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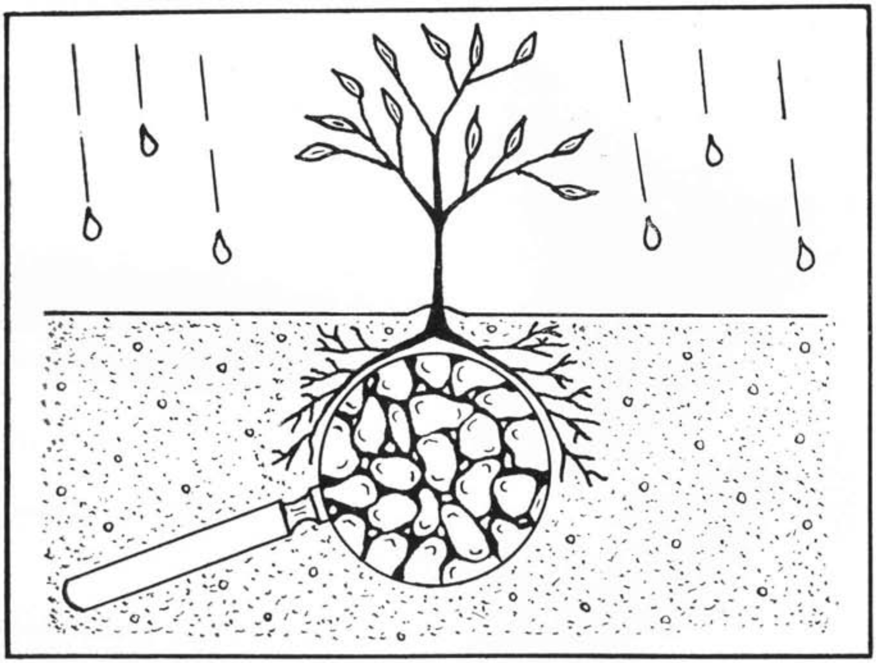


Bulletin 627
December 1959

The CONNECTICUT Agricultural Experiment Station
NEW HAVEN

Contents

Acknowledgment

The author wishes to express his sincere appreciation to Dr. Paul E. Waggoner, Chief, Department of Soils and Climatology, for his many helpful suggestions and contributions to this publication. The author is also indebted to Mr. Dwight B. Downs for his generous assistance in obtaining physical data and applying them to statistical analyses.

THE STORAGE OF MOISTURE IN CONNECTICUT SOILS

David E. Hill

The ability of soils to store moisture and release it for the use of growing plants is a primary determinant of the agricultural value of land. This bulletin describes a survey of the storage abilities of Connecticut soils. This knowledge is especially useful in irrigation practices.

The use of irrigation in the Northeast has been increasing steadily during the past two decades. The need for sound irrigation practices was never more dramatically realized than during the 1957 growing season. In the period from May through October only about 9 inches of rain fell in comparison to an average of 18 inches in the Hartford area. Many farmers suffered heavy losses. Were it not for irrigation, the loss would have been more severe.

Successful irrigation practices call for knowledge of the moisture requirements of the plant, the nature of the root system, and the capacity of the soil to store moisture in the root zone and to release it effectively.

The present study deals with the third consideration: the moisture storage capacities of soils common to Connecticut, the physical conditions which effect moisture storage and release, and methods which may be used in readily estimating the storage and release characteristics for irrigation operations. The soils chosen for study were selected to include not only the important agricultural soils but also the wide range in soil texture found in the state. A detailed soil survey has been completed for Hartford County, and is progressing in Tolland and Litchfield Counties. Soils of many farms in other counties have been mapped in connection with soil conservation programs. If the grower is familiar with the soil types on his farm, he can apply the information presented in this bulletin to his land. Any questions pertaining to soil types may be directed to the Soil Conservation Service or Extension Service office or to The Connecticut Agricultural Experiment Station in New Haven or (Tobacco Laboratory) Windsor.

Review of Literature

Much attention has been focused in the past 50 years on soil, moisture, and plant relationships. Early investigations were primarily concerned with the limits of moisture availability to plants. Not all water entering the soil is available to the plant. Some moisture evaporates from the surface of the soil and some percolates through the soil beyond the reach of plant roots. The moisture retained in the soil within rooting depth is the most important source of moisture for the plant. The term field capacity (38) was used to describe the total amount of water that a soil could hold against the force of gravity. It was defined as the moisture content of a soil when downward drainage materially decreased. This occurs after 1 day in coarse, well drained sandy soils or 4 to 5 days in well drained soils of a silty clay loam or clay loam texture. For medium textured soils, the field capacity is attained about 48 hours after a heavy rainfall. It was established that plants could not extract all of the moisture stored in the soil. The point at which the plant could no longer extract moisture was called the permanent wilting point or wilting coefficient (5). It was defined as the moisture content of a soil at which plants growing in the soil would not recover from a wilted condition when placed in an atmosphere saturated with moisture. Briggs and Shantz realized that wilting occurred over a small range of moisture contents. Furr and Reeves (12) used a more appropriate term, the permanent wilting range.

Subsequent investigations have followed two paths, one dealing with the laboratory determination of such soil moisture constants (5) as field capacity and permanent wilting point and the other with the relationships between these constants and the physical properties of the soil.

Briggs and McLane (3) in 1907 were first to suggest the moisture equivalent as a measure of the field capacity. The moisture equivalent is a measure of the amount of water held in the soil after it has been subjected to a centrifugal force 1,000 times the force of gravity and is comparable to the moisture held in the soil after natural drainage has occurred. This method was later improved upon by Briggs and Shantz (5). Since 1912, many investigators (7) (9) (12) (21) (23) (24) (35) (38) have found that field capacity and moisture equivalent are virtually the same when the moisture equivalent is between 12 and 30 per cent. If below 12 per cent in very sandy soils, the moisture equivalent is slightly lower than field capacity; and if above 30 per cent, in fine textured clayey soils, the moisture equivalent is higher than field capacity. Minor variations reported by investigators were apparently due to local soil conditions or differences in laboratory techniques.

Briggs and Shantz (5) proposed that the moisture equivalent divided by 1.84 be used as a measure of the permanent wilting point. This method of estimation was later considered inaccurate (20) (37).

A laboratory method for estimating the field capacity and wilting percentage of soils was developed by Richards and his associates (26) (27) (28) (30). It requires the use of pressure plate and pressure membrane apparatus. Saturated soils are placed under various tensions and the amount of water extracted at any given tension may be graphically presented (4) (8).

Richards and Weaver (31) (32) found that 1/3 atmosphere tension corresponded quite closely to the moisture equivalent of soils. This has been substantiated by further work of Richards (29) and Coleman (9). Richards and Weaver (31) (32) also found a close relation between the permanent wilting point and 15 atmospheres tension; a fact since confirmed (12) (21) (22) (26).

The moisture retained at 1/3 atmosphere tension is now generally accepted as an estimate of the moisture equivalent or field capacity of medium textured soils and that at 15 atmospheres tension as an estimate of the permanent wilting percentage. Errors occur in these relationships in coarse or fine textured soils. The numerical difference between the moisture content at 1/3 and 15 atmospheres tension is regarded as the available moisture holding capacity of a soil.

While some soil scientists were determining such contents as field capacity, moisture equivalent, 1/3 atmosphere tension, permanent wilting point, and 15 atmospheres tension and studying the relationships amongst them, others were interested in the factors affecting these soil constants. Briggs and McLane (4) suggested that the use of moisture equivalents would someday replace mechanical analysis as a basis for the classification of soils. Further investigations (18) (34) proved inconclusive. It was generally agreed, however, that mechanical analysis reflects only the amounts of various particle size fractions, while moisture equivalent reflects size, amount, and shape of particles, organic matter content, colloid content, and chemical composition.

Much attention has been given to the role that texture plays in determining the limits of the available moisture range. A number of formulas have been derived using regression analyses in an attempt to relate moisture equivalent to mechanical analyses (1) (5) (10) (20) (34). The differences among formulas can be attributed to local variations in soils and to slightly different laboratory techniques. Many soil scientists agree that the moisture equivalent is related to the silt, clay, and organic matter content (3) (10) (15) (20) (25), but do not agree upon the relative importance of each. The relation of the permanent wilting point or 15 atmospheres tension to texture and organic matter is clearer. Briggs and Shantz (5) demonstrated a linear relation involving sand, silt, and clay. Neilson and Shaw (19) found that the simple correlation between the per cent moisture at 15 atmospheres tension and clay content was highly significant when the organic matter content was less than 5 per cent.

