THE EFFECT OF ORGANIC MATTER ON "AVAILABLE SOIL WATER"

by

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INTRODUCTION

Early in the history of agriculture, the value of organic manures came to be recognized. Manures benefited the soil as reflected in the growth and yield of crops. The effect of organic matter was rapid and influenced their continued use to the present time. It influences the soil physically, chemically, and biologically. As a result of studies of the physical effects of organic matter, it came to be recognized that the soil moisture-holding capacity was increased thereby. The question arises as to whether there is any improvement in "available soil water"[1] and the exact nature of its effect on the useful moisture.

The primary purpose of this experiment was to study the effect of soil organic matter on the available range, and the amount of useful water a soil may hold. Consid-

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1. "Available soil water" as used herein is measured by the range between the point of <u>permanent wilting percentage</u> as its lower limit and the <u>moisture equivalent</u> as the excess point.

eration was also given to the effect of the organic matter level in virgin and old cultivated soils of the same type throughout the state. It is general knowledge that maintenance of organic matter in cultivated soils is necessary for optimum growth and soil conditions. Conservative use of water is especially important to the farmer who is interested in irrigation.

Within the last few years, the committee on Physics of Soil Moisture of the American Geophysical Union, whose chairman is Dr. F. J. Veihmeyer, has made a nationwide review of several problems concerning soil water. There is a divergent opinion as to whether organic matter will affect the available water in a soil. Veihmeyer, et al (1935, 1938).

Does soil organic matter improve soil water relations only indirectly? It is supposed that the addition of manure, or other organic material, can directly affect the soil moisture constants and favorably affect the capillary range.

Using water efficiently is still a major problem of irrigation farming, and its conservation is to the interest of those living on arid soils.

Herein is an attempt to clarify this situation by the experimental procedure.

HISTORICAL REVIEW

Systematic study of organic matter and soil moisture relations has only been recently made; however, the earliest demonstrations of the effect of manure on physical properties of the soil were first shown by Shyler and Davy in the early part of the nineteenth century. Keen (1917).

In the early part of the twentieth century, work was done on the effect of organic matter in a soil and the specific effects on soil moisture relations. Mosier (1905) noted the loss of organic matter and its effects on the physical properties of soils from the Morrow plats at the Illinois Agricultural Experiment Station. From this, he stated that its loss was detrimental to water-holding capacity of the soil. Later, Mosier (1906) gave reasons for the influence of organic matter as:

(1) Increasing the storage capacity and absorbent power for water, and

(2) Preventing evaporation by its retentive power.

The organic colloid is highly retentive of water, as Feustal (1936) found in his experiments with peat. Peat is capable of holding water several times its own dry weight. Mosier (1906) found that additions of peat to sand appreciably affected retention of water. Nystrom (1930) used peat in field trials as a means for improvement of poor sand soils, and found that under normal rainfall, the treatment of soil moisture was noticeably increased. Keen (1927) adds that the moisture content of unmanured and manured plats vary, the latter having a five per cent additional moisture.

The question of the organic matter effect on the available moisture has been studied by several prominent workers, with divergent results.

On the Minnesota University Farm, Alway and Neller (1919) reported that "the surface foot showed a very marked difference in the moisture content, especially in the available portion; the soil that was the richer in organic matter retaining the more water."

Quite recently Yoder (1937) reported that organic matter raised and widened the moisture range in which tillage operations were effective. Duncan (1938) suggested that the presence of large amounts of organic materials in surface soils may account for differences in moisture equivalents. His data was incomplete as to its effect on the available water. Powers (1939) supports Yoder by showing the effect of irrigation and manure as to increase the available water over the controls, the irrigated manured plat having the wider range.

Recent work by Bouyoucos (1938) reports data showing an agreement with these workers mentioned above. He concludes that "although organic matter does tend to increase the total water-holding capacity of mineral soils, it also increases their wilting point, the result being that the amount of available water is not greatly affected." He obtains this wilting point by the dilatometer method, and using no plants. Correlation of the increase is comparable by either weight or volume basis. However, there was a greater increase in available water capacity in the lighter soils than in the clays. In the latter, the volume weight changed but little by organic matter additions.

Recently Stone and Garrison (1940) at Michigan showed favorable correlation between available water and organic matter in soils varying from loamy sand to clay loam, with samples taken from cultivated fields and adjacent soil under fence lines. Supporting this line of thought, Keen (1927) states that well-rotted manure is "far more effective on sandy soils for it helps aggregate the soil, indirectly, improving the water-holding capacity of the soil. The effective difference in available water is directly related to the modification of structure by organic matter."

However, in disagreement with the theory brought out by the above discussion, work done by Veihmeyer and Hendrickson (1938) led them to conclude after considerable study, that "neither the permanent wilting percentage nor the field capacity can be changed greatly by the application of organic matter or other fertilizers."

EXPERIMENTAL PROCEDURE

The plan of using soils of different texture has been followed in experiments contained herein. The four soils used were Newberg sandy loam, Chehalis fine sandy loam, Willamette silty clay loam, and Wapato silty clay loam.

Methods and Materials:

Chemical and physical determinations made on these soils and soil mixtures were as follows:

Wilting point determination was by the sunflower method. A variety of dwarf sunflowers was used. Seedling plants were transplanted and allowed to grow to six or eight inches high. The allowance of two of the apical leaves to wilt at this height was considered to be the wilting point of the soil or soil mixture. This procedure is similar to that described by Work and Lewis (1934).

