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USE OF THE MOISTURE EQUIVALENT FOR THE INDIRECT DETERMINATION OF THE HYGROSCOPIC COEFFICIENT

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INTRODUCTION

The maximum amount of soil water available for growth and for the maintenance of life in the case of ordinary crop plants appears to be approximately equal to the free water—the difference between the total amount of water and the hygroscopic coefficient—in those portions of the soil and the subsoil occupied by the roots (1, p. 121).[1] The hygroscopic coefficient (8, p. x; 10, p. 243) expresses the percentage of moisture contained in a soil which, in an air-dry condition, has been brought into a saturated atmosphere, kept at a constant temperature, and allowed to remain until in approximate equilibrium with this atmosphere.

Hilgard's method for the direct determination (10, p. 243; 11, p. 17) of the hygroscopic coefficient requires provision for the maintenance of a constant temperature in the room in which the absorption boxes are placed and also presents difficulties in insuring the actual saturation of the atmosphere in these boxes. Accordingly, any indirect method which gives results in satisfactory accord with those obtained by direct determination and at the same time requires only apparatus which is less inconvenient, either of installation or of operation, will prove useful.

Briggs and Shantz (7, p. 73) have recently proposed several indirect methods, and to the consideration of the reliability of one of these the present paper is devoted. These authors derived formulas for the indirect determination of what they designate the "wilting coefficient," defined as the moisture remaining in the soil in immediate contact with the roots when the permanent wilting of a plant occurs, from the moisture equivalent (6, p. 140; 4, p. 276), from the maximum water capacity as

[1] Reference is made by number to "Literature cited," p. 845.

defined by Hilgard (10, p. 256), and from the mechanical analysis. Subsidiary formulas for the indirect determination of the hygroscopic coefficient, following as a result of the interrelationships thus established, they report (7, p. 73) as follows:

$$\text{Hygroscopic coefficient} = \begin{cases} \text{Wilting coefficient} \times 0.68. \\ \text{Moisture equivalent} \times 0.37. \\ (\text{Maximum water capacity} - 21) \times 0.234. \\ (0.007 \text{ sand} + 0.082 \text{ silt} + 0.39 \text{ clay}). \end{cases}$$

As the mechanical analysis of a soil is a far more difficult and time-consuming operation than the determination of the hygroscopic coefficient, the latter could advantageously be calculated from the former only where this is already available, as, for example, in the reports of soil surveys. Even then there is a probability of introducting serious errors. Thus, with a series of loess soils (3, p. 411) it has recently been shown that the values for the hygroscopic coefficient calculated by the Briggs-Shantz formula agree satisfactorily with those obtained by direct determination only in the case of those samples which carry the smallest proportion of very fine sand. However, by altering the values assigned the sands there was obtained the following modified formula, which was found applicable to all the loess soils investigated.

Hygroscopic coefficient = 0.005 coarser fractions + 0.07 very fine sand + 0.82 silt + 0.39 clay.

"Coarser fractions" is here used to designate all soil particles having a diameter greater than 0.10 mm.

The wilting coefficient also is so inconvenient of determination that, unless it has to be determined for some other purpose, it will not be used to calculate the hygroscopic coefficient.

In connection with field studies of available soil moisture on the Nebraska loess, of which only a few data (1, p. 118) have as yet been published, one of us had arrived at conclusions so widely at variance with those of Briggs and Shantz, who, in somewhat similar studies, had employed the wilting coefficient, either determined directly or calculated from the moisture equivalent, that we suspected the explanation might lie in the differences in the values of the hygroscopic coefficient obtained for similar soils by our respective methods. However, as no moisture-equivalent apparatus was at that time available for our use we were unable then to decide the question. Now, using 135 samples of which hygroscopic coefficient determinations had been made at the Nebraska Experiment Station, we have determined the moisture equivalents, thus obtaining a definite answer to the question.

Lipman and Waynick (12) have recently reported both the moisture equivalents and the hygroscopic coefficients of 27 soils, and from these the ratios may be calculated. In so far as we are aware, there are no published data except those in the two articles mentioned from which the relationship of the moisture equivalent to the hygroscopic coefficient can be computed.