More recently, attempts have been made to correlate texture and organic matter with the available moisture holding capacity of soils rather than the moisture constants which form its limits. Peele *et al.* (22) found that the available capacity of South Carolina soils was primarily influenced by organic matter and clay: soils low in clay and organic matter had low moisture holding capacities, soils high in organic matter had high capacities, and soils high in clay might or might not have high capacities depending upon the nature of the clay. Wilcox and Spilsbury (40) found that the available capacity was correlated with silt and clay: soils increase in available capacity up to a colloid concentration of 60 per cent, but beyond that, moisture is tied up as surface films. Recently Ferrari *et al.* (11) found a similar relationship in the soils of Holland although their "clay" as reported actually includes some fine silt.

Jamison (13) and Jamison and Kroth (14) suggested that the available moisture holding capacity of the predominantly silty soils of Missouri is primarily influenced by silt and that this capacity actually decreases with increasing clay percentage. Organic matter increases the available moisture holding capacity on very sandy soils. Organic matter also increases the available capacity of soils having 13 to 20 percent clay because it forms silt-sized microaggregates from the clay. Jamison and Kroth also suggested that aggregation of silty textured soils by soil improvement practices causes a reduction in the available capacity by increasing non-capillary porosity at the expense of capillary porosity.

Lund (17) in Louisiana and Bartelli and Peters (2) in Illinois found similar results: the available moisture holding capacity was correlated with silt content but not with clay.

Methods and Materials

Selection of Profiles

Profile sites sampled in 1957 covered the important soil surface textures in Connecticut (ranging from loamy sand to silty clay loam), soils of significant area, with a wide range of cover and management. A brief description of each follows:

1. Windsor loamy sand: yellowish brown, excessively drained soils developed on water-sorted terraces derived principally from granite and schist. These water-laid deposits have been reworked in places by wind action, giving dune features to the topography. Where dunes occur, the sands are deep and gravel-free; on the broader terraces, gravel may be present in the substrata.

2. Merrimac sandy loam: yellowish brown, somewhat excessively drained water-sorted terrace soils developed on stratified sand and gravel derived mainly from granite and schist.

3. Cheshire fine sandy loam: reddish colored, well drained soils developed on loose to firm glacial till derived principally from red Triassic conglomerates, sandstones, and shales.

4. Agawam very fine sandy loam: yellowish brown, well drained soils developed on deep sandy terraces which are almost gravel-free to a depth of 5 or 6 feet and principally derived from granite and schist materials.

5. Wethersfield loam: reddish colored, well drained soils developed on very firm, compact glacial till derived principally from red Triassic sandstone and shale with some dark colored basalt or trap rock present. A fragipan at about 24 inches somewhat restricts internal drainage.

6. Narragansett silt loam: yellowish brown, well drained soil developed on silt-mantled, glacial till. The till is loose to firm and derived principally from red Triassic sandstone and shale but may include till from granite, gneiss, or schist. The silt mantle is the result of wind deposition of silty sediments blown from glaciolacustrine or alluvial terraces adjacent to the major rivers after the stagnation and retreat of the last continental glacier.

7. Buxton silty clay loam: yellowish brown to grayish brown moderately well drained soils derived from gray varved silty and clayey glaciolacustrine terraces.

Three profiles were selected for each series: two recently cultivated and one that had been forested for an estimated 40 years or more. Nineteen profiles were sampled in 1957. The two profiles representing cultivated Wethersfield loam were sampled in 1958 and used for verification of the statistical relationship between moisture holding capacities and the various physical properties of the soil.

The 12 profiles sampled from cultivated fields represented a wide variation in cultural practices. They were as follows:

Sweet corn and other market garden vegetables	2
Tobacco — shade and outdoor types	4
Potatoes	1
Silage corn	1
Improved pasture	2
Experimental plots — Agr. Exp. Sta.	2

Of the seven forested profiles, the Agawam, Windsor, Merrimac, and Narragansett soils showed evidence of a former plow layer. The Wethersfield, Buxton, and Cheshire soils did not show a plow layer; nevertheless, these soils likely had been pastured or the forests on them had been clear cut at some time.

Laboratory Procedures

Undisturbed soil cores were taken with a modified Lutz core sampler (36), with cores encased in brass retaining rings (3 inches o.d.; 2.25 inches high). Duplicate cores were taken from each horizon and put in suitable closed containers and placed in a cold storage room to prevent the evaporation of moisture. Bulk samples of each horizon were also taken.

The soil cores were taken from the cold room in lots of twelve. Duplicate cores were run in separate lots. The cores were covered with about 1/8 inch of water and saturated for at least 16 hours.

The cores were then put on ceramic plates and placed under a tension of 60 cm. of water for 24 hours. The cores were then weighed and the difference in weight compared to the saturated weight represented the volume of non-capillary pores drained from each core. The soils were saturated again for at least 16 hours and placed on ceramic pressure plates. A pressure of 1/3 atmosphere was applied to the system for 24 hours, after which the cores were removed and weighed. Equilibration was not attained in a 24-hour period; however, trial runs established that in most soils sampled, equilibration was at least 95 per cent complete at the end of 24 hours. Additional time for equilibration was not considered worthwhile in view of the other larger sources of variation involved in sampling. The water that remained under 1/3 atmosphere pressure was defined as the moisture content at field capacity. Finally, the bulk density was determined.

In order to evaluate discrepancies in the bulk densities of duplicate cores, they were removed from the brass rings and examined. Large stone fragments in a core resulted in higher bulk densities. Large root channels resulted in lower bulk densities. In all but one case, the discrepancy between duplicates was small. One core had a large stone fragment occupying over 50 per cent of the volume. This core was discarded and its duplicate alone was used in further calculations.

The bulk sample taken from the field was air dried and passed through a sieve with 2 mm. openings. Subsequent laboratory investigations were performed on the material passing through this sieve.

The pressure membrane (26) (27) (28) (30) was used to determine the moisture content of the soils at 2 atmospheres and 15 atmospheres pressure.

Fragmented soil samples were placed in rubber rings on top of the pressure membrane and saturated for several hours. The unit was sealed and constant pressure was then applied. Duplicate runs were made on each soil sample at both 2 and 15 atmospheres pressure. Pressure was applied for about 24 hours. The moisture content at 15 atmospheres was defined as the moisture content at the permanent wilting point or the lower range of moisture availability to the plant. The moisture content at 2 atmospheres represented a point halfway between 1/3 and 15 atmospheres on a logarithmic or pF scale, and was valuable in determining the moisture release characteristics of the soil. The moisture contents at the various tensions were calculated on a volumetric basis.

A mechanical analysis was performed on each sample employing the methods of Kilmer and Alexander (16). Silt and clay were determined by sedimentation techniques with a pipette. In order to obtain particle size distribution of the various sand separates, the entire sand fraction was dried and passed through a nest of sieves.

Organic carbon was estimated by the chromic acid oxidation method of Schollenberger (33).

The data accumulated during the laboratory analyses were statistically analyzed. The moisture percentages at 1/3, 2, and 15 atmospheres tension were converted into three dependent variables that presented them in terms of the moisture release curve and in quantities that could be interpreted in terms of plant growth.

These dependent variables were plotted against such physical properties as the percentage of sand, silt, clay, organic carbon, and capillary porosity. Where relationships were evident between the dependent variables and the physical properties, a multiple correlation analysis was made. The resulting regression equations were used to estimate the characteristics of the 57 samples involved in the correlation analysis.

In order to evaluate the validity of the regression equations for prediction, several additional profiles were collected in 1958. These included two cultivated Wethersfield profiles, eight plow zone samples from Merrimac fine sandy loam, two forested Charlton profiles, and two forested Gloucester profiles. The physical characteristics were determined by the same laboratory techniques as before. A comparison was then made between the values predicted by the regression equations and the values determined in the laboratory.

Results

The results of the laboratory analyses are found in Table 1. Several important features are worthy of note. The soils of Connecticut are notably deficient in clay. The water-laid terrace soils such as Windsor, Merrimac, and Agawam have clay contents in the surface horizons which seldom exceed 5 per cent. The Cheshire, Wethersfield, and Narragansett soils have slightly higher clay contents in the surface horizons than the terrace soils and range from 5 to 10 per cent. Only the glaciolacustrine Buxton soils have a relatively high clay content, ranging from 8 to 16 per cent in the surface horizon and from 6 to 30 per cent in the subsoil. As a general rule the clay content is highest in the surface horizon and decreases with depth. Obvious exceptions to this are Buxton IIC and Buxton IF. These glaciolacustrine terrace soils usually have finer textures in the subsoil. The clays are of sedimentary origin and are not the result of weathering processes.

