COMPARATIVE VALUE OF VARIOUS METHODS OF APPROXIMATING THE PERMANENT WILTING PERCENTAGE

M. A. Lugo López[1]

Introduction

The permanent wilting percentage is of utmost significance in the evaluation of the moisture relationships of soils. Its consideration introduces a biological factor in the classification of soil water. It marks the division between readily available water and water the availability of which is so slight that plants are unable to absorb it at the necessary rate to balance their transpiration requirements. It is generally accepted that the permanent wilting percentage is identical for all plants grown in a given soil. Therefore, it is a soil constant and any differences which may be suggested by plant characteristics are reduced to a negligible minimum. The tenacity with which water is retained in soils when permanent wilting occurs have been fixed at a value of pF 4.2. This is an intermediate position in the moisture range between the hygroscopic coefficient (pF 4.5) and the moisture equivalent (pF 2.7).

Several methods have been proposed to obtain the permanent wilting percentage all of which have certain advantages and also marked shortcomings. The objective of this work was to compare the standard biological method with a purely physical technique and with several indirect approaches.

Materials and Methods

The samples used for this work were those obtained in connection with a more extensive work project on the moisture relationships of Puerto Rican soils (3).[2] Samples were taken from 106 soil types representing the humid and arid regions of the Island. The soils of the humid area were further subdivided into two broad groups, lateritic and nonlateritic. In sampling an area the maps of the Soil Survey of Puerto Rico were used as a guide (7). Composite samples were obtained from the topmost 6 or 8 inches. They were air-dried and passed through a 2-mm. sieve.

The standard biological method was used in determining the permanent wilting percentage (5). Soybean plants were selected as indicator plants because the standard dwarf sunflower was not available at the time the investigation was initiated. In addition, soybeans have been observed to give

[1] Associate Soil Scientist, Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R.

[2] Numbers in parentheses refer to Literature Cited, p. 133.

a good indication of the onset of wilting. Four replications were used for each soil. Samples of 46 soil types were submitted to 15 times atmospheric pressure on special plates of the type developed by Richards in California, using a special visking membrane (6). Six replications were used.

The moisture content was determined gravimetrically after the samples reached equilibrium. The values were further compared with those of the permanent wilting percentage as obtained by the biological method. In determining moisture-equivalent values, duplicate determinations were made according to the method outlined by Briggs and McLane by use of a special centrifuge (1). Hygroscopic coefficients were determined by bringing the soil samples to equilibrium with a 3.3-percent solution of sulphuric acid. The clay content was determined by means of sedimentation techniques using the Bouyoucos hydrometer. The Schollenberger colorimetric method was used in determining organic matter. To convert some of the moisture determinations to a volume basis undisturbed cores of soil were taken and oven-dried and their bulk density was calculated. The least-squares method was employed in the statistical interpretation of the data (4).

Experimental Results

The results are all presented in tabular form, and in some cases supplemented by graphs. The experimental data have been organized under two headings: 1, Biological versus purely physical approach, and 2, Indirect approach.

BIOLOGICAL VERSUS PURELY PHYSICAL APPROACH

The biological approach is probably the most widely used and is perhaps the most accurate in hands of a skilled investigator. It is rather simple, the underlying principles are easy to understand, and if due care is exercised in determining the onset of wilting and in following the general procedure, accurate results are likely to be obtained when adequate replications are used. The materials and apparatus used are easily obtained at very low cost. The disadvantage of this approach is that it takes considerable time before results can be obtained. Very often the plants die, causing much delay or decreasing the reliability of the test because of reduction in the number of replicates. Furthermore, the method is completely useless if harmful salt concentrations are present in the soil. It also requires considerable greenhouse space.

