Field-Measured Limits of Soil Water Availability as Related to Laboratory-Measured Properties[1]

L. F. RATLIFF, J. T. RITCHIE, AND D. K. CASSEL[2]

ABSTRACT

Accurate evaluation of the soil water reserves available for plant use is vital in developing optimum water management for crop production in marginally dry regions. Laboratory estimates of the upper and lower limits of soil water availability used to calculate the soil water reservoir often deviate significantly from the limits measured in the field. To make a unified and broad assessment of the accuracy of laboratory measurements for estimating field soil water, we obtained and evaluated a comprehensive data base of field-measured upper and lower limits of the soil water reservoir. The field-measured upper limit was taken as the water content at which drainage from a prewetted soil had practically ceased. The lower limit was taken as the water content of the soil at which plants were practically dead or dormant as a result of the soil water deficit. These field-measured limits were compared to laboratory measurements at −0.33 and −15 bar made on samples removed from each field site. A total of 401 observations were available for the comparisons of −15 bar measurements to the field-measured lower limits and 282 observations of −0.33 bar measurements were available for comparison with the field-measured upper limit. Variation often existed within a soil series at a particular site for the field-measured upper and lower limits. However, the differences between the field-measured limits, the total available water reservoir, were relatively constant. Crop species caused only minor differences in the lower limit water content for the upper part of the soil profile where root length density was apparently above some critical limit. However, some annuals extracted water to greater depths than others. The laboratory estimates of the upper limit obtained by −0.33 bar water contents were significantly less than the field-measured drained upper limit for sands, sandy loams, and sandy clay loams and were significantly more than field measurements for silt loams, silty clay loams, and silty clays. The laboratory estimates of the lower limit obtained by −15 bar water content measurements were significantly less than field lower limit measurements for sands, silt loams, and sandy clay loams and significantly more than field observations for loams, silty clays, and clays. Because our study included relatively few measurements of loamy sands, silts, sandy clays, and clays, it was difficult to generalize about differences in field-measured and laboratory-estimated water limits for those textures. The results suggest that if absolute accuracy is necessary in water balance calculations, laboratory-estimated soil water limits should be used with caution and field-measured limits, if available, would be preferred.

Additional Index Words: soil water reservoir, matric potential, in-situ water limits.

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AGRICULTURAL WATER PROBLEMS are related to both weather and to the reserves of soil water available to plants. The dynamics of water in the soil are related to the drainage process, the capacity of the reservoir, its depletion and replenishment, and its efficient management for agricultural production. Accurate calculation of the soil water balance is becoming increasingly important because of the need to manage water as efficiently as possible.

Evaluation of the capacity of the soil water reservoir requires knowledge of its upper and lower limits in the plant root zone. The most common procedure for estimating the upper limit water content is to extract water from a disturbed or undisturbed soil sample using a soil water extraction apparatus or "pressure chamber" (Richards and Weaver, 1943). A matric potential of −0.33 bar is used for moderately coarse- and finer-textured soils whereas a −0.10 bar potential is used for coarse-textured soils (Jamison and Kroth, 1958; Colman, 1947). The lower limit water content is also estimated using the pressure chamber at a matric potential of −15 bar. The soil water reservoir for a soil profile is estimated by collecting soil samples from the different soil horizons or depths, determining the water content at the upper and lower limits for each horizon, and summing the differences over the entire rooting depth.

Laboratory methods for estimating the soil water reservoir have been criticized (Richards, 1960; Gardner, 1966; Ritchie, 1981). It has been argued that some plants remove water from the soil at matric potentials <-15 bar. Other plants may not remove water to a matric potential of −15 bar. Few field-measured values of the matric potential at the lower limit have been reported. For the upper limit, field measurements often do not agree well with those values estimated using the −0.10 and −0.33 bar pressure apparatus in the laboratory. Estimates of the upper limit made by using the pressure chamber for different depths of a single soil profile may overestimate in-situ measurements at some depths, underestimate it at others, and be nearly equal to it at still others (Cassel and Sweeney, 1974).