COMPUTATIONS FROM DATA OF BRIGGS AND SHANTZ

Briggs and Shantz have reported (7, p. 57–65) both the hygroscopic coefficients and the moisture equivalents in the case of 17 soils ranging in texture from a coarse sand with a hygroscopic coefficient of 0.5 to a clay loam with a value of 13.2. Their data, however, were not presented in such form as to show the concordance of the hygroscopic coefficients calculated from the moisture equivalents with those directly determined, and for this reason we consider it desirable to so present them (Table I).

TABLE I.—*Relation of the moisture equivalent to the hygroscopic coefficient shown by data of Briggs and Shantz* [1]

Soil.	Type of soil.	Moisture equivalent.	Hygroscopic coefficient.	Ratio of moisture equivalent to hygroscopic coefficient.	Hygroscopic coefficient calculated from moisture equivalent.	Departure of calculated from determined hygroscopic coefficient.
7	Coarse sand	1.6	0.5	3.20	0.6	0.1
2	Fine sand	4.7	1.5	3.13	1.7	.2
8	....do	5.5	2.3	2.39	2.0	−.3
9	....do	6.7	2.3	2.91	2.5	.2
3	Sandy loam	9.7	3.5	2.77	3.6	.1
10	....do	11.9	4.4	2.70	4.4	.0
4	Fine sandy loam	18.1	6.5	2.78	6.7	.2
12	Loam	18.9	7.8	2.42	7.0	−.8
A	Sandy loam	19.6	6.3	3.11	7.2	.9
B	Fine sandy loam	19.9	6.6	3.01	7.3	.7
C	....do	22.1	7.5	2.94	8.2	.7
5	Loam	25.0	9.8	2.55	9.2	−.6
D	....do	27.0	9.6	2.81	10.0	.4
13	Clay loam	27.4	11.8	2.32	10.1	−1.7
14	....do	29.3	13.2	2.22	10.8	−2.4
E	....do	30.0	11.2	2.68	11.1	−.1
6	....do	30.2	11.4	2.65	11.2	−.2
	Mean [2]			2.71		
	Maximum			3.11		
	Minimum			2.22		

[1] Derived from Briggs and Shantz (7, p. 57, 60, 65, Tables XVII, XIX, and XX).
[2] Omitting 7 and 2.

Excepting the two sands, 1 and 2, the ratio varies from 3.11 to 2.22, a range of 40 per cent, reaching a maximum in the case of a sandy loam with a hygroscopic coefficient of 6.3 and a minimum in a clay loam with the coefficient 13.2. In the case of the latter the value calculated from the mean ratio, 2.71, differs by 2.4 from that obtained by direct determination. Two of the four clay-loam samples give concordant and two rather discordant results, the divergence in the case of the latter being similar to that obtained from the mechanical analysis of many of the loess soils (3, p. 411).

COMPUTATIONS FROM DATA OF LIPMAN AND WAYNICK

Lipman and Waynick report (12, p. 8–9) both the hygroscopic coefficients and the moisture equivalents on 27 samples used in the well-known so-called Tri-State Soil Exchange Experiment. The ratios, which evidently they did not compare, we show in Table II. These data have an added interest in that they are from the laboratory of the late Dr. Hilgard, who introduced the determination of the hygroscopic coefficient (8, 9, 10).

TABLE II.—*Relation of the moisture equivalent to the hygroscopic coefficient shown by the data of Lipman and Waynick*

Depth.	California soil.			Kansas soil.			Maryland soil.		
	In California.	In Kansas.	In Maryland.	In California.	In Kansas.	In Maryland.	In California.	In Kansas.	In Maryland.
HYGROSCOPIC COEFFICIENT [1]									
Feet.									
1	8.55	8.29	6.68	12.12	10.74	11.00	5.97	5.15	4.69
2	8.67	7.69	8.44	12.42	12.38	11.68	6.82	5.82	7.66
3	8.98	8.68	9.04	11.28	10.54	11.18	8.87	6.75	9.23
Average	8.73	8.22	8.05	11.94	11.22	11.29	7.22	5.91	7.19
MOISTURE EQUIVALENT [2]									
1	24.09	22.32	22.67	32.61	29.63	29.80	23.62	23.67	21.92
2	22.81	22.20	20.32	33.33	30.78	31.14	24.26	26.02	19.37
3	24.02	24.24	23.53	30.21	27.57	29.40	29.17	29.16	27.38
Average	23.64	22.92	22.17	32.05	29.33	30.11	25.68	26.28	22.89
RATIO OF MOISTURE EQUIVALENT TO HYGROSCOPIC COEFFICIENT									
1	2.82	2.69	3.39	2.69	2.76	2.71	3.96	4.60	4.67
2	2.63	2.89	2.41	2.68	2.49	2.67	3.56	4.47	2.53
3	2.67	2.79	2.60	2.68	2.61	2.63	3.29	4.32	2.97
Average	2.71	2.79	2.80	2.68	2.62	2.67	3.60	4.46	3.39