Values from 15-atmosphere percentages determined in pressure chambers, as proposed by Richards, were correlated with permanent wilting-percentage values (6). The time required to complete the test is rather short. The greatest handicap of this approach lies in the high initial cost of installation

TABLE 1.—*Relation between the percentage of water by weight remaining in the soil when plants permanently wilt and that remaining after a 15-atmosphere pressure is applied to a saturated soil sample*

Soil type	Sample No.	Permanent wilting percentage	15-atmosphere moisture percentage	Variation
Tiburones muck	94	12.4	15.7	−3.3
Fajardo clay	16	24.0	13.8	+10.2
Mabí clay	21	17.0	18.2	−1.2
Matanzas clay	26	21.6	21.7	− .1
Descalabrado clay	27	18.8	21.4	−2.6
Ponceña clay	31	25.7	36.3	−10.6
Coamo clay	34	17.7	20.8	−3.5
Paso Seco clay	49	18.2	22.8	−4.6
Malaya clay	65	26.6	30.5	−3.9
Vega Baja clay	78	23.5	26.4	−2.9
Ursula clay	96	17.4	22.5	−5.1
Santa Clara clay	107	22.6	30.4	−7.8
San Antón clay	10	24.5	17.9	+6.6
Yunes clay	113	14.9	21.3	−6.4
Rosario clay	118	21.5	23.4	−1.9
Mercedita clay	14	18.6	26.2	−7.6
Moca clay	18	18.2	21.9	−3.7
Espinosa clay loam	25	19.9	21.3	−1.4
Alonso clay loam	48	14.0	15.6	−1.6
Piñones clay loam	53	18.2	19.6	−1.4
Río Cañas clay loam	66	13.6	16.3	−2.7
Maunabo clay loam	81	15.1	17.4	−2.3
Vega Baja clay loam	92	27.5	25.6	+1.9
Sabana Seca sandy clay loam	30	12.0	11.2	− .8
Guayama sandy clay loam	50	14.5	16.1	−1.6
Jayuya sandy clay loam	67	15.1	15.9	− .8
Teresa sandy clay loam	70	18.7	21.3	−2.6
Vives sandy clay loam	74	16.7	17.7	−1.0
Daguao sandy clay loam	84	11.7	12.5	− .8
Palmas Altas sandy clay loam	87	12.6	13.1	− .5
Naranjito sandy clay loam	90	12.3	15.4	−3.1
Múcara sandy clay loam	3	17.8	17.5	+ .3
Guánica silt loam	42	27.3	29.0	−1.7
Maleza fine sandy loam	24	8.8	9.4	− .6
Estación sandy loam	35	11.7	12.2	− .5
Jácana sandy loam	38	13.6	15.0	−1.4
Utuado sandy loam	47	9.7	10.6	− .9
Caguas sandy loam	51	11.0	12.5	−1.5
Viví sandy loam	54	9.0	11.0	−2.0
Juana Díaz sandy loam	61	10.9	13.0	−2.1
Amelia sandy loam	64	9.8	11.7	−1.9
Irurena sandy loam	86	9.0	8.6	+ .4
San Germán sandy loam	112	24.6	32.9	−8.3
Corozo fine sand	105	1.4	1.4	0
Cataño sand	32	2.5	3.5	−1.0
Dune sand	106	1.2	1.1	+ .1

of the necessary equipment to run such tests. The results obtained compare very favorably as to accuracy with those from more time-consuming methods.

Table 1 gives the results obtained on 46 Puerto Rico soils where permanent wilting-percentage values were determined both by the biological and the pressure-plate methods. In 37 of the 46 soils, the permanent wilting percentage values lie in the moisture range between the 15-atmosphere percentage and 4-percent moisture above or below it. Examination of the tabular and graphical data indicates that there is rather a good agreement between results obtained by the two techniques (fig. 1).

A correlation coefficient of 0.90 was obtained between the two methods. It is very high indeed. A functional relationship was established and the

