

A NEW CLASSIFICATION OF THE SOIL MOISTURE

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Received for publication November 26, 1920

INTRODUCTION

The water in the soil is now generally divided into three forms: gravitational, capillary and hygroscopic. The gravitational water is defined as that which is in excess of the amount the soil can retain and which can, therefore, be drawn away by the force of gravity. The capillary water is that part retained in the capillary spaces of the soil and is capable of movement through capillary action. The hygroscopic moisture is the thin film on the surface of the soil particles and is not capable of movement through gravitational or capillary forces. This classification is based on the old idea that the soil is a static framework of solid particles varying in shapes and sizes over the surfaces of which the water spreads as a film and remaining unaffected by the soil and functions as a free liquid. This conception is well reflected by the attempts that have been made to measure the movement and average thickness of the films at definite moisture content, to extract this film of water, to calculate the specific surface of the soil from the size of its particles, etc.

With our present recognition of the colloidal and absorptive properties of the soil, however, we can no longer properly regard the soil as a simple, inactive mass of particles with no influence of its own upon the water. It is now generally admitted that colloidal material does exist in the soil derived both from the humus and clay fractions. This colloidal material is probably responsible for the major portion of the activity of the soil, exerts a controlling influence on the water relationships and makes these relationships between soil and water most intimate and complex.

The present classification of the soil moisture is probably serviceable for practical purposes, but is too general and empirical, and fails to reveal the true facts.

It is the purpose of this paper to present a new classification of the soil moisture which is founded upon a scientific basis, giving the true condition of the moisture in the soil and revealing the intimate and complex relationships that exist between soil and water. According to this new classification the soil water which has heretofore been classed as capillary does not exist in one form but in three different forms: free, capillary-adsorbed and combined.

Before this new classification is presented it will be profitable and advantageous to present first some data revealing the intimate and complex relationships that exist between soil and water and thus to show that the assumptions of the old classification are not correct and that a truer classification is needed.

THE COMPLEX RELATIONSHIPS EXISTING BETWEEN SOIL AND WATER

A few years ago we conceived the idea of trying to measure the concentration of the soil solution directly in the soil by means of the freezing-point method (4). This method has proved very successful and very unique for this purpose. We can now determine the concentration of the soil solution from any maximum to a very low moisture content directly in the soil. The results obtained by this method revealed the intimate and intricate relationships existing between soil and water most clearly and forcibly. It was shown, for instance, that in coarse-textured and uncolloidal soils such as quartz sand and extreme types of sand, the concentration of the soil solution increased

TABLE 1
Lowering of the freezing point of quartz sand at various moisture contents

MOISTURE	OBSERVED LOWERING OF THE FREEZING POINT	CONSTANT <i>K</i>
<i>per cent</i>	<i>°C.</i>	
2	0.091	0.182
6	0.027	0.162
10	0.018	0.180
14	0.012	0.168
18	0.009	0.162

inversely proportionally to the moisture content, and could be expressed by the simple equation $MD = K$, where K is the resultant constant, M the percentage of moisture and D the observed depression of the freezing point. In the fine-textured and colloidal soils, on the other hand, the concentration of the soil solution increased in a geometric progression as the water content decreased in an arithmetic progression and could be mathematically expressed by the equation $D = AR^{n-1}$ where D is the freezing-point depression, A the first depression, R the ratio of any depression (except the first) to the preceding one, and N the number of the depression. Typical examples of these two sets of results are shown in tables 1 and 2.

It is readily seen, therefore, that in the case of the quartz sand the concentration increases in a direct ratio with the decrease of the moisture content, while in the case of the soil it increases at an abnormally greater rate than the moisture decreases.

The freezing-point method revealed the intimate and complex relationships that exist between soil and water still in another way. It was found that in all classes of soil, with the exception of sands, the magnitude of the freezing-

TABLE 2

Lowering of the freezing point of clay loam at various moisture contents

MOISTURE	OBSERVED LOWERING OF THE FREEZING POINT	CALCULATED LOWERING OF THE FREEZING POINT
<i>per cent</i>	<i>°C.</i>	
10.0	1.292	
12.5	0.612	0.956
15.0	0.377	0.453
17.5	0.252	0.279
20.0	0.162	0.186
22.5	0.112	0.120
25.0	0.082	0.083
27.5	0.050	0.060
30.0	0.037	0.037

TABLE 3

Effect of repeated freezing and thawing upon the lowering of the freezing point

MOISTURE	NUMBER OF TIMES FROZEN	LOWERING OF THE FREEZING POINT
Sandy loam		
<i>per cent</i>		<i>°C.</i>
4	1	0.380
	2	0.340
	3	0.330
Clay loam		
15	1	0.820
	2	0.530
	3	0.520
	4	0.515
Silt loam		
16	1	0.430
	2	0.280
	3	0.220
	4	0.220
Clay		
18	1	0.870
	2	0.600
	3	0.470
	4	0.465

point lowering at a low moisture content, decreased with successive freezing and thawing, and the magnitude of this diminution tended to increase with the fine texture and colloidal content of the soil. Typical examples of these results are shown in table 3.