In most Connecticut soils, silt represents the major portion of the fine textured material. Its distribution in soils in variable: in some soils the highest concentration is at the surface and in others the silt content increases with depth for the top 18 inches.

Organic carbon contents are quite low in the soils represented here, ranging from 0.76 to 2.54 per cent. On an organic matter basis, this is a range of 1.2 to 4.4 per cent. The organic matter content of most well drained, cultivated soils in Connecticut is between 2 and 3 per cent. In general, organic matter content in the surface horizons of most cultivated soils increases with finer textures and decreases markedly with depth.

The moisture content at 1/3 atmosphere generally is higher in soils with finer textures. In a majority of the profiles, regardless of texture, the highest moisture contents at 1/3 atmosphere are found in the surface horizons and decrease with depth. Several exceptions may be noted, especially in forested profiles, where the highest moisture holding capacities are in the B horizon.

The moisture contents at 15 atmospheres are generally highest at the surface horizon and decrease with depth. The reverse trend is noted in the Buxton soils and is undoubtedly due to the increase in clay with depth. Other exceptions are noted in cultivated terrace soils where the moisture content at 15 atmospheres is highest in the upper B horizon or plow pan zone.

Capillary porosity is related to texture in that it increases with progressively finer textures. This is important in considering that it is in these capillary pores that moisture is retained. Total

Table 1. Physical properties of cultivated and forested soils

Soil profile	Horizon[a]		% sand	% silt	% clay	% organic carbon[b]	USDA text.	1/3 atm. % vol.	2 atm. % vol.	15 atm. % vol.	Cap. por.	Non-cap. por.	Bulk density
	Sample	Depth											
						1957							
Windsor IC													
	Ap	6-8″	83.5	14.9	1.6	0.81	lcs	19.5	8.5	5.4	37.3	5.4	1.47
	B$_{21}$	9-11″	84.2	13.8	2.0	0.10	lcs	15.7	7.2	4.1	27.5	9.2	1.62
	B$_{22}$	16-18″	84.6	14.2	1.2	0.13	lcs	14.5	6.4	3.7	26.8	13.6	1.53
Windsor IIC													
	Ap	6-8″	75.0	21.8	3.2	0.76	lcs	20.1	9.3	5.3	31.3	14.8	1.41
	B$_{21}$	11-13″	73.8	24.6	1.6	0.21	lcs	17.6	9.9	5.7	34.2	2.3	1.62
	B$_{22}$	16-18″	82.7	16.1	1.2	0.15	lcs	11.8	6.8	3.7	20.1	19.9	1.55
Windsor IF													
	Ap	5-7″	78.2	19.0	2.8	0.68	lcs	12.7	7.7	4.7	34.4	18.8	1.18
	B$_{21}$	10-12″	78.8	18.8	2.4	0.26	lcs	12.0	7.9	4.7	24.0	22.3	1.37
	B$_{22}$	14-16″	77.3	20.7	2.0	0.24	lcs	12.7	8.8	4.7	29.2	16.9	1.40
Merrimac IC													
	Ap	4-6″	70.4	25.6	4.0	0.84	sl	28.6	10.8	6.3	37.7	6.3	1.42
	B$_{21}$	9-11″	66.0	30.8	3.2	0.29	sl	22.5	11.8	7.2	31.2	6.6	1.61
	B$_{22}$	16-18″	65.6	30.8	3.6	0.26	sl	21.0	10.5	6.0	30.2	12.4	1.47
Merrimac IIC													
	Ap	4-6″	74.4	23.6	2.0	0.80	lcs	20.9	9.4	5.3	39.7	6.0	1.38
	B$_{21}$	9-11″	64.5	32.3	3.2	0.25	sl	24.5	11.2	6.6	34.7	3.0	1.61
	B$_{22}$	16-18″	72.3	27.3	0.4	0.14	lcs/sl	17.7	7.2	4.1	36.2	6.7	1.45
Merrimac IF													
	Ap	4-6″	69.2	27.2	3.6	1.08	sl	18.8	9.0	5.3	37.9	13.3	1.22
	B$_{21}$	8-10″	68.6	29.8	1.6	0.44	sl	19.4	11.3	7.2	32.6	13.6	1.37
	B$_{22}$	14-16″	67.8	30.2	2.0	0.26	sl	25.3	8.5	5.7	36.4	9.3	1.39
Agawam IC													
	Ap	4-6″	53.6	43.2	3.2	1.23	vfsl	33.6	12.6	8.2	44.7	4.3	1.31
	B$_{21}$	10-12″	36.3	61.7	2.0	0.36	sil	31.6	12.7	6.8	46.3	0.7	1.37
	B$_{22}$	15-17″	53.1	46.1	0.8	0.26	vfsl	24.1	7.5	4.4	43.9	8.5	1.24

Table 1. Physical properties of cultivated and forested soils (continued)

Soil profile	Horizon[a]		% sand	% silt	% clay	% organic carbon[b]	USDA text.	1/3 atm. % vol.	2 atm. % vol.	15 atm. % vol.	Cap. por.	Non-cap. por.	Bulk density
	Sample	Depth											
Agawam IIC													
	Ap	4-6″	63.3	35.1	1.6	1.01	vfsl	25.3	11.3	7.2	40.4	6.0	1.39
	B$_{21}$	10-12″	66.7	32.9	0.4	0.32	vfsl	21.7	8.5	5.7	42.6	2.8	1.41
	B$_{22}$	16-18″	67.4	32.2	0.4	0.22	vfsl	19.5	6.4	4.3	39.5	9.0	1.33
Agawam IF													
	Ap	4-6″	61.8	36.2	2.0	0.91	vfsl	26.2	8.9	6.3	42.0	7.6	1.25
	B$_{21}$	8-10″	61.9	35.7	2.4	0.31	vfsl	23.3	8.3	5.5	38.0	9.7	1.32
	B$_{22}$	15-17″	68.0	31.2	0.8	0.22	vfsl	16.9	8.5	6.9	38.6	10.4	1.31
Cheshire IC													
	Ap	6-8″	51.1	40.9	8.0	1.28	l/fsl	28.1	18.7	10.7	33.9	8.9	1.43
	B$_{21}$	11-13″	44.1	48.4	7.5	0.59	l/fsl	28.8	17.8	11.3	37.4	5.7	1.44
	B$_{22}$	19-21″	54.6	38.7	6.7	0.25	fsl	24.4	17.2	10.6	29.1	9.1	1.58
Cheshire IIC													
	Ap	4-6″	48.8	44.8	6.4	1.10	l/fsl	24.4	15.3	9.2	31.4	14.2	1.38[d]
	B$_{21}$	8-10″	52.8	43.2	4.0	0.27	fsl	23.5	14.7	9.0	34.6	3.3	1.58
	B$_{22}$	16-18″	41.4	56.6	2.0	0.22	sil	26.3	13.5	8.1	39.7	3.7	1.45
Cheshire IF													
	Ap	4-6″	60.6	33.8	5.6	1.38	fsl	18.4	14.6	11.0	31.7	13.5	1.37
	B$_{21}$	8-10″	62.2	34.6	3.2	0.49	fsl	19.6	13.1	8.5	29.6	11.7	1.48
	B$_{22}$	15-17″	63.5	33.8	2.7	0.41	fsl	18.6	12.3	8.0	29.3	12.0	1.49
Wethersfield IF													
	A$_1$	2-4″	29.1	60.4	10.5	1.87	sil	32.3	19.7	11.8	40.0	10.3	1.21
	B$_{21}$	9-11″	33.1	59.4	7.5	0.43	sil	29.3	20.5	8.6	36.9	4.0	1.51
	B$_{22}$	14-16″	30.6	57.6	11.8	0.25	sil	26.8	23.6	10.7	33.3	2.3	1.67
Narragansett IC													
	Ap	2-4″	40.5	53.1	6.4	1.48	sil	34.1	18.1	10.3	43.0	2.1	1.38
	B$_{21}$	6-8″	42.0	53.2	4.8	1.07	sil	31.4	17.2	10.0	44.3	1.0	1.45
	B$_{22}$	14-16″	68.7	29.3	2.0	0.16	fsl	18.4	10.0	5.2	32.2	6.5	1.57
Narragansett IIC													
	Ap	2-4″	39.4	55.3	5.3	1.60	sil	34.7	16.4	9.6	41.5	6.0	1.32
	B$_{21}$	11-13″	49.2	49.6	1.2	0.43	vfsl/sil	29.9	10.0	6.5	43.5	4.5	1.32
	B$_{22}$	16-18″	52.2	47.0	0.8	0.25	vfsl	21.0	8.6	5.3	42.4	3.8	1.39