Moisture equivalents were found by using the method of Briggs and Shantz as described by Work and Lewis (1934). Results from the soil mixtures are the averages of four trials. Average determinations were used for the illustrations.

Organic matter was determined by Alexander's modification of the Rather method. Alexander and Byers (1932). Silt and clay determinations were made by the Bouyoucos method using the hydrometer. Bouyoucos (1934). Nitrogen was determined by the Kjeldahl method.

Characteristics of these soils are presented in Table I.

The selection of these soils represent a wide variety of textural classes. By using these soils, the effect of the organic amendments on each type of soil could be determined. A representative light-textured soil of the Willamette Valley is the Newberg sandy loam. Gradually increasing in texture is Chehalis fine sandy loam which is of medium texture. The heavier-textured soilsare those represented by Willamette silty clay loam

TABLE 1. CHARACTERISTICS OF THE SOILS USED

Soil Type	Wilting Point		Moisture Equivalent	Mechanical Analysis sand	silt	clay	Organic Matter	Total Nitrogen
	per cent		per cent	per cent	per cent	per cent	per cent	per cent
Newberg Sandy Loam	6.18	0.12	13.3	78.54	12.00	9.46	1.10	0.110
Chehalis Fine Sandy Loam	10.03	0.15	26.7	54.08	26.00	19.92	2.72	0.483
Willamette Silty Clay Loam	9.89	0.15	31.4	12.08	48.52	39.4	3.71	0.538
Wapato Silty Clay Loam	13.18	0.17	31.3	31.08	32.00	36.92	3.55	0.523

and Wapato silty clay loam.

With these soils, it is interesting to note that all the determinations made gradually increase with the texture. Variation in capillary and non-capillary pore space as well as sand, silt, and clay ratios, are influenced. Organic matter and total nitrogen show a general increase with the increase in texture.

Organic Amendments:

The forms of organic matter added were alfalfa meal, neutral peat, and barnyard manure. Each material was added to portions of each soil to the amount of two, four, and eight per cent, based on dry weight. Moisture contents which these materials used are shown in Table II. Additions were made on a dry weight basis.

TABLE II

CHARACTERISTICS OF ORGANIC AMENDMENTS

Amendment	Field Moisture Content	Organic Matter
Alfalfa Leaf Mold	15.5	85-93
Labish Reed Peat	230.0	70-90
Barnyard Manure	260.0	40-50

Figures are given in percentages.

The alfalfa meal was pure and finely ground. The fine-textured neutral peat was obtained from Lake Labish, located five miles north of Salem, Oregon. The horse manure was passed through a five millimeter mesh screen before being added to the soil.

Experiments With Newberg Sandy Loam:

Newberg sandy loam is a recent, river-bottom soil. The topography is rolling. It is the lightest of the soil types found in the Willamette Valley and has excellent drainage, due to the sandy condition of the soil. The effect of organic matter additions in moisture relations is shown in the upper part of Table III and Figure 1.

The mixtures of Newberg sandy loam gave definite increases in available water with peat and alfalfa meal mixtures. There was some increase in available water with the use of manure. Alfalfa meal gave the largest increase for the wilting point. Possibly the dryness of the alfalfa meal and the minute particles held water that was unavailable to the plants. Better results were given by the peat, showing a small rise in wilting point, but a larger increase in the moisture equivalent. Barnyard manure in this soil gave an increase in available

