Effect of Sample Disturbance on Water Retention in Three Soils

By

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DEDICATION

This work is dedicated to my wife, Nilma, for her moral support and inspiration.

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INTRODUCTION

Most soil moisture retention measurements are made with air-dried sieved soil because of convenience and uniformity of samples. However, the amount of water retained by sieved soil may differ markedly from that retained by undisturbed soil cores or soil in the field. While this is well recognized, it often is ignored and can lead to serious misinterpretation. A good example is the use of water retention of sieved samples at -0.33 atm soil water matric potential as an estimate of field capacity. This procedure is on a reasonable basis since it was established by correlation with the moisture equivalent, another laboratory estimate. However, because of its use, there is wide-spread association of -0.33 atm matric potential with field capacity in field soils, while the actual values generally are appreciably higher. (Richards and Marsh, 1961).

The complete soil water retention curve is valuable in assessing a number of water-related soil characteristics as well as availability of water to plants and water transport in the soil-plant system. However, inaccurate curves destroy the value of such assessments and may cause them to be erroneous.

Several workers have compared water retention by sieved and core samples. However, only a few have presented the complete curves, and more data are needed, especially for irrigated soils. Furthermore, many previous studies were conducted on samples from the plow later where "undisturbed" soil is the result of the recent history with respect to tillage and other forces tending to alter porosity and pore size distribution.

The objective of the present study was to determine if water retention throughout the range of available water, measured on disturbed soils, was representative of the same parameters in undisturbed soils. Three soils at the University of California at Davis were selected, ranging in texture from fine to medium.

LITERATURE REVIEW

Along with their development of the apparatus and precedures for studying water retention by soils, Richards and Fireman (1943) determined effects of various forms of sample treatment. They showed that water retention by cores of Fallbrook loam differed from that of sieved samples in the 0 to -1 atm range of matric potential. Oven-dried and air-dried cores produced identical water retention curves.

Elrick and Tanner (1955) compared water retention curves for sieved and core samples with eight Wisconsin, U.S.A., soils. They concluded that water retention was greater in sieved samples from 0 to -0.4 atm, that between -0.4 and -1.0 there was no general relationship between retention by sieved samples and by cores, and that sieving decreased retention about 10% below -1 atm. They recommended using core camples for determinations within the range of 0 to -1 atm.

Perrier and Evans (1961) and Werenfels[1] developed water retention curves in the field by taking samples for soil water content adjacent to tensiometer cups with simultaneous tensiometer readings. Perrier and Evans also compared these curves with core and sieved

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[1] Werenfels, Lucas, 1963. Range of soil moisture coverage by tensiometers in the field. Irrigation and Drainage Letter, #21, University of California Agricultural Extension Service Memo.

sample water retention in the laboratory with the range of 0 to -1 atm. The field procedure with tensiometers produced great variation, and they fitted linear curves to the logarithm of matric potential vs. soil water content. In the laboratory, core retention curves were much closer to the field curves than to those of sieved samples for three of the four soils studied. (Werenfels' conclusions will be cited later).

Use of sieved samples for water retention in the wetter ranges can lead to absurdities, as pointed out by Young and Dixon (1965). They showed that apparent water retention can exceed total porosity. Some of the data of Jamison and Kroth (1952) also show the same impossibility although this fact is not indicated by the authors.

Childs (1940) pointed out the close relation between water retention and pore size distribution and proposed using changes in water retention curves in soils after cyclic drying and wetting as a measure of structural stability. Bruce (1972) was concerned with water content-matric potential-hydraulic conductivity relations. He found that in the Ap horizon of Cecil loamy coarse sand there was little difference in water retention by sieved and core samples but that in the B_2 horizon (clay loam texture) cores retained markedly less water to -2 atm, the lowest potential tested. Shaykewich

(1970) also was concerned with hydraulic conductivity and presents complete curves of conductivity vs. matric potential, but provides water retention data at -0.33 and -15 atm. At -0.33 atm four out of seven sieved samples retained significantly more water than cores; in two there was no significant difference; in one sample cores retained significantly less. At -15 atm there was no significant difference in four of seven; two cores retained less; and one core retained appreciably more water.

Soil water retention curves are used to assess availability of water to plants. Hagan (1955) suggested the fraction of available water held at low soil water tension as an important criterion. Salter and Williams (1965) were concerned about the shapes of water retention curves relative to crop responses to irrigation regimes, but gave no specific basis for their use. They provide complete curves for five soils, with the greatest difference in water retention between core and sieved samples in a clay soil. Richards and Marsh (1943) present several curves for different soils where the percent available water depleted is plotted against matric potential. No data points are shown and the sample treatment was not described, so it can be assumed that the curves were for sieved samples. They emphasize the different shapes of curves of soils of different textures. These curves were reproduced and used by Haise et.al. (1967) and Taylor (1965) in interpretation of water availability to plants even though the curve shapes probably are incorrect and therefore misleading.

Unger (1975) compares water retention by cores and sieved samples only at -0.33 atm and -15 atm. Except for the coarsest soils, retention at -0.33 atm was greater in sieved samples. At -15 atm agreement was closer. Unger used his data to estimate available water storage capacities of soils incorrectly comparing the difference in water retention between -0.33 atm and -15 atm with cores and sieved samples.

Werenfels (1963) estimated the percent available water remaining at the upper limit of tensiometer functioning (about -0.75 atm) from field tensiometer measurements and field and laboratory estimates of upper and lower limits of available water. He found values of available water for different soils and soil depths from 34 to 86% with no apparent relation to texture since the 34% was in a clay soil and the 86% in a clay loam.

Jamison and Kroth (1958) estimated the percent available water remaining at -1.0 atm in the laboratory for undisturbed silt loam at different depths ranging from 32 to 88%.

No data were located comparing variability in replicate core samples with that from sieved subsamples. Theoretically, with the great effect of macrostructure on water retention at high matric potentials, variability of core samples could be very large. Thus some information on this point will be valuable.

To summarize, core samples generally retain less water than sieved samples at high matric potentials. Although there were exceptions reported, at -15 atm the differences were less, but often significant, with a tendency to have less water retained in sieved than core samples. No reason for this phenomenon is apparent. In several papers, the values appear inconsistent. The exceptions to general relationships and the inconsistencies point to the need for additional data, taken with special care to eliminate questions in interpretation.

MATERIALS AND METHODS

Soil samples of different textures were obtained from three different field sites at the University of California, Davis. The two coarser soils are of the Yolo series; the clay is mapped as Capay. All samples were obtained from cultivated cropland, free of vegetation. Each sampling site contained an area of 9m^2 (3m X 3m). To obtain samples relatively unaffected by tillage the upper 30cm layer was removed. The soil beneath was irrigated, covered with polyethylene film to minimize evaporation, and allowed to drain for several days before the initial sampling. This procedure provided and maintained favorable soil water content and physical conditions for obtaining core samples. Undisturbed soil was sampled with a hammer-driven soil core sampler similar to that described in U.S. Department of Agriculture Handbook 60 (1954) and is shown in Figure 1. In ordinary usage the core sampling apparatus has a removable inner cylinder or liner to retain the soil core. As the sampler is driven into the soil, the core is forced into the retainer cylinder. The retainer cylinder and core can then be removed from the sampler. For the present study where core samples of small height or thickness were essential, the 7.5 cm high retainer cylinder was replaced with five transparent plastic rings of the same diameter and wall

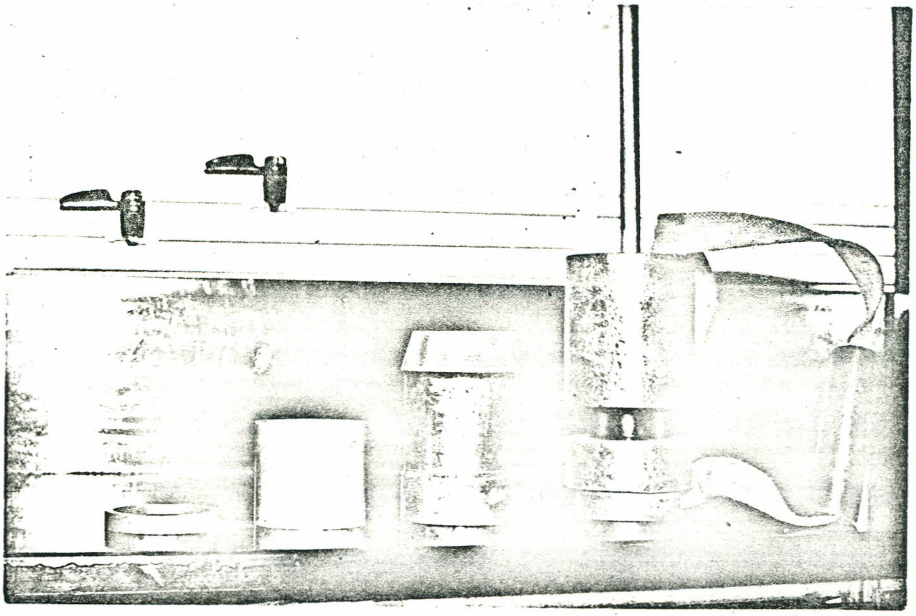

Figure 1: From left to right the display shows: the ring, core retainer cylinder, sampler and the hammer.

thickness as the original retainer cylinder. Each plastic ring was 1.5 cm high and 7.5 cm in diameter. The sampler containing the soil was carefully excavated. The core was removed from the sampler and the excess soil was shaved from the upper and lower core surfaces. The samples contained in the plastic cylinders were carefully examined to determine whether any visible disturbance had occurred during the sampling procedure. They were then transferred to the laboratory in boxes. The full core was sliced into five segments by the following procedure: in the laboratory, the cores were mounted horizontally and clamped between two pieces of wood in a vise or clamp with the base supported (see Figure 2). The core was cut into segments by forcing a very fine wire slowly perpendicularly between the plastic rings (Figure 3). A visual check again was made and those core samples that showed signs of disturbance were discarded.