Table 1. Physical properties of cultivated and forested soils (continued)

Soil profile	Horizon[a] Sample	Depth	% sand	% silt	% clay	% organic carbon[b]	USDA text.	1/3 atm. % vol.	2 atm. % vol.	15 atm. % vol.	Cap. por.	Non-cap. por.	Bulk density
Narragansett IF													
	Ap	3-5″	43.8	51.4	4.8	1.58	sil	27.6	12.6	8.9	48.3	9.0	1.08
	B_{21}	8-10″	42.6	53.4	4.0	0.52	sil	23.3	12.0	7.6	43.5	9.4	1.21
	B_{22}	16-18″	53.3	43.9	2.8	0.26	vfsl	18.6	9.7	5.8	38.3	11.2	1.30
Buxton IC													
	Ap	4-6″	50.1	41.1	8.8	1.32	l	27.4	19.6	10.1	36.5	13.6	1.27
	B_{21}	9-11″	51.1	42.5	6.4	0.65	l/fsl	25.4	19.0	9.1	33.7	10.4	1.44
	B_{22}	13-15″	61.1	32.2	6.7	0.19	fsl	26.0	15.4	8.2	36.2	6.2	1.50
Buxton IIC													
	Ap	3-5″	37.3	46.5	16.2	1.44	l	35.9	29.5	14.1	44.5	1.2	1.37
	B_{21}	7-9″	36.7	47.1	16.2	1.59	l	35.5	29.4	13.6	39.0	5.5	1.39
	B_{22}	12-14″	20.7	52.1	27.2	0.37	cl/sicl	37.8	38.6[c]	18.7	40.6	4.0	1.44
Buxton IF													
	A_1	1-3″	16.1	67.3	16.6	2.54	sil	36.3	25.4	11.6	50.2	11.6	0.93
	B_{21}	7-9″	10.8	65.9	23.3	0.60	sil	40.7	34.8	14.1	45.1	2.6	1.37
	B_{22}	11-13″	6.3	62.8	30.9	0.45	sicl	43.5	40.4	20.4	46.1	0.4	1.40
						1958							
Wethersfield IC													
	Ap	3-5″	46.9	43.3	9.8	—	l	28.9	23.9	16.1	32.6	—	1.16
	B_{22}	8-10″	58.1	35.1	6.8	—	fsl	26.6	18.6	10.6	29.5	—	1.46
	B_{23}	16-18″	55.5	36.2	8.3	—	fsl	26.2	18.1	9.9	29.7	—	1.57
Wethersfield IIC													
	Ap	3-5″	36.3	54.5	9.3	—	sil	32.2	25.9	15.1	37.1	—	1.30
	B_{22}	10-12″	40.5	51.2	8.3	—	sil	28.5	19.6	9.5	33.4	—	1.59
	B_{23}	16-18″	37.0	54.4	8.6	—	sil	28.2	18.2	9.4	33.0	—	1.59
Charlton IF													
	B_{21}	2-4″	57.2	36.3	6.5	—	fsl	26.1	11.4	6.3	31.2	—	0.96
	B_{22}	11-13″	61.2	34.0	4.8	—	fsl	17.6	12.4	7.1	31.7	—	1.37
	B_{23}	19-21″	63.9	33.3	2.8	—	fsl	14.2	10.7	5.9	27.0	—	1.48

Table 1. Physical properties of cultivated and forested soils (continued)

Soil profile	Horizon[a] Sample	Depth	% sand	% silt	% clay	% organic carbon[b]	USDA text.	1/3 atm. % vol.	2 atm. % vol.	15 atm. % vol.	Cap. por.	Non-cap. por.	Bulk density
Charlton IIF													
	B_{21}	2-4″	58.5	36.3	5.2	—	fsl	18.9	12.1	7.4	35.4	—	1.32
	B_{22}	9-11″	60.1	32.0	7.9	—	fsl	15.0	11.0	7.1	30.6	—	1.44
	B_{23}	19-21″	66.1	31.9	2.0	—	fsl	15.7	9.1	5.8	29.7	—	1.43
Gloucester IF													
	B_{21}	1-3″	61.2	36.3	2.5	—	fsl	25.4	12.4	7.8	35.2	—	0.95
	B_{22}	7-9″	57.9	37.7	4.4	—	fsl	19.4	11.0	6.7	24.0	—	1.31
Gloucester IIF													
	B_{21}	3-5″	69.1	29.7	1.2	—	fsl	16.2	9.6	6.5	33.2	—	1.21
	B_{22}	11-13″	74.8	22.8	2.4	—	lfs	12.0	6.5	3.9	23.4	—	1.45
	B_{23}	18-20″	78.2	21.0	0.8	—	lfs	12.1	5.0	2.9	24.7	—	1.53
Merrimac													
	Ap 1	3-5″	58.5	33.3	8.2	—	fsl	29.6	18.4	8.9	36.2	—	1.42
	2	7-9″	58.4	33.8	7.8	—	fsl	26.9	17.5	8.7	33.8	—	1.39
	3	5-7″	63.2	31.0	5.8	—	fsl	24.6	14.5	7.3	33.5	—	1.47
	4	5-7″	58.4	34.2	7.4	—	fsl	25.8	16.9	8.6	35.6	—	1.42
	5	5-7″	74.1	21.6	4.3	—	fsl/lfs	17.1	9.6	5.2	30.4	—	1.52
	6	3-5″	70.4	24.9	4.7	—	fsl	20.4	10.3	5.8	33.2	—	1.48
	7	7-9″	69.7	22.9	7.4	—	fsl	20.3	10.2	5.9	32.8	—	1.46
	8	5-7″	70.3	25.4	4.3	—	fsl	19.6	9.8	5.4	31.1	—	1.51

[a] Ap horizon refers to plow zone; plow pan when it occurs is usually in the B_{21} horizon; B_{22} horizon is generally referred to in this bulletin as the subsoil.

[b] Organic matter contents may be determined by multiplying organic carbon by a factor of 1.724.

[c] Apparent increase in moisture content at 2 atmospheres tension due to experimental error.

[d] One core discarded due to large stone fragment. Single value for bulk density used in further calculations.

pore space is generally lower in cultivated soils because tillage destroys soil structure and thereby reduces pore space volume. This may be noted in the higher bulk density of cultivated soils in comparison to forested soils. In the cultivated soils pore space volume is usually greater in the plow layers and less in the horizons below the plow layer. Compact zones beneath the plow layer may be seen in several soil profiles, evidenced by comparatively higher bulk densities and an increase in capillary porosity at the expense of non-capillary porosity.

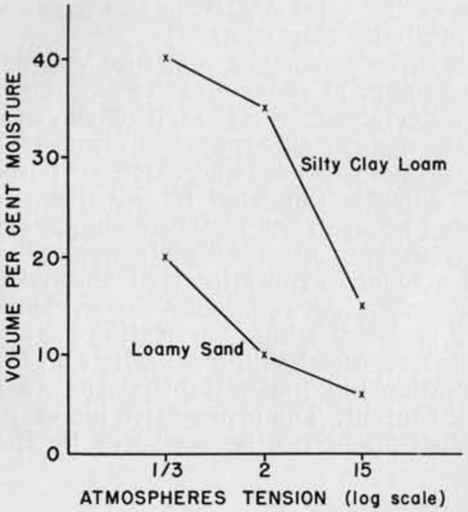
Discussion

Casual observations of the results may reveal several interesting features of soil properties and their inter-relationships, but this alone will not suffice to bring out the more subtle relationships. These were estimated by statistical analysis which provided the answers to a series of questions: What physical properties primarily determine the moisture characteristics of the soil? Can the determinative properties be measured easily and then be employed to predict the moisture characteristics? When the influence of the obvious determinative properties has been removed statistically, are further effects of soil type, cultivation and horizon still evident?