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ORGANIC AMENDMENTS

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NEWBERG SANDY LOAM

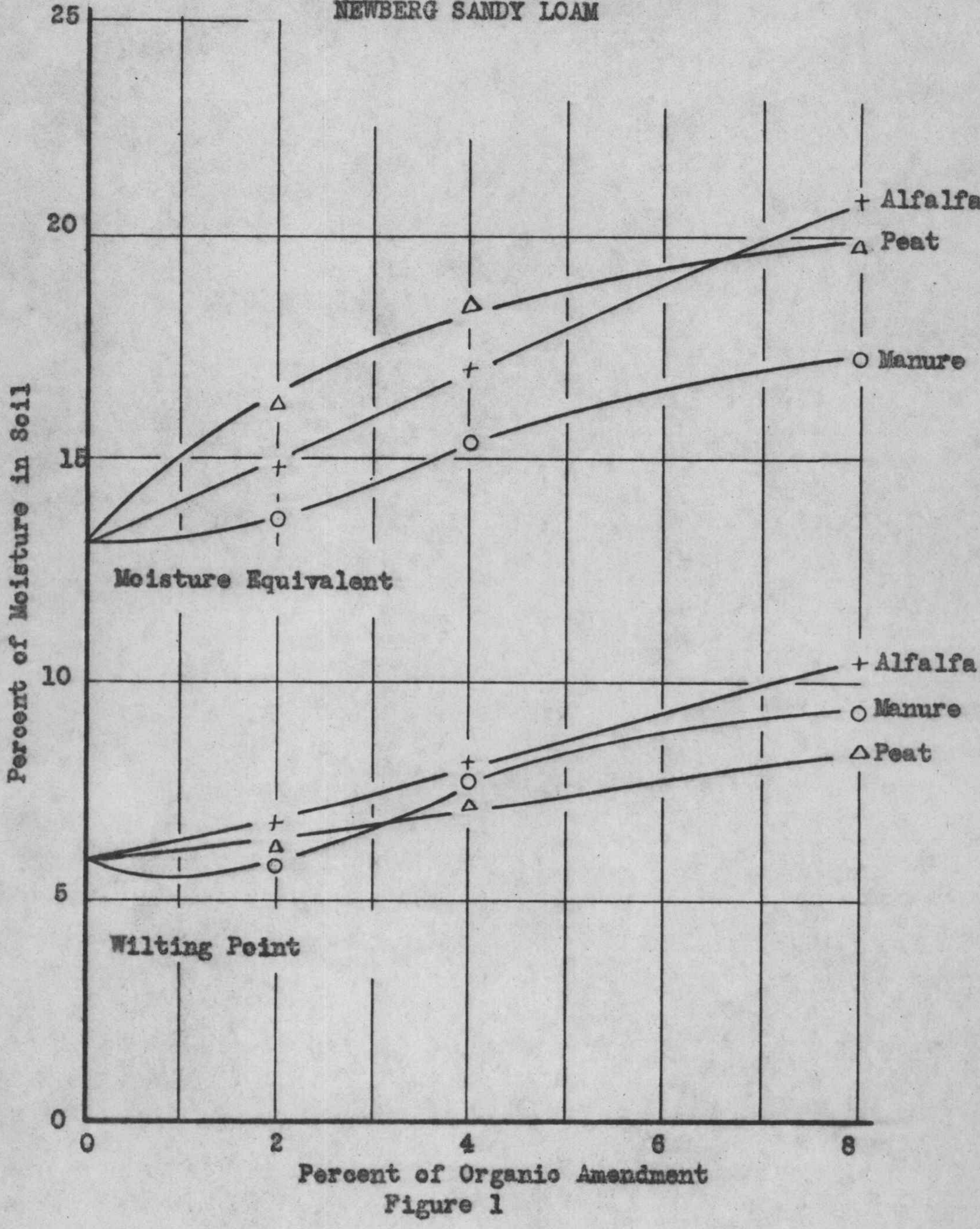

Figure 1

TABLE III. EFFECT OF ORGANIC MATTER ON USEFUL WATER CAPACITY OF NEWBERG SANDY LOAM AND CHEHALIS FINE SANDY LOAM

Soil Type	Depth	Treatment and Rate	Wilting Point Average		Wilting Point Gain	Moisture Equivalent Average	Moisture Equivalent Gain	Increase in Available Water
	Inches	per cent	per cent		per cent	per cent	per cent	per cent
Newberg								
Sandy Loam	0-12	none	6.18	0.15	----	13.3	----	----
Sandy Loam	0-12	alfalfa meal 2	7.31	0.38	1.13	15.4	2.1	1.07
Sandy Loam	0-12	alfalfa meal 4	7.74	0.42	1.56	17.35	4.05	2.49
Sandy Loam	0-12	alfalfa meal 8	10.76	0.90	4.58	20.6	7.35	2.77
Sandy Loam	0-12	neutral peat 2	6.90	0.68	0.81	18.9	5.6	4.79
Sandy Loam	0-12	neutral peat 4	7.52	0.24	1.34	18.9	5.6	4.26
Sandy Loam	0-12	neutral peat 8	8.18	0.25	2.00	20.2	6.9	4.90
Sandy Loam	0-12	manure 2	6.41	0.03	0.23	14.2	0.9	0.67
Sandy Loam	0-12	manure 4	8.05	0.02	1.87	15.9	2.3	0.43
Sandy Loam	0-12	manure 8	9.34	0.20	3.16	17.3	4.0	0.34
Chehalis								
Fine Sandy Loam	0-12	none	10.03	0.15	----	19.9	----	----
Fine Sandy Loam	0-12	alfalfa meal 2	10.62	0.24	0.59	21.1	1.0	0.31
Fine Sandy Loam	0-12	alfalfa meal 4	10.75	0.22	0.72	22.9	3.0	2.28
Fine Sandy Loam	0-12	alfalfa meal 8	18.7	0.95	8.63	25.6	5.8	-2.70
Fine Sandy Loam	0-12	neutral peat 2	10.59	0.25	0.56	25.2	3.9	3.36
Fine Sandy Loam	0-12	neutral peat 4	10.56	0.10	0.83	28.2	8.4	7.57
Fine Sandy Loam	0-12	neutral peat 8	11.88	0.19	1.83	29.7	9.5	7.67
Fine Sandy Loam	0-12	manure 2	9.97	0.18	-0.06	25.1	5.2	4.60
Fine Sandy Loam	0-12	manure 4	10.09	0.18	0.87	25.6	5.7	4.83
Fine Sandy Loam	0-12	manure 8	13.17	0.02	3.64	28.1	8.3	5.16

water but the increase was small, with wilting point and moisture equivalent increasing accordingly.

<u>Experiments With Chehalis Fine Sandy Loam</u>:

Chehalis fine sandy loam is also a recent soil that is adjacent to the Newberg series but is slightly higher in elevation. The topography is quite level. The soil is slightly heavier than the Newberg soils and has definite horizons. Drainage is excellent. Table III and Figure 2 show the effect of organic matter on Chehalis fine sandy loam.

With Chehalis soil, the increase in wilting point of the soil mixtures is small. Moisture equivalent increased and widened the range of useful water with increase in the amount of amendment.

