

A QUANTITATIVE RELATION BETWEEN SOIL AND THE SOIL SOLUTION BROUGHT OUT BY FREEZING-POINT DETERMINATIONS.

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INTRODUCTION.

AN interesting series of papers has recently been published by Bouyoucos¹ and his fellow workers, on the nature and composition of the soil solution. The results appear to be of considerable significance, pointing to the existence of intimate and complex relationships between the soil and its water content, and possible qualitative explanations of the observed facts are advanced by the authors. The present paper is an attempt to give a definite quantitative expression to some of these relations, by means of a critical examination of part of the experimental data recorded in the papers mentioned. Bouyoucos points out that the various methods hitherto employed to study the soil solution give data which at the best are scarcely qualitative as to the actual concentration in the soil complex; they entirely fail to give any information on the physical relationships existing between soil and its water content. Using other methods of attacking the problem he is able to carry it a stage nearer solution. His results show broadly that the water in soil behaves differently from that in sand, in that it exists in two different conditions, called by him "free" and "unfree." This terminology is employed throughout the present paper, for convenience in referring to Bouyoucos' results, and because we have not, at present, sufficient information to justify the immediate use of more definite terms. The names are not, however, entirely satisfactory. It is quite possible that some of the water in the "unfree" state may be capable of evaporating directly from this condition when the soil is drying, and on the other hand, it is by no means certain that all the "free" water is really free in the strict sense of the word.

¹ Michigan Agric. Coll. Expt. Station. *Tech. Bulls.* Nos. 24 (1915), 31 (1916), 36 (1917), 37 (1917), 42 (1918).

Also in *Journ. Agric. Res.* 8 (1917), p. 195; 15 (1918), p. 331.

The present writer has shown¹ that the course of the evaporation of water from the soil can only be explained on the assumption that an intimate connection exists between the soil and its moisture content over a wide range. The evaporation was quite different from that shown by moist sand. The latter could be readily explained from known laws of diffusion, but in the evaporation from soil other factors were distinguished. A definite mathematical expression was found for this

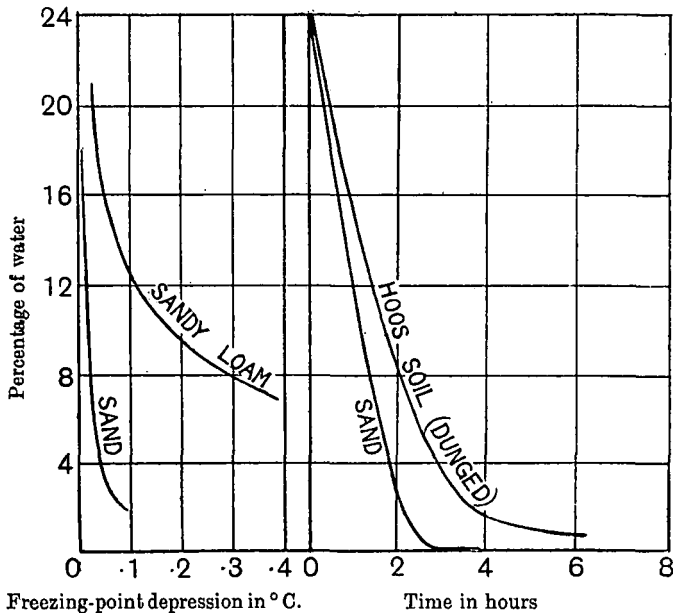


Fig. 1. Comparison for sand and soil at varying moisture contents, of freezing-point depression and evaporation.

relationship, and all the available data pointed to the importance of the soil colloids in controlling it. These differences in the relations of sand and soil to their water content can be very well seen by comparing the writer's curves showing the evaporation from sand and soil, with Bouyoucos' curves for the depression of the freezing-point at various moisture contents (Fig. 1). It is significant that two such diverse methods of examining the soil solution should both show a fundamental difference in its relation to a group of inert particles such as quartz sand on the one hand, and to soil on the other.

Bearing these facts in mind one can readily understand the incomplete and sometimes conflicting results obtained from all methods of

¹ B. A. Keen. *Journ. Agric. Sci.* 6 (1914), p. 456.

