that the soil of this block is somewhat more heavily charged with gypsum. The soda and potash are normal. The calcium and magnesia are high. The carbon dioxide is high; the sulphuric acid is also high, and in the case of the soil of block 2 and 4 is exceptionally high. Again, the phosphoric acid is low. The humus is slightly lower than in Plot A, while the nitrogen content is about constant. Again, considering the "lime" as being the total calcium present, the ratio of magnesia to lime in the first foot is 1:2.1, while, subtracting the amount of the oxide in the form of the sulphate from the total oxide present, the ratio is 1:1.9. In case of the third foot, the ratios are 1:2.32 and 1:2.19 respectively.

TABLE IV.

FERTILITY IN THE SOIL OF FIRST FOOT PLOT B.

Block No.	1	2	3	4	
Lots No.	1, 3, 5	2, 4	1, 3, 5	2, 4	Average
Lab. No.	45045	45046	45047	45048	
Insoluble Residue	80.91	77.04	79.65	73.61	77.83
Potash, K_2O	0.43	0.44	0.51	0.73	0.52
Soda, Na_2O	0.64	0.45	0.16	0.14	0.35
Lime, CaO	4.64	5.67	4.66	6.44	5.35
Magnesia, MgO	2.39	3.45	2.05	2.27	2.54
Sulphuric Acid, SO_3	0.55	1.02	0.19	1.50	0.82
Oxide of Iron, Fe_2O_3	2.19	2.45	2.30	2.45	2.34
Alumina, Al_2O_3	2.51	2.72	4.06	5.54	3.70
Phosphoric Acid, P_2O_5	0.10	0.14	0.15	0.24	0.15
Carbon Dioxide, CO_2	4.42	4.68	4.50	5.84	4.86
Difference	1.22	1.94	1.77	1.24	1.54
Total	100.00	100.00	100.00	100.00	100.00
Humus	0.89	0.54	0.60	0.51	0.63
Nitrogen	0.031	0.031	0.028	0.031	0.03

TABLE V.

FERTILITY IN THE SOIL OF THIRD FOOT PLOT B.

Block No	1	3	
Lots No	1, 3, 5	1, 3, 5	Average
Lab. No	45059	45060	
Insoluble Residue	81.70	76.15	78.92
Potash, K_2O	0.40	0.58	0.49
Soda, Na_2O	0.22	0.10	0.16
Lime, CaO	4.95	5.90	5.42
Magnesia, MgO	1.81	2.77	2.29
Sulphuric Acid, SO_3	0.64	0.46	0.55
Oxide of Iron, Fe_2O_3	2.01	2.12	2.06
Alumina, Al_2O_3	1.47	3.02	2.24
Phosphoric Acid, P_2O_5	0.17	0.18	0.17
Carbon Dioxide, CO_2	2.06	3.40	2.73
Difference	4.57	5.32	4.94
Total	100.00	100.00	99.97
Humus	0.27	0.49	0.38
Nitrogen	0.022	0.035	0.028

3. Composition of Plot C.

In general as shown by tables 6 and 7 the results for insoluble residue in the soil of this plot are slightly lower than that of the preceding two plots. This is readily accounted for by the increased amounts of sulphuric acid and carbon dioxide which shows a higher amount of gypsum and calcium carbonate present. The potash is normal, while the soda is very low. The lime, sulphuric acid, carbon dioxide and magnesia are higher. The phosphoric acid is slightly higher. The humus is still low, while the nitrogen content is nearly constant. The ratios of magnesia to lime, obtained as indicated before, are 1:2.05 and 1:1.86, respectively.

In the third foot similar conclusions may be drawn. The ratio of magnesia are 1:2.0 and 1:1.82, respectively.

TABLE VI.

FERTILITY IN THE SOIL OF THE FIRST FOOT OF PLOT C.