[1] From Lipman and Waynick (12, p. 8, Table I). [2] From Lipman and Waynick (12, p. 9, Table II).

The average ratio for the 27 samples is 3.08, with a minimum of 2.41 and a maximum of 4.67, a range of 93 per cent. On inspection of Tables I and II it will be seen that for the Kansas soils the ratio varies only between 2.49 and 2.76, and for the California soils between 2.41 and 3.39, with an average for these 18 samples of 2.72, which is practically identical with the mean found by Briggs and Shantz—viz, 2.71.

In the case of the 9 samples of Maryland soils, the ratio varies from 2.53 to 4.67, with an average of 3.75. As none of the samples is to be considered lighter in texture than a loam or heavier than a clay loam, any ratio sufficiently accurate for ordinary purposes should apply to all of them.

EXPERIMENTAL WORK

The moisture equivalents were determined according to Briggs and Shantz (7, p. 57), bringing the soils into equilibrium with a force 1,000 times that of gravity, using a centrifuge (6, p. 141) made according to specifications kindly furnished by Dr. L. J. Briggs, of the Bureau of Plant Industry. The determination of the moisture equivalent has been found to be convenient of execution, and the results from day to day are very concordant.

In Table III are given the moisture equivalent, the hygroscopic coefficient, the ratio of these to one another, and the content of organic matter in 36 samples. The soils were collected from 30 virgin prairie fields in Nebraska, 5 near each of the six towns indicated in the table. All are from fields classified by the United States Bureau of Soils either as Marshall silt loams or as Colby silt loam. In each field 10 borings were made to a depth of 6 feet and composite samples prepared of each foot section, thus securing 6 samples from each field. From these were prepared the samples used in this work, equal weights of the corresponding 5 field samples being combined. The details of the method of sampling are reported elsewhere (2, p. 204). In the same article (2, p. 215) are given the hygroscopic coefficients for the foot sections from each of all the fields. Each value in B of Table III represents the average of 10 determinations. The data on the organic matter reported in D of the table were calculated from the organic carbon reported in the same article (2, p. 228; organic matter $= C \times 1.724$). The data on the moisture equivalents are the means of duplicate determinations.

The ratio (Table III–C) averages 2.38, varying from 2.14 to 2.73, a quite similar, although somewhat narrower, range than that found by Briggs and Shantz. In general, in each area it is highest in the surface foot as though influenced by the proportion of the organic matter.

TABLE III.—*Moisture equivalent, hygroscopic coefficient, ratio of these two values, and organic-matter content of the foot sections from six different areas in Nebraska*

(A) MOISTURE EQUIVALENT

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
Feet.							
1	22.3	24.0	26.7	26.2	30.7	30.3	26.7
2	22.1	24.8	27.6	28.6	31.5	31.2	27.6
3	23.0	24.6	26.8	28.2	29.2	30.9	27.1
4	23.3	23.6	25.1	26.9	27.8	29.2	26.0
5	21.1	22.5	24.1	26.5	28.3	28.2	25.1
6	19.8	22.1	24.0	26.6	26.3	28.3	24.8
Average	21.9	23.6	25.7	27.2	29.3	29.7	26.2

(B) HYGROSCOPIC COEFFICIENT

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
1	9.1	10.0	10.1	9.6	12.0	12.1	10.5
2	9.6	10.9	11.2	11.6	14.4	13.7	11.9
3	9.7	10.7	11.3	12.4	13.6	13.9	11.9
4	9.9	9.7	10.2	11.1	13.0	13.0	11.1
5	9.0	9.1	9.6	10.7	12.8	12.6	10.6
6	8.3	9.1	9.4	10.7	12.7	12.5	10.5
Average	9.3	9.9	10.3	11.0	13.1	13.0	11.1