Since the sliced core segments in their plastic rings were placed directly on the porous plates of the pressure apparatus, low sample height was essential for reasonably short equilibration times, especially at low matric potentials where hydraulic conductivity is extremely low. On the other hand, since slicing alters the natural pore configuration for some distance from core surfaces into the interior of the sample, even with

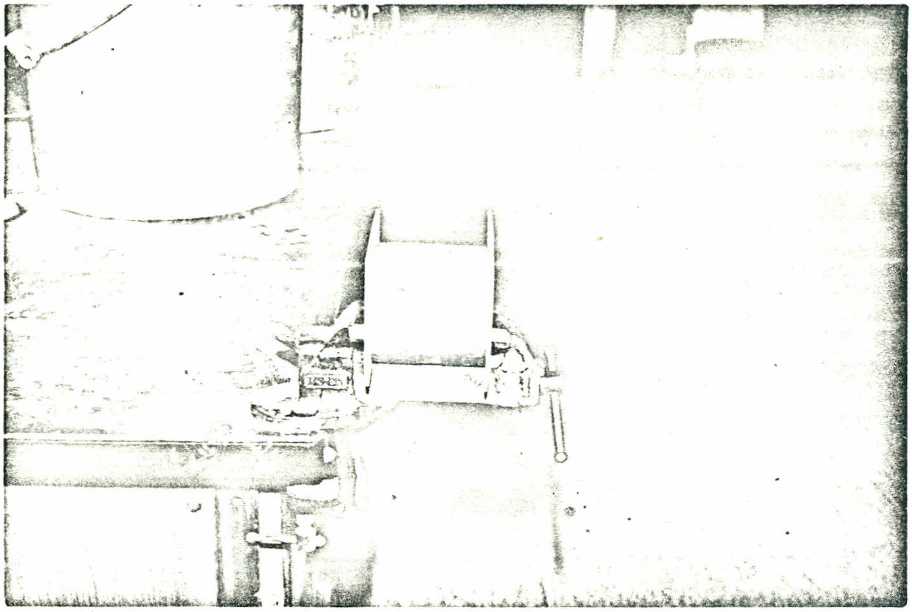

Figure 2: Core clamped in vise for slicing

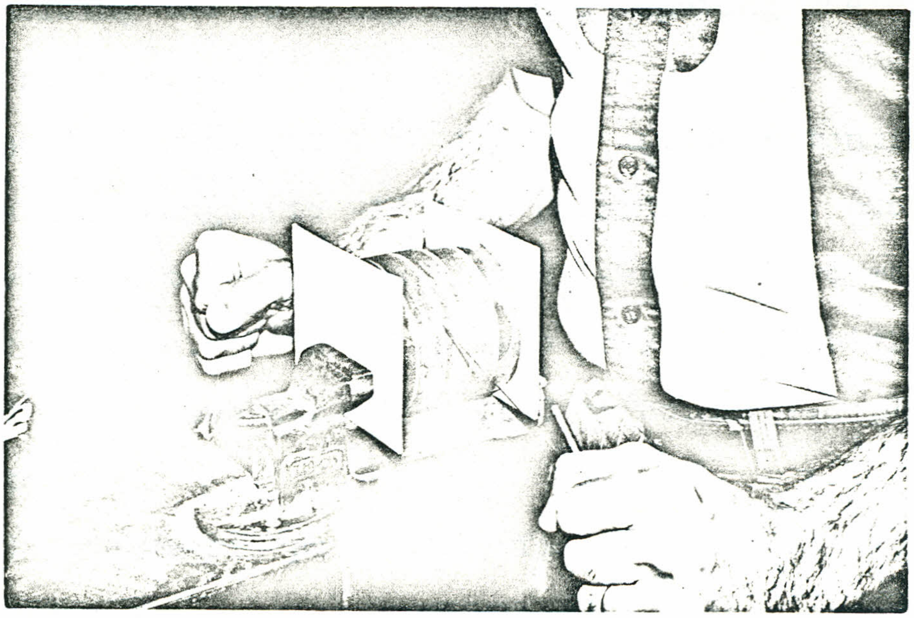

Figure 3: Slicing the core with a fine wire

great care in slicing, reliable results require a minimum thickness of the sample. As a preliminary compromise, 1.5 cm height was selected. One of the objectives of this study was to observe equilibration times at that sample height as a measure of its suitability.

Disturbed samples were obtained with a shovel from the same depth as the cores within the 9m^2 sampling sites. A large bulk sample was taken, air dried, and ground with mortar and pestle to pass a 2 mm round-hole screen. Grinding was moderate to retain some particles just less than 2 mm diameter. The bulk sample was thoroughly mixed and subsampled as needed. Disturbed soil samples were placed on the porous plates by pouring an excess into plastic rings of the same dimensions as those holding the core segments and removing the excess with a spatula.

One low-range (-0.1 to 1.0 atm matric potential) and one high range (to -15 atm) pressure cell, each equipped with three porous plates, were used to measure water retention. Both cells were pressurized with bottled compressed air controlled by commercial pressure regulators.

At each matric potential, five replicate samples were used. All samples were placed on the plate at random positions within plates and among the three plates and were allowed to stand at least 24 hours with an excess of water on the plate surface to assure saturation. The air pressure was adjusted to a predetermined value and held until equilibrium was reached. In all cases, equilibrium at the imposed pressure was declared when no outflow from the plate outlets was measured over a 12-hour period. The samples were transferred quickly to moisture boxes, weighed and then placed in a drying oven at 105° C. where the samples remained at least 72 hours until they reached a constant weight. Moisture content on a percent, dry weight basis was then determined. Following the same prodedure, new samples were used for each water retention value.

To provide a measure of the difference in bulk density and total porosity between core and sieved samples these values were calculated from the mass of dry soil in the ring used in water retention studies and the volume of the ring, and an assumed particle density of 2.65. The volume of sieved samples is that of the dry soil as placed in the rings while that of the core samples is more realistic since it is the volume at field water content. To characterize the soils studied, particle size distribution was estimated by a modification of the hydrometer method. The procedure has been described in detail elsewhere (Day, 1956). Summation percentages versus particle diameter were plotted, based on seven hydrometer readings at 30 seconds, 1, 3, 10, 30, and 90 minutes and at 12 hours, respectively, at 20° C.

RESULTS AND DISCUSSION

The particle size distribution and textural classification of three soils are presented in Figure 4 and in Table 1. The two coarser soils had about the same two-micron clay content (28-29%) but differed markedly in content of silt and fine sand, especially fine sand, as well as coarse sand. The clay content of the finest soil was 54%, nearly double that of the coarser soils. Thus the three soils studied vary appreciably in particle size distribution.

Gravimetric water content as a function of soil water matric potential is shown for the three soils in Figures 5, 6, and 7. The sieved samples retained appreciably more water at high matric potentials (-0.1 to -1 atm) than the cores in all three soils. For example, comparison between undisturbed and disturbed samples at -0.33 atm shows that disturbed soils retained 5, 12, and 13% more water than undisturbed soils for clay, silty clay loam and clay loam, respectively. The two finer soils tended to retain somewhat less water in sieved samples than in core samples at the lowest matric potentials, although the differences generally were small.