Block No.	1	2	3	4	
Lots Nos.	1, 3, 5	2, 4	1, 3, 5	2, 4	Average
Lab. No.	45049	45050	45051	45052	
Insoluble Residue	73.80	72.37	78.24	73.09	74.37
Potash, K_2O	0.70	0.78	0.65	0.78	0.73
Soda, Na_2O	0.16	0.19	0.13	0.18	0.17
Lime, CaO	6.27	6.61	5.01	6.16	6.01
Magnesia, MgO	2.86	2.26	2.97	3.59	2.92
Sulphuric Acid, SO_3	1.59	1.04	0.39	0.66	0.92
Oxide of Iron, Fe_2O_3	2.83	2.81	2.40	2.89	2.73
Alumina, Al_2O_3	4.48	5.92	3.54	4.53	4.63
Phosphoric Acid, P_2O_5	0.26	0.31	0.26	0.25	0.27
Carbon Dioxide, CO_2	5.60	5.97	4.11	5.63	5.32
Difference	1.45	1.74	2.30	2.24	1.94
Total	100.00	100.00	100.00	100.00	100.00
Humus	0.60	0.50	0.54	0.56	0.55
Nitrogen	0.028	0.030	0.025	0.028	0.027

TABLE VII.

FERTILITY IN THE SOIL OF THE THIRD FOOT OF PLOT C.

Block No.	1	3	
Lots Nos.	1, 3, 5	1, 3, 5	Average
Lab. No.	45061	45062	
Insoluble Residue	77.14	80.52	78.83
Potash, K_2O	0.56	0.45	0.51
Soda, Na_2O	0.20	0.12	0.16
Lime, CaO	5.57	2.44	4.01
Magnesia, MgO	2.98	1.06	2.02
Sulphuric Acid, SO_3	0.42	0.51	0.47
Oxide of Iron, Fe_2O_3	2.32	1.61	1.96
Alumina, Al_2O_3	2.69	2.29	1.47
Phosphoric Acid, P_2O_5	1.18	0.15	0.16
Carbon Dioxide, CO_2	3.59	1.89	2.74
Difference	4.35	8.96	7.67
Total	100.00	100.00	100.00
Humus	0.55	0.51	0.53
Nitrogen	0.029	0.028	0.0285

4. Composition of Plot D.

Table 8 shows that the insoluble residue of the first foot of the soil of Plot D is more nearly like that of Plots A and B. There is less lime present in the form of carbonate. The potash is normal, while the soda is very low. The magnesia is high. The phosphoric acid is lower than in Plot C, but higher than in Plots A and B. The sulphuric acid is very high. The humus is very low. The nitrogen is practically the same as in the other plots. The ratios of magnesia to lime are 1:2.27 and 1:1.70, respectively.

In the third foot (see Table 8) the insoluble residue is much lower, which is due to the excess of lime in the form of gypsum. It is important to note that as the sulphuric acid increases the magnesia likewise slightly increases. The phosphoric acid and nitrogen are nearly the same. The humus is slightly higher. The ratios of magnesia to lime are 1:1.69 and 1:1.3, respectively.

TABLE VIII.

FERTILITY IN THE SOIL OF THE FIRST FOOT OF PLOT D.

Block No.	1	2	3	4	
Lots Nos.	1, 3, 5	2, 4	1, 3, 5	2, 4	Average
Lab. No.	45053	45054	45055	45056	
Insoluble Residue	76.41	82.20	75.85	79.49	78.48
Potash, K_2O	0.46	0.51	0.51	0.37	0.46
Soda, Na_2O	0.15	0.12	0.12	0.11	0.12
Lime, CaO	5.82	4.35	6.04	5.27	5.37
Magnesia, MgO	2.30	1.89	3.08	2.25	2.37
Sulphuric Acid, SO_3	2.23	0.82	1.95	2.76	1.94
Oxide of Iron, Fe_2O_3	2.11	1.91	2.24	1.72	1.99
Alumina, Al_2O_3	1.35	3.13	3.33	2.21	2.50
Phosphoric Acid, P_2O_5	0.23	0.18	0.21	0.13	0.187
Carbon Dioxide, CO_2	4.08	3.49	5.25	3.66	4.12
Difference	4.86	1.40	1.42	2.05	2.42
Total	100.00	100.00	100.00	100.00	100.00
Humus	0.54	0.46	0.42	0.33	0.43
Nitrogen	0.024	0.022	0.027	0.035	0.02

TABLE IX.