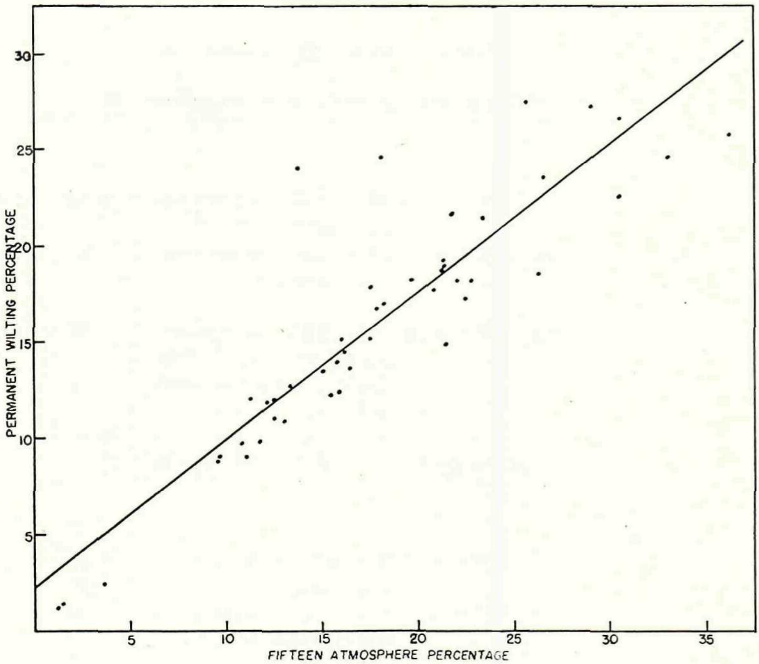

FIG. 1.—Relationship between permanent wilting percentage and 15-atmosphere percentage.

following equation obtained for estimation of accurate permanent wilting percentages on basis of pressure plate data:

$$PWP = 2.37 + 0.76\ X,$$

where X is the amount of moisture remaining in a soil after submitting a saturated sample to a 15-atmosphere pressure.

INDIRECT APPROACH

Numerous investigators have proposed the estimation of permanent wilting-percentage values in terms of other more easily determined soil constants. The work of Briggs and Shantz on this is well known (2).

TABLE 2.—*Relation of the permanent wilting percentage to clay content, organic-matter content, moisture equivalent, and hygroscopic coefficient in the soils of Puerto Rico*

Soil group	Samples	Functional relationship	Coefficient of determination	Correlation coefficient
Permanent wilting percentage and clay content				
	Number			
Humid- and subhumid-region soils				
Lateritic	19	PWP = 5.80 + 0.53 (percent clay)	0.80	+0.89
Nonlateritic	52	PWP = 3.28 + .53 (percent clay)	.76	+ .87
Arid- and semiarid-region soils	34	PWP = 13.85 + .25 (percent clay)	.31	+ .55
Permanent wilting percentage and organic-matter content				
Humid- and subhumid-region soils				
Lateritic	19	PWP = 4.33 + 6.80 (percent organic matter)	0.44	+0.66
Nonlateritic	48	PWP = 7.25 + 3.93 (percent organic matter)	.29	+ .54
Arid- and semiarid-region soils	32	PWP = 11.96 + 5.75 (percent organic matter) −0.88 (percent organic matter)	.07	+ .27
Permanent wilting percentage and moisture equivalent				
Humid- and subhumid-region soils				
Lateritic	19	PWP = 2.75 + 0.73 (moisture equivalent)	0.35	+0.59
Nonlateritic	52	PWP = 2.16 + .56 (moisture equivalent)	.44	+ .66
Arid- and semiarid-region soils	34	PWP = 1.75 + .58 (moisture equivalent)	.53	+ .73
Permanent wilting percentage and hygroscopic equivalent				
Humid- and subhumid-region soils				
Lateritic	19	PWP = 4.49 + 1.11 (hygroscopic coefficient)	0.83	+0.90
Nonlateritic	52	PWP = 1.46 + 1.21 (hygroscopic coefficient)	.73	+ .85
Arid- and semiarid-region soils	34	PWP = 5.25 + .98 (hygroscopic coefficient)	.74	+ .85
Puerto Rico, all soils	105	PWP = 2.84 + 1.14 (hygroscopic coefficient)	0.76	+0.87

Table 2 gives regression equations to estimate permanent wilting percentages on a basis of the clay and organic-matter content, respectively, of three groups of soils. The correlation between permanent wilting percentage and clay content is very good for humid-region soils, both lateritic and nonlateritic, but is unsatisfactory for soils of the arid areas. As far as organic matter is concerned no good correlation was obtained, except perhaps a fairly acceptable one for lateritic soils.