The total porosity of soil is the fraction of the soil space not occupied by soil particles. There are two components of the total porosity in moist soils;

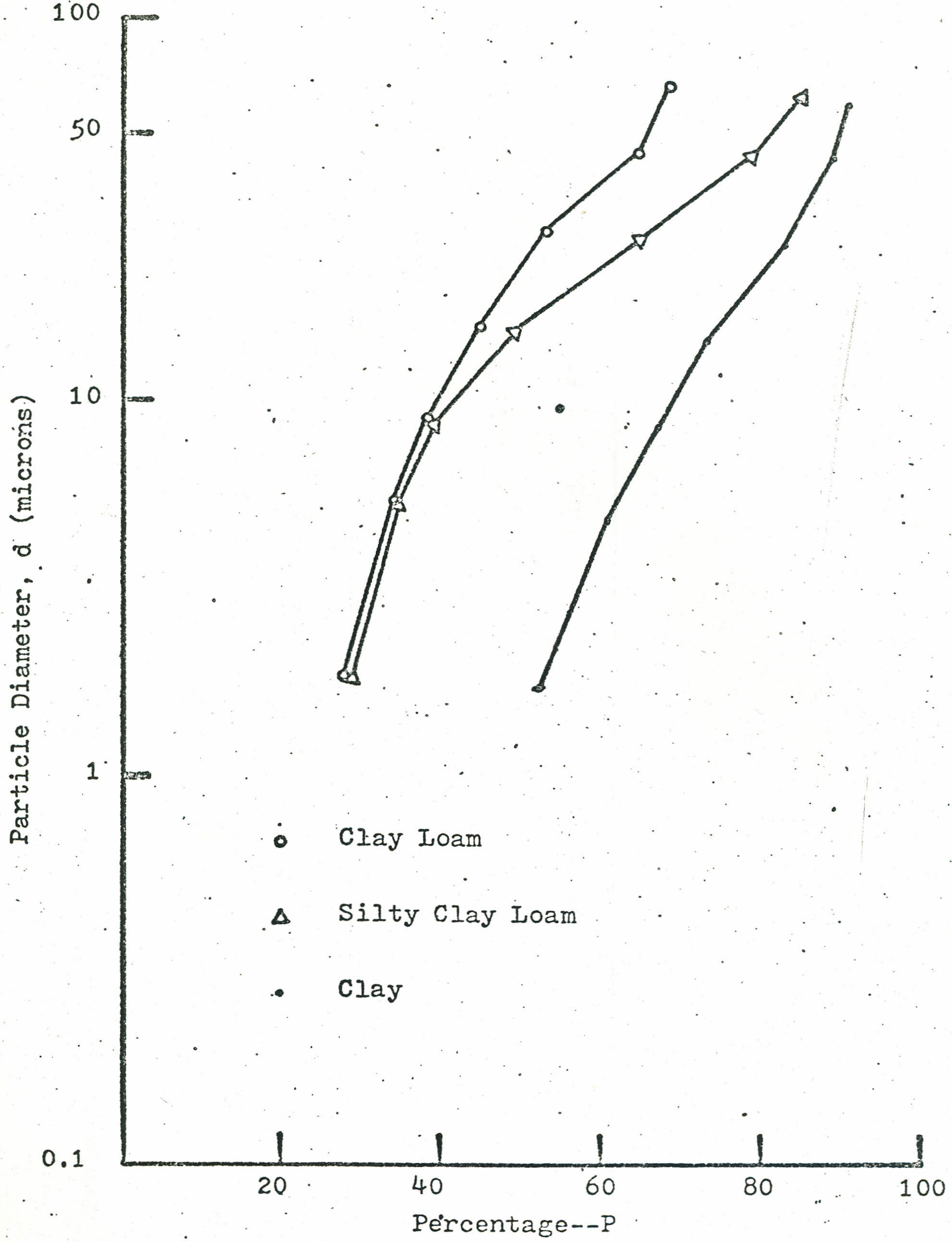

Figure 4: Size Distribution of Particles in Three Soils

Table 1: Soil clay, silt and sand content, undisturbed bulk density, total porosity, and texture

Clay	Silt	Sand	Bulk Density	Total Porosity		Texture
%	%	%	gm/cm3	Undist.	Dist.	
54.0	36.0	10.0	1.63	0.38	0.54	Clay
29.0	52.0	19.0	1.47	0.44	0.57	Silty Clay Loam
28.0	38.0	34.0	1.38	0.48	0.60	Clay Loam

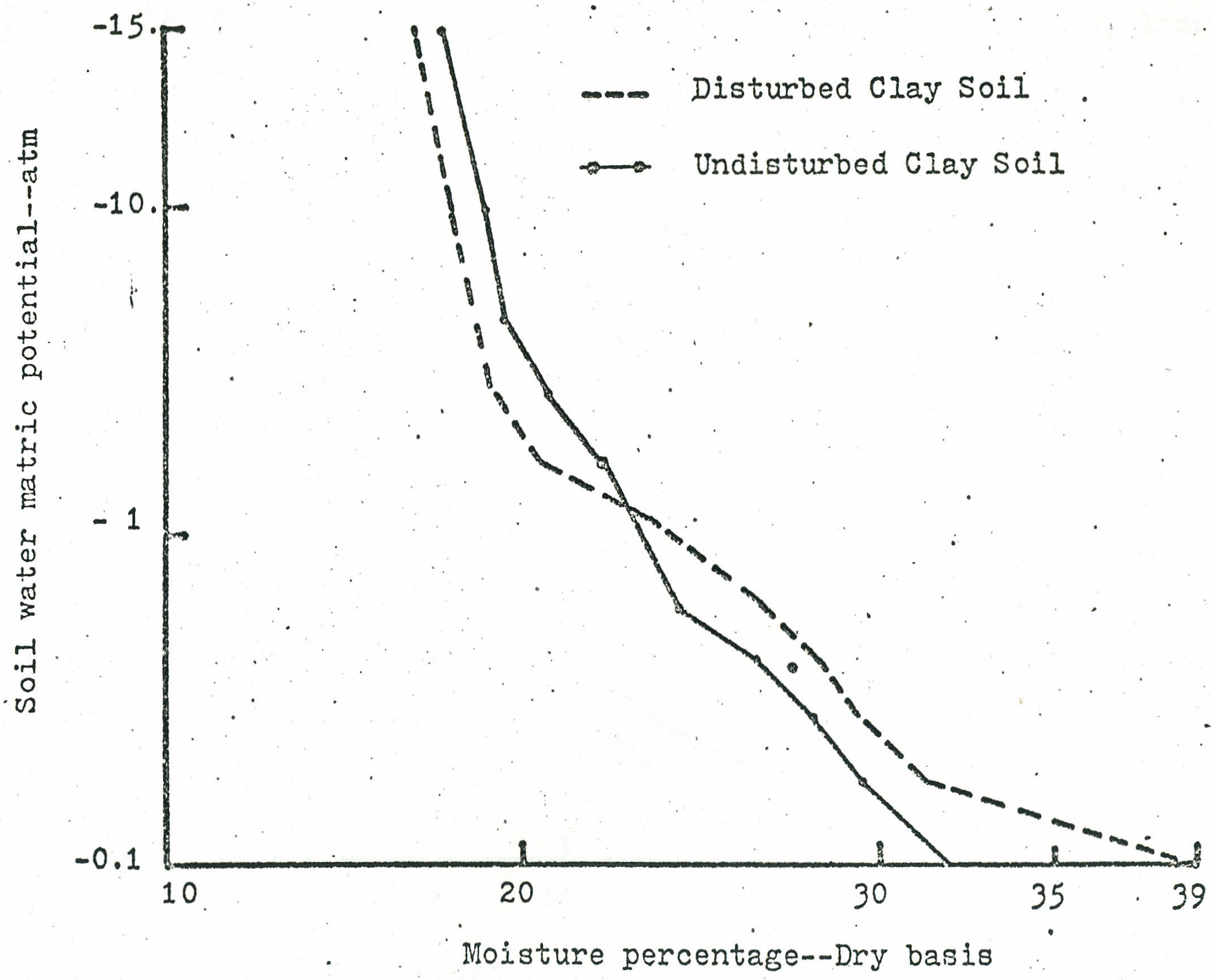

Figure 5: Moisture retention curve for clay soil with disturbed and undisturbed structures