These data show most strikingly and unmistakably, therefore, that the process of repeated freezing and thawing tends to reduce the initial freezing-point lowering considerably.

For an explanation of these phenomena as well as those showing that the freezing-point depression increases at an abnormally greater rate than the moisture content decreases, the following hypotheses were offered:

(a) The soils have the ability to cause a certain amount of water to become unfree. This unfree water may be in the soil either as capillary-adsorbed or chemically combined or both. In either event this unfree water is not free or active to function as a solvent but is removed from the active liquid phase and also from the field of action as far as the freezing-point lowering is concerned. Thus, if a clay causes 15 per cent of water to become unfree, and at 39 per cent of moisture this clay gives a depression of 0.075°C . and at 22 per cent 0.987° , then in the first case there is 24 per cent of moisture free or active to dissolve the salts, while in the second case there is only 7 per cent of free or active water for the same purpose. The depression of the freezing-point lowering at the low moisture content, therefore, would be many times greater than at the high, than would be expected from the total percentage of water.

(b) The water which the soils cause to become unfree and thus removed from the field of action as far as the freezing-point lowering is concerned, is due to the colloids which the soils contain and to the capillarities of the soil. A portion of the unfree water exists in the colloids as physically adsorbed and loosely chemically combined (3) and another portion as unfree capillary water in the capillarities of the soil. Upon freezing the colloids are coagulated, the bonds uniting them with the water break and some of the unfree water becomes liberated. The capillarities of the soil are also destroyed by the process of freezing and the unfree capillary water also becomes liberated. This liberated and now free water from both sources goes to dilute the original soil solution and thereby decreases the original lowering of the freezing point.

The results yielded by the freezing-point method together with the hypotheses advanced to explain them and the conclusions derived therefrom were confirmed completely and in a most remarkable way by the dilatometer method (2). In brief, this method has shown absolutely: (a) that soils do cause water to become unfree, (b) that the process of repeated freezing and thawing liberates some of this unfree water and (c) that the moisture which has heretofore been classed as capillary does not exist all in one form but can be divided into three different forms: free, capillary-adsorbed and combined.

The principle of the dilatometer method is based upon the fact that water expands upon freezing. Knowing the coefficient of expansion of water upon freezing and also the total water content of a soil, then the amount of water that freezes and does not freeze can be easily calculated.

The general procedure of the method consists of adding a definite amount of soil and water or a soil of known moisture content into the dilatometer,

filling the empty space with ligroin and then causing the moisture to freeze at different degrees of supercooling.¹

It was found by this method that part of the moisture of a wet soil freezes very readily at slightly below $0^{\circ}\text{C}.$, another portion does not freeze until a temperature of $-4^{\circ}\text{C}.$ was reached, and a third portion does not freeze at any temperature—not even down to -78° . In many clays and clay loams as much as 40 per cent of the water added failed to freeze even at the extreme low temperature of -78° , while in quartz sand and sands all the water added froze readily at slightly below 0° .

NEW CLASSIFICATION OF THE SOIL MOISTURE

Most obviously, therefore, the moisture in the heavier classes of soil above the hygroscopic point does not all exist in one form. If it all existed in one form it certainly should have all frozen at one temperature and at the temperature of slightly below 0° as was the case of the moisture in the quartz sand and sands. Since it required different degrees of cooling to freeze, and some did not freeze at all, then there seems to be a strong proof that the moisture which has heretofore been classed as capillary exists in more than one form in all the agricultural soils with the exception of the plain sands and some coarse sandy loams containing no organic matter. On the basis of the dilatometer method it would appear reasonable and logical to consider that portion of the water which freezes readily at slightly below 0° to be different from that which freezes at -4° and $-78^{\circ}\text{C}.$, and this to be different from that which does not freeze even at the extreme lower temperature. Accordingly, therefore, the moisture of the soils should be classified into the following forms on the basis of the dilatometer method:

Gravitational	
Free	
Unfree	$\left\{ \begin{array}{l} \text{capillary-adsorbed} \\ \text{combined} \left\{ \begin{array}{l} \text{water of solid solution or} \\ \text{water of hydration.} \end{array} \right. \end{array} \right.$

The gravitational water needs no explanation of course. The free water is that which freezes for the first time at the supercooling of $-1.5^{\circ}\text{C}.$ The capillary-adsorbed water is that which freezes finally at the supercooling of -4° and also in the temperature of -78° minus the free water. The combined water is that which does not freeze at all.