Because of the problems encountered in estimating the soil water reservoir, we assembled a comprehensive data base of upper and lower limits of soil water availability measured in the field for a broad range of soils throughout the United States. Our purposes were to make a broad assessment of the value of laboratory measurements for estimating field soil water limits and to determine if alternative techniques might be needed for the accurate evaluation of the soil water reservoir. In this paper we summarize these field-measured upper and lower limits and compare them to the −0.33 and −15 bar laboratory determinations. In a companion paper we report equations for estimating the potential upper and lower water limits of soils based on routinely measured soil physical and chemical properties.

PROCEDURES

Soil Selection Process

To develop a data base encompassing a broad range of soils with respect to texture and other chemical and physical properties, both published and unpublished data meeting certain criteria were collected, summarized, and tabulated.

Initially a literature review was conducted to locate published data on upper and lower limits measured in situ. The literature review was followed by a survey of about 250 researchers who were conducting or had recently conducted research that in-

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cluded field measurements of soil water content under various crops. Questionnaires were sent to researchers identified during the literature search and also to researchers at state and federal institutions having research programs in soil physics or soil water management. The questionnaire was designed to identify those studies which met the following criteria: (i) the crops growing on the soil in question had undergone severe water stress, (ii) the soil water content had been measured throughout the rooting zone periodically during the stress period, and (iii) the water content measurement sites could be precisely located. Applicable data were found from 28 respondents who agreed to contribute to the survey. After identifying the soils to be included in the data base, the senior author visited all sites, discussed the in-situ measured water content data with the researcher, described or helped describe the soil at the site where the data were collected, and collected soil samples. At one location the soils had previously been described and sampled by individuals experienced in soil classification. These soil samples had been submitted to the same laboratory being used in this study and the resulting analyses were included in the data base. Eighteen months were required to assemble the data base. During the study, several other sets of water limit data were identified. However, the data and soil properties were either similar to those of soils already included in the data base or the cost of obtaining a single data set from one location was prohibitive.

Methods for Defining the Soil Water Limits

The methods used to define the in-situ upper and lower limits of the soil water reservoir available to plants were similar to those described by Franzmeier et al. (1973) and Ritchie (1981). Slight modifications were required to accommodate the various experimental approaches used by investigators throughout the United States. Comparing the methods presented below with the above references will show the differences.

To maintain uniformity, we defined the water limits to be investigated before accumulating the data base as: (i) drained upper limit (DUL)—the highest field-measured water content of a soil after it had been thoroughly wetted and allowed to drain until drainage became practically negligible; (ii) lower limit (LOL)—the lowest field-measured water content of a soil after plants had stopped extracting water and were at or near premature death or became dormant as a result of water stress; (iii) potential extractable soil water (PLEXW)—the difference in water content between DUL and LOL. These three parameters—DUL, LOL, and PLEXW—are expressed in percent by volume.

The DUL for a particular soil was derived from analysis of successive measurements of soil water content with depth after the soil had been thoroughly wetted and allowed to drain. Successive measurements of such a thoroughly wetted soil exhibit a monotonic decrease in soil water with time until the drainage rate becomes negligible. The soil profile was considered to attain a negligible drainage rate and to reach the DUL when the water content decrease was about 0.1 to 0.2% water content per day. Soils with a water table shallower than 200 cm at the time DUL was measured were excluded. Some soil sites were covered with rainfall shelters or plastic sheeting which prevented evaporation losses or precipitation gains of water. Other plots were uncovered and were subjected to the above gains and losses. Typically, 2 to 12 d were required for soils to reach the DUL. Some fine-textured soils and soils with restrictive layers required up to 20 d of drainage.

The LOL was derived from successive measurements of soil water content with depth during a period when a field crop was subjected to severe water stress. Water content measurements were continued until the plant died, nearly died, or became dormant. Data from adequately fertilized field plots in which plants had reached maximum vegetative growth before undergoing severe water stress were preferentially selected over data from plots inadequately fertilized or early season stressed.

The definitions and methods of selecting the DUL and LOL were designed to identify the limits of the soil water reservoir and do not address water that can be taken up by plants while drainage is occurring (Ritchie, 1981). In addition, evaporative losses of soil water from the soil surface or from near soil surface layers of uncovered plots result in an underestimation of DUL. Similarly, soil evaporation causes an underestimation of LOL for layers near the soil surface. Also, there is a rooting depth below which root density is inadequate for complete extraction of available soil water, and this would cause the water content at the LOL to be overestimated. The above problems were recognized before compiling the data base; hence, the following procedures were used to minimize underestimation of DUL and LOL and overestimation of LOL. All possible values of LOL, DUL, and PLEXW were plotted vs. depth for each soil profile. Possible LOL and DUL values near the soil surface that appeared to be affected by soil evaporation and those that appeared to have inadequate root density and hence, incomplete water extraction, were identified and omitted in the comparison of field-measured and laboratory-estimated water limits and in subsequent data analysis.