FERTILITY IN THE SOIL OF THIRD FOOT OF PLOT D.

Block No.	1	3	
Lots Nos.	1, 3, 5	1, 3, 5	Average
Lab. No.	45063	45064	
Insoluble Residue	73.70	69.59	71.65
Potash, K_2O	0.77	0.76	0.77
Soda, Na_2O	0.15	0.18	.0.17
Lime, CaO	6.11	6.88	6.49
Magnesia, MgO	3.46	4.21	3.83
Sulphuric Acid, SO_3	1.58	3.15	2.36
Oxide of Iron, Fe_2O_3	2.85	2.63	2.74
Alumina, Al_2O_3	3.55	3.72	3.63
Phosphoric Acid, P_2O_5	0.22	0.23	0.23
Carbon Dioxide, CO_2	4.22	6.38	5.30
Difference	3.39	2.27	2.83
Total	100.00	100.00	100.00
Humus	0.79	0.69	0.74
Nitrogen	0.034	0.042	0.038

5. The Farm as a Whole.

In Table 10 will be found the average of sixteen analyses of the surface foot of soil and the average of eight analyses of the third foot of soil. These results ought to represent pretty well the average composition of the farm as a whole. The uniformity of the results for the first and third foot samples is remarkable. With the exception of the low results for alumina in the third foot and the high difference, the results for the two foot sections are almost the same.

When taken in connection with the high lime contents in the form of sulphate and carbonate, the results for insoluble residue are normal for a sandy soil. The amount of potash and soda are normal. The phosphoric acid, humus and nitrogen are low. The humus and nitrogen especially are remarkably low, and indicate a serious deficiency which which we would expect to be felt soon in crop production. The ratios of magnesia to lime in the first foot are 1:2.1

TABLE X.

AVERAGE FERTILITY OF THE SOILS OF SOUTHERN EXPERIMENTAL FARM.

	Composition of surface foot. Average of 15 analyses.	Composition of third foot Average of 8 analyses.
Insoluble Residue	77.93	77.60
Potash, K_2O	0.58	0.49
Soda, Na_2O	0.36	0.15
Lime, CaO	5.37	5.20
Magnesia, MgO	2.54	2.57
Sulphuric Acid, SO_3	1.01	1.44
Oxide of Iron, Fe_2O_3	2.36	2.22
Alumina, Al_2O_3	3.45	2.34
Phosphoric Acid, P_2O_5	0.17	0.17
Carbon Dioxide, CO_2	4.49	3.48
Difference	1.74	4.34
Total	100.00	100.00
Humus	0.58	0.49
Nitrogen	0.029	0.0214

and 1:1.9, respectively, while in the third foot they are 1:2.0 and 1.7, respectively.

In a study of these results we must keep in mind the fact that there are ten essential elements of fertility. If any one of these elements is deficient the crop will not grow normally. These ten elements of fertility are, carbon, oxygen, hydrogen, nitrogen, calcium, iron, sulphur, magnesium, potassium and phosphorus. The carbon and oxygen are obtained from the air, the hydrogen from the water, while the nitrogen is obtained chiefly from the organic matter of the soil. The remaining six, calcium, iron, sulphur, magnesium, potassium and phosphorus are obtained from the soil. Of these, calcium, magnesium, iron and sulphur occur in the soil and especially in the soil of Utah to such an extent that their supply is apt never to become exhausted. We are coming more and more to realize that such also is the case with potassium. The hydrogen is obtained from the soil water and the people of Utah realize the importance of a supply of soil moisture. The two remaining elements, phosphorus and nitrogen, are deficient in our soils and the maintaining of the supply of these two elements forms the problem of soil fertility over a large area of our State.