402 *Soil, Soil Solution and Freezing-Point Determinations*

investigating the soil solution which depend on its isolation from the soil¹.

None of these methods can give, as a final product, the soil solution in the state in which it exists in the soil. Only a fraction of the total moisture content can be obtained by direct methods such as centrifuging, while indirect methods such as mixing the soil with water and filtering, give a solution bearing an unknown, but probably qualitative, relation to the original soil solution. In other words, any modification of the moisture content causes a change in the complicated colloidal phenomena existing in the soil, and hence the portion of soil solution extracted will bear no simple relation to either the portion unextracted, or the original amount.

Further progress in our knowledge of the soil solution must depend on the use of fresh methods. Bouyoucos has attacked the problem in two ways, of which brief descriptions follow. The essential feature is that in each case the solution is examined *in situ*.

DILATOMETER AND FREEZING-POINT METHODS OF INVESTIGATING THE SOIL SOLUTION.

The dilatometer method is an application to soil of Foote and Saxton's² experiments on the freezing of inorganic hydrogels. The moist soil is placed in the bulb of the dilatometer and the free space then filled with ligroin. From the reading of the meniscus and the known bore of the tube, the expansion occurring when some of the soil moisture freezes can be calculated, and hence the amount of water frozen. It was found that the water present in soil did not all freeze at one given temperature (-1.5°C.) and the amount which failed to freeze varied considerably in different soils. A similar result was obtained at -4°C. and -78°C. , although the amounts of unfrozen water were smaller, especially in the colloidal types. No definite relationships could be traced between the amounts of unfrozen water at these temperatures.

On the basis of these results, the soil temperature is classified into three groups: "free," freezing at -1.5°C. ; "capillary-adsorbed," freezing at -4°C. down to -78°C. ; and "combined," not frozen at -78°C. The divisions of course merge insensibly into one another, but the values obtained at the temperatures chosen are considered as giving

¹ A summary of these methods is given by Bouyoucos (*Tech. Bull.* No. 24), and also by Stiles and Jørgensen (*Journ. Ecology*, 2 (1914), p. 245). The latter is the more detailed account, but does not include the Morgan oil pressure method (*Soil Sci.* 3 (1917), p. 531).

² *Journ. American Chem. Soc.* 38 (1916), p. 588; 39 (1917), p. 1103.

very fair approximations to the amounts present in these three forms. The actual amount of any one division varies considerably from soil to soil, but generally speaking, the amount of free water decreases, while the capillary-adsorbed and combined water increase as the soils pass from non-colloidal to colloidal in type, although Bouyoucos finds many exceptions to this rule.

It will be observed that the dilatometer method as used gives qualitative information only. The observed fact that the capillary-adsorbed group passes gradually at one end to combined water, and at the other to free, suggests that the variants controlling its relation to the soil alter in a continuous manner over the whole range of this division, a view confirmed by the present writer's experiments cited above. This view is also supported by Bouyoucos' second set of experiments on the lowering of the freezing-point of the soil solution.

These experiments were done in the usual Beckmann apparatus, on the moist soils and sands. It was found that solidification could be readily induced, except when the moisture content was quite low. In quartz sand for instance, the lowering of the freezing-point could be measured when the moisture content was only 0.7 per cent.

In quartz sand and some extreme types of sandy soil, the depression of the freezing-point was found to be approximately inversely proportional to the moisture content, *i.e.*

$$MD = K, \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where M = moisture content,

D = depression of freezing-point,

K = constant.

With soils a different relationship holds, the depression of the freezing-point increasing in geometrical progression as the moisture content decreases in arithmetical progression. Bouyoucos interpreted this as indicating that the soil solution increases in concentration at a greater rate than would be accounted for by the known decrease in total moisture content, and the general hypothesis is advanced that in soils some of the water is rendered "unfree," and thus does not enter into the actual soil solution, as determined by the freezing-point method. It is the quantitative examination of this suggestion, which is supported by a considerable amount of evidence in addition to that advanced by Bouyoucos, with which the present paper is mainly concerned.