The temperature of -1.5° has been chosen for the free water first because the freezing point of the soil is not 0° but somewhat less than 0° , and second because the rate of freezing near 0° is very slow. The temperature of -4° is chosen for the capillary-adsorbed water, first because this is the greatest degree of supercooling that the soil will withstand without premature solidification,

¹ For detailed description of the method and procedure see (2).

and second because at this temperature nearly all the water that is freezable will freeze. This is shown by the fact that very little if any additional water freezes at -78° which does not freeze at -4° .

It appears logical to call all the water which freezes near 0° free water because pure water in mass freezes at 0° . Water which does not freeze at this temperature must be different from free water. Since the physical condition of the soil presupposes that some of its water must exist around and in the interstices of its particles, and that this water probably has a lower vapor pressure corresponding to a lower freezing point, it appears reasonable to call this water capillary-adsorbed. Water on the other hand, which does not freeze at all even at the extreme low temperature of -78° must also be different from the capillary-adsorbed water. Since it is known that certain solid materials contain water of hydration, solid solution of water, etc., it has seemed reasonable to call this water which does not freeze combined.

RELATIVE AMOUNTS OF THE DIFFERENT FORMS OF WATER

The ability of the dilatometer method to distinguish and classify the moisture within any soil into the various forms between the various types of soil is revealed in tables 4 and 5. In these tables are presented the results of a very comprehensive list of soils representing all classes and many types. In table 4 the relative amounts of the different forms of water are based only on the water added, while in table 5 they are based both on the water added and also on the hygroscopic moisture.

The data in these tables reveal many facts of great interest. They show first of all that water in the soils does exist in different forms and that the amount of these different forms varies tremendously in the various soils. In some soils only one or two forms predominate, while in others all three are about equally divided. In sands and fine sandy loams it is the free water that predominates, which amounts in many cases to about 95 per cent of the total water present; the other 5 per cent consists as a rule of combined water; capillary-adsorbed water is apparently not common in most of these classes of soil. In loams and silt loams practically the same conditions hold except that more water is present in the combined form. In the clay loams, humus loams and clays it is the combined water that predominates followed in order by capillary adsorbed and free water, respectively.

SIGNIFICANCE OF THE NEW CLASSIFICATION OF SOIL MOISTURE

The dilatometer method not only affords us a true and scientific basis for the classification of the soil moisture into its proper forms but also gives us a deeper and truer insight regarding the behavior and functions of the soil moisture and its bearing upon other phenomena in the soil, such as the movement of moisture, evaporation, wilting coefficient, physiologically unavailable

TABLE 4
Relative amounts of the different forms of water based on the amount of water added

NUM- BER	SOILS	FREE WATER		CAPILLARY- ADSORBED WATER		COMBINED WATER
		cc.	per cent	cc.	per cent	per cent
1	Quartz sand	5.0	100.0	0	0	0
2	Coarse sand	4.80	96.0	0	0	4.0
3	Medium fine sand	4.70	94.0	0	0	6.0
4	Illinois medium fine sand	4.70	94.0	0	0	6.0
5	Wisconsin Plainfield fine sand	4.45	89.0	0	0	11.0
6	Fine sandy loam	4.20	84.0	0	0	16.0
7	California Yolo fine sandy loam	4.20	84.0	0.20	4.0	12.0
8	California Harford fine sandy loam	4.25	85.0	0.15	3.0	12.0
9	Kentucky LaCrosse sandy loam	4.00	80.0	0.35	7.0	13.0
10	Illinois White silt loam	4.15	83.0	0.25	5.0	12.0
11	Kentucky Miami silt loam	4.05	81.0	0.05	1.0	18.0
12	Holland loam	3.40	68.0	0.70	14.0	18.0
13	Illinois Brown silt loam	3.40	68.0	0.50	10.0	22.0
14	Wisconsin Colby silt loam	3.50	70.0	0.20	4.0	26.0
15	Illinois brown silt loam	3.25	65.0	0.65	13.0	22.0
16	Wisconsin Carrington silt loam	3.05	61.0	0.25	5.0	34.0
17	Kentucky Carrington loam	3.05	61.0	0.15	3.0	36.0
18	Heavy brown silt loam	2.70	54.0	0.55	11.0	35.0
19	Heavy dark brown silt loam	1.70	34.0	1.50	30.0	36.0
20	Heavy dark brown silt loam	1.85	31.0	1.20	24.0	39.0
21	Kentucky Marshall silt loam	2.25	45.0	1.05	21.0	34.0
22	California Romona clay loam	2.30	46.0	1.00	20.0	34.0
23	Illinois black clay loam	1.70	34.0	1.50	30.0	36.0
24	California Chino silty clay loam	1.00	20.0	1.75	35.0	45.0
25	Kentucky Carrington clay loam					
26	Wisconsin Superior clay	1.60	32.0	1.50	30.0	38.0
27	Clay	1.20	24.0	1.80	36.0	40.0
28	Minnesota Superior clay	0.80	16.0	2.45	49.0	35.0
29	Norfolk sand, Coffee County, Ala.	4.50	90.0	0	0	10.0
30	Norfolk sand, Anne Arundel Co., Ind.	4.70	94.0	0	0	6.0
31	Norfolk sand, Johnson County, N. C.	4.65	93.0	0	0	7.0
32	Dekalb sandy loam, Blount County, Ala.	4.50	90.0	0	0	10.0
33	Dekalb sandy loam, Etowah County, Ala.	4.35	87.0	0	0	13.0
34	Dekalb sandy loam, Blount County, Ala.	4.30	86.0	0	0	14.0
35	Norfolk sandy loam, Jones County, Ga.	4.65	93.0	0	0	7.0
36	Norfolk sandy loam, Bamberg County, S. C.	4.70	94.0	0	0	6.0
37	Norfolk sandy loam, Milles County, Ga.	4.50	90.0	0	0	10.0
38	Norfolk fine sandy loam, Wayne County, Miss.	4.40	88.0	0	0	12.0
39	Norfolk fine sandy loam, Bamberg County, S. C.	4.60	92.0	0	0	8.0
40	Norfolk fine sandy loam, Winston County, Miss.	4.50	90.0	0	0	10.0