(C) RATIO OF MOISTURE EQUIVALENT TO HYGROSCOPIC COEFFICIENT

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
1	2.45	2.40	2.64	2.73	2.56	2.50	2.55
2	2.30	2.28	2.46	2.47	2.19	2.28	2.32
3	2.37	2.30	2.37	2.27	2.15	2.22	2.28
4	2.35	2.43	2.46	2.42	2.14	2.25	2.34
5	2.34	2.47	2.51	2.48	2.21	2.24	2.38
6	2.39	2.43	2.55	2.49	2.23	2.26	2.39
Average	2.37	2.38	2.50	2.48	2.25	2.29	2.38

(D) PERCENTAGE OF ORGANIC MATTER

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
1	2.77	2.85	3.90	3.55	4.96	4.98	3.83
2	1.38	1.44	1.86	1.81	2.28	3.02	1.96
3	1.09	.97	1.01	.98	1.14	1.38	1.09
4	.79	.59	.66	.60	.60	.83	.68
5	.55	.48	.41	.41	.43	.45	.45
6	.45	.36	.36	.31	.40	.36	.37
Average	1.17	1.11	1.37	1.28	1.63	1.84	1.40

Table IV shows the values for the hygroscopic coefficients calculated from the moisture equivalents, using the Briggs-Shantz formula, and the departure from those directly determined. In all cases the values are more or less too low; using these there might appear to be as much as from 1.0 to 2.8 per cent of free water in the case of a subsoil which actually carried none.

TABLE IV.—*The hygroscopic coefficients calculated from the moisture equivalents and the departure of these from the values obtained by direct determination*

(A) CALCULATED HYGROSCOPIC COEFFICIENTS

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
Feet.							
1	8.2	8.9	9.9	9.7	11.3	11.2	9.9
2	8.2	9.2	10.2	10.6	11.6	11.5	10.2
3	8.5	9.1	9.9	10.4	10.8	11.4	10.0
4	8.6	8.7	9.3	9.9	10.3	10.8	9.6
5	7.8	8.3	8.9	9.8	10.4	10.4	9.3
6	7.3	8.2	8.9	9.8	10.4	10.4	9.2
Average	8.1	8.7	9.5	10.0	10.8	11.0	9.7

(B) DEPARTURE FROM DIRECTLY DETERMINED VALUES

1	−0.9	−1.1	−0.2	−0.1	−0.7	−0.9	−0.6
2	−1.4	−1.7	−1.0	−1.0	−2.8	−2.2	−1.7
3	−1.2	−1.6	−1.4	−2.0	−2.8	−2.5	−1.9
4	−1.3	−1.0	−.9	−1.2	−2.7	−2.2	−1.5
5	−1.2	−.8	−.7	−.9	−2.4	−2.2	−1.3
6	−1.0	−.9	−.5	−.9	−2.3	−2.1	−1.3
Average	−1.2	−1.2	−.8	−1.0	−2.3	−2.0	−1.4

Table V gives similar data on another set of samples from the same 30 fields. These consisted of 1-inch sections from the surface foot (2, p. 206). In the case of these, however, each datum on hygroscopic coefficients as well as on moisture equivalents is the mean of only duplicate determinations. The ratio averages 2.75, compared with 2.71 found by Briggs and Shantz (Table I), and varies from 2.33 to 3.29, a range of 41 per cent, compared with 40 found by them with their 17 soils. Their samples also were probably surface soils rather than subsoils, such as predominate in Table III. In the inch sections, as in the foot sections, a decrease in the ratio is to be observed in passing from the surface to the subsoil. This may be attributed to the organic matter which appears to have a marked influence upon the moisture equivalent, although it shows little effect upon the hygroscopic coefficient (2, p. 217). Briggs and McLane (5, p. 18), found that organic matter had practically the same effect upon the moisture equivalent as an equal amount of clay.