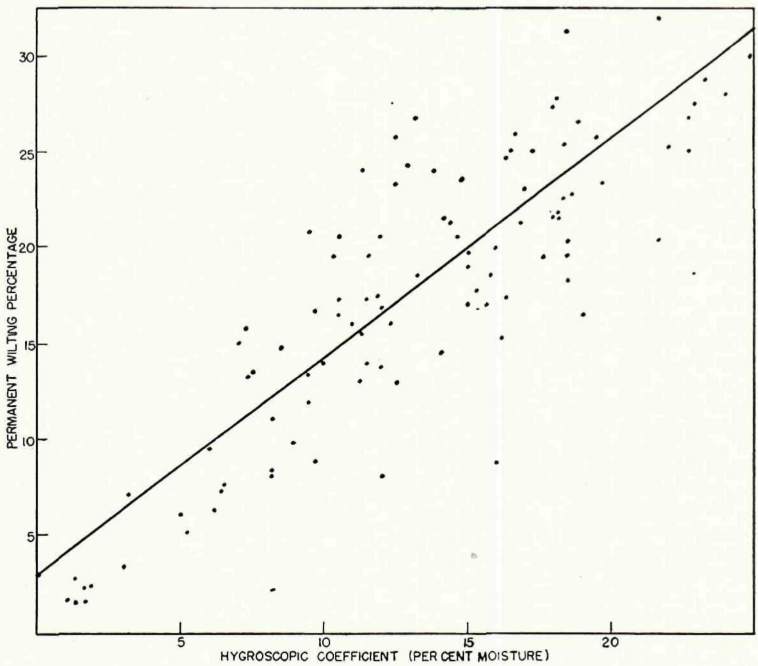

FIG. 2.—Relationship between permanent wilting percentage and hygroscopic coefficient.

Further correlations were attempted between permanent wilting percentage and other soil physical constants. Table 2 also shows the functional relationships established between permanent wilting percentage and moisture equivalent. The correlation is more satisfactory for soils of the arid and semiarid regions than for those of humid regions. For both arid- and humid-region soils there was a better correlation than that obtained between permanent wilting percentage and organic-matter content. The correlation between permanent wilting percentage and hygroscopic coefficient is very highly satisfactory in all cases (table 2) (fig. 2). Coefficients of correlation are high and errors of estimate are at a minimum.

TABLE 3.—*Relation of the permanent wilting percentage of various Puerto Rican soil types as determined by the biological method to the permanent wilting percentage as calculated from the 15-atmosphere moisture percentage*