TABLE 4—*Concluded*

NUM- BER	SOILS	FREE WATER		CAPILLARY- ADSORBED WATER		COMBINED WATER
		cc.	per cent	cc.	per cent	per cent
41	Vernon fine sandy loam, Archer County, Texas.....	3.55	71.0	0.55	11.0	18.0
42	Vernon fine sandy loam, Archer County, Texas.....	3.70	74.0	0.60	12.0	14.0
43	Vernon fine sandy loam, Taylor County, Texas.....	3.85	77.0	0.15	3.0	20.0
44	Hagerstown loam, Polk County, Ga.....	3.80	76.0	0.45	9.0	15.0
45	Hagerstown loam, Lawrence County, Ala..	3.55	71.0	0.35	7.0	22.0
46	Hagerstown loam, Madison County, Ala..	3.95	79.0	0.10	2.0	19.0
47	Carrington loam, Barnes County, N. D....	2.20	44.0	0.80	16.0	40.0
48	Carrington loam, Goodline County, Minn..	1.60	32.0	1.90	38.0	30.0
49	Carrington loam, Sioux County, Ia.....	3.20	64.0	0.60	12.0	24.0
50	Summit silt loam, Cass County, Mo.....	2.40	48.0	1.15	23.0	29.0
51	Summit silt loam, Barton County, Mo....	3.20	64.0	0.60	12.0	24.0
52	Miami silt loam, Delaware County, Ind....	3.60	72.0	0.60	12.0	16.0
53	Miami silt loam, Hendricks County, Ind..	3.75	75.0	0.65	13.0	12.0
54	Miami silt loam, Boone County, Ind.....					
55	Memphis silt loam, Wilkinson County, Miss.....	2.45	49.0	1.10	22.0	29.0
56	Memphis silt loam, Wilkinson County, Miss.....	4.05	81.0	0.25	5.0	14.0
57	Marshall silt loam, Sioux County, Ia.....	2.40	48.0	1.00	20.0	32.0
58	Marshall silt loam, Goodline County, Minn.....	1.85	37.0	1.70	34.0	29.0
59	Marshall silt loam, Nodaway County, Mo..	2.40	48.0	1.15	23.0	29.0
60	Kirkland silt loam, Payne County, Okla...	2.95	59.0	1.00	20.0	21.0
61	Kirkland silt loam, Payne County, Okla...	3.25	65.0	0.75	15.0	20.0
62	Vernon clay loam, Kay County, Okla.....	2.65	53.0	0.60	12.0	35.0
63	Vernon clay loam, Archer County, Texas..	3.70	74.0	0.30	6.0	20.0
64	Vernon clay loam, Roger Mills County, Okla.....	3.25	65.0	0.65	13.0	22.0
65	Lufkin clay, Columbia County, Ark.....	2.50	50.0	1.10	22.0	28.0
66	Lufkin clay, Caddo Parish, La.....	3.50	70.0	0.50	10.0	20.0
67	Lufkin clay, Winston County, Miss.....	1.00	20.0	2.65	53.0	27.0
68	Houston clay, Franklin County, Texas....	0.75	15.0	2.25	45.0	40.0
69	Houston clay, Grayson County, Texas....	1.85	37.0	1.80	36.0	27.0
70	Houston clay, Ellis County, Texas.....	2.70	54.0	1.00	20.0	26.0
71	Cecil clay, Troup County, Ga.....	1.65	33.0	1.35	27.0	40.0
72	Cecil clay, Jackson County, La.....	0.80	16.0	2.45	49.0	35.0
73	Cecil clay, Randolph County, N. C.....	1.55	31.0	1.50	30.0	39.0