TABLE V.—*Moisture equivalent, hygroscopic coefficient, ratio of these two values, and the organic content of the inch sections of the surface foot*

(A) MOISTURE EQUIVALENT

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
Inches.							
1	24.4	24.3	31.6	31.5	31.0	32.7	29.2
2	22.3	22.2	29.6	27.6	30.0	31.5	27.2
3	22.5	22.9	28.3	27.3	30.2	31.3	27.1
4	22.3	23.3	28.3	27.6	30.5	30.6	27.1
5	22.6	24.5	27.5	27.3	29.9	31.7	27.2
6	22.5	25.7	27.7	27.8	30.0	31.9	27.6
7	22.3	25.4	28.1	27.5	30.1	32.4	27.6
8	22.3	25.6	27.9	27.3	30.3	31.9	27.5
9	22.8	27.2	28.0	27.6	30.9	31.4	28.0
10	22.8	27.3	28.2	27.4	30.7	32.2	28.1
11	23.0	27.9	28.0	27.9	30.0	31.9	28.1
12	23.0	26.8	28.1	28.4	30.8	32.3	28.2
Average	22.7	25.2	28.4	27.9	30.4	31.8	27.7

(B) HYGROSCOPIC COEFFICIENT

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
1	8.5	8.5	10.9	10.9	11.5	11.5	10.3
2	8.2	8.3	10.3	9.7	11.2	11.0	9.8
3	8.2	8.4	9.9	8.9	11.0	11.0	9.6
4	8.3	8.3	9.5	8.5	11.1	11.1	9.5
5	8.2	8.7	9.4	8.3	11.4	11.2	9.5
6	8.6	9.3	9.4	9.0	11.8	11.2	9.9
7	8.7	9.5	9.7	9.5	11.9	11.5	10.1
8	8.8	9.8	9.9	9.5	12.1	12.1	10.4
9	8.6	9.9	10.0	9.5	13.0	12.3	10.6
10	8.8	10.3	10.4	9.7	12.6	12.6	10.7
11	9.0	10.3	10.2	10.0	12.9	12.5	10.8
12	8.7	10.2	10.2	10.2	13.1	12.8	10.9
Average	8.6	9.3	10.0	9.5	12.0	11.7	10.2

(C) RATIO OF MOISTURE EQUIVALENT TO HYGROSCOPIC COEFFICIENT

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
1	2.87	2.86	2.90	2.89	2.70	2.84	2.84
2	2.72	2.68	2.87	2.85	2.68	2.86	2.78
3	2.74	2.73	2.86	3.07	2.75	2.85	2.84
4	2.69	2.81	2.98	3.25	2.75	2.76	2.87
5	2.76	2.82	2.93	3.29	2.62	2.83	2.88
6	2.62	2.76	2.95	3.09	2.54	2.85	2.79
7	2.56	2.67	2.90	2.89	2.53	2.82	2.73
8	2.53	2.61	2.82	2.87	2.50	2.64	2.66
9	2.65	2.75	2.80	2.91	2.38	2.56	2.68
10	2.59	2.65	2.71	2.83	2.44	2.56	2.63
11	2.56	2.71	2.74	2.79	2.33	2.55	2.62
12	2.64	2.63	2.75	2.78	2.35	2.52	2.61
Average	2.66	2.72	2.85	2.96	2.55	2.72	2.74

TABLE V.—*Moisture equivalent, hygroscopic coefficient, ratio of these two values, and the organic content of the inch sections of the surface foot*—Continued.

(D) PERCENTAGE OF ORGANIC MATTER

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
Inches.							
1	4.91	4.17	7.93	7.79	8.10	7.79	6.78
2	3.64	3.35	6.03	5.46	6.29	6.39	5.19
3	3.19	3.27	4.95	4.45	5.70	5.60	4.53
4	2.88	3.14	4.22	3.93	5.37	5.29	4.14
5	2.55	2.84	3.74	3.50	4.89	4.87	3.73
6	2.52	2.66	3.46	3.20	4.72	4.56	3.52
7	2.26	2.48	3.05	3.09	4.31	4.08	3.21
8	2.19	2.31	2.97	2.88	4.12	4.03	3.08
9	2.12	2.17	2.79	2.74	3.98	3.95	2.96
10	1.97	2.00	2.67	2.64	3.59	3.76	2.77
11	1.77	1.84	2.58	2.62	3.40	3.69	2.65
12	1.77	1.72	2.50	2.50	3.26	3.60	2.56
Average	2.67	2.69	3.90	3.72	4.77	4.81	3.76

The samples reported in Table VI are partly from the loess of Nebraska and partly from the residual soils of that State. A few are from New Mexico, Arizona, and California. The data upon both the hygroscopic coefficient and the moisture equivalent are the means of 5 to 10 concordant determinations. Nine of the samples are from the surface 6 to 12 inches, and the seven others from the subsoil. The range in texture represented by them is much the same as that of the soils reported by Briggs and Shantz (Table I).