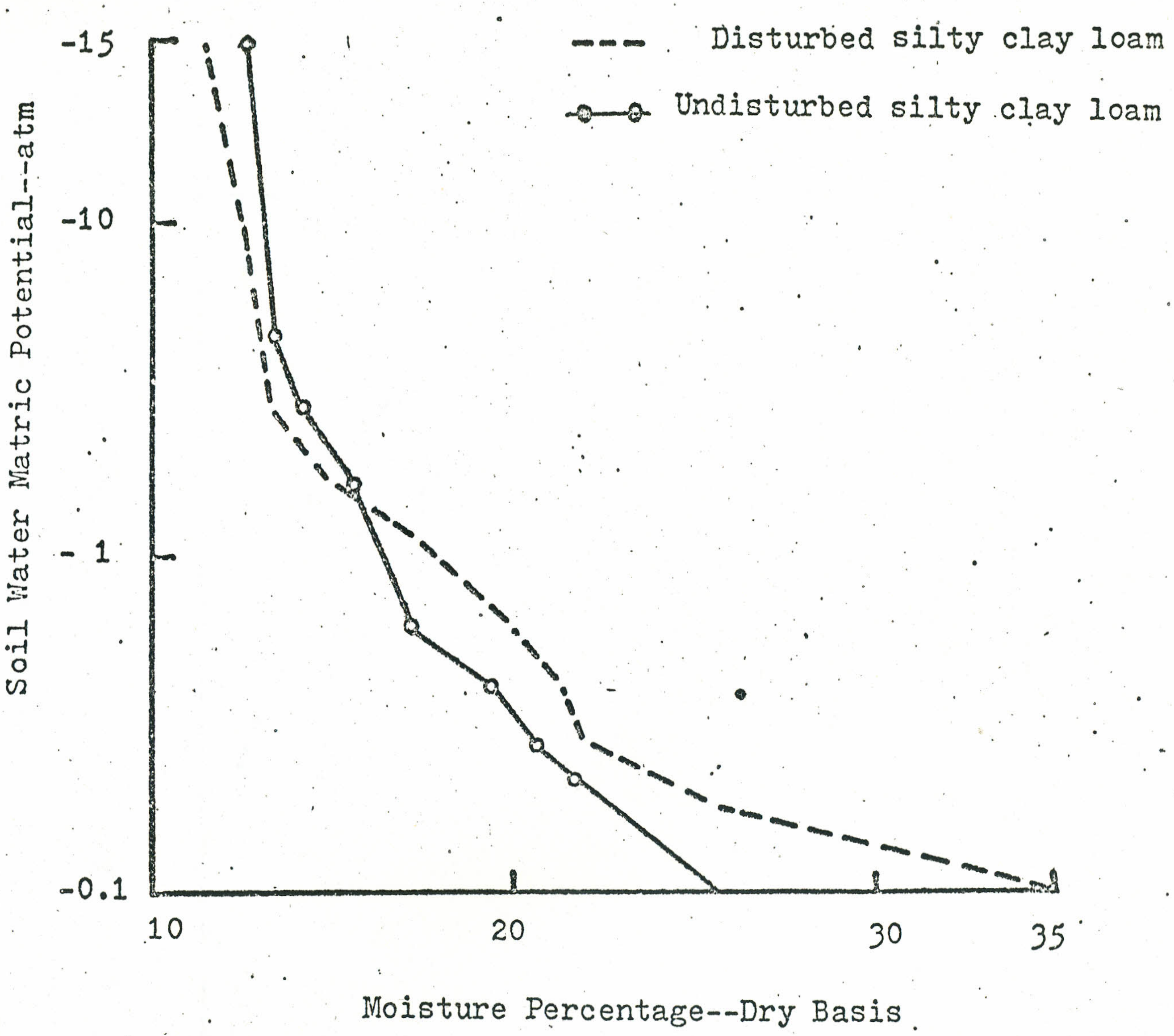

Figure 6: Moisture retention curve for silty clay loam soil with disturbed and undisturbed structures.

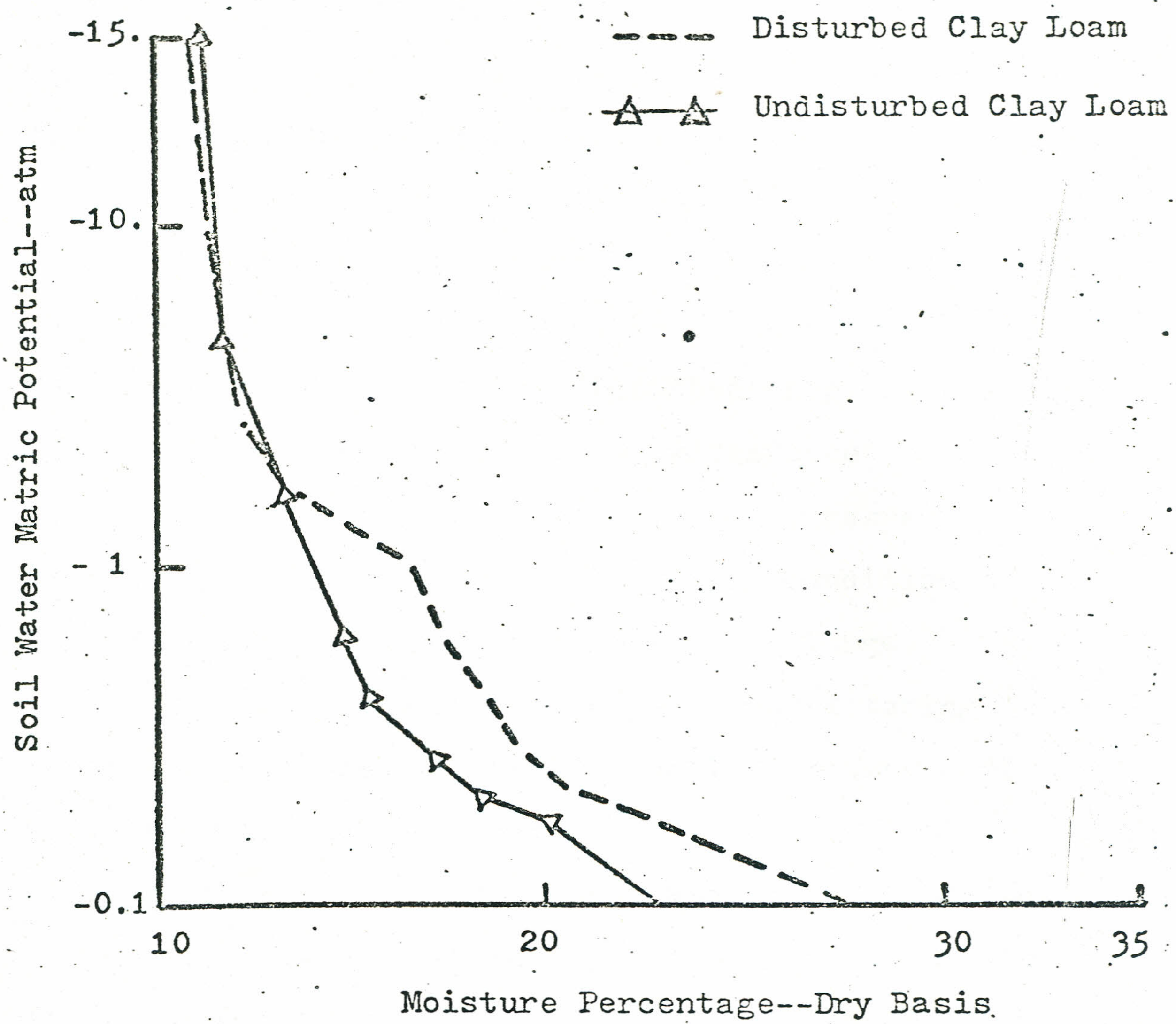

Figure 7: Moisture retention curve for clay loam soil with disturbed and undisturbed structures.

$E = \epsilon + \theta$, where E is the total porosity (cm^3/cm^3), ϵ is the air porosity (cm^3/cm^3), and θ is the water content (cm^3/cm^3). The total porosity was estimated by using the equation $E = 1 - \frac{\rho_b}{\rho_p}$ where ρ_b is the bulk density (gm of dry soil/cm^3 of bulk soil. The particle density (gm of dry soil/cm^3 of particles) was assumed to be 2.65. Using these criteria, total porosity was determined for the three different soils with undisturbed and disturbed structures as they were placed on the porous plates in the pressure cells (Table 1). The total porosities of the disturbed samples were 42, 30 and 25% greater than those of undisturbed samples for clay, silty clay loam and clay loam, respectively, indicating that the change in physical condition of the samples caused by grinding was very large.

Drying and sieving of the sample by altering bulk density, total porosity and the soil structure modified the moisture characteristics on all the soils studied, especially in the range above -1 atm matric potential, i.e., the range where macro-structure had the greatest influence on water retention properties. Pore size distribution plays a very important part in water retention and on the soil moisture characteristic curve. The pores vary in both size and shape. However, assuming a spherical interface provides one way to analyze the system, two ranges of water retention should be considered. One is that in which macro structure has the greater influence, where water is largely held in the pores. The other is at low matric potential where water is held only in the smallest pores or is adsorbed on the soil particle surfaces. In order to evaluate these two ranges, the Kelvin equation (Kirkham and Powers, 1971) was used to calculate the magnitude of apparent radius of the largest port that will remain filled with water at a given tension (which is referred to here as matric potential):

$T = h_t g \rho_w = 2\sigma / r$ where T is the tension with respect to atmospheric (dynes/cm^2). σ is the surface tension coeffecient (72.75 dynes/cm) at 20° C., h_t is water height (cm), g is the acceleration of gravity (981 dynes/gm), ρ_w is the water density (1.00 gm/cm^3) and r is the diameter of pores (cm). This relationship assumes zero contact angle. As the matric potential decreases, the moisture content progressively decreases as a result of the successive emptying of pores of smaller and smaller radius. At -0.1 atm the calculated pore radius is about 20 microns, while at -15 atm the calculated radius decreases to a fraction of a micron (about 0.2).

However, in the dry range at low matric potential the water retention can not be explained only by capillary forces. Adsorbtive forces acting between the soil particle surface and water molecules are responsible for holding the water. The forces that act in the wet and dry ranges do not change suddenly from capillary to adsorptive, and at intermediate moisture both are operative. At high matric potentials, pore size effects dominate with decreasing influence as matric potential decreases. At low water potentials, perhaps in the vicinity of -15 atm, adsorption is the only effective water retention mechanism, and soil grinding which does not break up primary particles and create new surface area should have little impact.

The data in Figures 5, 6, and 7 generally correspond to predictions from the above analysis, since sieved samples retained appreciably more water in the wetter range because of creation of additional pore space made up of larger pores. Retention in sieved samples tended to be a little less than in core samples at lower matric potentials. If the difference is real, there is no current explanation.

The results agree generally with data of Richards and Fireman (1943) for a loam soil and those of Elrich and Tanner (1965) for soils ranging in texture from loamy sand to silty clay loam. Generally, core samples should be used for water retention measurements at matric potentials above -1 atm.