TYPICAL EXPERIMENTAL DATA GIVEN BY BOUYOUCOS.

For convenience, typical data for quartz sand and four types of soil are reproduced here, in Tables I and II, and Fig. 2.

TABLE I.

Lowering of the Freezing-point of Quartz Sand at various moisture contents.

Percentage of moisture	Observed lowering of the freezing-point ° C.	Constant (K)
2	·091	·182
6	·027	·162
10	·018	·180
14	·012	·168
18	·009	·162

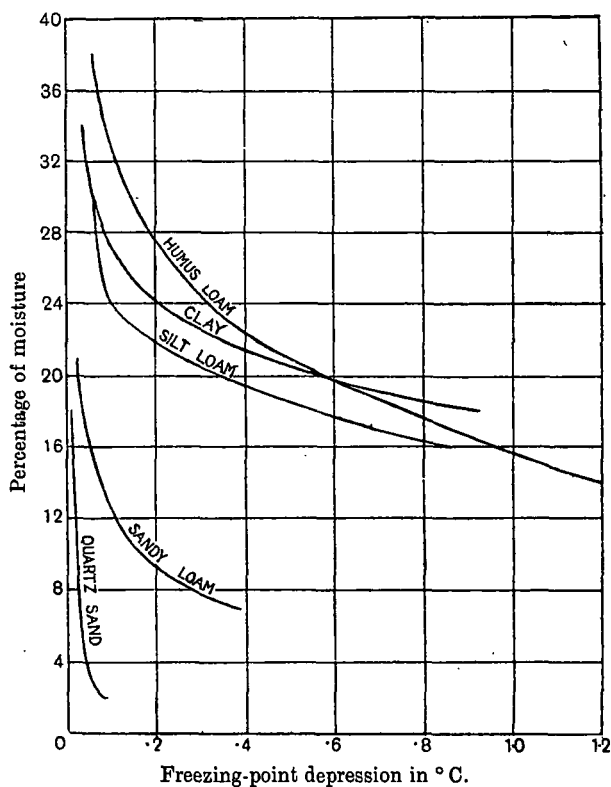


Fig. 2. Increase in freezing-point depression, with decrease in moisture content (Bouyoucos).

TABLE II.

Lowering of the Freezing-point of various types of Soil at different moisture contents.

CLAY			SILT LOAM		
Percentage of moisture	Observed lowering of freezing-point	Calculated lowering of freezing-point	Percentage of moisture	Observed lowering of freezing-point	Calculated lowering of freezing-point
18	.922	—	16	.860	—
20	.580	.6242	18	.560	.688
22	.307	.3916	20	.350	.448
24	.212	.2078	22	.200	.280
26	.127	.1435	24	.095	.160
28	.082	.0859	26	.076	.076
30	.062	.0555	28	.071	.0608
32	.042	.0419	30	.060	.0568
34	.034	.0284	—	—	—
HUMUS LOAM			SANDY LOAM		
14	1.200	—	7	.390	—
18	.760	.7888	9	.220	.2925
22	.420	.4995	11	.130	.1650
26	.245	.2761	13	.087	.0975
30	.140	.1610	15	.065	.0642
34	.089	.0920	17	.040	.0487
38	.0585	.0585	19	.030	.0300
—	—	—	21	.025	.0225

DISCUSSION OF THE EXPERIMENTAL DATA.

Taking the values for quartz sand (Table I) it is seen that very fair agreement holds with equation (1) above, the freezing-point depression being inversely proportional to the moisture content. This points to the moisture in the sand obeying the same law as dilute solutions—the freezing-point depression varying approximately as the concentration.

With soils this relation does not hold, but is replaced by an approximate geometrical progression ratio. The question at once arises, is any proportion of the soil moisture “unfree,” in the sense that it is not part of the soil solution as understood in these experiments?