6. THE POTASSIUM PROBLEM.

The amount of potassium (socalled Potash) in the soils of the Southern Utah Experiment Farm is normal for sandy soils. The method of analysis used does not give all of the potassium which is present in the soil but only about, in general terms, one-fourth of the total amount present. While potassium is one of the essential elements of plant food and is usually regarded as one of the three most likely to be deficient in the soil, it is the least important of the three socalled essential elements of plant production. When the products of the farm are fed to the animals, very little if any of this element is retained by the animal, but is all voided in the waste products of the body and may with care be returned to the soil. It occurs in the soil in far greater quantities than nitrogen or phosphorus and is not utilized by the animal body so extensively as the other two. The potassium problem for the farmer then is to so control the operations on the farm as to liberate the potassium from its insoluble compounds and render it available for plant production. Now it so happens that decomposing organic matter is the key which unlocks the sealed door and liberates the potassium. The soils of St. George need organic matter for this purpose. The results for humus indicate a marked deficiency in organic matter which may be added in one of two ways: either by adding barnyard manure or ploughing under crop residues or crops grown for that purpose. Crops which are used for the purpose of adding organic matter to the soil should belong to the leguminous family (that is, peas, lucern, etc.,) in order, also, to make use of the nitrogen of the air.

7. THE PHOSPHORUS PROBLEM.

Phosphorus is deficient in the soil of the Southern Utah Experiment Farm. If no provision is made for the return of this important plant food the time is not far distant when a marked deficiency will result, and it will become the limiting element of plant production. There are two ways in which this material may be added to the soil: First, it may be added in the form of barnyard manure, but a ton of barnyard manure only contains two pounds of phosphorus, so if the supply is to be maintained in this way large quantities of manure must be added; second, it may be added in the form of the commercial product, either as the superphosphate or in the raw state. The addition of the material as the raw rock phosphate is advisable under certain conditions, provided sufficient decomposing organic matter is present to convert it into the available form. If the value of the crops produced is sufficient to warrant it, a more available and therefore a higher priced product, may be purchased. The economical use of commercial fertilizers, must be subjected to experiment before reliable advice can be given on this point.

8. The Nitrogen Problem.

Nitrogen is undoubtedly the limiting element of crop production in this soil. The amount present is only 0.028 per cent, and the amount is practically constant with depth. The ploughed surface of this soil to a depth of say seven inches would weigh approximately 2,000,000 pounds per acre. Therefore, there would be only 560 pounds of nitrogen in this much soil, while one year's growth of the number of apple trees necessary to produce a 600 bushel crop of apples would remove 112 pounds of nitrogen per acre. It can thus be readily seen that nitrogen is the limiting element of plant production of this soil, and that nitrogen must be added in some form or another and that very soon.

All of the nitrogen of the soil must first be converted from the organic form to the form of nitrates by the process of nitrification before it can be utilized for plant production. Nitrification is a process which is caused by the action of bacteria. These bacteria must have oxygen for their growth and it has been determined for our arid soils that this process does not ordinarily take place to any appreciable extent below four feet. Therefore, the nitrogen available even for a deep rooted plant like a tree would only be that in the first four feet. The first four feet of the soil of this farm would weigh approximately 16,000,000 pounds and the maximum amount of nitrogen available for crop production in the surface four feet of soil would be 4480 pounds, a little more than the average contained in the ploughed surface of sandy soils of America. That is, there would be enough nitrogen present to support an orchard for not over forty years. But it is probable that long before that time the orchard would be nitrogen hungry. This is not theory but calculated facts based upon accurate chemical and mathematical data. The following table compiled by Hilgard* can be profitably studied in this connection.

TABLE XI.

Practical Rating of Soils by Plant Food Percentages, According to Professor Maercker, Halle Station, Germany.