TABLE VI.—*Relation of the moisture equivalent to the hygroscopic coefficient in a series of soils showing a wide range in texture*

Soil No.	Description of soil.	Moisture equivalent.	Hygroscopic coefficient.	Ratio of moisture equivalent to hygroscopic coefficient.	Hygroscopic coefficient calculated from moisture equivalent.[1]	Departure of calculated from found hygroscopic coefficient.
1	Desert sand, Palm Springs, Cal.	1.6	0.9	1.77	0.6	−0.3
2	Sandy subsoil, Palm Springs, Cal.	2.8	1.1	2.54	1.0	−.1
3	Desert sand, Orogrande, N. Mex.	3.0	1.7	1.76	1.1	−.6
4	Sandy surface, W. Nebraska	7.9	3.3	2.39	2.9	−.4
5	Sandy subsoil (A), W. Nebraska	7.2	3.4	2.12	2.6	−.8
6	Sandy subsoil (B), W. Nebraska	7.5	3.4	2.21	2.8	−.6
7	Sandy loam subsoil, W. Nebraska	13.5	5.6	2.41	5.0	−.6
8	Sandy loam surface, W. Nebraska	16.8	7.1	2.37	6.2	−.9
9	Silt loam subsoil (A), W. Nebraska	19.7	7.6	2.59	7.3	−.3
10	Silt loam subsoil (B), W. Nebraska	21.2	8.2	2.59	7.8	−.4
11	Red loam surface, Cuervo, N. Mex.	19.2	10.0	1.92	7.1	−2.9
12	Silt loam surface (A), W. Nebraska	22.5	10.1	2.23	8.3	−1.8
13	Silt loam surface, E. Nebraska	27.8	10.2	2.73	10.3	.1
14	Silt loam surface (B), W. Nebraska	24.1	10.5	2.30	8.9	−1.6
15	Adobe surface, McNeal, Ariz.	25.8	12.9	2.00	9.6	−3.3
16	Silt loam subsoil, E. Nebraska	29.5	13.3	2.22	10.9	−2.4

[1] Using Briggs and Shantz formula M. E.=hyg. coeff.×2.71.

Excepting the two sands, 1 and 3, the average ratio of moisture equivalent to hygroscopic coefficient is 2.33, with a maximum of 2.73 and a minimum of 1.92. The lowest ratios are shown by the arid or semiarid soils, 1, 3, 11, and 15. The exceptional behavior of 11 and 15 is not to be attributed to error of determination, as, after finding these exceptional ratios, we made repeated determinations of both values. The ratios found for both subsoils and surface soils from Nebraska are quite similar to those reported in Table III, the average ratio, 2.38, being identical with that obtained for the 36 loess samples.

If the two sands, 1 and 3, in Table VI, be omitted, the variation of our ratios in Tables III, V, and VI are of much the same order as those of Briggs and Shantz, shown in Table I. Thus, the divergence in our conclusions as to the availability to plants of the portion of the soil moisture lying between the hygroscopic coefficient and the wilting coefficient is not to be explained by any differences in our respective methods of arriving at the value of the hygroscopic coefficient. Neither are there sufficient reasons to attribute it to the particular range of soils with which we have worked, for the data above show that our soils range as widely as those which they have employed.

Their data, as well as our own work, make it evident that in any accurate experiments to determine the relation of the nonavailable water of the soil to the hygroscopic coefficient it is not permissible to calculate the value of the latter from the moisture equivalent, unless a previous thorough investigation has been made to determine just what formula is applicable to the soil type in question. From the data of Lipman and Waynick it would appear that in the case of certain soils this indirect method would be scarcely allowable for even the crudest studies on soil moisture. However, in the case of any extensive study, involving many soil types, the same general conclusions as to the relation of the nonavailable moisture to the hygroscopic coefficient are to be expected, no matter whether the latter value be directly determined or be calculated from the moisture equivalent by the Briggs-Shantz or by some more satisfactory formula.