If this were so the soil solution would become increasingly concentrated as the total moisture content decreased towards the value of this unfree water. To repeat the example given by Bouyoucos in support of this idea, a clay soil which renders 15 per cent. of water unfree, by adsorption or chemical combination for instance, and which at 36 per cent. and 18 per cent. of total moisture content gave depressions of .034° C. and .955° C. respectively, would have available for the soil

406 *Soil, Soil Solution and Freezing-Point Determinations*

solution, 21 per cent. and 3 per cent. of water in the two cases. Hence one would expect the freezing-point lowering to be many times greater in the second case, than in the first. This idea can be easily tested:

Let Z be the water rendered unfree. Then if the inverse proportionality law still holds for the remaining ("free") water we have:

$$D(M - Z) = K, \quad (2)$$

where M = total moisture content,

D = corresponding depression,

K = constant.

This equation should define the soil curves, *i.e.* the curves would still be rectangular hyperbolae, of the type given by the equation $MD = K$ for quartz sand, with the D axis displaced a distance Z along the M axis. Substituting in equation (2) for the sandy loam soil (Table II) at moisture contents of 7 per cent. and 21 per cent.:

$$\cdot 390 (7 - Z) = K,$$

$$\cdot 025 (21 - Z) = K.$$

Solving these two equations we have, very approximately,

$$Z = 6; \quad K = \cdot 390;$$

and hence the general equation becomes

$$D(M - 6) = K = \cdot 390. \quad (3)$$

A test of this equation for the remaining values of M and D , leads to the following values for K :

TABLE III.

M	K
7	$\cdot 390$
9	$\cdot 660$
11	$\cdot 650$
13	$\cdot 609$
15	$\cdot 585$
17	$\cdot 440$
19	$\cdot 390$
21	$\cdot 390$

There is a considerable change in K , hence the assumption that a definite amount of water is rendered unfree by the soil is incorrect, if the inverse proportionality law for M and D is considered to hold. This result leads to two alternatives, either the law does not hold, which means that the effective proportion of dissolved salts alters with moisture content, or else the actual amount of unfree water changes with total

moisture content. It is of course possible that both of these alternatives will operate together in the soil. The former will almost certainly occur, to judge by a general survey of the data Bouyoucos advances for the concentration of the soil solution. Its explanation is a matter of great complexity and is not considered in the present paper, which is devoted to the second alternative, that the actual amount of unfree water changes with the total moisture content.

Let Y_n be the amount of *free* water, when the total moisture content is M_n , and D_n be the corresponding freezing-point depression. We have the general equation:

$$Y_n D_n = K, \text{ where } K \text{ is a constant,}$$

or
$$Y_n = \frac{K}{D_n}.$$

Using again the figures of D_n for the sandy loam soil (Table II) we obtain a series of values for Y_n :

$$Y_7 = \frac{K}{.390}; \quad Y_9 = \frac{K}{.220} \dots Y_{19} = \frac{K}{.030}; \quad Y_{21} = \frac{K}{.025}.$$

The suffix of Y indicates the corresponding value of M_n , the total moisture content. The values of Y_7 to Y_{19} can be obtained in terms of Y_{21} , by substituting $.025 Y_{21}$ for K in each case:

$$\left. \begin{aligned} Y_{19} &= .833 Y_{21} \\ Y_{17} &= .625 Y_{21} \\ Y_{15} &= .385 Y_{21} \\ Y_{13} &= .287 Y_{21} \\ Y_{11} &= .192 Y_{21} \\ Y_9 &= .114 Y_{21} \\ Y_7 &= .064 Y_{21} \end{aligned} \right\} \dots \dots \dots (4)$$

This set of equations shows that the actual amount of free water rapidly diminishes as the total moisture content decreases. For instance, comparing Y_{19} with Y_9 , the amount of free water decreases to about $\frac{1}{4}$ th, while the total water is decreased only by $\frac{1}{2}$. This indicates that the amounts of free and unfree water bear respectively a decreasing and increasing percentage ratio to the amount of total water, as the latter diminishes. That the relation of the free, and therefore the unfree water, to the total moisture is quantitative can be clearly seen by an inspection of Fig. 3, in which the amount of free water, expressed in terms of Y_{21} (equations (4)) is plotted against the total moisture. In the same figure the curve for clay soil (Table II) is also given, the values

for Y_n being obtained in exactly the same way as for the sandy loam soil.

The curves both seem to be of the type

$$Y_n = cM_n^x, \quad (5)$$

where c and x are constant for any one curve, and M_n is total moisture.