Grade of Soil.	Potash.	Phosphoric Acid.	Lime— Clay Soil.	Lime— Sandy Soil.	Total Nitrogen.
Poor	Below 0.05	Below 0.05	Below 0.10	Below 0.05	Below 0.05
Medium	0.05—0.15	0.05—0.10	0.10—0.25	0.10—0.15	0.05—0.10
Normal	0.15—0.25	0.10—0.15	0.25—0.50	0.15—0.20	0.10—0.15
Good	0.25—0.40	0.15—0.25	0.50—1.00	0.20—0.30	0.15—0.25
Rich	Above 0.40	Above 0.25	Above 1.00	Above 0.30	Above 0.25

	Potash.	Phosphoric Acid.	Lime.	Nitrogen.
Average for California	0.70	0.08	1.08	0.11
Average for Arid Region	0.73	0.12	1.36	0.11
Average for Humid Region	0.22	0.11	0.11	0.12

* Hilgard, Soils, p. 369.

The nitrogen which is so markedly deficient in the soil of this farm may be added in one of three ways, by the addition of barnyard manure, ploughing under of legumes, or purchase of commercial nitrogen.

Another way of emphasizing the same truth is to consider the ability of this soil to produce some common farm product. The sugar beet is a common crop in Utah, although it is not grown in this section and probably never will be. A twenty-ton crop would be regarded as a good crop for Utah soils to produce although many of our soils do far better. The soils of the Southern Utah Experiment Farm contains only 560 pounds of nitrogen in the ploughed surface of the soil. Assuming that the beet crop can draw on the food supply of the full surface foot of soil, there would be available 1020 pounds of nitrogen for the production of a sugar beet crop. A twenty-ton crop of sugar beets would remove from the soil 100 pounds of nitrogen. There would be, therefore, only nitrogen enough for eleven such crops in this soil. Of course under such conditions maximum crops of twenty tons would be impossible and the soil would probably produce indifferent crops from the beginning. Nitrogen is the limiting element of crop production in this soil

b. ALKALI IN THE SOIL.

The "alkali" in the soil was determined as follows: 50 grams of the soil were treated with 500 cc of distilled water and allowed to stand with occasional shaking for 24 hours. The aqueous extract was separated from the residue by filtration with a Chamberlain-Pasteur filter. An aliquot portion of the filtrate was evaporated to dryness and the residue weighed. This weight represents the total "alkali" or water-soluble salts. A second portion of the filtrate was used for the determination of chlorine by the silver nitrate volumetric method. The chlorine found was reported as sodium chloride. The residue obtained from the determination of the total salts was redissolved in water with the addition of a few drops of hydrochloric acid, and in this solution the sulphuric acid was determined by precipitation with barium chloride as barium sulphate. In a third portion of the filtrate the amount of calcium was determined and the results reported as hydrated calcium sulphate. Any excess of sulphuric acid was regarded as combined with sodium and reported as sodium sulphate. A fourth portion of the filtrate was used for the determination of black alkali by tritration against a $\frac{N}{50}$ sulphuric acid solution. The result was reported as sodium carbonate.

TABLE XII.

Average Composition of Alkali in Plot A.

(Each result is the average of ten separate determinations.)

Depth	1st foot.	2d foot.	3d foot.	5th foot.	10th foot.
Total Soluble Salts...	0.58	1.57	2.30	2.41	2.77
Calcium Sulphate.....	0.29	1.53	1.90	2.03	2.34
Sodium Chloride.....	0.03	0.04	0.02	0.05	0.06
Sodium Carbonate....	0.09	0.07	0.07	0.07	0.10
Sodium Sulphate......	0.10	0.22	0.41	0.29	0.29

1. Alkali In the Soil of Plot A.

In the first foot of Plot A there is a total soluble salt content of 0.58 per cent. The total increases with depth to a maximum in the tenth foot. This increase is due to the increase in the percentage of gypsum or calcium sulphate as is distinctly shown in table 12. The amount of sodium chloride, or common salt, is very small and is constant with depth. The content of sodium carbonate is small and is almost constant with depth. The sodium sulphate is small and the content increases slightly with depth. A careful study of the table clearly shows that an average of 88 per cent of the water soluble salts or total "alkali" consists of gypsum.