The available range is widened to some extent with two and four per cent mixtures of all the amendments, with the moisture equivalents giving the most significant increase. The wilting point with the eight per cent mixture is extremely high and apparently incorrect. With the peat additions, the wilting point was not increased significantly, while moisture equivalents substantially increased with the amount of the material added. A decided increase in available water is clearly

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CHEHALIS FINE SAND LOAM

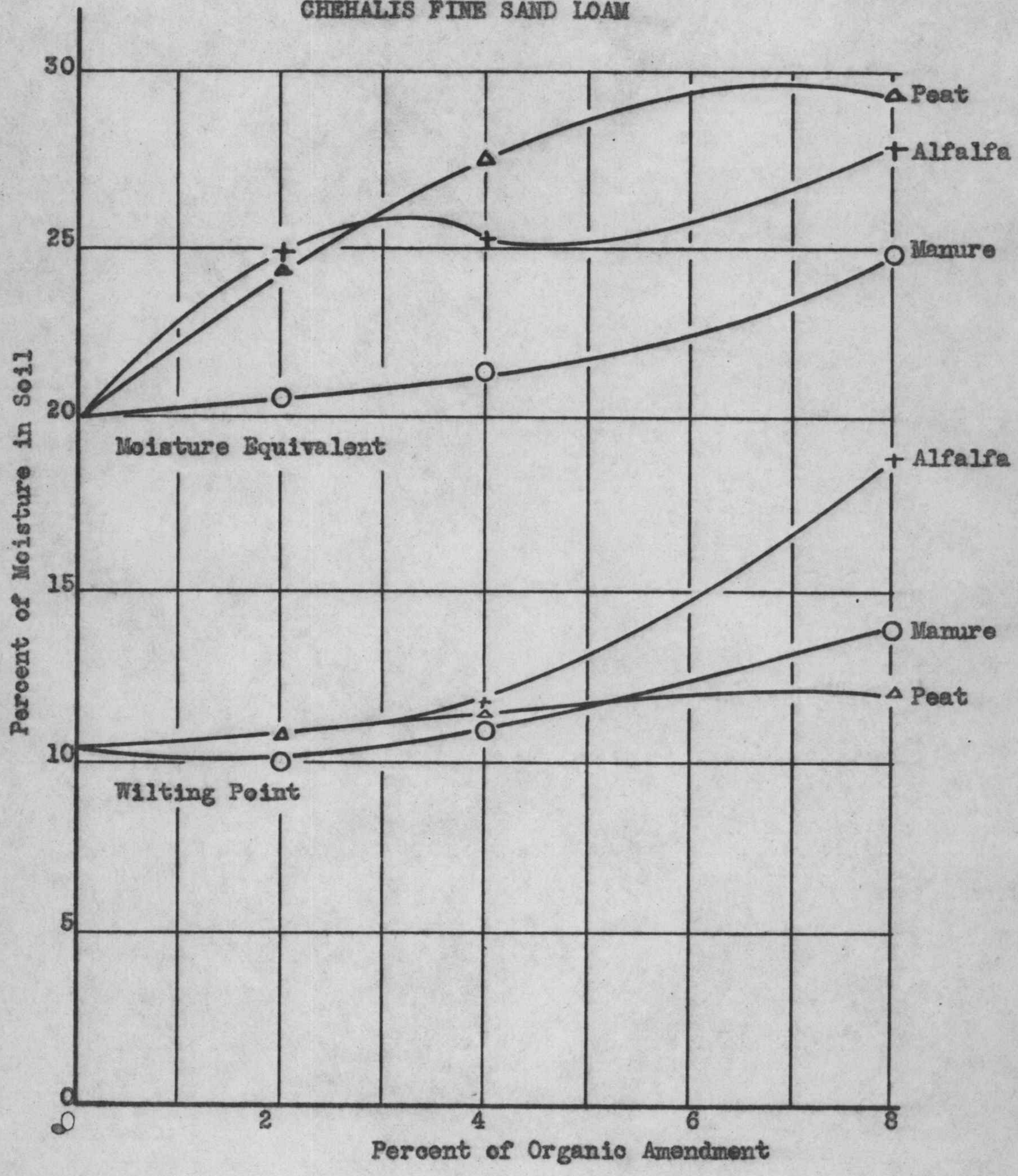

Figure 2

shown. When barnyard manure was added, it produced the largest significant increase in wilting point, but this was offset by an increase in the moisture equivalent, which widened the range of available water.

These results are as significant as those for the Newberg soil. The range is somewhat increased in the Chehalis soil organic mixtures, and beneficial results are obtained from the use of the manure.

Experiments With Willamette Silty Clay Loam:

The Willamette soil series is found above the stream terraces formed by the Willamette River. These soils are formed by old valley formations. This series is predominantly silty clay loam, has level topography, and is slightly higher in elevation than the Newberg and Chehalis soil series. It is a mature soil and has good drainage.

The results of the trials on Willamette soil shows no correlation of the amount of organic matter to the mixtures; although there is an increase in available water. This effect is shown in Table IV and Figure 3.

With the use of peat and manure amendments, there is no increase in the available water. The only significant increase is the four per cent mixture of alfalfa meal.