TABLE 5
Relative amounts of the different forms of water, based on the amount of water added and also
on the hygroscopic water

NUM- BER	SOILS	FREE WATER		CAPILLARY- ADSORBED WATER		COMBINED WATER
		cc.	per cent	cc.	per cent	per cent
1	Quartz sand.....	5.0	100.00	0	0	0
2	Coarse sand.....	4.80	94.12	0	0	5.88
3	Medium fine sand.....	4.70	91.10	0	0	8.90
4	Illinois medium fine sand.....	4.70	91.10	0	0	8.90
5	Wisconsin Plainfield fine sand.....	4.45	85.81	0	0	14.19
6	Fine sandy loam.....	4.20	80.00	0	0	20.00
7	California Yolo fine sandy loam.....	4.20	79.56	0.20	3.78	16.66
8	California Harford fine sandy loam.....	4.25	78.70	0.15	2.77	18.53
9	Kentucky La Crosse sandy loam.....	4.00	75.19	0.35	6.57	18.24
10	Illinois white silt loam.....	4.15	78.16	0.25	4.71	17.13
11	Kentucky Miami silt loam.....	4.05	75.70	0.05	0.93	23.37
12	California Holland loam.....	3.40	63.09	0.70	12.99	23.92
13	Illinois brown silt loam.....	3.40	59.66	0.50	8.77	31.57
14	Wisconsin Colby silt loam.....	3.50	61.40	0.20	3.52	35.08
15	Illinois brown silt loam.....	3.25	57.01	0.50	8.77	34.22
16	Wisconsin Carrington silt loam.....	3.05	53.50	0.25	4.38	42.12
17	Kentucky Carrington loam.....	3.05	51.26	0.15	1.93	46.81
18	Heavy brown silt loam.....	2.70	46.55	0.55	9.48	43.97
19	Heavy dark brown silt loam.....	1.70	29.56	1.50	26.09	43.35
20	Heavy dark brown silt loam.....	1.85	31.10	1.20	20.17	48.73
21	Kentucky Marshall silt loam.....	2.25	39.48	1.05	18.42	41.10
22	California Romona clay loam.....	2.30	38.34	1.00	16.67	44.99
23	Illinois black clay loam.....	1.70	16.70	1.50	23.55	49.75
24	California Chino silty clay loam.....	1.00	15.80	1.75	27.65	56.55
25	Kentucky Carrington clay loam.....					
26	Wisconsin Superior clay.....	1.60	26.40	1.50	24.75	48.85
27	Clay.....	1.20	19.80	1.80	29.70	50.50
28	Minnesota Superior clay.....	0.80	12.61	2.28	36.00	51.36
29	Norfolk sand, Coffee County, Ala.....	4.50	89.23	0	0	10.77
30	Norfolk sand, Anne Arundel County, Ind..	4.70	93.26	0	0	6.74
31	Norfolk sand, Johnson County, N. C.....	4.65	92.28	0	0	7.72
32	Dekalb sandy loam, Blount County, Ala..	4.50	88.24	0	0	11.76
33	Dekalb sandy loam, Etowah County, Ala..	4.35	85.30	0	0	14.70
34	Dekalb sandy loam, Blount County, Ala..	4.30	84.30	0	0	15.70
35	Norfolk sandy loam, Jones County, Ga...	4.65	91.54	0	0	8.46
36	Norfolk sandy loam, Bamberg County, S. C.	4.70	92.52	0	0	7.48
37	Norfolk sandy loam, Milles County, Ga...	4.50	88.60	0	0	11.40
38	Norfolk fine sandy loam, Wayne County, Miss.....	4.40	84.94	0	0	15.06
39	Norfolk fine sandy loam, Bamberg County, S. C.....	4.60	88.80	0	0	11.20
40	Norfolk fine sandy loam, Winston County, Miss.....	4.50	86.88	0	0	13.12