The moisture release curve is used in interpreting or asessing the availability of water to plants (see discussion by Satter and Williams, 1965). Hagan lists the curve as one of several factors to consider in judging required frequency of irrigation. He used the fraction of total available water held at low soil water tension as a qualitative criterion. Richards and Marsh (1961) presented curves of percent available water depletion as a function of matric potential and emphasized that the curves differed for differrent soils. Such curves have been reproduced and used by Taylor (1965) and by Haise and Hagan (1967) in interpreting plant responses to irrigation despite the fact that they probably were from disturbed samples, making shapes of the curves rather questionable. The shape distortion is increased by plotting available water depletion vs. the logarithm of matric potential, expanding the low matric potential portion of the curves where pore size influence is greatest.

In expressing soil water as percent available water, upper and lower limits must be adopted. While the -15 atm value is generally accepted as the lower limit, the -1/3 atm value of disturbed samples is used to estimate field capacity. In the field, matric potentials following irrigation and some period of drainage usually are in the range between -0.1 and

-0.2 atm. For this reason curves for the three soils studied analogous to those of Richards and Marsh are presented in Figures 8, 9, and 10 to allow different comparisons. Figure 8 shows water retention data for sieved samples with -1/3 atm as the upper limit; Figure 9 gives corresponding data for core samples. Figure 10 shows available water retention of core samples using -0.1 atm as the upper limit of available water. Probably the most valid comparison is between the curves in Figure 8 and in Figure 10, and they differ markedly.

To quantify Hagan's (1955) criterion of fraction of available water at low tensions, percent of available water depletion at -0.75 atm or -1.0 atm was selected (% available water depletion = 100 - available water remaining). The -0.75 atm level is the limit of functioning of most tensiometers, and -1.0 atm values allow comparisons with some published data.

Judging from the curves in Figure 8 (sieved samples) available water depletion at -0.75 atm was 39, 37, and 29% for the clay loam, silty clay loam, and the clay, respectively. Corresponding values for cores from Figure 10 are 66, 60 and 47%, indicating that much more water is held in these soils at higher matric potentials than would be interpreted from water retention by sieved samples; in fact, 34, 58 and 79% more, respectively.

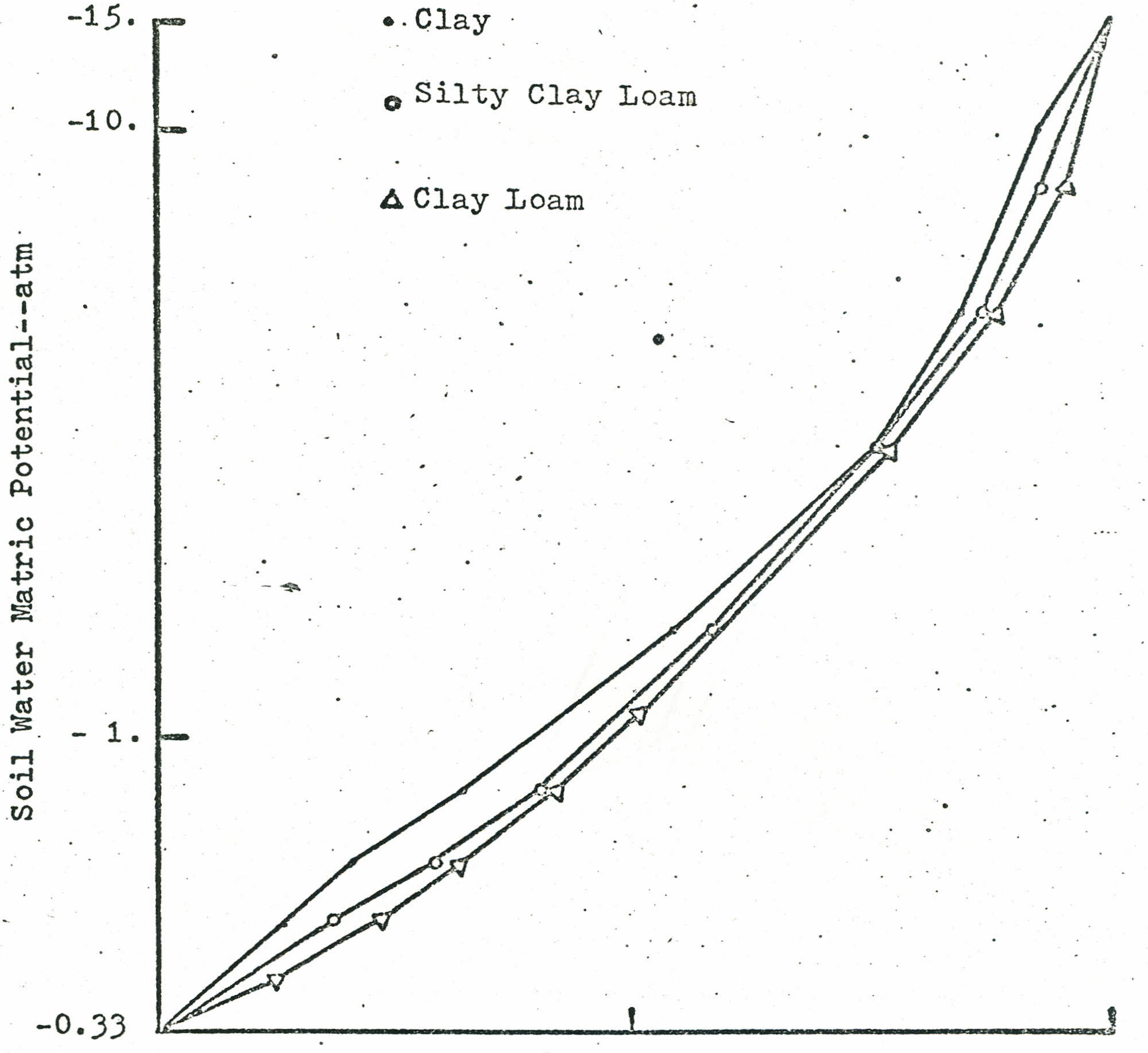

Figure 8: Moisture retention in disturbed soils of different textures.

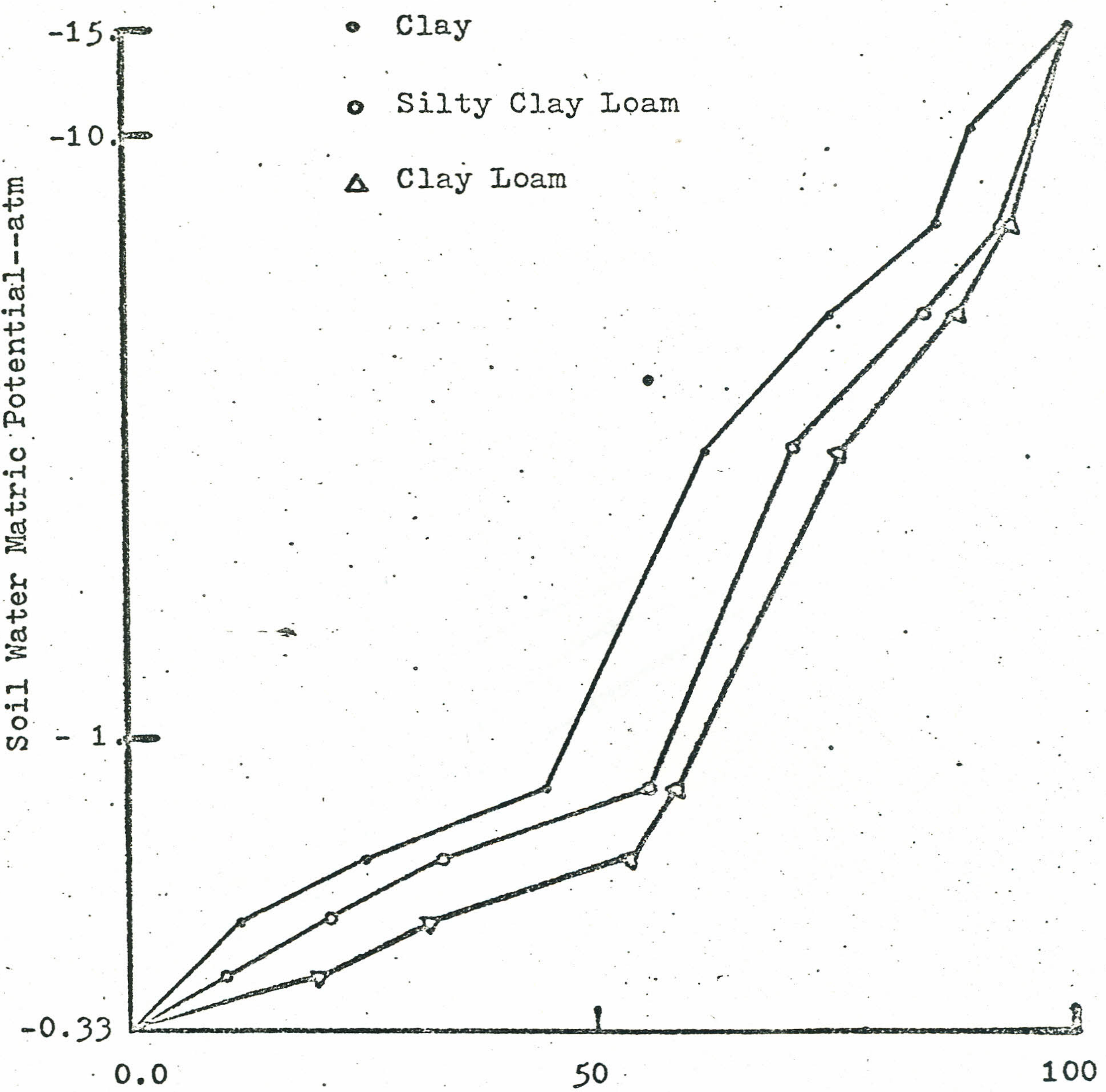

Figure 9: Moisture retention in undisturbed soils of different textures.