COMPUTATION OF THE MOISTURE EQUIVALENT FROM THE MECHANICAL ANALYSIS

Table VII shows the concordance of the moisture equivalents directly determined with the values computed from the mechanical analyses in the cases of the loess samples reported in Table III, using the formula proposed by Briggs and Shantz:

Moisture equivalent = 0.02 sands + 0.22 silt + 1.05 clay, and also a modified form of this formula:

Moisture equivalent = 0.14 sands + 0.27 silt + 0.53 clay. In these formulas "sands" include particles ranging from 2 to 0.05 mm. in diameter. The separates referred to in the table as "coarser fractions" include the particles ranging from 2 to 0.10 mm. It will be seen that the formula of Briggs and Shantz gives values too low for the coarsest textured members of the series and too high for the finest textured. In the modified formula the value assigned to the clay is lowered, that to the "sands" much increased, and that to the silt slightly raised. This formula gives results in close concordance with the directly determined values. The explanation of the need of altering the values is not far to seek. As has already been pointed out in connection with the computation of the hygroscopic coefficients from the mechanical analyses of the same samples (3, p. 406), the material coarser than silt is chiefly very fine sand, consisting mainly of particles but little larger than the upper limit for silt, while the so-called "clay" contains a very large proportion of silt particles with a diameter not much less than 0.005 mm.

Briggs and McLane (5, p. 21), in applying their generalized formula based upon the analysis of 104 soils, found that for the Marshall series it was necessary to give the clay a lower value and also to make allowance for the content of organic matter. As has been mentioned above, the samples in Table VII belong to the Marshall and Colby series.

Thus, it appears that if the mechanical analyses are to be used for the computation of moisture equivalents, it will be necessary, at least in the case of some widely differing soil types, to employ several different formulas.

TABLE VII.—*Concordance of the values for the moisture equivalent obtained by computation from the mechanical analysis with those directly determined*

WAUNETA

Depth.	Coarser fract (2.0—0.1 mm.).	Very fine sand (0.1—0.05 mm.).	Silt (0.05—0.005 mm.).	Clay (0.005—0.000 mm.).	Moisture equivalent. Determined.	Computed by formula. B. and S.[1]	Computed by formula. Mod.[2]	Departure, using formula. B. and S.	Departure, using formula. Mod.
Feet.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*					
1	4.8	48.7	41.2	5.4	22.3	15.9	21.5	−5.4	−0.8
2	2.4	47.8	43.3	6.6	22.1	17.5	22.2	−4.6	.1
3	2.0	46.8	43.8	7.5	23.0	18.5	22.6	−4.5	− .4
4	1.7	47.6	41.3	9.5	23.3	20.1	23.1	−3.2	− .2
5	1.5	50.0	43.6	4.9	21.1	15.8	21.6	−5.3	.5
6	1.3	54.9	39.8	4.2	19.8	14.3	20.8	−5.5	1.0
Average	2.3	49.3	42.2	6.3	21.9	17.0	21.9	−4.9	0

M'COOK

Depth.	Coarser fract	Very fine sand	Silt	Clay	Determined	B. and S.	Mod.	B. and S.	Mod.
1	3.7	39.0	48.6	8.7	24.0	20.7	23.7	−3.3	−0.3
2	2.6	37.8	50.1	9.5	24.8	21.8	24.2	−3.0	− .6
3	1.3	36.4	53.9	8.4	24.6	21.4	24.3	−3.2	− .3
4	1.4	38.9	52.4	7.4	23.6	20.0	23.7	−3.6	.1
5	1.8	39.3	52.6	6.3	22.5	19.0	23.3	−3.5	.8
6	1.2	40.4	51.8	6.6	22.1	19.2	23.3	−2.9	1.2
Average	2.0	38.6	51.6	7.8	23.6	20.4	23.7	−3.2	.1

[1] Moisture equivalent=0.02 sands+0.22 silt+1.05 clay.

[2] Moisture equivalent=0.14 sands+0.27 silt+0.53 clay.

TABLE VII.—*Concordance of the values for the moisture equivalent obtained by computation from the mechanical analysis with those directly determined*—Continued.