TABLE 5—*Concluded*

NUM- BER	SOILS	FREE WATER		CAPILLARY- ADSORBED WATER		COMBINED WATER
		cc.	per cent	cc.	per cent	per cent
41	Vernon fine sandy loam, Archer County, Texas.....	3.55	65.14	0.55	10.09	24.77
42	Vernon fine sandy loam, Archer County, Texas.....	3.70	67.90	0.60	11.01	21.09
43	Vernon fine sandy loam, Taylor County, Texas.....	3.85	70.64	0.15	2.11	27.25
44	Hagerstown loam, Polk County, Ga.....	3.80	70.00	0.45	8.20	21.80
45	Hagerstown loam, Lawrence County, Ala..	3.55	65.40	0.35	6.44	28.16
46	Hagerstown loam, Madison County, Ala..	3.95	72.75	0.10	1.84	25.41
47	Carrington loam, Barnes County, N. D. . .	2.20	39.43	0.80	14.36	46.21
48	Carrington loam, Goodline County, Minn..	1.60	28.68	1.90	34.05	37.27
49	Carrington loam, Sioux County, Ia.....	3.20	57.35	0.60	10.75	31.90
50	Summit silt loam, Cass County, Mo.....	2.40	43.17	1.15	20.68	36.18
51	Summit silt loam, Barton County, Mo. . .	3.20	57.55	0.60	10.77	31.68
52	Miami silt loam, Delaware County, Ind. . .	3.60	67.42	0.60	11.24	21.34
53	Miami silt loam, Hendricks County, Ind. .	3.75	70.22	0.65	12.17	17.61
54	Miami silt loam, Boone County, Ind.....					
55	Memphis silt loam, Wilkinson County, Miss.....	2.45	42.62	1.10	19.13	38.25
56	Memphis silt loam, Wilkinson County, Miss.....	4.05	70.43	0.25	4.35	25.22
57	Marshall silt loam, Sioux County, Ia.....	2.40	41.17	1.00	17.16	41.67
58	Marshall silt loam, Goodline County, Minn.	1.85	31.73	1.70	29.16	39.11
59	Marshall silt loam, Nodaway County, Mo..	2.40	41.17	1.15	19.73	39.10
60	Kirkland silt loam, Payne County, Okla. .	2.95	51.76	1.00	17.55	30.69
61	Kirkland silt loam, Payne County, Okla. .	3.25	57.02	0.75	13.16	29.82
62	Vernon clay loam, Kay County, Okla. . . .	2.65	44.85	0.60	10.15	45.00
63	Vernon clay loam, Archer County, Texas. .	3.70	62.60	0.30	5.07	32.33
64	Vernon clay loam, Roger Mills County, Okla.....	3.25	55.00	0.65	11.00	34.00
65	Lufkin clay, Columbia County, Ark.....	2.50	46.00	1.10	20.26	33.74
66	Lufkin clay, Caddo Parish, La.....	3.50	64.46	0.50	9.21	26.33
67	Lufkin clay, Winston County, Texas.....	1.00	18.42	2.65	48.80	32.78
68	Houston clay, Franklin County, Texas.....	0.75	12.50	2.25	37.50	50.00
69	Houston clay, Grayson County, Texas.....	1.85	30.83	1.80	30.00	39.17
70	Houston clay, Ellis County, Texas.....	2.70	4.50	1.00	16.67	38.33
71	Cecil clay, Troup County, Ga.....	1.65	29.68	1.35	24.28	46.04
72	Cecil clay, Jackson County, La.....	0.80	14.39	2.45	44.05	41.56
73	Cecil clay, Randolph County, N. C.....	1.55	27.88	1.50	26.98	45.14

water, etc. Indeed with a knowledge of this new classification we are enabled not only to understand but also to predict what to expect regarding these phenomena. Thus for instance, in regard to the movement of moisture it could be safely predicted that a large percentage of water in the fine-textured or colloidal soils is immovable as far as capillary movement is concerned. This conclusion would be self-evident and justifiable from the fact that a large amount of water is not free to freeze in these soils even at the extreme low temperature of -78°C. , and if it is not free to freeze at this low temperature it is certainly not free to move capillarily.

As regards the rate of evaporation, it could be predicted and expected that the rate would be different at the various moisture contents. The free water would possess one velocity of evaporation, the capillary-adsorbed another and the combined still another. The free water would possess the greatest velocity of evaporation, the combined the smallest and the capillary-adsorbed an intermediate.