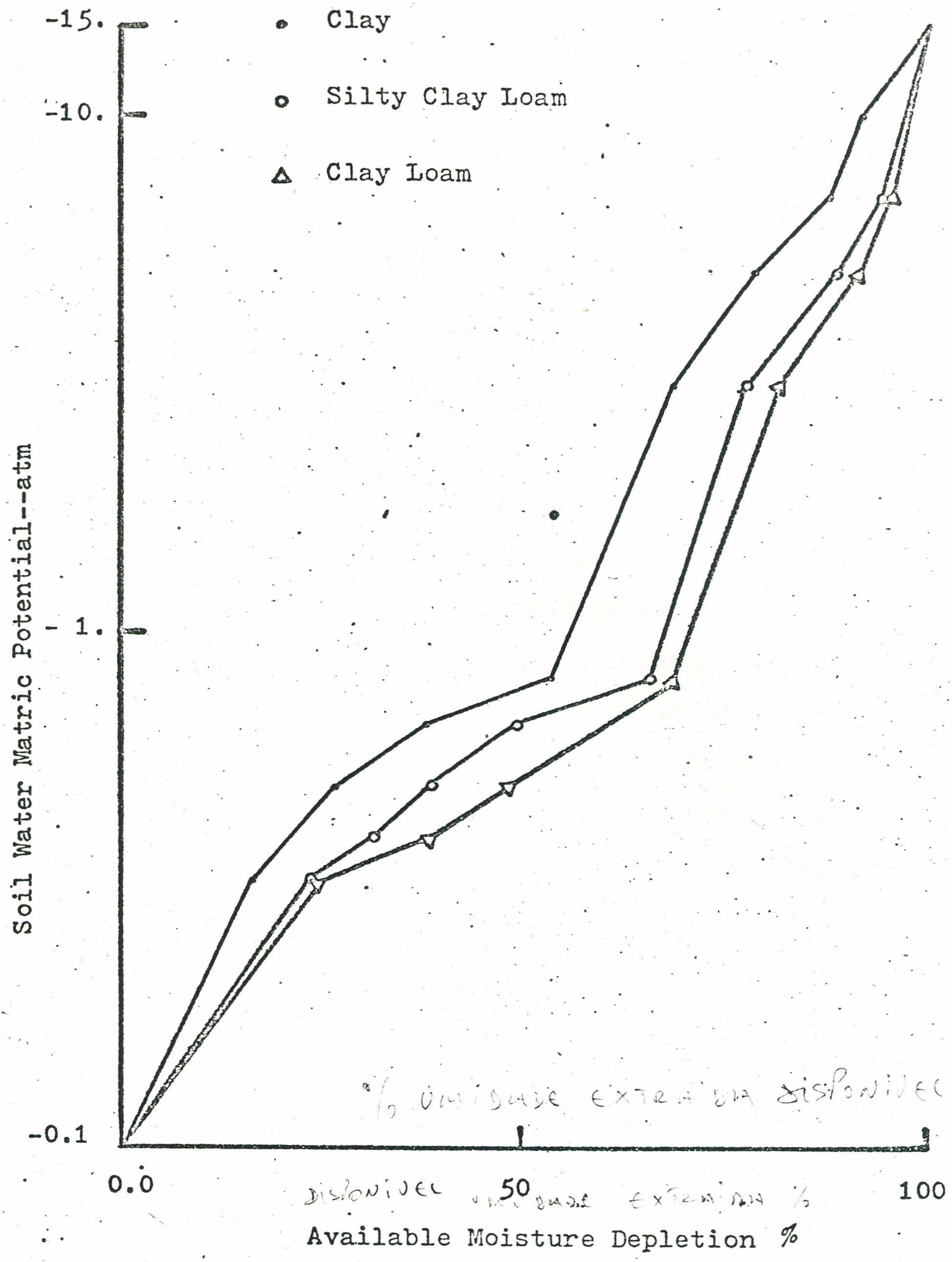

Figure 10: Moisture retention in undisturbed soils of different textures.

The shapes of the water retention curves tend to conform to those plotted form the data of Elrick and Tanner (1955), and all curves, including that for Capay clay, conform more closely to those of Richards and Marsh for coarser soils, not to their "clay" curve.

One advantage of sieved samples is the ease of obtaining replicate measurements with a minimum of variability because the replicates are taken as subsamples from a well-mixed, homogeneous sample. Such subsampling is obviously impossible with cores, and variability is greater. The following statistical comparison of coefficient of variation given in Table 2 provides some idea of whether sample variability is a serious limitation in using cores. Comparing the coefficient of variation of undisturbed and disturbed soils at -0.33 atm shows that there was 1.1, 3.0, and 1.9 times more variability in undisturbed replicates for the clay, silty clay loam, and clay loam soils, respectively, and 1.9, 6.2, and 1.7 times greater variability at -15 atm. However, most values of coefficient of variation ranged between 1 and 2% with five replicates. Values of standard deviation are given in Appendix. Variability in core samples was therefore not an important limitation to studying soil water retention in soils with field structure for the soils studied.

Table 2: Coefficient of Variation From 0.10 to 15.0 atm for Three Soils with Undisturbed and Disturbed Structures. Each value is for five subsamples.

	Soils	Atmospheres											
		0.10	0.33	0.40	0.50	0.66	0.82	1.50	3.0	5.0	7.0	10.0	15.0
Undist.	Clay	0.93	0.93	----	0.79	2.24	2.22	----	1.75	1.76	0.98	1.48	2.26
	Silty Clay Loam	1.03	2.42	3.41	0.69	1.81	2.13	----	2.60	3.99	0.76	----	2.06
	Clay Loam	2.27	2.78	2.27	0.91	1.30	1.62	----	2.15	1.42	0.83	----	1.94
Dist.	Clay	0.81	0.85	----	2.75	1.14	1.06	1.55	1.89	2.06	----	4.86	1.18
	Silty Clay Loam	0.69	0.80	----	4.17	1.31	0.49	1.27	1.91	0.88	----	1.53	0.33
	Clay Loam	1.08	1.44	1.70	0.79	1.40	1.62	----	2.20	1.95	----	1.61	1.13

Correlations between undisturbed and disturbed soil water content on a weight basis at -0.33 atm and -15.0 atm (equations 1 and 2, Table 3, Figures 11 and 12) were significant at the 0.1% probability level. The regression line slope for the relationship at -0.33 atm (Figure 11) was markedly different from the slope at -15.0 atm. At -0.33 atm, the slope was 1.109, showing a deviation from the 1:1 line. Based on Figure 11, for all three soils the sieved sample contained more water than undisturbed soils. According to Figure 12, there was no real difference between core and sieved soil water contents at -15 atm.

The small deviation of slope at -15 atm compared to that at -0.33 atm confirms that the major effect of sample disturbance on water retention is in the range where pore sizes effective in retaining water are most likely to be changed. These results agree with those of Richards and Fireman (1943), who found little effect of sample disturbance for a loam soil below -1 atm.

With respect to core sample variability, every precaution was taken to minimize differences. All samples were taken from within small areas (3m X 3m), and very close together, just far enough apart to avoid disturbance during the sampling operation. It should be emphasized that this work did not deal with soil

Table 3: Undisturbed-Disturbed Soil Water Content Relationship

Equation Number	Y Variable % Undist. Soil Water, atm	X Variable % Dist. Soil Water, atm	Regression Equation	Correlation Value r	Coefficient Level of Signif. %
1	0.33	0.33	$Y=1.109x-5.16$	0.987	0.1
2	15.0	15.0	$Y=1.001x+0.84$	0.972	0.1