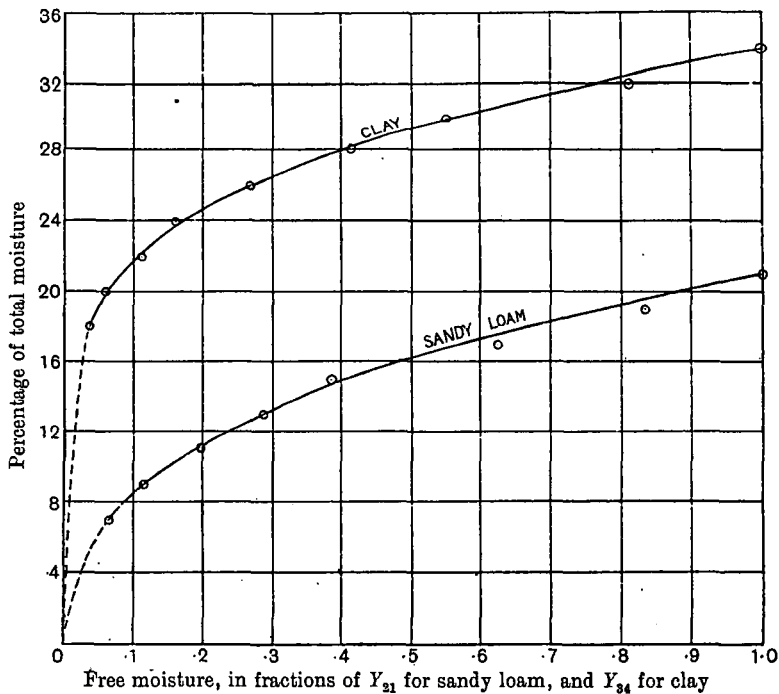


Fig. 3. Relation between free water and total moisture for clay and sandy loam soils.

To test this, a more convenient form of (5) is obtained by taking logarithms of each side:

$$\log Y_n = \log c + x \log M_n, \quad (6)$$

but $Y_n = f \cdot Y_{21}$, where f varies from 0 to 1. Hence equation (6) becomes

$$\log f + \log Y_{21} = \log c + x \log M_n. \quad (7)$$

To solve (7) for c and x convenient values of f and M_n to take from the curve for sandy loam, are

$$(f = .1, M_n = 8.5); \quad (f = 1.0, M_n = 21).$$

This leads to the values

$$x = 2.55; \quad \log c = (\log Y_{21} - 3.366).$$

$$\therefore c = 10^{-3.366} Y_{21}.$$

The values for the clay soil are, $x = 5.18$, $c = Y_{34} \cdot 10^{-7.934}$. Hence equation (5) becomes in the two cases,

$$Y_n = 10^{-3.366} Y_{21} \cdot M_n^{2.55}, \quad (8)$$

$$Y_n = 10^{-7.934} Y_{34} \cdot M_n^{5.18}. \quad (9)$$

To test how accurately these equations fit the curve, it is simpler to return to the logarithmic form, equation (7). This can be written:

$$\log Y_{21 \text{ or } 34} - \log c = x \log M_n - \log f. \quad (10)$$

The left hand side of this equation is constant, hence the right hand side should be constant also. In Table IV, the values of $(x \log M_n - \log f)$ are given for various values of M_n and f , taken from the curves. It will be seen that excellent agreement holds over the whole range for both soils. Hence the relation between free and total moisture content is defined by the general equation (5), on the assumption that the freezing-point depression is proportional to the concentration of the soil solution.

TABLE IV.