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WILLAMETTE SILTY CLAY LOAM

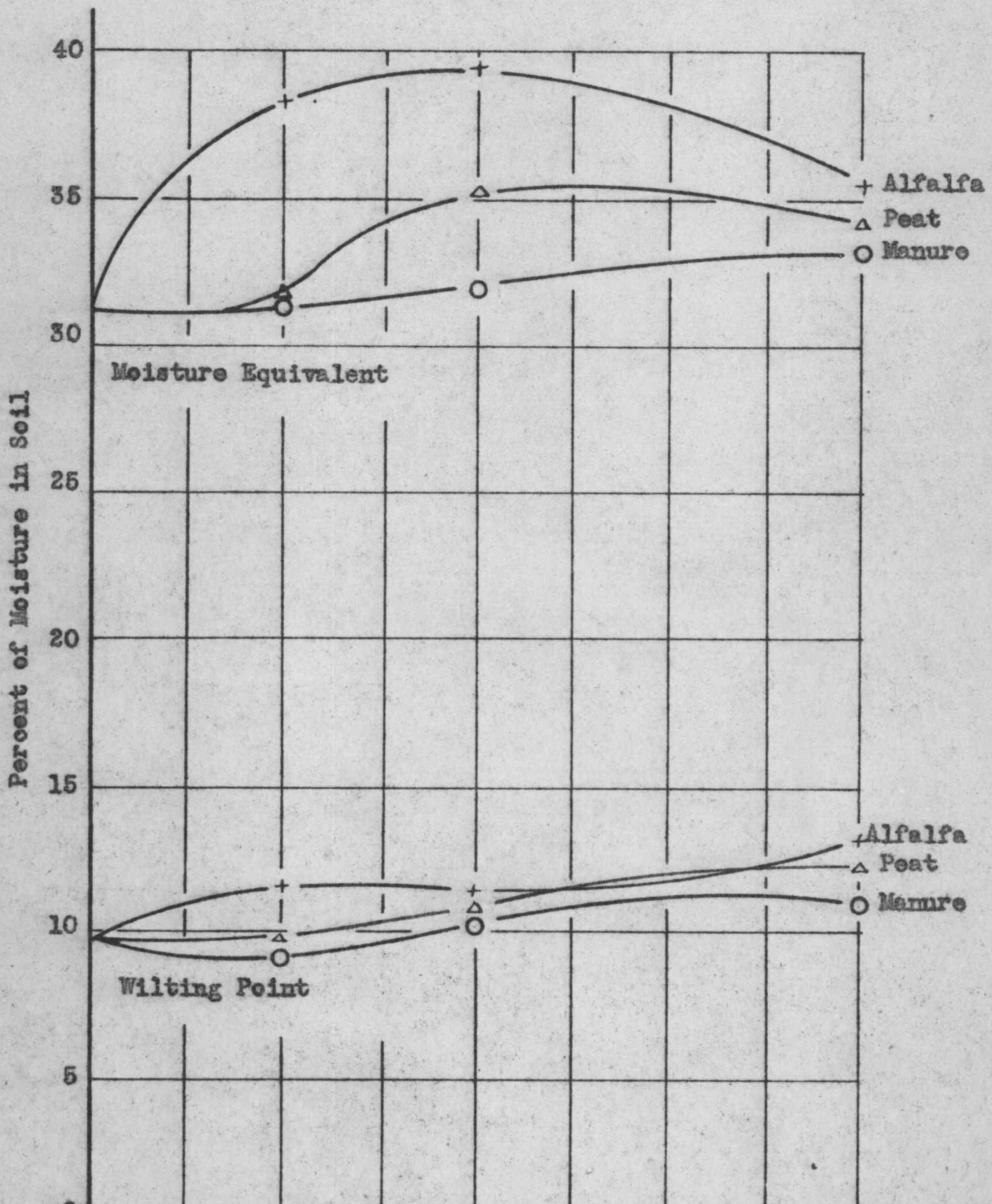

Figure 3

TABLE IV. EFFECT OF ORGANIC MATTER ON USEFUL WATER CAPACITY OF WILLAMETTE SILTY CLAY LOAM AND WAPATO SILTY CLAY LOAM

Soil Type	Depth	Treatment and Rate	Wilting Point Average		Wilting Point Gain	Moisture Equivalent Average	Moisture Equivalent Gain	Increase in Available Water
	Inches	per cent	per cent		per cent	per cent	per cent	per cent
Willamette								
Silty Clay Loam	0-12	none	9.89	0.15	----	31.5	----	----
Silty Clay Loam	0-12	alfalfa meal 2	9.89	0.22	0.00	36.9	5.95	5.95
Silty Clay Loam	0-12	alfalfa meal 4	10.70	0.28	1.59	27.9	6.50	4.91
Silty Clay Loam	0-12	alfalfa meal 8	13.03	0.76	4.14	35.5	4.00	-0.09
Silty Clay Loam	0-12	neutral peat 2	9.46	0.24	-0.43	31.2	0.35	-0.08
Silty Clay Loam	0-12	neutral peat 4	10.7	0.18	0.81	35.0	3.55	2.74
Silty Clay Loam	0-12	neutral peat 8	11.56	0.18	1.67	34.4	3.00	1.33
Silty Clay Loam	0-12	manure 2	11.43	0.02	1.54	31.1	0.00	-1.54
Silty Clay Loam	0-12	manure 4	11.30	0.03	1.41	32.9	1.4	0.00
Silty Clay Loam	0-12	manure 8	13.60	0.02	3.71	33.6	2.4	-1.31
Wapato								
Silty Clay Loam	0-12	none	13.18	0.17	----	31.3	----	----
Silty Clay Loam	0-12	alfalfa meal 2	13.48	0.22	0.30	32.3	1.05	0.75
Silty Clay Loam	0-12	alfalfa meal 4	14.19	0.11	0.92	35.3	4.00	3.08
Silty Clay Loam	0-12	alfalfa meal 8	22.60	0.28	9.42	33.0	1.75	-7.67
Silty Clay Loam	0-12	neutral peat 2	12.96	0.14	-0.22	31.8	0.5	0.28
Silty Clay Loam	0-12	neutral peat 4	15.03	0.21	1.85	32.3	1.1	0.75
Silty Clay Loam	0-12	neutral peat 8	15.93	0.23	2.75	33.1	0.8	-1.95
Silty Clay Loam	0-12	manure 2	14.46	0.03	1.28	31.3	0.0	-1.28
Silty Clay Loam	0-12	manure 4	14.40	0.63	0.82	32.9	1.6	0.78
Silty Clay Loam	0-12	manure 8	15.67	0.01	2.49	34.2	2.9	0.51