Two procedures for measuring soil water content used by the various investigators were gravimetric sampling and neutron attenuation. Inherent in the data set are errors associated with the variation in techniques used by the investigators providing the data. This sampling error could not be removed from the data.

Additional Soil Measurements

At each location, the soil was described and sampled as close as possible to the point at which the soil water content was measured when DUL and LOL were being determined. About 3 to 5 kg of disturbed soil material and duplicate 5 cm thick and 7 cm diameter undisturbed soil cores were collected at depth increments that coincided with the depth of water measurement and/or soil horizon. All samples were shipped to the National Soil Survey Laboratory, Lincoln, Nebr., for analysis by procedures described in Soil Survey Investigations Report no. 1 (SCS, 1972). Percent sand, silt, and clay were determined by pipette analysis. The water content at -0.33 bar was determined with the pressure extractor, using 1-cm thick slices of the undisturbed soil cores. Disturbed soil samples were used for the -15 bar determination. The water contents obtained at -0.33 and -15 bar were expressed in percent by volume.

RESULTS AND DISCUSSION

The geographical distribution and number of soils at each location in the data base are shown in Fig. 1. The data will eventually be published in the Soil Survey Investigative Report series. Seven soil orders are represented in the data base, but over 60% of the soils are Mollisols or Alfisols. Histosols, Oxisols, and Spodosols are not represented. It would have been desirable to include more soils from the humid temperate midwest, northeast, and southeast regions of the United States. More data from these regions were not included because additional data meeting the aforementioned criteria could not be located. The fact that these regions experience frequent precipitation events during the crop growing season precludes the casual collection of field-measured LOL data.

Variation of DUL, LOL, and PLEXW for Morphologically Similar Soils

Before analyzing the amassed data in its entirety, we examined the uniformity of measured DUL, LOL, and PLEXW values for a given soil series. Data were avail-

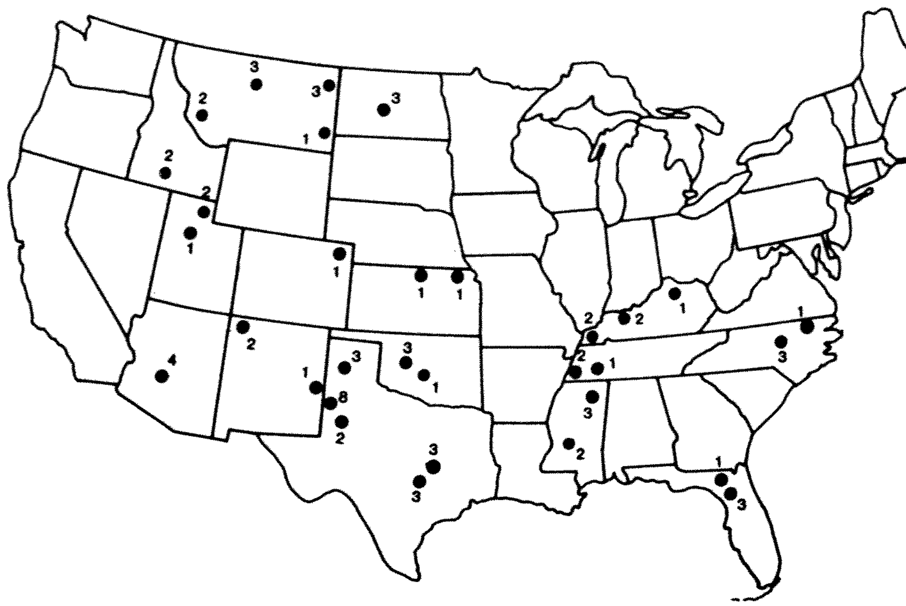

Fig. 1—Geographical distribution and number of soils at each location in the data base.