Soil type	Sample No.	Permanent wilting percentage by the biological method	15-atmosphere moisture percentage	Calculated permanent wilting percentage[1]
Tiburones muck	94	12.4	15.7	14.3
Fajardo clay	16	24.0	13.8	12.9
Mabí clay	21	17.0	18.2	16.2
Matanzas clay	26	21.6	21.7	18.9
Descalabrado clay	27	18.8	21.4	18.7
Ponceña clay	31	25.7	36.3	30.0
Coamo clay	34	17.7	20.8	18.2
Paso Seco clay	49	18.2	22.8	19.7
Malaya clay	65	26.6	30.5	25.6
Vega Baja clay	78	23.5	26.4	22.5
Ursula clay	96	17.4	22.5	19.5
Santa Clara clay	107	22.6	30.4	25.5
San Anton clay	10	24.5	17.9	16.0
Yunes clay	113	14.9	21.3	18.6
Rosario clay	118	21.5	23.4	20.2
Mercedita clay	14	18.6	26.2	22.3
Moca clay	18	18.2	21.9	19.0
Espinosa clay loam	25	19.9	21.3	18.6
Alonso clay loam	48	14.0	15.6	14.2
Piñones clay loam	53	18.2	19.6	17.3
Río Cañas clay loam	66	13.6	16.3	14.8
Maunabo clay loam	81	15.1	17.4	15.6
Vega Baja clay loam	92	27.5	25.6	21.9
Sabana Seca sandy clay loam	30	12.0	11.2	10.9
Guayama sandy clay loam	50	14.5	16.1	14.6
Jayuya sandy clay loam	67	15.1	15.9	14.5
Teresa sandy clay loam	70	18.7	21.3	18.6
Vives sandy clay loam	74	16.7	17.7	15.9
Daguao sandy clay loam	84	11.7	12.5	11.9
Palmas Altas sandy clay loam	87	12.6	13.1	12.4
Naranjito sandy clay loam	90	12.3	15.4	14.1
Múcara sandy clay loam	3	17.8	17.5	15.7
Guánica silt loam	42	27.3	29.0	24.5
Maleza fine sandy loam	24	8.8	9.4	9.5
Estación sandy loam	35	11.7	12.2	11.7
Jácana sandy loam	38	13.6	15.0	13.8
Utuado sandy loam	47	9.7	10.6	10.4
Caguas sandy loam	51	11.0	12.5	11.9
Viví sandy loam	54	9.0	11.0	10.7
Juana Díaz sandy loam	61	10.9	13.0	12.3
Amelia sandy loam	64	9.8	11.7	11.3
Irurena sandy loam	86	9.0	8.6	8.9
San Germán sandy loam	112	24.6	32.9	27.4
Corozo fine sand	105	1.4	1.4	3.4
Cataño sand	32	2.5	3.5	5.0
Dune sand	106	1.2	1.1	3.2

[1] Calculated from the equation: $PWP = 2.37 + 0.76\ X$, where X is the 15-atmosphere-moisture percentage.

DISCUSSION OF RESULTS

A comparison of permanent wilting-percentage values obtained directly by biological methods with 15-atmosphere-percentage values obtained in

TABLE 4.—*Relation of the permanent wilting percentage of various Puerto Rican soil types as determined by the biological method to the permanent wilting percentage as calculated from the hygroscopic coefficient*

Soil type	Sample No.	Permanent wilting percentage by the biological method	Hygroscopic coefficient (percent moisture)	Calculated permanent wilting percentage[1]
Nipe clay	8	30.1	21.2	27.0
Rosario clay	118	21.5	20.3	25.9
Catalina clay	4	28.1	18.7	24.2
Cialitos clay	6	30.4	25.1	31.5
Matanzas clay	26	25.2	22.0	27.9
Lajas clay	45	26.7	13.2	17.9
Tanamá clay	58	25.8	16.4	21.6
Malaya clay	65	32.1	21.6	27.4
Río Piedras clay	114	26.6	20.0	24.6
Lares clay	1	28.9	23.4	29.5
Coloso clay	2	23.4	14.7	19.6
Fajardo clay	16	25.1	22.7	28.8
Moca clay	18	22.5	18.3	23.7
Mabí clay	21	19.4	17.7	22.9
Cabo Rojo clay	44	23.1	17.1	22.3
Colinas clay	59	25.8	12.6	17.2
Plata clay	62	20.6	11.8	16.3
Soller clay	76	32.9	16.6	21.7
Fortuna clay	77	24.9	17.2	22.4
Vega Baja clay	78	25.8	19.4	25.0
Yabucoa clay	88	14.0	11.4	15.9
Santa Clara clay	107	22.6	18.6	24.0
Yunes clay	113	14.9	8.4	12.4
Fraternidad clay	9	22.0	21.3	27.2
San Antón clay	10	27.9	24.3	30.6
Mercedita clay	14	25.3	18.4	23.8
Descalabrado clay	27	25.0	22.9	28.9
Ponceña clay	31	39.2	27.4	34.1
Reparada clay	33	25.0	16.5	21.6
Coamo clay	34	21.4	18.0	23.3
Fe clay	36	21.9	18.2	23.6
Vayas clay	37	20.3	13.2	17.8
Paso Seco clay	49	21.5	18.2	23.5
Portugués clay	60	21.1	16.8	22.0
Aguirre clay	63	18.6	18.6	24.1
Ursula clay	96	17.4	15.8	20.9
Espinosa clay loam	25	26.7	22.7	28.7
Alonso clay loam	48	17.2	11.2	15.6
Vega Alta clay loam	92	24.2	12.9	17.5
Córcega clay loam	19	17.4	11.8	16.3
Toa clay loam	28	18.9	15.1	20.0
Piñones clay loam	53	20.1	15.9	20.9