2. Alkali in Soil of Plot B.

A study of Table 13 shows that the total soluble salts in the first two feet are slightly higher than in the corresponding portion of Plot A. The total soluble salt content in the deeper portions is practically the same as in Plot A. Again, the increase is due to an increase of gypsum. The sodium chloride and sodium carbonate contents are practically the same as before. The sodium sulphate content is slightly lower. A study of this table shows that 83 per cent of the total water-soluble salts or "alkali" is gypsum.

TABLE XIII.

Average Composition of Alkali in Plot B.

(Each result is the average of ten separate determinations.)

Depth	1st foot.	2d foot.	3d foot.	5th foot.	10th foot.
Total Soluble Salts	0.98	2.33	2.21	2.29	2.52
Calcium Sulphate	0.74	2.06	1.99	1.98	1.98
Sodium Chloride	0.04	0.09	0.03	0.03	0.03
Sodium Carbonate	0.07	0.05	0.05	0.05	0.06
Sodium Sulphate	0.07	0.02	0.15	0.20	0.02

3. Alkali In Soil of Plot C.

A study of Table 14 shows that the total alkali content is slightly greater in the surface foot of Plot C, as compared with the other plots, and that the increase again is due to an increase of gypsum. In the lower depths, the total salts and the gypsum differs little from that of the previous plots. The sodium chloride is slightly higher. The sodium carbonate is practically the same as before and is constant with depth. The sodium sulphate is practically the same as before. A study of the table shows that 80 per cent of the water-soluble salts is in the form of gypsum.

TABLE XIV.

Average Composition of Alkali in Plot C.

(Each result is the average of ten separate determinations.)

Depth	1st foot.	2d foot.	3d foot.	5th foot.	10th foot.
Total Soluble Salts	1.24	2.10	2.51	2.18	2.84
Calcium Sulphate	0.90	1.57	2.11	1.84	2.42
Sodium Chloride	0.08	0.12	0.06	0.05	0.04
Sodium Carbonate	0.06	0.06	0.06	0.06	0.07
Sodium Sulphate	0.16	0.25	0.34	0.16	0.22

4. Alkali In Soil of Plot D.

A study of Table 15 shows a marked increase in the water-soluble salts and that the increase is due in the main to an increase of gypsum. The sodium chloride is lower than in Plot C, and is constant with depth. The sodium carbonate is higher in the surface foot. The sodium sulphate is higher throughout. Again we learn by a study of the table that 78 per cent of the water-soluble salts consists of gypsum.

TABLE XV.

Average Composition of Alkali in Plot D.

(Each result is the average of ten separate determinations.)

Depth	1st foot.	2d foot.	3d foot.	5th foot.	10th foot.
Total Soluble Salts...	2.34	2.82	2.87	2.66	2.80
Calcium Sulphate.....	1.60	2.16	2.49	2.14	2.16
Sodium Chloride.....	0.04	0.05	0.05	0.04	0.04
Sodium Carbonate....	0.16	0.08	0.06	0.06	0.06
Sodium Sulphate.....	0.31	0.24	0.35	0.28	0.31

5. Average Composition of the Alkali in the Soil of the Farm.

The results given in Table 16 are the average of forty separate analyses and therefore indicate the truth very closely. The total salts are at a minimum in the surface soil and increase to a maximum in the tenth foot. The calcium sulphate increases in the same order. The sodium chloride content is small and is practically constant with depth. The sodium carbonate approximates one-tenth of one per cent and decreases slightly with depth. The sodium sulphate approximates about two-tenths of one per cent, and varies very slightly with depth. The table indicates that 81 per cent of the total salts or total "alkali" is in the form of gypsum.

TABLE XVI.

Average Composition of Alkali in Southern Utah Experiment Station.

(Each result is the average of forty separate determinations.)

Depth	1st foot.	2d foot.	3d foot.	5th foot.	10th foot.
Total Soluble Salts....	1.29	2.20	2.47	2.39	2.73
Calcium Sulphate......	0.91	1.83	2.14	1.99	2.22
Sodium Chloride......	0.05	0.07	0.04	0.04	0.04
Sodium Carbonate.....	0.10	0.07	0.06	0.06	0.07
Sodium Sulphate......	0.16	0.18	0.31	0.23	0.21

7. The Analysis of Composite Samples.

The significance of the results obtained led us to confirm the method of calculation of the chlorides, carbonates and sulphates by the complete analysis of representative samples. Therefore, four composite samples representing the first, third, fifth and tenth feet were made by weighing out 10 grams of each of the foot sections corresponding to those represented in Table 16. The averages of the determinations are given in Table 17.