able from several locations which could be used for this task. For one of the locations, DUL and LOL were measured in the center of each of 18 adjoining plots on a fine-loamy, mixed, hyperthermic Typic Camborthid which is a Variant of the Avondale series. Graphs of DUL and LOL vs. depth showed that the 18 sets of soil water content measurements could be grouped into three closely related, but different soil water content profiles. In Fig. 2 we show DUL, LOL, and PLEXW for one representative profile from each of the three groups. Field observation of the soils showed that they were morphologically similar except for detectable differences in clay content with depth. Percent clay and sand determined in the laboratory for the three profiles are shown in Table 1. The lowest DUL and LOL values below the depth of 40 cm were for profile C which had the lowest clay content. Profiles A and B had a similar clay content between 0 and 150 cm, thus suggesting that some factor other than clay content influenced DUL and LOL. When PLEXW was computed, the three profiles held nearly identical amounts of extractable water. Thus, for this field, minor variations in soil properties give rise to different DUL and LOL values but the amount of extractable water is relatively constant.

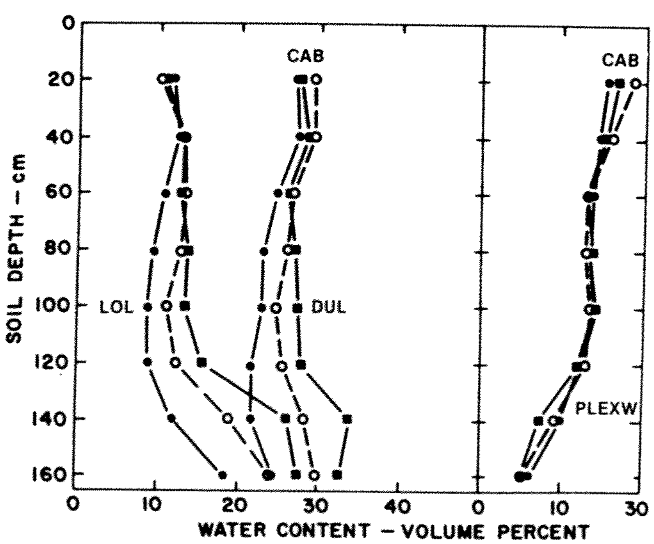

Fig. 2—Representative field-measured DUL, LOL, and PLEXW for three pedons of the same soil series.

Crop Effects

DUL should not vary with the crop, but LOL may be crop dependent. To determine the effect of crop type upon LOL, both crops would have to be grown on the same soil at the same time. Two crops may be grown in close proximity, but because of the nonuniformity that exists within one soil series as discussed above, such data must be carefully interpreted. Fortunately, LOL determinations made on the same plots for different crops in different years allow an objective evaluation of the effect of crop type on LOL and PLEXW.

The DUL, LOL, and PLEXW values in Fig. 3 are for wheat (*Triticum aestivum* L.) and sunflower (*Helianthus annuus* L.) growing on a well-drained clayey Pullman soil (fine, mixed, thermic Torrertic Paleustolls) with a pronounced calcic horizon at a depth of 112 cm. Measurements were made on the same site 6 years apart. The two crops extracted about the same amount of water to

Table 1—Percentages of clay and sand for three pedons of the same soil series.

	A		B		C	
Depth	Clay	Sand	Clay	Sand	Clay	Sand
cm	%					
0–15†	20.5	37.2	20.5	38.9	21.0	38.0
15–50	22.9	34.3	20.5	38.5	20.3	37.4
50–130	23.5	36.0	22.9	32.8	18.6	44.5
130–150	31.5	39.0	31.5	33.3	17.5	54.3
150–170	39.8	33.4	29.4	23.9	19.1	50.6

† Upper and lower boundary layers are within ± 4 cm of depths listed.