TABLE 4.—*Continued*

Soil type	Sample No.	Permanent wilting percentage by the biological method	Hygroscopic coefficient (percent moisture)	Calculated permanent wilting percentage[1]
Camagüey clay loam	75	23.9	11.3	15.7
Los Guineos clay loam	79	13.1	7.5	11.4
Maunabo clay loam	81	19.5	10.3	14.6
Juncos clay loam	95	16.6	18.5	23.9
Sabana clay loam	100	15.3	16.1	21.2
Aguilita clay loam	15	17.6	15.2	20.1
Yauco clay loam	29	19.6	18.5	23.9
Santa Isabel clay loam	39	23.4	19.8	25.3
Pozo Blanco clay loam	41	21.7	14.2	19.0
Río Cañas clay loam	66	19.9	14.2	19.0
Coto sandy clay loam	12	17.3	10.7	15.1
Múcara sandy clay loam	3	21.2	14.4	19.3
Sabana Seca sandy clay loam	30	17.4	16.4	21.5
Jayuya sandy clay loam	67	20.6	10.7	15.0
Daguao sandy clay loam	84	15.7	7.2	11.1
Palmas Altas sandy clay loam	87	16.0	12.3	16.9
Las Piedras sandy clay loam	89	17.1	14.9	19.8
Naranjito sandy clay loam	90	13.9	11.8	16.2
Vía sandy clay loam	97	9.7	8.9	12.9
Martín Peña sandy clay loam	104	19.7	14.9	19.8
Teresa sandy clay loam	70	23.9	13.8	18.6
Vives sandy clay loam	74	23.8	12.5	17.1
Picacho silt loam	110	12.0	9.6	13.7
Cintrona silt loam	40	18.5	13.4	18.1
Guánica silt loam	42	27.1	17.8	23.1
Serrano silt loam	68	17.2	15.6	20.6
Torres loam	91	16.7	9.7	13.9
Barrancas loam	72	19.5	11.5	15.9
Almirante fine sandy loam	17	6.9	3.1	6.3
Maleza fine sandy loam	24	12.9	12.5	17.1
Bayamón fine sandy loam	93	20.6	9.4	13.5
Caguas sandy loam	51	14.1	9.9	14.2
Estación sandy loam	35	15.2	14.0	18.8
Utuado sandy loam	47	13.1	11.3	15.7
Viví sandy loam	54	11.0	12.9	17.6
Humacao sandy loam	55	16.4	10.7	15.1
Ciales sandy loam	56	15.4	11.3	15.7
Josefa sandy loam	82	11.0	8.3	12.3
Irurena sandy loam	86	13.5	9.3	13.4
Pandura sandy loam	98	8.0	8.3	12.3
Cayaguá sandy loam	99	6.2	6.0	9.7
Talante sandy loam	101	8.7	9.6	13.8
Teja sandy loam	102	6.9	6.3	10.0
Candelero sandy loam	103	8.3	8.3	12.2

TABLE 4.—*Concluded*

Soil type	Sample No.	Permanent wilting percentage by the biological method	Hygroscopic coefficient (percent moisture)	Calculated permanent wilting percentage[1]
Jácana sandy loam	38	15.9	10.9	15.2
Guayama sandy loam	50	16.7	11.9	16.4
Juana Díaz sandy loam	61	16.0	8.9	13.0
Amelia sandy loam	64	12.4	8.0	12.0
Machete sandy loam	71	13.6	7.4	11.3
Altura sandy loam	73	15.3	6.9	10.8
San Germán sandy loam	112	24.5	16.2	21.4
Ensenada sandy loam	115	20.2	18.8	24.3
Algarrobo fine sand	7	5.1	5.1	8.7
St. Lucie fine sand	11	2.1	1.6	4.6
Guayabo fine sand	23	2.0	1.4	4.5
Corozo fine sand	105	1.5	1.4	4.5
Islote sand	20	9.5	6.0	9.7
Aguadilla sand	22	7.5	6.2	9.8
Cataño sand	32	3.4	2.9	6.1
Dune sand	106	1.2	1.1	4.1
Meros sand	69	6.0	5.1	8.6
Río Lajas sand	80	1.6	1.0	4.0
Jaucas sand	116	2.6	1.4	4.4