HOLDREGE

Depth.	Coarser fract (2.1—0.1 mm.).	Very fine sand (0.1—0.05 mm.).	Silt (0.05—0.005 mm.).	Clay (0.005—0.000 mm).	Moisture equivalent.				
					Determined.	Computed by formula.		Departure, using formula.	
						B. and S.	Mod.	B. and S.	Mod.
Feet.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*					
1	2.8	25.9	64.6	6.7	26.7	21.8	25.0	−4.9	−1.7
2	1.3	24.6	62.9	11.6	27.6	26.1	26.5	−1.5	−1.2
3	.8	26.5	62.5	10.5	26.8	25.3	26.2	−1.5	−.6
4	.9	27.8	64.8	6.4	25.1	21.6	24.9	−3.5	−.2
5	2.5	31.7	60.0	5.8	24.1	20.0	24.1	−4.1	.0
6	2.4	31.1	60.7	5.8	24.0	20.1	24.2	−3.9	.2
Average.	1.8	27.9	62.6	7.7	25.7	22.5	25.1	−3.2	−.6

HASTINGS

1	3.9	23.9	64.6	7.6	26.2	22.8	25.4	−3.4	−0.8
2	2.7	20.3	64.5	12.5	28.6	27.8	27.3	−.8	−1.5
3	2.3	22.2	61.9	13.6	28.2	28.4	27.4	.2	−.8
4	2.1	21.5	62.4	14.0	26.9	28.9	27.6	2.0	.7
5	2.4	20.9	66.7	10.0	26.5	25.6	26.6	−.9	.1
6	2.2	20.7	67.2	9.9	26.6	25.6	26.6	−1.0	0
Average.	2.6	21.6	64.5	11.3	27.2	26.5	26.8	−0.7	−0.4

LINCOLN

1	3.8	13.5	68.0	14.8	30.7	30.8	28.6	0.1	−2.1
2	3.7	9.8	67.6	18.9	31.5	35.0	30.2	3.5	−1.3
3	3.4	9.3	68.0	19.3	29.2	35.5	30.4	6.3	1.2
4	3.2	9.6	68.1	18.9	27.8	35.1	30.2	7.3	2.4
5	3.7	9.9	69.4	17.0	28.3	33.4	29.7	5.1	1.4
6	3.9	9.5	70.2	16.5	28.3	33.0	29.6	4.7	1.5
Average.	3.6	10.3	68.5	17.6	29.3	33.8	29.8	4.5	.5

WEEPING WATER

1	4.2	9.7	72.2	13.9	30.3	30.8	28.8	0.5	−1.5
2	2.8	8.2	69.5	19.6	31.2	36.1	30.7	4.9	−.5
3	1.0	13.8	66.7	18.6	30.9	34.5	29.9	3.6	−1.0
4	.6	14.9	67.0	17.6	29.2	33.5	29.6	4.3	.4
5	.5	14.7	67.9	17.0	28.2	33.1	29.5	4.9	1.3
6	.5	15.0	67.5	17.1	28.3	33.1	29.5	4.8	1.2
Average.	1.7	12.7	68.5	17.3	29.7	33.5	29.7	3.8	0
Average of all.	2.3	26.7	59.7	11.3	26.2	25.6	26.2	−0.6	0

SUMMARY

The hygroscopic coefficient may in most cases be calculated from the moisture equivalent with sufficient accuracy to permit its use in soil-moisture studies. For certain types of soil, however, the ratio departs so widely from that assigned by Briggs and Shantz that the indiscriminate use of the latter value does not seem permissible. Before employing this indirect method for the determination of the hygroscopic coefficient in connection with soil-moisture studies the ratio should be experimentally established for each of the particular types of soil involved.

The effect of considerable quantities of organic matter is, in general, to give the ratio of the moisture equivalent to the hygroscopic coefficient a higher value.

In the case of any extensive study of soil moisture involving many soil types the same general conclusions as to the relation of the non-available moisture to the hygroscopic coefficient are to be expected no matter whether the latter value be directly determined or be calculated from the moisture equivalent by the Briggs-Shantz formula.

For the calculation of the moisture equivalent from the mechanical analysis no general formula appears universally applicable, the formula needing modification according to the soil type to which it is to be applied.

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