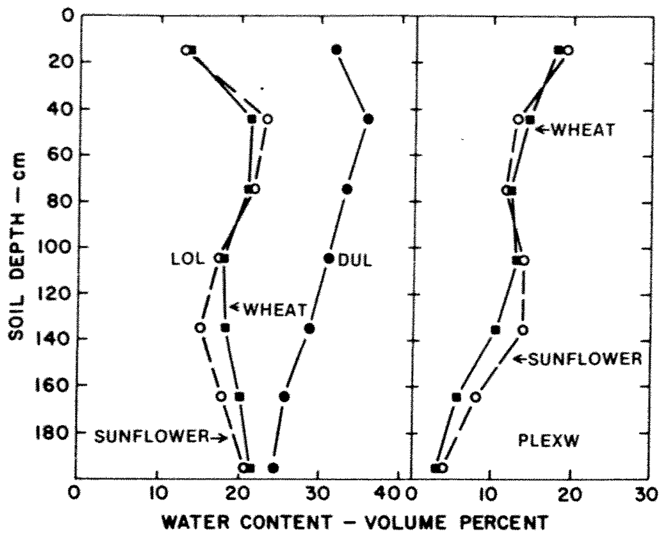

Fig. 3—Field-measured values of DUL, LOL, and PLEXW for two crops grown on the same soil.

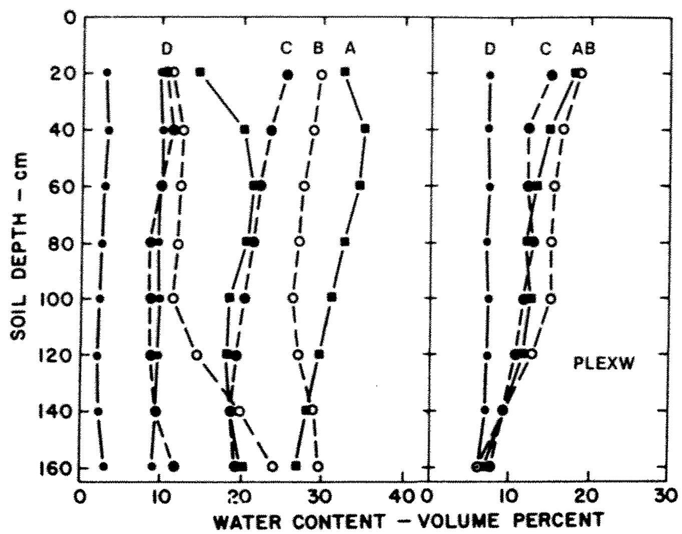

Fig. 4—Field-measured values of DUL, LOL, and PLEXW for four soils having different textures. DUL and LOL values are plotted on the left side of the figure. DUL values are identified as soils A, B, C, and D. For a given set of symbols, the line on the left represents the LOL.

a depth of about 110 cm. Below this depth the wheat root density was apparently inadequate for complete water extraction, whereas the sunflower roots were able to penetrate the calcic horizon and obtain more water to a depth > 180 cm. Grain sorghum [*Sorghum bicolor* (L.) Moench] grown on a nearby plot with almost identical soil properties extracted about 1.5 volume percent less water than wheat for all depth increments. Total water removed by evapotranspiration from a 210-cm deep soil profile was 24.6, 22.9, and 20.1 cm for sunflower, wheat, and grain sorghum, respectively.

An evaluation of all data collected in this study suggests that the effect of crop type on LOL and PLEXW for the same soil is not large among many annual crops, particularly in the upper portion of the soil profile where root density is high. The major difference observed is the apparent ability of some annuals to extract water at greater depths. Although evidence is not conclusive, the observed trend is for annual taproot systems to extract water from deeper in the soil than fibrous root systems and for perennials to extract water deeper than annuals. Evidence also exists to support the idea suggested by Franzmeier et al. (1973) that perennials may extract slightly more water than annuals at all depths. The apparent differences observed for the effect of crop type on the water limits may be related to genetic, climatic, or soil factors or to experimental errors associated with the soil water content measurements.

Texture Effects on DUL, LOL, and PLEXW

The field-measured values of DUL, LOL, and PLEXW for four soils representing a wide range in soil texture are presented in Fig. 4. The four soils were deep, well drained or excessively drained, and had no root restricting layers in the upper 1 m. Soil A was classified as a fine, mixed, thermic Torrertic Paleustoll. Texture ranged from silty clay to silty clay loam in the upper 64 cm and was clay loam from 64 to 200 cm. A pronounced calcic horizon that might partially restrict rooting occurred at 112 cm. Soil B, a fine-loamy, mixed, hyperthermic Typic Camborthid, had loam texture to 127 cm and clay loam to 2 m. Soil C had silt loam texture from 0 to 2 m and was classified as a fine-silty, mixed Argic Cryoboroll. Soil D was a thermic, coated Typic Quartzipsamment with a texture of fine sand or sand throughout the 2-m depth. Corn (*Zea mays* L.) was cropped on soil D whereas wheat was cropped on the others.