In order to relate moisture characteristics of a soil to its physical properties, we must first define "characteristics." The available moisture holding capacity is one important characteristic. We must remember that not all moisture stored in the soil is available to plant growth. Some is held tightly by soil particles as surface films. Plants cannot extract this moisture because they cannot overcome the force of attraction of the particle in holding the moisture. For our purpose, we shall consider the available moisture holding capacity (referred to as AMHC) as the numerical difference between the moisture held by the soil at 1/3 atmosphere tension or field capacity and the moisture held by the soil at 15 atmospheres tension or permanent wilting point. Of course, some water that is held by the soil with tensions less than 1/3 atmosphere is available to the plant. Its utilization, however, is infrequent and depends upon the length of time it takes a soil to drain to field capacity.

Another important moisture characteristic is the manner in which the soil releases its available moisture to the growing plant within the available range. Is most of the moisture released at low tension, at high tension, or evenly throughout the available moisture range? To determine these moisture release characteristics, a moisture release curve is invaluable. This is a graphic presentation in which the moisture concentration is plotted against atmospheric tension. The resulting points on a graph can be joined by a curve. We can then use the curvature (referred to as CURV) as a means of indicating the moisture release characteristics of the soil. The AMHC may be considered the mean slope of the moisture release curve and the CURV is the deviation of the moisture release curve from the mean slope.

A third moisture characteristic is the location of the moisture release curve on the graph, with respect to the moisture levels. In coarse soils, they operate at low moisture contents; while in fine textured soils, they operate at high levels of moisture. The level at which the AMHC operates, may be indicated by the sum of the fixed points on the moisture release curve (referred to as SUM).



	LOAMY SAND	SILTY CLAY LOAM
1) AMHC = $W_{1/3} - W_{15}$	$20 - 5 = 15$	$40 - 15 = 25$
2) CURV = $(W_{1/3} - W_2) - (W_2 - W_{15})$	$(20 - 10) - (10 - 5) = +5$	$(40 - 35) - (35 - 15) = -15$
3) SUM = $W_{1/3} + W_2 + W_{15}$	$20 + 10 + 5 = 35$	$40 + 35 + 15 = 90$

Figure 1. Derivation of moisture characteristics from moisture release curves.

The moisture characteristics can be defined in terms of three formulas whose relationships are seen in Figure 1. In Figure 1, the AMHC of a silty clay loam is nearly twice that of a loamy sand. The CURV of a loamy sand is concave upward and is represented by a positive value. The CURV of a silty clay loam is convex upward, and is represented by a negative value. A soil whose curvature is positive, releases more of its water at low tensions (below 2 atmospheres tension) while a soil with a negative value releases more of its moisture at high tensions (above 2 atmospheres tension). A soil that releases its moisture evenly over the available moisture range will have a CURV of zero. The SUM of a loamy sand indicates that it operates at a low moisture level, while the SUM of a silty clay loam indicates that it operates at a high moisture level.

The three moisture characteristics have desirable properties: they are not correlated and they contain all of the information available in our three laboratory observations. Consequently, any other moisture characteristic can be determined from them. For example, the moisture stored in the "easily available" range between 1/3 and 2 atmospheres of tension is:

$$\frac{1}{2}\,(\mathrm{AMHC} + \mathrm{CURV}) = \frac{1}{2}\,[(W1/3 - W15) + (W1/3 + W15 - 2W2)] = W1/3 - W2$$

In the examples of Figure 1, this moisture available at low tension is fully two-thirds of the total AMHC in the loamy sand, but only one-fifth of that in a silty clay loam.

Now that the three important moisture characteristics have been defined, the important determinative physical properties of the soil must be ascertained. First, each of the moisture characteristics was plotted against such physical properties as sand, silt, and clay content, organic carbon, and capillary porosity. Plotting the results of 57 samples indicated if any linear or curvilinear relationships existed between the moisture characteristics and any of the physical properties. After all plots were made, some good correlations were evident. Properties that showed poor relations were promptly discarded. All relations were evidently linear. For example, Figure 2 shows the high correlation that was found between the available moisture holding capacity and the silt content. This is a linear relationship, indicating that the AMHC is a linear function of the silt content. The progressive increase in the AMHC with increasing silt content can be measured by the slope of the line.

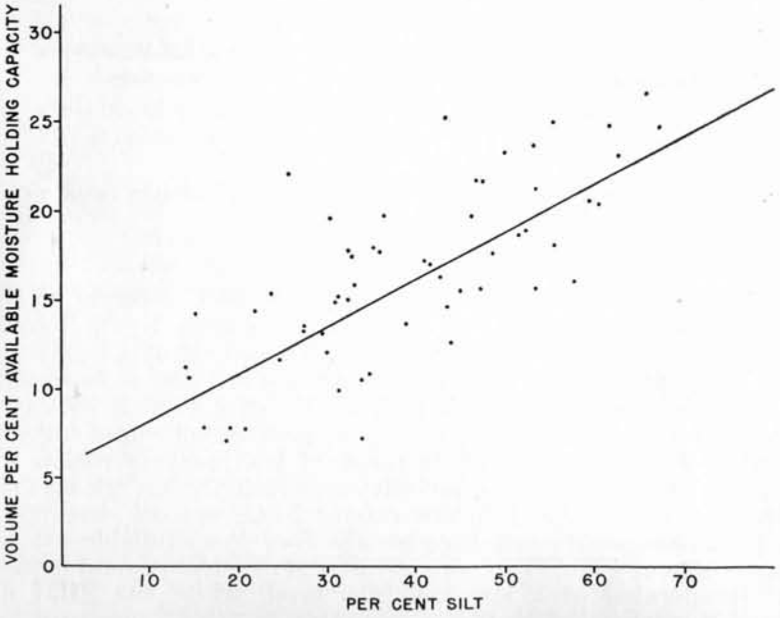


Figure 2. Linear relationship between the available moisture holding capacity and the silt content.

After all graphs had been made, and such relationships were discarded as were thought unnecessary, correlation coefficients were estimated for the graphs that suggested some degree of correlation. These correlation coefficients have been summarized in Table 2. A value of 1.00 is a perfect correlation, while a value of 0.00 indicates no correlation at all.

Examination of Table 2 reveals that there is a correlation between the AMHC and silt content and capillary porosity. The correlation between AMHC and clay or organic matter content was low, as expected (13) (14) (17). Most of the moisture retained by the soil in available form will be that associated with the silt size particles. Since there is also a high correlation between silt and capillary porosity, silt must favor the formation of these small pores. Further, correlation between AMHC and capillary porosity indicates that available water is held in pores of this size. Clay increases the moisture content at field capacity of a soil, but it also increases the moisture content at the wilting point. Thus, there is no appreciable increase in the available moisture holding capacity, unless, under natural conditions, clay sized particles from microaggregates in the silt size range. By the same token, increased organic matter contents could have the same relationship on the available moisture holding capacities as increased clay contents. The available moisture supply is not materially increased by addition of organic matter in the amounts found in Connecticut soils.

Table 2. Correlation coefficients between moisture characteristics and various physical properties of the soil[a]

	Sand	Clay	Organic carbon	Capillary porosity	AMHC	CURV	SUM
Silt	....	.58	.40	.73	.73	....	.77
Sand	....	—.78	....	....	....	.49	....
Clay	....	....	.33	.34	....	—.83	.92
Organic carbon	....	....	....	.45	.45	....	.45
Capillary porosity	....	....	....	....	.78	....	.53

[a] The 5 per cent and 1 per cent significance points for the correlation coefficients are .26 and .34.

Turning to the curvature or CURV of the moisture release curve, we see from Table 2 that it is primarily a function of the clay content, as indicated by a high negative coefficient. Some degree of correlation also exists between the curvature and the sand content. These results can be explained by the same reasoning as that concerning particle size and AMHC. Clay particles are associated with small pores that require more than 2 atmospheres of tension to empty; this is reflected in a negative CURV. Sand particles have the opposite effect. Silt changes the AMHC, but not the CURV.

The SUM, as anticipated, is largely a reflection of the clay and silt content. These soil fractions are responsible for the retention of water against the forces of gravity and would naturally influence the level at which moisture was retained. Some degree of correlation exists between the SUM and capillary porosity and organic matter content.