TABLE XVII.

Composition of Water-Soluble Material of Composite Samples.

(Results reported as per cent of dry soil.)

Lab. No....................	71233	71234	71235	71236
Depth of Sample...........	1st foot.	3d foot.	5th foot.	10th foot.
Total Solids................	1.55	2.67	2.68	2.85
Sodium Chloride............	0.043	0.037	0.033	0.038
Sodium Sulphate............	0.148	0.086	0.118	0.091
Potassium Sulphate.........	0.045	0.036	0.030	0.029
Sodium Carbonate..........	0.052	0.052	0.075	0.097
Hydrated Calcium Sulphate.	1.340	2.410	2.430	2.470

One hundred grams of each of these composite samples were extracted with one litre of distilled water for twenty-four hours, filtered through a Chamberlain-Pasteur filter and the solution thus obtained was submitted to analysis. Actual determinations were made of potassium, sodium, sulphuric acid, chlorine, calcium, magnesium, and aluminum. From this data calculations were made of the probable state of combination in which the various substances occurred in the soil. The results obtained are reported in Table 17. The results obtained confirm in an emphatic way those already obtained, as may be readily seen by comparing this Table with Table 16. The sodium chloride and the sodium carbonate are in remarkable accord. Total salts are slightly higher, due to the greater extraction of gypsum. The results indicate that some potassium sulphate is present and when taken into consideration with the presence of water-soluble alumina would seem to indicate the existence of a little potassic alum in the soil. The conservative character of the method followed of estimating the sulphates may be readily seen by an examination of Table 18. In this table the sulphates calculated from the excess sulphuric acid and reported as sodium sulphates are compared with the sodium and potassium sulphates as calculated from the actual determination of sodium potassium. These determinations clearly indicate that the method of reporting the sulphates at any rate fully reports all of the sulphate present in the form of alkali sulphates.

TABLE XVIII.

Sulphates as Calculated and Reported. Sodium and Potassium Sulphates as Determined.

Depth of Sample...............	1st foot.	3d foot.	5th foot.	10th foot.
Sulphates as Calculated........	0.27	0.25	0.13	0.20
Sodium and Potassium Sulph...	0.19	0.12	0.15	0.12

The method of reporting the calcium sulphate is also very conservative. This may be demonstrated by a study of Table 19. In this table the hydrated calcium sulphate as calculated from the calcium and reported, is compared with hydrated sulphate as calculated from all of the sulphuric acid present and also as calculated from the loss of water of crystallization (1) when the total solids are heated with a blast lamp.

TABLE XIX.

Calcium Sulphate as Determined by Several Methods.

Depth of Sample	1st foot.	3d foot.	5th foot.	10th foot.
Calculated from Water of Crystallization	1.69	2.65	2.71	2.86
Calculated from Sulphuric Acid	1.67	2.51	2.58	2.71
Calculated from Calcium	1.34	2.41	2.43	2.47

The results clearly indicate that only the minimum amount of calcium sulphate actually present has been reported. The slight excess of calcium sulphate as calculated from the water of crystallization offers additional evidence of the existence of some potassic alumina sulphate which has 24 molecules of water of crystallization.