The soil water content at the DUL for the four soils was highly correlated with soil texture. Soil A had the highest DUL and the highest average clay content throughout the profile; its clay content reached a maximum at a depth of 38 cm and then gradually decreased with depth. Soil B had an intermediate clay content that remained nearly constant to about 120 cm and then increased with depth. The DUL for soil B was less than that for soil A except at the 135-cm depth. Soil C had a lower clay, but a higher silt content than soils A and B. The clay content of soil C reached a maximum at 25 cm and gradually decreased with depth. This gradual decrease in clay with depth is reflected in the gradually decreasing DUL. Soil D, which had a relatively uniform and low (< 5%) clay content, had a low DUL.

The soil water content at the LOL for the four soils was also highly correlated with texture. For soils A, B, and C, the respective DUL and LOL curves are nearly parallel from the 20- to 120-cm depth (Fig. 4). The DUL and LOL curves for soil D are nearly parallel to the 150-cm depth. For soil B the LOL curve below 120 cm increases sharply compared to DUL, thus indicating inadequate extraction of soil water to the true LOL. This behavior exists for soils A and C also, but to a lesser degree. The differences in depth of water extraction to the true LOL between soil D and the others cannot be conclusively explained.

Extractable water for the four soils is also shown in Fig. 4. The patterns and amounts of water extracted by wheat from soils A, B, and C are very similar. For example, between depths of 30 to 120 cm an average of 12.8, 14.8, and 11.9 volume percent water was extracted from soils A, B, and C, respectively. In contrast, an average of 7.1% was extracted from soil D over the same depth.

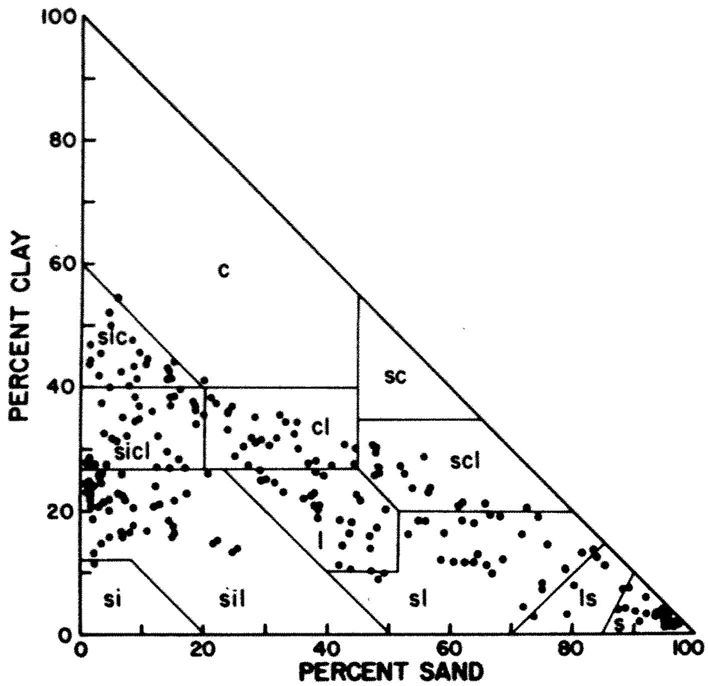

Fig. 5—Textural distribution of the 401 observations in the data base.

In Fig. 5 we show the textural distribution of the 401 observations available for comparison of the laboratory-estimated water limits with the field-measured limits. Some samples that had nearly identical textures appear as single points on the graph. The number of samples and the observed range of sand, silt, and clay for each textural class are presented in Table 2. All textural classes were well represented except for sandy clay, silt, and clay.

The mean and standard deviation for DUL, LOL, and PLEXW for each textural class are also shown in Table 2. Values of the DUL range from a minimum of 11.8 ± 4.9% for sand to a maximum of 35.0 ± 6.2% for silty clay. The LOL ranged from a minimum of 3.8 ± 2.2% for sand to a maximum of 21.9 ± 1.0 for clay (based on only three observations).