SANDY LOAM SOIL.		
M_n	f	$x \log M_n - \log f$
8.5	.1	3.37
11.2	.2	3.37
13.2	.3	3.38
16.0	.5	3.37
18.65	.75	3.36
21.0	1.0	3.37
CLAY SOIL.		
18	.037	7.934
20	.059	7.969
23	.140	7.906
26	.268	7.901
30	.575	7.891
34	1.000	7.933

If the approximate truth of this assumption be admitted, then we have an important and very interesting insight into the general relations existing between the soil and its moisture content. Of the total moisture present at any time a certain part remains free, and the remainder becomes unfree. The free water is related to the total moisture, and therefore to the unfree water, by a definite mathematical relation over the complete experimental range. We need not at present attempt to define the exact meaning of "free" and "unfree"; indeed there is not, as yet, nearly enough experimental evidence to enable definitions to be made with any degree of accuracy. But it is difficult to resist the con-

clusion that the soil colloids are mainly operative in causing the division, especially when it is noted the general equation (5) connecting free and total moisture is of the familiar adsorption type. The deduction can also be made that as the total moisture content varies, the relative amounts of "free" and "unfree" water also change.

We can obtain a clearer view of the conditions imposed on the soil solution by this equation, if the unfree water (Z_n) is considered.

We have

$$M_n = Y_n + Z_n \quad . \quad . \quad . \quad . \quad (11)$$

and $Y_n = cM_n^x \quad . \quad . \quad . \quad . \quad (5)$

Equation (5) can be written

$$\frac{1}{c^x} \cdot Y_n^{\frac{1}{x}} = Y_n + Z_n, \quad . \quad . \quad . \quad . \quad (12)$$

$$\therefore Z_n = \frac{1}{c^x} Y_n^{\frac{1}{x}} - Y_n. \quad . \quad . \quad . \quad . \quad (13)$$

This equation connects the value of the free and unfree water at any moisture content, but owing to the presence of the unknown quantity, Y_{21} (or Y_{34}) in the term $\frac{1}{c^x}$, the values of Z_n will also contain this

same unknown. But we can proceed to obtain a series of values for Z_n in a different manner, using Fig. 3. If we give Y_{21} any arbitrary value, with the obvious restriction that it must lie between 0 and 21, we get a set of values for Y_n at various known total moisture contents, and hence obtain by subtraction the corresponding values of Z_n . Table V shows the values for Y_n and Z_n for the sandy loam soil obtained in this manner, for various assumed values of Y_{21} between 0 and 21.

TABLE V.
Values of Z_n and Y_n for various values of Y_{21} .

M_n	$Y_{21}=21$		$Y_{21}=15$		$Y_{21}=9$		$Y_{21}=5$	
	Y_n	Z_n	Y_n	Z_n	Y_n	Z_n	Y_n	Z_n
21	21.0	0.0	15.0	6.0	9.0	12.0	5.0	16.0
19	16.5	2.5	11.8	7.2	7.0	12.0	3.9	15.1
17	12.4	4.6	8.9	8.1	5.3	11.7	2.9	14.1
15	8.8	6.2	6.3	8.7	3.8	11.2	2.1	12.9
13	6.0	7.0	4.3	8.7	2.6	10.4	1.4	11.6
11	4.0	7.0	2.9	8.1	1.7	9.3	1.0	10.0
9	2.4	6.6	1.7	7.3	1.0	8.0	0.6	8.4
7	1.3	5.7	1.0	6.0	0.6	6.4	0.3	6.7

At first sight the figures appear to show a remarkable relation. If Y_{21} has any value greater than about 9, the actual amount of unfree water increases and then decreases, while the free water continually decreases. It is not until Y_{21} is less than 9 that the free and unfree water both decrease together. The results are shown graphically in Fig. 4, where Y_n is plotted against Z_n ¹. It is necessary to understand that the same *general* equation (13) holds for each curve in Fig. 3. The actual changes in the *numerical* values of Z_n , mentioned above, are due to the fact that Y_{21} , and therefore $\frac{1}{c^x}$, have a different value for each curve².

It is clear from Fig. 4 that if the upper curves were produced they too would show a maximum value for Z_n , but it would eventually correspond to a total moisture content of a greater amount than the undisturbed soil could take up, and is therefore not compatible with the actual conditions. Obviously if Y_{21} were known the true curve showing Z_n and Y_n would also be expressible by equation (13). The question then arises as to which one of the family of curves shown in Fig. 4 best represents the true amounts of free and unfree water in the soil solution, at varying total moisture contents.