Experiments With Wapato Silty Clay Loam:

Wapato silty clay loam is classified as a recent soil although it is quite similar to Willamette series in types, but it is different in elevation and drainage. The soil is mature and has definite horizons, but it has poor drainage. Level topography and infiltration of fine particles have caused this condition. Drainage can be improved by tiling. The best use for this soil series is that of pasture.

Wapato silty clay loam gave little response to any beneficial change from any organic amendment used. The results were erratic with little or no increase in available water. The impervious condition of this soil and its colloid content makes it impossible to improve favorable relation between the use of the organic amendments. The only significant increase on this soil is the four per cent mixture of alfalfa meal. Table III and Figure 4 support these results.

Determinations On Other Soils:

As a further check on the effect of organic matter, soils from a more arid section of the state were used, and the soil moisture constants were determined. These soils are compared with the virgin condition, and the

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WAPATO SILTY CLAY LOAM

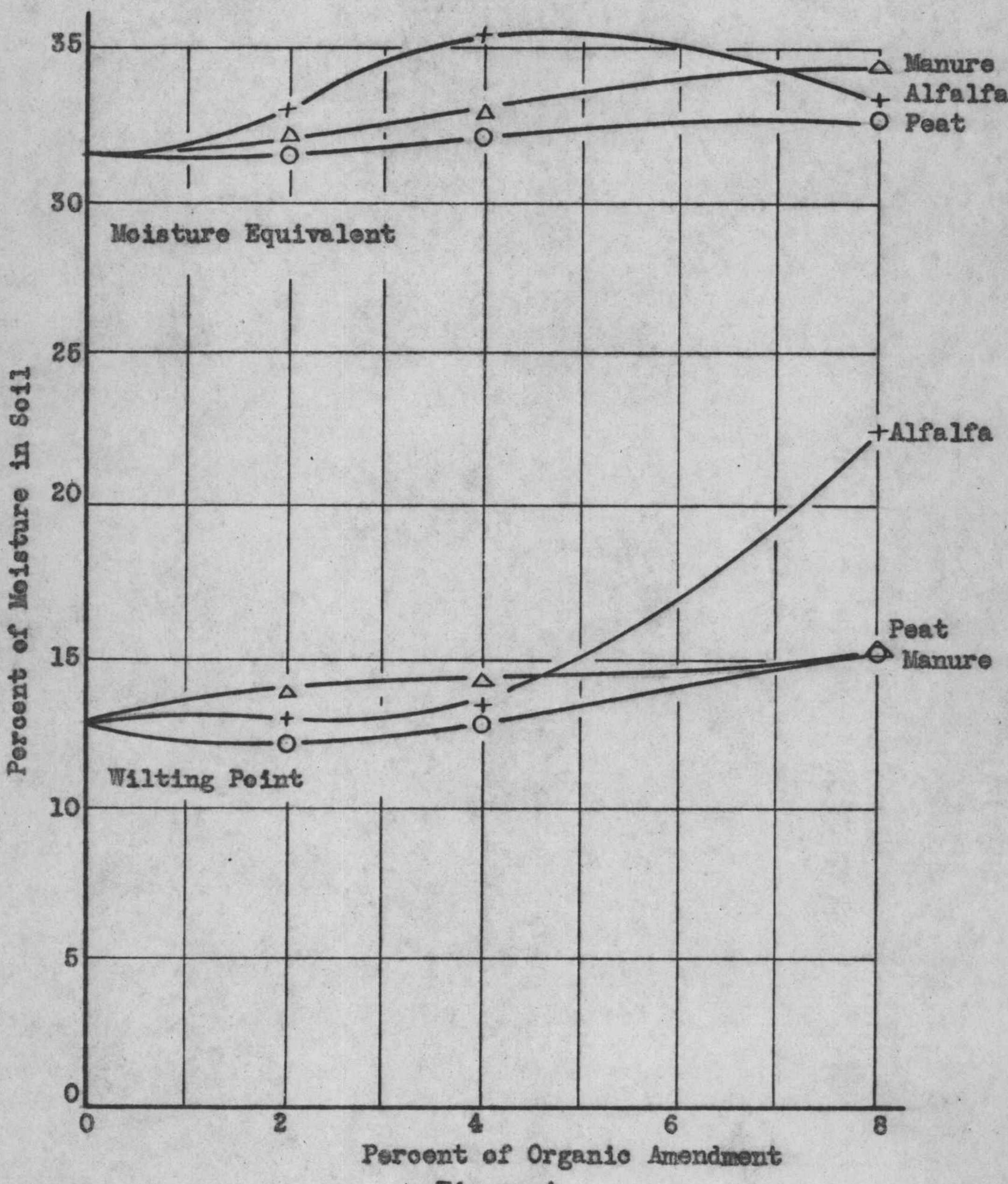

Figure 4

effect of organic matter and irrigation create the difference.