[1] Calculated from the equation: $PWP = 2.84 + 1.14\,X$, where X is the hygroscopic coefficient.

pressure chambers shows that the latter can be used with reliability to indicate the water remaining in the soil when the plants permanently wilt (table 3). Moreover, predictions of these values can be ascertained with reasonable accuracy by use of regression equations based on the hygroscopic coefficient (table 4). In determining hygroscopic coefficients for soils it usually takes three or more weeks before the samples attain equilibrium with the special environment in which they must be placed. However, the determination requires less work, much smaller samples, and not as much space as the direct biological determination. Besides, no large initial expenditures are involved as compared with the method in which pressure plates are used. Of course, the hygroscopic-coefficient method is not as accurate as the other.

A very high correlation such as the one obtained between the 15-atmosphere percentage and the permanent wilting percentage determined by the biological method is observed only with the lateritic group of soils using the indirect determination with the hygroscopic coefficient as the independent factor. Nevertheless the correlation is high enough in all cases to indicate that the approach based on the hygroscopic coefficients is acceptable where precise measurements are not required or when the equipment needed for more accurate work is not available.

The indirect approach of estimating permanent wilting-percentage values on a basis of the clay content seems to be reliable for soils of the humid areas. In such cases it is recommended because of the rapidity with which clay contents can be approximated by use of the hydrometer technique. Regression equations using organic-matter content to estimate permanent wilting-percentage values are not to be relied upon, except perhaps when dealing with lateritic soils. Where feasible, 15-atmosphere percentages are to be preferred not only for their accuracy but for the speed with which results can be obtained.

Summary

Very accurate estimations of the permanent wilting percentage can be obtained for soils of all regions of Puerto Rico by use of regression equations based on the hygroscopic coefficient. Reliable estimates can also be obtained for humid-region soils by using the clay content as a basis. Attempts to correlate permanent wilting-percentage values with moisture equivalents and organic-matter content did not give such satisfactory results. The 15-atmosphere percentage as determined by using pressure plates gives an accurate approximation of permanent wilting-percentage values. It is time-saving, but initial expense in laboratory equipment is rather high. This approach is to be preferred whenever feasible. A regression equation is given relating pressure-plate values to the permanent wilting percentage. Whenever less precise estimates are acceptable and time is not a factor, advantage should be taken of the established correlation between the hygroscopic coefficient and the permanent wilting percentage.

Resumen

Mediante ecuaciones de regresión, basadas en el coeficiente de higroscopicidad, se puede predecir con bastante exactitud el punto de marchitez permanente en suelos de diversas regiones de Puerto Rico. El contenido de arcilla de los suelos de regiones húmedas puede también servir como base para hacer predicciones bastante aceptables de dicha constante. Las tentativas para establecer predicciones, a base del equivalente de humedad y del contenido de materia orgánica, no dieron resultados tan satisfactorios. La determinación de la humedad en muestras sometidas a una presión de 15 atmósferas en cámaras especiales, da una idea bastante exacta del punto de marchitez permanente. La determinación toma poco tiempo, pero el costo inicial del equipo de laboratorio necesario es alto. Siempre que sea posible, se debe preferir este método para aproximar los valores del punto de marchitez permanente. Se presenta una ecuación de regresión relacio-

nando los valores obtenidos en dichas cámaras con los obtenidos por el método biológico. Se recomienda aprovecharse de la relación entre el coeficiente de higroscopicidad y el punto de marchitez permanente, siempre que no precise mucha exactitud y cuando el tiempo no sea un factor limitante.

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