We obtain no help in this respect from a knowledge of the fact pointed out above (p. 407) that the percentage ratio of unfree water to total moisture increases as the latter diminishes, because, on testing, it will be seen that each series of values of Z_n in Table V fulfils this condition. It would seem probable that Y_{21} must be fairly large, in view of the low freezing-point depression at that point, but it is not easy to

¹ Actually, Fig. 3 represents a family of parabolae passing through the origin, with their axes inclined to the axes of co-ordinates.

² A numerical example may make this clearer. Take as a special case of equation (13):

$$Z_n = AY_n^{\frac{1}{2}} - Y_n,$$

and let A , the constant, have the values 100 and 5. By simple calculation we then have, in the two cases:

Y_n	$A=100$ Z_n	$A=5$ Z_n
25	475	0
16	384	4
9	291	6
4	196	6
1	99	4
0.25	49.75	2.25

This table shows that if $A=100$, Z_n decreases with Y_n , while if $A=5$ the value increases and then decreases.

conceive of any physical reason why the amount of unfree moisture actually increases and then decreases as the total moisture content diminishes. For this reason it would seem more probable that the real relation is expressed by a curve of the shape given when Y_{21} is put equal to 9, in which case, both Y_n and Z_n decrease in actual numerical value as the soil gets drier, while the percentage ratio they bear to the total moisture content decreases and increases respectively. An

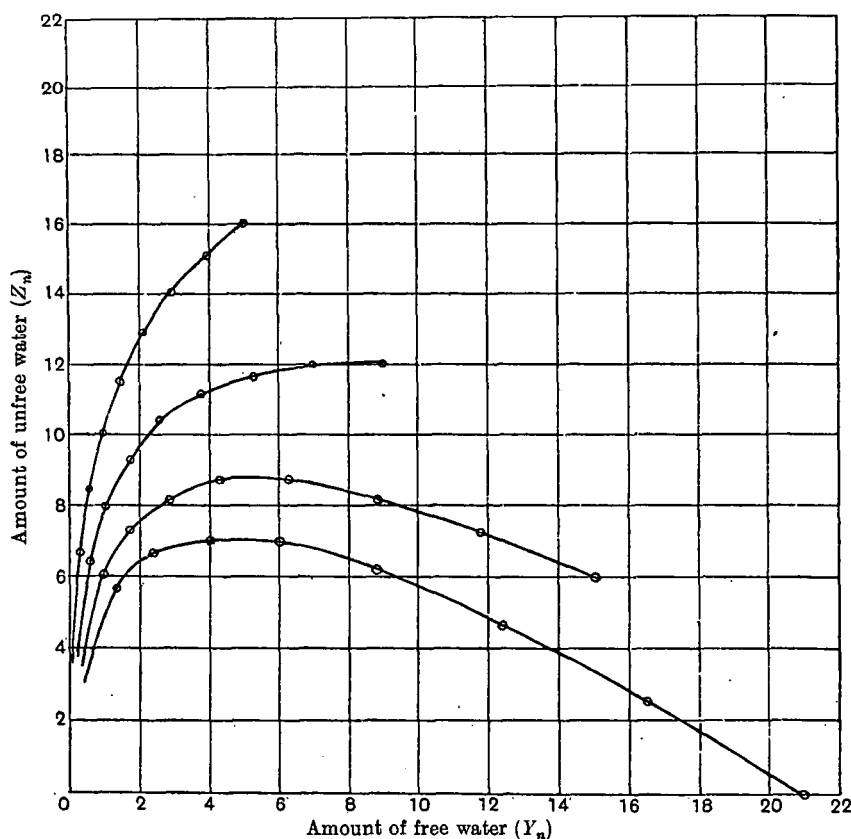


Fig. 4. Relation between free and unfree water, for various values of Y_{21} .

examination of the numerical values for this curve shows that at low percentages nearly all the water is present in the unfree condition. At a total moisture content of 7, only .58 is free and 6.48 is rendered unfree. The question as to whether this very small amount of free water would make it impossible for the freezing-point depression to be measured is partially answered by the experiments with quartz sand where a moisture content of .7 per cent. gave satisfactory measurements.