A sandy loam soil from near Sisters, Oregon, having an 1880 water right, and the adjacent virgin land was considered. Determinations of wilting point and moisture equivalents were made. The results were as follows:

TABLE V

COMPARISON OF VIRGIN AND CULTIVATED SOIL
NEAR SISTERS, OREGON

Soil	Wilting Point		Moisture Equivalent	Available water Ave.	Available water Gain
Sisters Sandy loam (cultivated	7.66	0.68	17.0	9.34	---
Sisters Sandy loam (Virgin)	7.66	0.10	18.4	10.74	1.30

The comparison of data for the virgin and cultivated soil from Sisters, Oregon, shows that a decrease in organic matter in the cultivated soils has possibly influenced the amount of available water.

Likewise, trials were made on reclaimed and nearby untreated alkali soil from near Vale, Oregon. In April, 1921, the Oregon Agricultural Experiment Station instituted a series of experimental plats for reclaiming this soil. Samples of soil from Plat A, which received sulfur and manure, and Plat B, untreated, are used; and wilting point, moisture equivalent, mechanical analysis, and organic matter content were taken into consideration.

In the comparison of the reclaimed and untreated alkali soils from the Vale plats, the organic matter content and soil moisture constants were affected. In comparison, the reclaimed soil has a lower wilting point, higher moisture equivalent, increased organic matter, and increased total nitrogen. The particle size of the reclaimed soil is changed, resulting in an increase in amount of clay-size material. The change did not affect the amount of silt-size particles. A reduction of four per cent in amount of sand is shown in Table VI to offset the increase in amount of clay-size particles.

DISCUSSION

The results obtained with the various soil mixtures and other trials were quite significant, but they vary considerably with both the soil series and the kind of organic matter used. With the increase in amount of organic matter, the available water is generally increased accordingly. Comparable results by Bouyoucos (1940)

TABLE VI

DATA ON ALKALI SOILS FROM NEAR VALE, OREGON

Soil Type	Wilting Point	Moisture Equivalent	Available Water	Mechanical Analysis Sand	Mechanical Analysis Silt	Mechanical Analysis Clay-size	Organic Matter[1]	Total Nitrogen[1]
	percent	percent	percent	percent	percent	percent	percent	percent
Vale A Silt Loam (Reclaimed)	15.9 ± 0.05	33.9	18.0	30.58	45.50	23.50	2.39	0.093
Vale B Silt Loam (Unreclaimed)	16.16 ± 0.04	32.2	16.1	34.58	45.50	19.92	1.08	0.046

[1] Ahi and Powers (1938)

agree with the data in Tables III and IV. In his study, using several organic amendments from mixtures ranging from two to sixteen per cent, he obtained better results on the lighter textured soils. This result is similar to those contained herein.

From the nature of the results of these studies, the beneficial effect of an organic matter is most definite in soil of medium texture.

The direct effect of organic matter in a soil is difficult to determine. If it were possible to study a definite soil by depleting it of its residual organic matter without changing any other characteristic it might have, the direct effect it has on soil moisture would be known. However, the nearest approach to this question is the additions of organic matter to the soil and the detailed study of virgin and cultivated soils. A study of this type by Stone and Garrison (1940) found that the organic matter did affect the available water by comparing virgin and cultivated soils of the same series which were lying within a few feet of each other in the field. In a study of this nature, the effect of organic matter cannot be entirely considered the direct result for any increase in available water, but only to a limited extent, since structure, which likewise affects available water, is improved by organic matter incorporated into the soil.

The effects, if any, of residual organic matter on several soils throughout the state were found and agree with the results of Stone and Garrison (1940). The decreased amount of organic matter on semi-arid cultivated soils directly affect and narrow the available range, while alkali soils reclaimed in 1921 by sulfur, manure, and irrigation have shown an increase in organic matter, and in turn, the effect on the upper limits of available water which increased the range of available water.

The plan of using the organic matter in a soil and observing a change, if any, over the soil as a check, seemed a most logical procedure for this study.

It was found that the additions of the organic matter increased both wilting point and moisture equivalent. It was anticipated that the latter increases a greater amount which also would increase the available water.

This appears to have occurred, for the moisture equivalent increased to a greater extent in the lighter and medium textured soils; namely, Newberg and Chehalis. Results were divergent in the heavier soils of the Willamette and Wapato series. Graphic illustrations of organic mixtures of the two latter soils show that there is no increase at all in the range of available water. From this data the effect of the clay colloid offsets any effect of the organic colloid.

The organic colloid is capable of holding hydroscopic water similar to that of clay. The predominance of the clay colloid in the heavier-textured soils probably counteracts any beneficial relationship, so the ratio of non-capillary to capillary water is quite equalized. In the sandy soils this ratio is increased; the soil which has a greater proportion of non-capillary pore-space by intermingling of the colloid in the pores of the soil. The water held by the colloids may not all be available, but the colloid would tend to decrease the pore size to one of capillary size.

Aggregation of the soil particles in any soil will increase the pore-space. The total porosity of the heavier soils used in the trials is greater than the lighter soils that were greatly influenced by the organic matter additions. These results agree with the hypothesis of Free, Browning, and Musgrave (1940). Keen (1927) has stated that the improvement of sandy soils with manure increased the water-holding capacity. This, however, does not prove that available water relations will be favorably affected. If there is some degree of aggregation in the lighter soils, the capillary moisture should be favorably affected. Colloidal material, either organic or inorganic, will help to aggregate the single-grain structure, which in turn will favorably affect the available water. The amount of clay-size particles in the Vale soils was increased through the effect of the residual organic matter and may support this theory.