The mean and standard deviation for the −0.33 and −15 bar determinations for each textural class are included in Table 2. The −0.33 bar determination overestimates by 2.0% or more the DULs for silt loams, clay loams, silty clays, and clays; underestimates by 2.0% or more the DULs for sands, loamy sands, sandy loams, and sandy clay loams; and is within ± 2.0% for loams and silty clay loams. It is recognized that a better laboratory procedure to estimate the DUL for sands and loamy sands would be −0.10 bar; however, incomplete data for the −0.10 bar value precluded such a comparison. The −15 bar determination overestimates by 1.0% or more the LOL for loams, silty clays, and clays; underestimates by 1.0% or more the LOL for loamy sands, silt loams, and sandy clay loams; and estimates within ± 1.0% the LOL for sands, sandy loams, silty clay loams, and clay loams.

In general, the standard deviations for the −0.33 and −15 bar determinations are less than those for the corresponding DUL and LOL determinations. The higher standard deviations for the field-measured values are thought to be attributable primarily to errors associated with the field measurements of water obtained by different techniques and different personnel.

The mean and standard deviation for PLEXW, which is equal to DUL minus LOL are also shown in Table 2 and are plotted as a function of soil textural class in Fig. 6. The values range from a minimum of 8.0 ± 3.1% for sands to 14.8% for just one observation for the silt. The second highest value is 14.3 ± 3.3% for silt loam. The sand, as expected, has the least PLEXW because the large pores in sandy soils drain easily and rapidly under field conditions; moreover, the particle surface area is low, resulting in the presence of little adsorbed water at the LOL. The mean PLEXW values for the remaining textural classes are relatively constant with a range of only 11.0 to 14.8%. The associated standard deviations range from 2.1 to 3.6%. The values support the commonly held concept that plant available water increases with fineness of texture up to silt loam but suggests that the amount of increase is not large.

The water retention difference (WRD) defined in Table 2 as −0.33 bar minus −15 bar, ranges from a minimum of 5.6 ± 1.9% for sand to a maximum of 18.6 ± 3.1% for silt loam. Silt has been omitted from the discussion because only one observation was available. Comparison of WRD with PLEXW reveals that WRD overestimated by 1.0% or more the observed PLEXW for silt loams, silty clay loams, and clay loams; underestimated by 1.0% or more PLEXW for sands, loamy sands, sandy loams, and loams; and estimated PLEXW to within ±1.0% for sandy clay loams, silty clays, and clays. For each of the textural classes except silt loam and silt, the mean WRD was within one standard deviation of the mean PLEXW.

Table 2—Texture and water retention data by textural class for the 401 observations.

Texture	No. samples	Soil separate: Sand	Silt	Clay	Upper limit: DUL	−0.33 bar	Lower limit: LOL	−15 bar	PLEXW (DUL-LOL)	WRD (−0.33 bar− −15 bar)
		Weight percent < 2 mm			Volume percent					
s	76	87.4-97.5	0.8- 8.5	1.2- 7.7	11.8 ± 4.9	8.9 ± 2.2	3.8 ± 2.2	3.3 ± 1.3	8.0 ± 3.1	5.6 ± 1.9
ls	7	73.7-88.3	3.4-23.5	2.8-12.6	18.9 ± 6.0	16.0 ± 5.3	5.9 ± 4.0	4.4 ± 2.3	12.9 ± 3.6	11.6 ± 3.3
sl	31	53.1-83.3	2.8-30.7	4.4-19.3	23.7 ± 5.4	21.4 ± 5.5	10.5 ± 5.2	9.9 ± 2.0	13.2 ± 2.2	11.5 ± 3.9
l	51	29.0-49.4	29.7-47.1	8.9-26.9	25.0 ± 5.1	25.2 ± 3.9	11.4 ± 4.5	13.8 ± 4.0	13.6 ± 3.0	11.4 ± 3.3
sil	83	0.9-25.4	53.6-84.8	13.1-27.0	29.0 ± 7.0	31.6 ± 4.1	14.7 ± 5.9	13.0 ± 2.3	14.3 ± 3.3	18.6 ± 3.1
si	1	2.2	86.4	11.4	32.3	36.1	17.5	6.9	14.8	25.4
sicl	53	0.9-18.8	44.0-71.8	27.0-39.9	33.8 ± 3.5	34.9 ± 2.8	20.8 ± 3.4	20.8 ± 2.6	13.0 ± 2.1	14.1 ± 3.6
cl	41	20.0-44.6	25.3-46.2	27.2-38.3	30.9 ± 4.5	33.0 ± 4.4	18.4 ± 4.9	19.2 ± 3.8	12.5 ± 3.2	13.8 ± 4.2
scl	24	47.4-72.7	6.6-26.5	20.7-30.7	29.0 ± 3.6	26.3 ± 3.3	18.0 ± 5.2	15.0 ± 2.7	11.0 ± 3.5	11.3 ± 2.4
sc	0									
sic	31	1.2-15.1	40.7-55.2	40.2-52.1	35.0 ± 6.2	37.3 ± 3.3	21.5 ± 6.8	24.1 ± 5.4	13.4 ± 3.0	13.2 ± 3.4
c	3	5.8-20.0	38.9-39.8	41.1-54.4	34.8 ± 2.9	39.3 ± 1.0	21.9 ± 1.0	27.0 ± 1.0	12.9 ± 3.6	12.3 ± 1.3