Although it seems more probable that the actual curve is similar to that given in Fig. 4 when $Y_n = 9$, yet if it be assumed that one of the lower curves is nearer the truth, there will be a certain amount of total water, for which the amount of unfree water is a maximum. It is suggestive to associate this point with the "optimum water content" of the soil, at which point, according to Cameron and Gallagher¹, various physical properties of the soil, such as specific gravity, resistance to penetration, rate of warming, etc., reach either a maximum or a minimum value.

This discussion as to the most probable type of curve expressing the relation between free and unfree moisture is put forward with reserve, owing to the very general nature of the possibilities considered. The essential point of the foregoing is that one equation defines the moisture over the whole range, and hence these various constants and critical points represent equilibrium points only, and do not indicate breaks in the physical state of the water in the soil, a conclusion in harmony with that advanced by the present writer in connection with the evaporation of water from soil.

Many other possibilities as to the behaviour of the soil solution could be considered in the light of the present results, but the discussion would necessarily be of a broad nature, and depend on the approximate truth of the initial assumption made in this paper—that the freezing-point depression is inversely proportional to the free moisture content. Hence it does not seem profitable to enter into this aspect of the question, until further information is obtained on this and allied assumptions. Sufficient data have been presented, however, to show that the freezing-point method of examining the soil solution demonstrates that the relations between soil and the moisture content are of no simple type, but that a complex connection holds in a continuous manner over a wide range of water content.

SUMMARY.

An examination has been made of some of the extensive experimental data obtained by Bouyoucos and his associates on the freezing-point depression of soil solution at varying moisture contents, examined *in situ*.

These workers find that the soil solution in quartz sand and extreme types of sandy soil obeys approximately the same law as dilute solutions—

¹ U.S. Bureau of Soils. *Bull.* No. 50 (1908).

414 *Soil, Soil Solution and Freezing-Point Determinations*

the freezing-point depression varying as the concentration, or in the present case, inversely as the moisture content. In other words

$$M_n D_n = K,$$

where K is a constant, and D_n is the freezing-point depression, at a moisture content of M_n . Soils do not obey this law, the freezing-point depression rapidly increasing as the moisture content decreases.

Bouyoucos qualitatively reconciles this difference in behaviour by the assumption that some of the water is rendered unfree, in the sense that it does not take part in the depression of the freezing-point.

The hypothesis is quantitatively examined in the present paper, and assuming its truth, it has been shown that:

(1) The water rendered unfree is not a constant amount, but varies with the total moisture content;

(2) A definite relation exists between the free, unfree and total moisture, expressed by the equations:

$$Y_n = cM_n,$$

$$Z_n = \frac{1}{c^x} Y_n^{\frac{1}{x}} - Y_n,$$

where c and x are constants for any one soil,

$$M_n = \text{total moisture content,}$$

$$Y_n = \text{free water,}$$

$$Z_n = \text{unfree water.}$$

(3) The proportion of free to total water continually decreases and that of unfree to total continually increases as the total moisture diminishes in amount, over the experimental range.

(4) The actual amount of free water continually decreases as the total moisture diminishes, but it cannot be definitely stated at present how the actual amount of unfree water changes as total moisture diminishes. The uncertainty is due to the presence of an unknown (but constant) factor in the constant " c " of the equation, viz. the quantity of free water present at the highest amount of total water used in the experiments of Bouyoucos. According to the value arbitrarily assigned to this quantity, so the amount of unfree water may continually decrease with decrease of total moisture over the experimental range, or may increase to a maximum and then decrease. It is probable that the former is more truly representative of the actual condition in soil, although the possibility of a maximum occurring in the amount of un-

free water is suggestive in any consideration of the "optimum-moisture-content," and the passage, according to Cameron and Gallagher, of various physical properties through a maximum or minimum value at that point.

(5) The same general conclusions on the relations existing between the soil and its moisture content that were drawn from the writer's experiments on the evaporation of water from soil, follow again. The soil colloids must be considered as primarily concerned in the relations; the water present is subjected to the same law over the whole experimental range and the various constant and critical points shown by soil at varying degrees of water contents, are approximate equilibrium values only and do not indicate any break or abrupt change in the physical condition of the soil moisture.

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