Before utilizing the correlation coefficients in determining the multiple regression equation, we must determine which factors contribute significantly to an explanation of the variations between samples. An analysis of variance revealed the following facts. With respect to the AMHC, the silt content alone will explain 54 per cent of the variation between samples. A knowledge of the capillary porosity will explain an additional 12 per cent of the variation between samples. The 34 per cent of the variation which remains is due to the many other factors responsible for the retention of soil moisture. None that we measured would contribute significantly to the explanation of variance.

A knowledge of the clay content will explain 69 per cent of the variation in CURV and sand will contribute an additional 6 per cent for a total of 75 per cent. This leaves only 25 per cent that could be explained by other factors.

With respect to the SUM, a knowledge of silt, clay, and organic carbon content accounts for 84 per cent of the variability. All three independent variables make a significant contribution to the explanation. The addition of capillary porosity as a fourth independent variable makes no significant improvement in the three-factor equation.

These three multiple relations between moisture characteristics and other physical factors can be summarized by three multiple regression equations:

$$\text{Expected AMHC} = -3.41 + 0.12\ \text{silt} + 0.41\ \text{capillary porosity.} \qquad 1)$$

$$\text{Expected CURV} = 21.57 - 1.41\ \text{clay} - 0.17\ \text{sand.} \qquad 2)$$

$$\text{Expected SUM} = 18.04 + 0.41\ \text{silt} + 1.91\ \text{clay} + 3.15\ \text{organic carbon.} \qquad 3)$$

The three equations permit one to predict the moisture characteristics from the percentage concentrations of sand, silt, clay, and capillary pores. If only a textural analysis is available, CURV can be predicted from equation 2, but the prediction of AMHC requires:

$$\text{Expected AMHC} = 6.5 + 0.26\ \text{silt.} \qquad 4)$$

Equation 4 accounts for 12 per cent less of the variability than equation 1; however, it would be useful if only a simple textural analysis had been made.

All the equations can be written in terms of silt and clay because sand + silt + clay = 100. Thus, equation 2 becomes:

$$\text{Expected CURV} = 4.57 - 1.24\ \text{clay} + 0.17\ \text{silt.} \qquad 5)$$

The reliability of the prediction equations has been stated as the percentage of the variability explained. A further statement is provided by substituting in equations 1, 2, and 3 the textural, organic carbon, and capillary porosity data of Table 1. For the most part, the predicted and observed values agree satisfactorily (Table 3).

The prediction equations remove statistically the effects of the obvious determinative properties. The difference between observa-

Table 3. Comparison between observed and predicted soil moisture features

	AMHC		CURV		SUM	
	Observed	Predicted	Observed	Predicted	Observed	Predicted
Windsor IC						
	14.1	13.7	7.9	4.8	33.4	29.8
	11.6	9.5	5.4	4.1	27.0	27.9
	10.8	9.3	5.4	5.2	24.6	26.6
Windsor IIC						
	14.8	12.0	6.8	4.0	34.7	35.6
	11.9	13.6	3.5	6.5	33.2	32.0
	8.1	6.8	1.9	5.5	22.3	27.4
Windsor IF						
	8.0	13.0	2.0	4.0	25.1	33.4
	7.3	8.7	0.9	4.5	24.6	31.2
	8.0	11.0	—0.2	5.3	26.2	31.2
Merrimac IC						
	22.3	15.1	13.3	3.7	45.7	39.0
	15.3	13.1	6.1	5.6	41.5	37.8
	15.0	12.7	6.0	5.1	37.5	38.5
Merrimac IIC						
	15.6	15.7	7.4	5.8	35.6	34.2
	17.9	14.7	8.7	5.8	42.5	38.3
	13.6	14.7	7.4	8.4	29.0	31.0
Merrimac IF						
	13.5	15.4	6.1	4.4	33.1	40.0
	12.2	13.5	4.0	7.4	37.7	35.0
	19.6	15.1	14.0	6.9	39.5	35.2
Agawam IC						
	25.4	20.1	16.6	7.7	54.4	45.9
	24.8	23.0	13.0	12.4	51.1	49.0
	19.7	20.1	13.5	11.2	36.0	39.5
Agawam IIC						
	18.1	17.4	9.9	8.3	43.8	38.8
	16.0	18.0	10.4	9.4	35.9	33.4
	15.2	16.6	11.0	9.3	30.2	33.0
Agawam IF						
	19.9	18.2	14.7	8.0	41.4	39.7
	17.8	16.4	12.2	7.4	37.1	38.4
	10.0	16.2	6.8	8.6	32.3	33.2
Cheshire IC						
	17.4	15.4	1.4	1.4	57.5	54.4
	17.5	17.7	4.5	3.3	57.9	54.3
	13.8	13.2	0.6	2.6	52.2	48.0
Cheshire IIC						
	15.2	14.8	3.0	4.0	48.9	52.4
	14.5	16.0	3.1	6.7	47.2	44.5
	18.2	19.6	7.4	11.5	47.9	46.0
Cheshire IF						
	7.4	13.6	0.2	3.1	44.0	47.1
	11.1	12.9	1.9	6.2	41.2	40.0
	10.6	12.6	2.0	6.7	38.9	38.5
Wethersfield IF						
	20.5	20.2	4.7	1.7	63.8	69.1
	20.7	18.8	—3.1	5.2	58.4	58.4
	16.1	17.2	—9.7	—0.4	61.1	65.4

Table 3. Comparison between observed and predicted soil moisture features (continued)

	AMHC		CURV		SUM	
	Observed	Predicted	Observed	Predicted	Observed	Predicted
Narragansett IC	23.8	20.6	8.2	5.5	62.5	57.0
	21.4	21.1	7.0	7.5	58.6	52.7
	13.3	13.3	3.6	6.8	33.6	35.0
Narragansett IIC	25.1	20.2	11.5	7.2	60.7	56.2
	23.4	20.4	16.4	11.3	46.4	42.2
	15.7	19.6	9.1	11.4	34.9	39.8
Narragansett IF	18.7	22.6	11.3	7.2	49.1	53.5
	15.7	20.8	6.9	8.5	42.9	49.5
	12.8	17.6	5.0	8.3	29.1	42.4
Buxton IC	17.3	16.5	0.4	—1.7	57.1	56.1
	16.3	15.5	3.6	—3.5	53.5	50.0
	17.8	15.3	1.5	3.4	49.6	45.0
Buxton IIC	21.8	20.4	—9.0	—7.8	79.5	73.0
	21.9	18.2	—9.7	—7.7	78.5	74.0
	19.1	19.5	—20.7	—20.4	95.1	93.1
Buxton IF	24.7	25.5	—2.9	—4.6	73.3	86.0
	26.6	23.0	—14.8	—13.8	89.6	92.0
	23.1	23.0	—16.9	—23.1	104.3	105.0

tion and prediction are, then, the effects of other factors. Analyses of variance were made of these differences which were classified by soil type, cultivation history, and depth.

Once the differences in silt and capillary porosity between the six soil series had been removed statistically by means of the prediction equation, no signficant differences in mean AMHC remained among the series. Considering the diversity of the series, this was a satisfying and surprising outcome. It emphasized the utility of the equation.

Cultivated soils were found, in Table 4, to have a higher AMHC than their silt content and capillary porosity indicated. Conversely, the forested sites had a lower AMHC than expected. The most probable explanation is that increased aggregation, which is known to occur beneath the forest cover, causes a redistribution of capillary pore sizes, rather than causing a redistribution between capillary and non-capillary pores which would have affected the prediction equation. In effect, the number of capillary pores evacuated between 1/3 and 15 atmospheres tension is reduced in forested sites but the total volume of capillary pores remains virtually unchanged. This is seen in Table 5.

Table 4. Differences in per cent available moisture holding capacity not explained by a linear relation based upon silt content and capillary porosity[a]

		Agawam + Narragansett	Others
Cultivated	Plow zone	2.8	1.8
	Plow pan	0.6	1.0
	Subsoil	—1.6	0.5
	Mean	0.8	1.1
Forested	Plow zone	—1.2	—3.5
	Plow pan	—2.0	—0.3
	Subsoil	—5.6	—0.3
	Mean	—3.2	—1.4

[a] The Wethersfield forested profile was omitted from this analysis because the data for the two cultivated profiles had not been determined.

Since the volume of capillary pores was nearly the same for cultivated and forested sites, we can see that in forested sites there is a shift in pore sizes from the 1/3 to 2 atmosphere range to the 1/17 to 1/3 atmosphere range, the latter being outside the range of measured moisture availability. The opposite is noted for cultivated sites where tillage operations have destroyed aggregation and redistributed capillary pore spaces in favor of a greater moisture holding capacity. The prediction equation has failed to indicate the effect of the redistribution of capillary pore sizes on the AMHC of cultivated and forested sites. Had the redistribution occurred between capillary and non-capillary pores, the prediction equation would have indicated this.