As to the improvement of water relations in a heavier soil with the addition of organic matter, neither the per cent of colloid material present nor the minute size of the colloid added to capillary openings fails to aid the available water. In some instances it would decrease that amount already present. This condition might result from the hydroscopic water attached to the colloid, which reduces the capillary pore-space.

In the trials using arid sandy soils of Eastern Oregon, increases in available water correspond with the increases of residual organic matter. In the virgin sandy loam of the Sisters area, the available water is greater than the amount in the cultivated soils.

In the reclamation of alkali soils in Eastern Oregon, the additions of water and organic matter appear to have actually increased the available water. Organic matter was increased and a decided increase in per cent of colloid was found. The increase in the colloid correlated closely with the decrease in per cent of sand. These results agree with the virgin and cultivated samples of soils as found by Stone and Garrison (1940).

CONCLUSION

From the results of these different trials using several soil types, some evidence is found to support the view that organic matter will increase the available water capacity of the soil. This was found true in the light-textured soil type soils of the Willamette Valley, but it did not hold true in the case of the heavier soils used.

It is concluded that the organic matter and the organic colloid when mixed with a light-textured soil favorably change the capillary pore-space. Residual organic matter or added organics show this effect.

In the heavier soil, the aggregation of the soil particles adequately controls the capillary pore-space, and the additional colloid which retains additional amounts of hydroscopic water.

From this study, it seems as though there is a definite relationship between the organic content of a soil and the capillary porosity.

BIBLIOGRAPHY

Ahi, S.M., and Powers, W.L. Salt Tolerance of Plants
1938 at Various Temperatures. Plant Physiology
13: 769-789.

Alexander, L.T., and Byers, H.G. A Critical Laboratory
1932 Review of Methods of Determining Organic
Matter and Carbonates in Soils. U.S.D.A.
Tech. Bull. 317.

Alway, F.J., and Neller, J.R. A Field Study of the
1919 Influence of Organic Matter Upon The Water-
holding Capacity of A Silt-loam Soil.
Journal of Agricultural Research 16: 263-278.

Baver, L. D. Report of the Committee on Physics of Soil
1935 Moisture, 1934-35. Transactions of the Amer-
ican Geophysical Union, Sixteenth Annual
Meeting. 16: 426-432.

Bouyoucos, G.J. Comparison Between the Pipette Method
1934 and the Hydrometer Method for Making Mechan-
ical Analysis of Soil. Soil Science 38:
335-345.

Bouyoucos, G.J. Effect of Organic Matter on the Water-
1938 holding Capacity and the Wilting Point of
Mineral Soils. Soil Science 47: 377-381.

Bruce, O.C. Report of the Committee on Physics of
1935 Soil-Moisture, 1934-35. Transactions of the
American Geophysical Union, Sixteenth Annual
Meeting, 1935. 16: 426-432.

Feustal, J.C., and Byers, H.G. The Comparative Moisture
1936 Absorbing and Moisture-Retaining Capacities
of Peat and Soil Mixtures. Proceedings of
Soil Science Society of America 1: 323.

Free, G.R., Browning, G.M., and Musgrave, G.W. Relative
1940 Infiltration and Related Physical Character-
istics of Certain Soils. U.S.D.A. Tech.
Bull. 729.

Harper, H.J. Soil Structure and Moisture Movement.
1937 Proceedings of Soil Science Society of America 2: 15-19.

Keen, B.A. Some Physical and Physico-Chemical Effects
1927 of Soil Organic Matter. Journal of American Society of Agronomy 19: 362.

Mosier, J.G. Laboratory Manual of Soil Physics.
1905 Illinois College Press.

Mosier, J.G. The Physical Improvement of Soils.
1906 University of Illinois Circular 82.

Nystrom, E. Peat Soils As A Means of Soil Improvement
1930 on Humus-poor Sand Soils. Experiment Station Record 63: 116.

Powers, W.L. Soil Changes Due to Irrigation and Related
1939 Treatments. Proceedings of Soil Science Society of America 4: 410-414.

Stone, J.T., and Garrison, C.S. Relationships Between
1940 Organic Matter and Moisture Constants. Soil Science 50: 253-256.

Veihmeyer, F.J., et al. Report of the Committee on
1935 Physics of Soil Moisture 1934-35. Transactions of the American Geophysical Union, Sixteenth Annual Meeting. 16: 426-432.

Veihmeyer, F.J., et al. Report of the Committee on
1938 Physics of the Soil Moisture 1937-38. Transactions of the American Geophysical Union, Sixteenth Annual Meeting. 19: 326-341.

Veihmeyer, F.J., and Hendrickson, A.H. Water-holding
1938 Capacity of Soils and Its Effect on Irrigation Practices. Agricultural Engineering 19: 487-490.

Work, R.A., and Lewis, M.R. Moisture Equivalent, Field
1934 Capacity, and Permanent Wilting Percentage and Their Ratios in Heavy Soils. Journal of Agricultural Engineering 15: 355-363.

Yoder, R.E. The Significance of Soil Structure in Rela-
1937 tion to the Tilth Problem. Proceedings of Soil Science Society of America 2: 21-33.