The phenomenon of the wilting coefficient of soils becomes also more intelligible in the light of the dilatometer results. The consensus of opinion among soils men and plant physiologists is that the plants wilt even when there is still plenty of moisture in the soil, because the movement of the moisture to the roots of the plants is not sufficiently rapid to supply the water lost by transportation. This consensus of opinion is well expressed by Shull (8). He says:

The wilting of plants at the wilting coefficient of the soil can not be due to lack of moisture in the soil nor to lack of a gradient of forces tending to move water toward the plant. The view is held, therefore, that the wilting at this critical soil-moisture content must be due to the increasing slowness of water movement from soil particle to soil particle and from these to the root hairs, the rate of movement falling below that necessary to maintain turgidity of the cells of the aerial parts, even under conditions of low transportation.

In the light of the dilatometer results, however, the plants wilt not because the soil moisture does not move at a sufficiently rapid rate but because it does not move at all. As has already been seen the capillary-adsorbed water freezes with great difficulty and the combined not at all. Now if the soil moisture is not free to freeze it is certainly not free to move capillarily.

The more correct reasons for the wilting of plants at the wilting coefficient of soils appears to be the following: (a) The moisture near the wilting coefficient is held by the soil with such force that the plants can not extract it. A large part of this water is probably not in the liquid state. (b) Near the wilting coefficient the concentration of the soil solution is comparatively high which would tend to influence the intake of water by the roots. At the moisture content where there is no more free water but only capillary-adsorbed and combined the concentrations of the soil solutions, as proved experimentally (4), is greater than that of the cell sap of the roots.

The new physical classification of the soil moisture on the basis of the dilatometer results enables us now to classify the soil moisture also on a true

and scientific physiological basis. The old physiological classification of the soil moisture consists of dividing the soil water broadly into available and unavailable. From a practical standpoint this classification is probably serviceable but it is too general, empirical and does not give a true, detailed and definite information regarding the availability and unavailability of the different forms of water. The new classification, however, which is suggested by the results of the dilatometer method and supported by physiological studies seems to meet all these requirements. This new physiological classification of the soil moisture is as follows:

Gravitational	{ unsuitable or superavailable
Free	{ readily available
	{ capillary-adsorbed { very slightly available
Unfree	{ combined { water of hydration } unavailable
	{ water of solid solution }

According to this classification it is only the free water or the water which freezes at the supercooling of about -1.5°C . that the plants can take up very readily. For this water the plant exerts very little, if any, force to utilize it because it exists in a free condition and is not held very rigidly by any outside forces. It is this water with which the plant makes its growth. After the plant uses up this free water it generally begins to wilt.

The capillary-adsorbed water, or the water which freezes at the supercooling of -4° and in the temperature of -78° is available to the plant only slightly and under certain conditions. For this water the plant has to exert force to obtain it, because it is held by the soil with considerable force. With this water the plant is probably not able to make growth but simply to sustain life.

The combined water, or the water which does not freeze at all, even at the extreme low temperature of -78° , is ordinarily not at all available to the plant. This water probably exists in the solid phase and is held by the soil with tremendous forces.

This new physiological classification of the soil moisture appears to be amply supported by the large amount of data obtained on the wilting of plants and by a direct comparison made between the wilting coefficient and the different forms of water. The work of Briggs and Shantz (5) shows that plants wilt when the total soil moisture is still high which is considerably above the combined water. A direct comparison made between the wilting coefficient of some of these soils employed by Briggs and Shantz and the dilatometer method results show that the percentage of moisture which fails to freeze at the supercooling of -1.5°C . is very closely the same as that at which plants begin to wilt, indicating that the wilting coefficient of soils is at the point where the free moisture ends and the capillary-adsorbed moisture begins. On the other hand, the extensive investigations of Alway (1) in which he allowed the plants to grow almost to maturity show that the plants are able to reduce

the soil moisture down to the hygroscopic coefficient. Now this hygroscopic coefficient seems to represent about the same degree of moisture as the combined water, indicating, therefore, that the capillary-adsorbed water is available to plants under certain conditions.

In view of the close agreement that appears to exist between the wilting coefficient and the unfree water as determined by the dilatometer method, it would seem logical and advisable, therefore, to determine this factor by the dilatometer method. The percentage of water that fails to freeze for the first time at the supercooling of -1.5°C . can be taken to represent the upper limits of moisture content at which plants may begin to wilt, while the percentage of moisture which fails to freeze at -4°C . can be taken to represent the lower limits at which plants are able at all to extract the moisture from the soil under the most favorable conditions.

The determination of the wilting coefficient of soils by means of the plant, besides being tedious and time consuming, is not accurate nor constant. The investigations of Caldwell (6) and of Shive and Livingston (7) show that the permanent wilting of the plant is a function of the intensity of atmospheric evaporation. By means of the dilatometer method on the other hand, the determination of the wilting coefficient is more definite and more comparable and, of course, infinitely easier, more convenient and rapid.