An examination of the AMHC before and after adjustment for silt and capillary pore content is informative:

	Forested	*Cultivated*	*Diff.*
Observed AMHC	14.8	17.3	2.5
Unexplained difference between predicted and observed AMHC	—2.0	+0.9	2.9

Thus, the forested soils store less moisture than cultivated soils whether or not the influences of texture and porosity have been removed statistically. The magnitude of the difference is of consequence. The mean difference of 2.5 or 2.9 between forested and cultivated sites is one-sixth to one-fifth of the total AMHC of the forested sites.

Table 5. Frequency distribution of capillary pores evacuated within four tension ranges[a]

	Atmospheres Tension			
	1/17 to 1/3	1/3 to 2	2 to 15	Greater than 15
Forest	38.7	23.7	15.7	21.9
Cultivated	32.0	30.6	16.5	20.9

[a] The average capillary porosity for all cultivated sites was 36.9 per cent volume, forested sites was 37.5 per cent volume.

The silt loam, Narragansett, and the very fine sandy loam, Agawam, exhibited differences from depth to depth unlike the other five soils. These two soils are more alike in texture than any other two texture classes and display a higher AMHC in the plow zone and lower AMHC in the subsoil than expected from the silt content and capillary porosity. This peculiarity, not exhibited in the other soils, was evident in both cultivated and forested sites. We must conclude that some unknown factor or interaction of the known factors is modifying the storage ability of these two soils.

Table 6. Differences in curvature not explained by a linear relation based upon clay and sand content

Plow zone	+2.2
Plow pan	—0.7
Subsoil	—0.6
Mean	+0.3

The CURVs of the plow zone were found to be about two units greater than the predicted values; a little more moisture is released at low tensions than was anticipated (Table 6). Conversely, the observed values are slightly lower than the predicted values in the plow pan and subsoil of all cultivated and forested samples; a little less water is released at lower tensions than anticipated. Stated another way, of those pores which retain water between 1/3 and 15 atmospheres tension, a relatively high proportion are large in the plow zone and small in the lower horizons. This appears to be a logical consequence of the greater disturbance by cultivation, growth of roots, and activities of animals in the upper as compared to the lower horizons.

Table 7. Differences in sum not explained by a linear relation based upon silt, clay, and organic carbon content

		Agawam + Narragansett	Others
Cultivated	Plow zone	5.9	2.2
	Plow pan	3.7	2.8
	Subsoil	—3.2	0.3
	Mean	+2.1	+1.8
Forested	Plow zone	—1.4	—7.8
	Plow pan	—4.0	—1.3
	Subsoil	—7.1	—0.2
	Mean	—4.3	—3.1

Table 7 shows that the SUM responded to the site location and soil series in the same way as did the AMHC. In the forested sites, the predominance of negative values indicates that the observed values were smaller than the estimated values, or that they retained less moisture at all tensions than expected. The opposite trend is noted in cultivated profiles. The Agawam and Narragansett soils, as before, behave differently from the other series represented in the study. Positive and negative values essentially follow the same pattern as shown in the AMHC.

In view of the results of Tables 4 and 6, further refinements in the prediction equations for AMHC and CURV were indicated. We saw from Table 4 that there was a tendency for underestimating the AMHC in cultivated sites and overestimating the AMHC in forested sites. Separate regression equations were, therefore, determined for the cultivated and forested sites. For cultivated sites alone, it was established that 55 per cent of the variation between samples could be explained by the silt concentration, while capillary porosity contributed an additional 17 per cent for a total of 72 per cent. This represents an increase of 6 per cent in the explanation of variation over that found by using composite data from both cultivated and forested sites. Most of this 6 per cent increase is contributed by capillary porosity.

In analyzing the data from forested sites alone, 68 per cent of the variability between samples could be attributed to silt content and an additional 7 per cent to capillary porosity for a total of 75 per cent. This represents an increase of 11 per cent over the original total. These increases in the explanation of the variability for both forested and cultivated sites are significant.

Regression equations for cultivated and forested sites are as follows:

AMHC Cultivated = —1.82 + 0.12 silt + 0.40 capillary porosity. 6)
AMHC Forested = —6.73 + 0.17 silt + 0.40 capillary porosity. 7)

Table 6 showed that the plow zone had a higher curvature value or proportion of moisture released at low tensions than expected by the prediction equation. The plow zone samples were analyzed separately from the plow pan and subsoil samples.

Regression equations based on a knowledge of clay and sand contents or clay and silt contents are as follows:

CURV plow zone = 34.16 — 2.06 clay — 0.29 sand.
or = 4.97 — 1.77 clay + 0.29 silt. 8)
CURV plow pan and subsoil = 18.00 — 1.30 clay — 0.14 sand.
or = 3.97 — 1.16 clay + 0.14 silt. 9)

To test the validity of the regression equations as prediction formulas, equations 6, 7, 8, 9 were applied to the data accumulated from the profiles sampled in 1958 (Table 1). Values were predicted only for AMHC and CURV. The results may be seen in Table 8, where in addition, a comparison is made between observed AMHC values and the methods of prediction proposed and currently in use. The current method may be found in the "Sprinkler Irrigation Guide for Connecticut" (6). Our aim is to establish whether the proposed methods offer an improvement over existing methods.

No comparison to present methods may be made from CURV as this concept is new and there are no values to compare it with. Only a comparison is made between values predicted by the regression equations.

Table 8. Observed and predicted AMHC and CURV for additional cultivated and forested soils: a comparison of present and proposed prediction methods

Soil series	Texture	Horizon	AMHC Observed	AMHC Predicted equation (1)	AMHC Predicted equations (6) and (7)	AMHC Predicted irrigation guide	CURV Observed	CURV Predicted equation (2)	CURV Predicted equations (8) and (9)
Wethersfield IC									
	loam	Ap	12.8	15.2	16.4	15.8	—2.8	—0.2	0.4
		B_{22}	16.0	12.9	14.2	15.8	0.0	3.5	1.0
		B_{23}	16.3	13.1	14.4	15.8	—0.1	0.4	0.6
Wethersfield IIC									
	silt loam	Ap	17.1	18.3	19.5	15.8	—4.5	2.3	4.5
		B_{22}	19.0	16.4	17.7	15.8	—1.2	3.0	1.5
		B_{23}	18.8	16.6	17.9	15.8	1.2	3.2	1.6
Merrimac									
	fine sandy loam	Ap-1	20.7	15.4	16.6	13.3	1.6	0.1	0.3
		2	18.2	14.5	15.8	13.3	—0.5	0.6	1.2
		3	17.2	14.0	15.3	13.3	3.0	2.4	3.9
		4	17.2	15.2	16.5	13.3	0.6	1.2	2.0
		5	11.9	11.7	13.1	13.3	3.1	3.0	3.8
		6	14.6	10.2	14.5	13.3	5.6	3.0	4.1
		7	14.4	12.8	14.0	13.3	5.9	—0.7	1.3
		8	14.1	12.4	13.7	13.3	5.4	3.6	4.9
Charlton IF									
	fine sandy loam	B_{21}	19.8	13.7	11.9	14.2	9.6	2.7	4.2
		B_{22}	10.5	13.7	11.7	14.2	—0.1	4.4	4.2
		B_{23}	8.3	11.7	9.7	14.2	—1.1	6.8	5.4
Charlton IIF									
	fine sandy loam	B_{21}	11.5	15.5	13.6	14.2	2.1	3.3	6.5
		B_{22}	7.9	13.0	11.0	14.2	0.1	0.2	0.7
		B_{23}	9.9	12.6	10.6	14.2	3.3	7.5	6.2
Gloucester IF									
	fine sandy loam	B_{21}	17.6	15.4	13.5	14.2	8.4	7.6	11.3
		B_{22}	12.7	11.0	9.3	14.2	4.1	5.5	4.2
Gloucester IIF									
	fine sandy loam	B_{21}	9.7	13.8	11.6	14.2	3.5	8.1	11.6
		B_{22}	8.1	8.9	6.5	14.2	2.9	5.5	4.4
		B_{23}	9.2	9.2	6.7	14.2	5.0	7.2	6.0
$\Sigma(\text{Diff})^2$				253.01	177.99	388.96		329.61	357.71

Table 9. Average available moisture storage capacities of representative, cultivated Connecticut soil classes expressed in inches of water

Soil class	In an 8″ plow zone	In an 18″ root zone
Loamy sand (Windsor)	1.0	1.9
Sandy loam (Merrimac)	1.3	2.8
Fine sandy loam (Cheshire)	1.3	2.9
Very fine sandy loam (Agawam)	1.4	3.2
Loam (Wethersfield)	1.6	3.2
Silt loam (Narragansett)	1.9	3.6
Silty clay loam (Buxton)	1.7[a]	3.7

[a] Surface textures are usually of loam or silt loam with silty clay loam texture in subsoil.