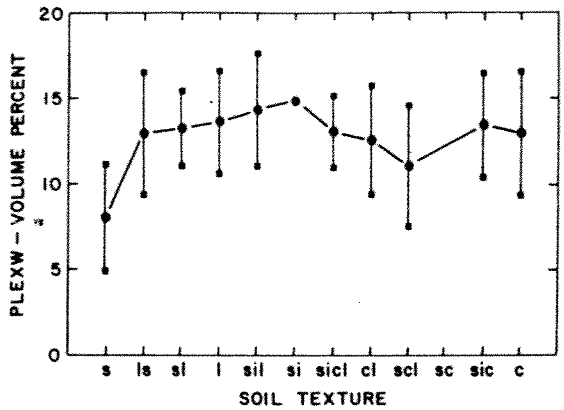

Fig. 6—Field-measured PLEXW as a function of soil textural class.

To determine if the field-measured limits were significantly different from the laboratory-estimated limits, a t statistic was calculated for the following comparisons for each textural class: DUL vs. −0.33 bar; LOL vs. −15 bar; and PLEXW vs. WRD. Results of these analyses are shown in Table 3. Examination of the table shows that one or more comparisons were significantly different at the 0.10 level, usually at the 0.05 level, for all textural classes except loamy sands and clay loams. However, the PLEXW and WRD values were significantly different only for sands, loams, silt loams, and silty clay loams. The mean DUL and −0.33 bar values reported in Table 2 suggests that better agreement between the field-measured and laboratory-estimated upper water limits can be expected by using matric potentials > −0.33 bar for soils with sandy textures and matric potentials < −0.33 bar for soils with silty textures. Similarly, better agreement between the field-measured and laboratory-estimated lower water limits can be expected by using matric potentials > −15 bar for sands, silt loams, and sandy clay loams and matric potentials < −15 bar for loams, silty clays, and clays. From our data, it is not possible to determine what alternative potentials would be needed to calculate more appropriate water content limits for various soil textures.

Soils in the data base we assembled were mostly deep and moderately well or better drained. Soils having root restrictive layers were included in the data base, but since root density in the restrictive layers was generally inadequate for complete water removal, the values were excluded from the data reported herein. We also recognize that some of the variation in the field-measured soil water data results from variations in techniques used by the investigators providing the data and from natural within-site soil variations. Assuming the errors due to variation in measuring technique and soil heterogeneity are random, our comparisons between field-measured limits and laboratory-estimated limits should be valid.

Table 3—Results of t-test for paired comparison between field-measured and laboratory-estimated soil water limits for each textural class.

Texture	DUL vs. −0.33 bar	LOL vs. −15 bars	PLEXW vs. WRD
s	*	*	*
ls	NS	NS	NS
sl	*	NS	NS
l	NS	*	*
sil	*	*	*
si	--	--	--
sicl	*	NS	*
cl	NS	NS	NS
scl	*	*	NS
sic	†	*	NS
c	NS	*	NS

* and † Indicate significant differences at the 0.05 and 0.10 levels, respectively.
NS indicates not significant at the 0.10 level.

The results suggest that if absolute accuracy is necessary in soil water balance calculations, laboratory estimates of limits of the soil water reservoir should be used with caution. Field-measured limits are usually a more accurate alternative if they are available.

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