The new classification of the soil moisture, therefore, is founded on experimental and scientific principles and appears to classify the soil moisture into its actual forms and thus reveals its actual conditions, its intimate and complex relationships with the soils and its bearing upon many phenomena in the soil.

SUMMARY

The object of this paper is to present a new classification of the soil moisture which is founded on experimental and scientific principles and which appears to show the actual condition of the moisture in the soil.

This new classification is based upon the principle of the freezing of water. It is found that a portion of the soil water freezes very readily near 0°C ., another portion freezes only when a temperature of -4° is reached and a third portion does not freeze at all, even at the extreme low temperature of -78°C .

Obviously, the water in the soil above the hygroscopic moisture, can not all be in one form, i.e. capillary, because if it were all in one form all of it ought to freeze at one temperature and indeed near 0° . Since different portions of it freeze at different temperatures or not at all, then it must exist in different conditions.

On the basis of these experimental and scientific facts the soil moisture lends itself to the following classification:

Gravitational	
Free	
Unfree	$\left\{ \begin{array}{l} \text{capillary-adsorbed} \\ \text{combined} \left\{ \begin{array}{l} \text{water of solid solution} \\ \text{water of hydration} \end{array} \right. \end{array} \right.$

The free water is that which freezes for the first time at the supercooling of $-1.5^{\circ}\text{C}.$, the capillary-adsorbed water is that which freezes finally at the supercooling of -4° and at the cooling of -78° , minus the free water. The combined water is that which does not freeze at all, even at the temperature of -78° .

It appears reasonable and logical to call all water freezing near 0° free water because pure water in mass freezes at 0° . Water which does not freeze at this temperature must be different from free water. Since the physical condition of the soil presupposes that some of its water must exist around and in the interstices of its particles, and that this water probably has a lower vapor pressure corresponding to a lower freezing point, it appears reasonable and logical to call this water capillary-adsorbed. Water on the other hand which does not freeze at all even at the extreme low temperature of $-78^{\circ}\text{C}.$ must also be different from the capillary-adsorbed. Since it is known that certain solid materials contain water of hydration, solid solution of water, etc., it has seemed reasonable to call this water which does not freeze combined water.

On the basis of this classification it was found that in some soils only one or two forms of water exist while in others all three forms exist but in different proportions.

The method that is capable of measuring the relative amounts of these various forms of water in the soil is the dilatometer method. The principle of this method is based upon the fact that water expands upon freezing. If the coefficient of expansion of water is known and also the total percentage of water in the soil, then the amount of water that freezes or fails to freeze can be readily ascertained.

The procedure of the method consists of adding a definite amount of soil and water or a soil of known moisture content, into the dilatometer, filling the empty space with ligroin and then causing the soil moisture to freeze. It is first supercooled to $-1.5^{\circ}\text{C}.$ and the free water allowed to freeze at this temperature. Then the contents of the dilatometer are thawed and frozen at the temperature of -15° for half an hour. Then they are thawed again and supercooled to -4° where the capillary-adsorbed water freezes. When the contents come in equilibrium with the temperature of -4° , they may be cooled to $-78^{\circ}\text{C}.$ and brought back again to the temperature of -4° . It is not always necessary, however, to cool the soil to -78° because practically all the water that is freezable will freeze at -4° .

It is found that repeated freezing and thawing causes some of the unfree water to become free. This unfree water which becomes free belongs entirely to the capillary-adsorbed water.

The new classification of the soil moisture gives a clearer and deeper insight of the actual condition of the soil moisture, its intimate and complex relationships with the soil and its bearing upon many phenomena in the soil such as the movement of moisture, evaporation, wilting coefficient of soils, availability and unavailability of moisture, etc.

In the light of the dilatometer results, together with those of physiological studies, the soil moisture can now be classified more definitely and scientifically, also on a physiological basis. This new physiological classification of the soil moisture is as follows:

Gravitational	{	superavailable	
Free	{	very available	
	{	capillary-adsorbed	{ only slightly available
Unfree	{	combined	{ water of solid solution
			{ water of hydration } unavailable

The dilatometer method is capable of determining also the wilting coefficient of soils, and this determination is more accurate, definite and comparable than that by means of the plant, and of course, infinitely more convenient, easier and rapid.

The old classification of the soil moisture is too empirical and general and does not tell the true story of the actual condition of the soil moisture. It is based on the old idea that the soil is a simple mass of solid particles over the surface of which the moisture spreads and remaining unaffected by the soil itself. The soil, however, is a very complex mass and its relationships with water are very intimate and intricate. This old classification, therefore, must sooner or later give way to a new one which is based upon actual facts, such as the new classification proposed in this paper.

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