Table 8 clearly indicates that there is considerable improvement when separate regression equations are used for AMHC for cultivated and forested sites. When both are compared with the present methods in the Irrigation Guide, we can see a large improvement. A useful means of comparing the several methods is through the calculation of the sum of the squares of the differences between the observed and predicted values, $\Sigma(\text{Diff})^2$. If we consider the $\Sigma(\text{Diff})^2$ of the Irrigation Guide data, column 4, as being 100 per cent, we see that the $\Sigma(\text{Diff})^2$ using a single regression equation, column 2, is 65 per cent and using separate regression equations for cultivated and forested sites, column 3, is 46 per cent. Clearly, the new methods are more precise. This is not surprising because the estimation of soil moisture storage capacity by the Irrigation Guide and by regression equations are clearly different in concept. The Irrigation Guide, which estimates the moisture holding capacity of a soil type, without respect to texture variations within the soil type, is an estimate of the *average* moisture holding capacity of the soil type. It follows that any method that takes into consideration the texture variations within a soil type should be more accurate. This, of course, involves the necessary laboratory determinations, no matter how easily obtainable they may be. Those who wish more precise control of soil moisture will find the prediction equations more accurate than the Irrigation Guide. For those who need only a rough estimate, information similar to that found in the Irrigation Guide or in Table 9 is sufficient.

Applications

The quantity of water a soil will hold for crop utilization determines the amount of irrigation needed. If a grower, for example, is interested in irrigating tobacco whose roots are mostly in the plow zone, it would not be practical to apply 2 inches of water to a soil whose plow zone only holds 1 inch. The extra inch of water applied would be wasted by leaching.

Soils which are stony do not hold as much available water as non-stony soils. The AMHC, as determined in the laboratory, is based on stone-free samples. Any material greater than 2 mm. in diameter (i.e. gravel, cobbles, boulders) is referred to as the coarse skeleton of soils. An estimation of the coarse skeleton is necessary to more accurately determine the AMHC. For example, a soil with a coarse skeleton volume of 25 per cent will have an AMHC nearly 25 per cent less than predicted. The real AMHC in a soil predicted to hold 4 inches of water would only be 3 inches. Most terrace soils, except Hinckley and Manchester, should be relatively unaffected because the amount of coarse skeleton in the solum is low. In upland glacial till soils, the coarse skeleton is appreciable and should be taken into consideration.

The manner in which soil moisture is released is important, too. We have used the term curvature to express the moisture release pattern. Soils with positive values of curvature release more of their available moisture below 2 atmospheres tension than above 2 atmospheres tension; conversely, those with negative curvatures release most of the available moisture above 2 atmospheres tension. A loamy sand, for example, released two-thirds of its available moisture between 1/3 atmosphere and 2 atmospheres tension, while a silty clay loam only released 20 per cent of its available moisture over the same range.

As illustrations, let us take three situations. First, tobacco is to be grown on Merrimac sandy loam. The AMHC of the plow zone, in which the majority of the tobacco roots are located, is 1.3 inches of water (Table 9). The moisture requirement for tobacco is 0.2 of an inch of water per day and the 1.3 inches would be enough moisture to last 6 or 7 days without serious injury to the plant. Since a sandy loam has a high positive curvature, fully two-thirds of the moisture or roughly 0.8 of an inch is available at low tension; this would be enough for 4 or 5 days. To keep the available moisture at low tensions and growth rapid as possible, an addition of 0.8 of an inch at the end of the 5th day would be needed to increase the moisture to field capacity. (Because irrigation application is only about 75 per cent effective due to loss of water by runoff and evaporation, one-third more water must be pumped than the amount required to bring the soil to field capacity.) If a forage, hay, or pasture crop were to be grown on this soil, the deeper root system could utilize an available moisture supply of 2.8 inches of moisture in the upper 18 inches of soil. Less frequent applications would be necessary and the amounts of application could be higher, particularly if one chooses to let the grasses and legumes extract moisture at slightly higher tensions.

In the second illustration, tobacco is to be grown on Narragansett silt loam. The available moisture is about 1.8 inches in the plow zone (Table 9). If the crop consumes 0.2 inches per day, it would have a 9-day supply. The curvature has a high positive value similar to Merrimac sandy loam. Again fully two-thirds of the moisture would be released below 2 atmospheres tension, and moisture would be available at low tension for 6 or 7 days. Irrigation could be less frequent on Narragansett silt loam than on Merrimac sandy loam and still low tensions could be maintained in the soil. (The coarse skeleton factor must be accounted for because of the natural stoniness of Narragansett soils.) If a hay, forage, or pasture crop were to be grown on this soil, the deeper root system could utilize 3.6 inches of available moisture in the upper 18 inches of soil.

In the final example, hay is to be grown on Buxton silty clay loam. The available moisture would be about 3.7 inches in an 18 inch deep zone. With a consumption of 0.2 inches per day, the hay would have nearly a 3-week supply of moisture. The curvature has a negative value here and only 1/4 of the moisture or a 5-day supply would be released below 2 atmospheres tension. Presumably, the grower of the relatively cheap crop, hay, would be more appreciative of the large total storage of water in Buxton than he would be concerned about any diminution of growth caused by tensions of 2 to 15 atmospheres. Hence, these soils are rarely, if ever, irrigated.

Conclusions and Summary

The observations of moisture retention by a range of soils have been translated into three characteristics: the capacity available to plants (AMHC); the curvature of the moisture release curve (CURV); and the level of moisture at which a soil operates (SUM). A large portion of the variation of these characteristics was related to soil texture; a smaller portion of AMHC variation to capillary porosity and of SUM variation to organic matter. When these relations were employed, no significant variation in moisture characteristics remained between soil series. However, forest soils did retain less and cultivated soils more moisture than expected. Further, the plow layer released its moisture at lower tensions and the plow pan and subsoil released theirs at higher tensions than expected from their texture.

The aforegoing results indicate that soil moisture characteristics may be predicted with fair reliability from a knowledge of such easily determined physical characteristics as soil texture and capillary porosity. The predictions represent a measurable improvement over the Tables of the earlier Irrigation Guide. The texture and porosity may be known from existing data, or are easy to determine in the laboratory, and texture may often be estimated in the field by trained soils technicians. The silt content and capillary porosity data could be substituted in a regression equation to estimate the available moisture holding capacity. In a similar manner, the curvature could be predicted, using sand and clay content, and the SUM could be predicted from a knowledge of the silt, clay, and organic matter.

Rough estimates of the moisture holding capacities can be made from the textures given in soil survey field maps. We know a silty clay loam will hold nearly twice as much available moisture as a loamy sand. Intermediate textures generally hold an amount between these two extremes.

To get an estimate of the average moisture holding capacity of each soil texture class that could be applied directly in the field, the wealth of available information supplied by the Soil Survey program was used. Detailed texture analyses were available on over 150 soil samples. The average texture in terms of the percentages of sand, silt, and clay was determined within each texture class. As examples, the average of all the loamy sand soils, whose texture had previously been determined by mechanical analyses, was 79 per cent sand, 18 per cent silt, and 3 per cent clay. The average texture of all silt loam soils was 35 per cent sand, 57 per cent silt, 8 per cent clay. The average capillary porosity for each texture class was determined in a similar manner. These data, once established, were applied to equation 6 to estimate the average available moisture holding capacity for each texture class. These were given in Table 9.

The moisture holding capacities reported herein are generally 0.3 to 0.6 inches higher than those reported in the "Sprinkler Irrigation Guide for Connecticut." The reason for these slight discrepancies is, no doubt, that the data in the Guide had to be estimated from soil moisture capacity information reported in other sections of the country. Few data were available prior to 1956 from soils indigenous to Connecticut in particular and New England in general.

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