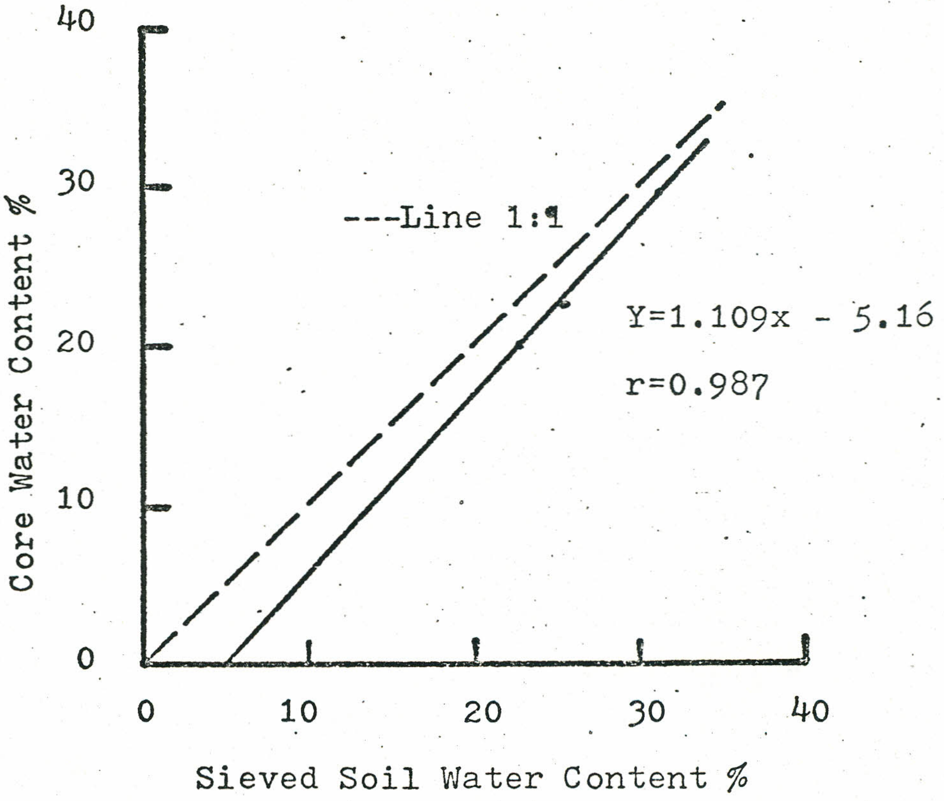

Figure 11: Undisturbed versus disturbed soil water content (weight basis at -0.33 atm matric potential)

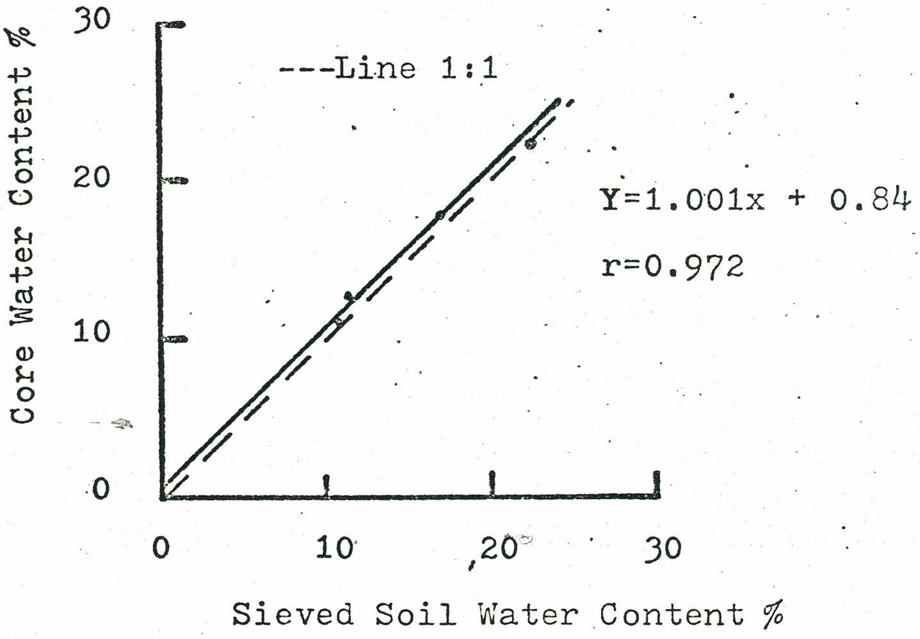

Figure 12: Undisturbed versus disturbed soil water content (weight basis at -15 atm matric potential).

spatial variability, which is an important consideration in some applications of soil water retention curves.

The core sampling procedure as described previously is easy at least at the shallow dpeths sampled. Obtaining samples is not seriously time consuming. A minimum of 10 to 15% of all samples taken were discarded during the whole procedure from field to the laboratory. Sampling difficulty is not a justification for using disturbed samples if one wants to rely on real measurements for having an accurate prediction of soil water matric potential from water content in field soils, as well as in estimating water availability to plants.

Using 1.5 cm sample height, equilibration time was not excessive at high soil water matric potential. In the range from -0.1 atm matric potential, equilibration time varied from 3 to 5 days. At -10.0 to -15.0 atm matric potential equilibration time was 13 to 16 days, which is 2 to 3 times that usually experienced with 1 cm height.

Since neither sampling difficulty, sample variability, nor equilibration time are major limitations in using core samples, all water retnetion curves should be obtained with cores, at least for matric potentials above -1 atm. Curves for disturbed samples differed markedly from those obtained on undisturbed samples and could lead to serious misinterpretation.

This does not mean that the practice of using water retention by disturbed samples at -0.33 atm for estimating water content at field capacity should be discarded. Its use was established by correlation with the moisture equivalent which had previously been found to correlate well with field capacity for medium- and fine-textured soils. However, this has led to the widely held misinterpretation that field capacity is associated with -0.33 atm matric potential in the field, where it generally is appreciably greater.

LITERATURE CITED

Bruce, R.R. 1972. Hydraulic conductivity evaluation of the soil profile from soil water retention relations. Soil Sci. Soc. Amer. Proc. 36: 555-561.

Childs, E.C. 1940. The use of soil moisture characteristics in the soil studies. Soil Sci. 50:239-252.

Day, Paul R. 1956. Report of the Committee on Physical Analyses, Soil Science Society Proc. 20:167-169.

Elrick, D.E. and Tanner, C.B. 1955. Influence of sample pretreatment on soil moisture retention. Soil Sci. Soc. Amer. Proc. 19:279-282.

Hagan, R.M. 1955. Factors affecting soil moisture--plant growth relations. Report of fourteenth International Horticulture Congress, Netherlands, Symposium 2, 1955, pp. 82-102.

Haise, H.R. and Hagan, R.M. 1967. Soil, plant, and evaporative measurements as criteria for scheduling irrigation In irrigation of agricultural lands. The American Soc. of Agronomy, Inc. Wisconsin, U.S.A. pp. 577-604.

Jamison, J.C. and Kroth, E.M. 1958. Available moisture storage capacity in relation to textural composition and organic matter content of several Missouri soils. Soil Sci. Amer. Proc. 22:189-192.

Kirkham, D. and Powers, W.L. 1972. Advanced Soil Physics. John Wiley and Sons, Inc. New York. pp. 21-24.

Kroth, E.M. and Jamison, J.C. 1960. Available water storage capacity estimates of a terraced claypan soil. Soil Sci. Soc. Amer. Proc. 24:146-147.

Perrier, E.E. and Evans, D.D. 1961. Soil moisture evaluation by tensiometers. Soil Sci. Soc. Amer. Proc. 25:173-175.

Richards, L.A., Editor, 1954. Diagnosis and Improvement of Saline and Alkali Soils, United States Dept. of Agriculture Handbook #60.

Richards, L.A. and Fireman, M. 1943. Pressure plate apparatus for measuring moisture sorption and transmission by soils. Soil Sci. 56:395-404.

Richards, S.J. and Marsh, A.W. 1961. Irrigation based on soil suction measurements. Soil Sci. Soc. Amer. Proc. 25:65-69.

Salter, P.S. and Williams, J.B. 1965. The influence of texture on the moisture characteristics of soils. I. A critical comparison of techniques for determining the available water capacity and moisture characteristic curve of a soil. J. Soil Sci. 16:1-15.

Shaykewich, D.F. 1970. Hydraulic properties of disturbed and undisturbed soils. Can. J. Soil Sci. 50:431-437.

Taylor, S.A. 1965. Managing irrigation water on the farm. Transaction of the ASAE. 8:433-436.

Unger, P.W. 1975. Water retention by core and sieved soil samples. Soil Sci. Soc. Amer. Proc. 39:1197-1200.

Young, K.K. and Dixon, J.D. 1965. Overestimation of water content at field capacity from sieved sample data. Soil Sci. 101:104-107.