8. Discussion of the Alkali Problem.

A consideration of the data pertaining to alkali in this soil would not cause it to be classified as an alkali soil. It is difficult to determine what percentage of the sulphate, carbonate, and chloride of sodium may be present and yet not be detrimental to plant growth. All may be present in greater or smaller quantity in all our arid soils, even in the best agricultural soils that we have. The important question is: What is the maximum amount which may be present and yet not be detrimental to crop production? This amount undoubtedly varies with the kind of soil and the treatment it receives. Hilgard, for the sandy soil of the Tulare sub-station, gives the percentage as one-tenth of one per cent of sodium carbonate, one-fourth of one per cent

1. The water of crystallization was determined by Mr. Wallace Macfarlane in a piece of crystallized gypsum, obtained near the farm, from a ledge which had undoubtedly contributed to the formation of the soil. Very concordant duplicate determinations showed conclusively that the gypsum contained two molecules of water of crystallization.

of sodium chloride and forty-five to fifty-one hundredths of one per cent. of sodium sulphate. In no case in the soil of this farm does the percentages approach these limits but fall far below them. Of course the soil is different. The presence of gypsum and its effect, favorable, or unfavorable, is an unknown factor. It may be that in the presence of gypsum the plant can withstand a greater or less amount of alkali. This needs to be determined by careful experimentation in the greenhouse. We do know, however, that gypsum is one of the most powerful plant stimulants we have. The presence of such amounts of gypsum as are present would cause the plant to make a rapid growth* as long as sufficient plant food was available, but as soon as the supply of one or more of the essential elements had been nearly exhausted the gypsum would still stimulate the plant to greater growth, but one of the essential foods being lacking the plant would be in a weakened condition and under such conditions would be unable to resist external influence such as in roads of plant diseases, effect of alkali, action of frost. Under normal conditions, such an amount of alkali would not be considered harmful but under the conditions of this farm it may be. The deficiency of nitrogen, however, is the fundamental cause of non-production and this deficiency must be made up first. The plant, like the animal, demands a balanced food. It would be difficult to secure even under artificial conditions a more unbalanced food than we actually have in the soil of this farm. The supply of nitrogen is limited, while the gypsum is constantly liberating the potassium and the essential elements from their insoluble compounds, and as a result we have too much available potassium and other elements and too little nitrogen. The natural result is a weakened condition of the plant and as a result there is liability to disease and death. Sometime in the future conditions may arise such as to render drainage necessary. Conditions may actually be such now as to render

---

* It is the common experience of farmers in this district that fruit trees make a marvelously rapid growth during the first few years of their life.

drainage necessary. But drainage alone is absolutely useless. It will not remove the cause of the trouble, but only magnify the trouble, since drainage will not only remove the alkali, but also the soluble nitrogen. These investigations do not necessarily solve the problem of the non-productiveness of this soil, but they furnish a basis upon which an intelligent solution of the problem may be made and the soil converted in a productive one.

9. Acknowledgements.

The authors wish to acknowledge their indebtedness to Mr. W. C. Snow, formerly Assistant Chemist, for the complete analysis of the soil, and to Mr. Wallace Macfarlane, Assistant Chemist, who made the complete alkali analysis of the composite samples.

CONCLUSIONS.

1. The soil of the Southern Utah Experimental Farm has been formed by the Virgin River, which has carried the material from the Terrace country of the High Plateaus.

2. The soil of this farm is very sandy in nature and contains crystalized gypsum.

3. The soil contains a normal amount of potassium, but a low amount of phosphorus and is extremely deficient in humus and nitrogen.

4. Nitrogen is the limiting element of plant production.

5. The soil contains a good supply of the other essential elements of plant food and well supplied with calcium carbonate. It contains a high percentage of magnesium.

6. The soil would not be classified as an alkali soil, although it contains small amounts of sodium chloride, sodium sulphate, and sodium carbonate.

7. The plot which is now producing the best crops (Plot D), contains the highest amount of alkali.

8. The soil contains a high percentage of water-soluble salts, but four-fifths of this "alkali" is gypsum, or hydrated calcium sulphate.

9. Conditions may arise in the future which will render drainage necessary, but drainage now alone will only aggravate the trouble.

10. Since the maximum supply of nitrogen is only sufficient for the maximum production of a producing orchard for forty years, the problem of adding nitrogen to the soil must be solved first of all.

11. These investigations ought to serve as a basis for the intelligent solution of the problem of non-productivity of the soil and help the converting of the soil into a very productive and profitable one.