APPENDIX

```
      WRITE(6,10)
   10 FORMAT(T16,"EFFECT OF SAMPLE DISTURBANCE ON",//
     1T16,"WATER RETENSION IN THREE SOILS"///,
     1T6,"RESEARCH DATA ANALYSIS"/)
      WRITE(6,11)
   11 FORMAT(T6,"LEGEND INFORMATION:",/
     1T20," A = CAN WEIGHT (GRAMS)"/
     1T20," B = WEIGHT OF WET SOIL + CAN (GRAMS)"/
     1T20," C = WEIGHT OF DRY SOIL + CAN (GRAMS)"/
     1T20," D = WEIGHT OF DRY SOIL (GRAMS)"/
     1T20," E = WEIGHT OF WATER (GRAMS)"/
     1T20," F = WATER CONTENT ON WEIGHT BASIS (%)"/)
    5 READ(5,100)N
  100 FORMAT(I1)
      IF(N.EQ.0)GO TO 99
      IF(N.EQ.1)GO TO 30
      IF(N.EQ.2)GO TO 40
      IF(N.EQ.3)GO TO 50
      IF(N.EQ.4)GO TO 60
      IF(N.EQ.5)GO TO 70
      IF(N.EQ.6)GO TO 80
      GO TO 99
   30 WRITE(6,200)
  200 FORMAT(" SOIL TYPE: CLAY,UNDISTURBED SAMPLE"/)
      GO TO 20
   40 WRITE(6,300)
  300 FORMAT(" SOIL TYPE: SILT CLAY LOAM,UNDIST. SAMPLE"/)
      GO TO 20
   50 WRITE(6,400)
  400 FORMAT(" SOIL TYPE: CLAY LOAM, UNDISTURBED SAMPLE"/)
      GO TO 20
   60 WRITE(6,500)
  500 FORMAT(" SOIL TYPE: CLAY, DISTURBED SAMPLE"/)
      GO TO 20
   70 WRITE(6,600)
  600 FORMAT(" SOIL TYPE: SILT CLAY LOAM, DIST. SAMPLE"/)
      GO TO 20
   80 WRITE(6,700)
  700 FORMAT(" SOIL TYPE: CLAY LOAM, DISTURBED SAMPLE"/)
   20 CONTINUE
   25 READ(5,105)ATM
  105 FORMAT(F5.2)
       IF(ATM.EQ.0.)GO TO 5
      WRITE(6,205)ATM
  205 FORMAT(" EXTRACTION AT ",F5.2," ATM.",/)
      WRITE(6,210)
  210 FORMAT(1H ,T3,"A",T13,"B",T23,"C",T33,"D",
     1T43,"E",T53,"F",/)
      TOT=0
      SQTO=0
      DO 12 J=1,5
```

```
         READ(5,110)A,B,C
  110 FORMAT(F4.1,F5.1,F5.1)
         D=C-A
         E=B-C
      F=(E/D)*100.
         TOT=TOT+F
         SQTO=SQTO+F**2
         WRITE(6,215)A,B,C,D,E,F
  215 FORMAT(1X,F4.1,T11,F5.1,T21,F5.1,T31,F5.1,T41,F4.1
     1,T51,F5.2)
   12 CONTINUE
      AVE=(TOT/5.)
      WRITE(6,220)AVE
  220 FORMAT(/,T18,"AVERAGE WATER CONT. WT. BASIS = ",
     1F5.2,"%",//)
      STOT=(TOT**2)/5.
      RS12=SQTO-STOT
      SSQ=RS12/4.
      SDEV=SQRT(SSQ)
      CVAR=(SDEV/AVE)*100.
      WRITE(6,225)SDEV
  225 FORMAT(T23," THE STANDARD DEVIATION IS =",F5.2/)
      WRITE(6,230)CVAR
  230 FORMAT(T19,"THE COEFFICIENT OF VARIATION IS=",
     1F5.2,//)
      GO TO 25
   99 CONTINUE
       STOP
      END
```

```
                    EFFECT OF SAMPLE DISTURBANCE ON

                    WATER RETENSION IN THREE SOILS

      RESEARCH DATA ANALYSIS

      LEGEND INFORMATION:
                          A = CAN WEIGHT (GRAMS)
                          B = WEIGHT OF WET SOIL + CAN (GRAMS)
                          C = WEIGHT OF DRY SOIL + CAN (GRAMS)
                          D = WEIGHT OF DRY SOIL (GRAMS)
                          E = WEIGHT OF WATER (GRAMS)
                          F = WATER CONTENT ON WEIGHT BASIS (%)

   SOIL TYPE: CLAY,UNDISTURBED SAMPLE

   EXTRACTION AT  0.10 ATM.

     A          B          C          D          E          F

   48.7       159.3      132.4       83.7       26.9       32.14
   49.0       149.7      125.4       76.4       24.3       31.81
   49.2       154.6      129.1       79.9       25.5       31.91
   46.5       156.6      129.9       83.4       26.7       32.01
   47.6       152.6      126.8       79.2       25.8       32.58

                  AVERAGE WATER CONT. WT. BASIS = 32.09%

                       THE STANDARD DEVIATION IS : 0.30

                  THE COEFFICIENT OF VARIATION IS: 0.93

   EXTRACTION AT  0.33 ATM.

     A          B          C          D          E          F

   50.2       179.5      149.6       99.4       29.9       30.08
   49.1       182.5      152.2      103.1       30.3       29.39
   51.2       179.2      149.7       98.5       29.5       29.95
   48.5       175.5      146.5       98.0       29.0       29.59
   48.2       181.0      150.6      102.4       30.4       29.69

                  AVERAGE WATER CONT. WT. BASIS = 29.74%

                       THE STANDARD DEVIATION IS : 0.28

                  THE COEFFICIENT OF VARIATION IS: 0.93
```

```
EXTRACTION AT  0.50 ATM.

 A          B          C          D          E          F

45.2      177.4      148.4      103.2      29.0       28.10
46.1      166.1      139.6       93.5      26.5       28.34
48.2      162.1      137.1       88.9      25.0       28.12
46.2      168.0      140.9       94.7      27.1       28.62
47.2      164.5      138.5       91.3      26.0       28.48

                      AVERAGE WATER CONT. WT. BASIS = 28.33%

                           THE STANDARD DEVIATION IS : 0.22

                      THE COEFFICIENT OF VARIATION IS: 0.79


EXTRACTION AT  0.66 ATM.

 A          B          C          D          E          F

50.7      181.3      154.1      103.4      27.2       26.31
37.3      180.6      151.0      113.7      29.6       26.03
38.6      183.3      152.4      113.8      30.9       27.15
47.7      178.6      151.2      103.5      27.4       26.47
47.5      181.2      152.4      104.9      28.8       27.45

                      AVERAGE WATER CONT. WT. BASIS = 26.68%

                           THE STANDARD DEVIATION IS : 0.60

                      THE COEFFICIENT OF VARIATION IS: 2.24


EXTRACTION AT  0.82 ATM.

 A          B          C          D          E          F

37.2      178.7      151.6      114.4      27.1       23.69
38.5      164.3      139.3      100.8      25.0       24.80
49.7      175.6      150.5      100.8      25.1       24.90
46.4      175.1      150.1      103.7      25.0       24.11
47.1      169.7      145.3       98.2      24.4       24.85

                      AVERAGE WATER CONT. WT. BASIS = 24.47%

                           THE STANDARD DEVIATION IS : 0.54
```

```
                                   THE COEFFICIENT OF VARIATION IS: 2.22
------------------------------------------------------------------------

   EXTRACTION AT  3.00 ATM.
------------------------------------------------------------------------
     A          B          C          D          E          F

   47.7       186.6      161.1      113.4      25.5       22.49
   47.5       181.7      157.2      109.7      24.5       22.33
   46.4       173.2      150.2      103.8      23.0       22.16
   47.1       169.3      147.2      100.1      22.1       22.08
   46.2       168.9      145.9       99.7      23.0       23.07
------------------------------------------------------------------------
                            AVERAGE WATER CONT. WT. BASIS = 22.43%

------------------------------------------------------------------------
                                  THE STANDARD DEVIATION IS : 0.39

                            THE COEFFICIENT OF VARIATION IS: 1.75
------------------------------------------------------------------------

------------------------------------------------------------------------
   EXTRACTION AT  5.00 ATM.

     A          B          C          D          E          F
------------------------------------------------------------------------

   48.5       178.3      155.5      107.0      22.8       21.31
   48.2       156.4      137.6       89.4      18.8       21.03
   49.2       169.1      148.2       99.0      20.9       21.11
   51.2       178.4      156.4      105.2      22.0       20.91
   51.5       182.3      160.2      108.7      22.1       20.33
------------------------------------------------------------------------
                            AVERAGE WATER CONT. WT. BASIS = 20.94%

------------------------------------------------------------------------
                                  THE STANDARD DEVIATION IS : 0.37
------------------------------------------------------------------------
                            THE COEFFICIENT OF VARIATION IS: 1.76

------------------------------------------------------------------------
   EXTRACTION AT  7.00 ATM.

------------------------------------------------------------------------
     A          B          C          D          E          F

   48.5       182.0      160.0      111.5      22.0       19.73
   49.2       178.7      157.2      103.0      21.5       19.91
   51.2       174.1      154.1      102.9      20.0       19.44
   50.2       178.4      157.3      107.1      21.1       19.70
   48.2       183.1      161.1      112.9      22.0       19.49

                            AVERAGE WATER CONT. WT. BASIS = 19.65%
------------------------------------------------------------------------
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                              THE STANDARD DEVIATION IS : 0.19

                           THE COEFFICIENT OF VARIATION IS: 0.98

  EXTRACTION AT 10.00 ATH.

   A          B          C          D          E          F

  46.7      192.5      169.4      122.7      23.1      18.83
  50.7      172.0      152.3      101.6      19.7      19.39
  37.2      159.2      139.5      102.3      19.7      19.26
  38.5      165.1      145.1      106.6      20.0      18.76
  46.4      177.1      156.0      109.6      21.1      19.25

                       AVERAGE WATER CONT. WT. BASIS = 19.10%

                              THE STANDARD DEVIATION IS : 0.28

                           THE COEFFICIENT OF VARIATION IS: 1.48

  EXTRACTION AT 15.00 ATH.

   A          B          C          D          E          F

  48.8      167.9      149.8      101.0      18.1      17.92
  50.7      180.0      160.5      109.8      19.5      17.76
  38.5      170.5      150.4      111.9      20.1      17.96
  48.2      179.5      160.0      111.8      19.5      17.44
  50.5      173.2      154.0      103.5      19.2      18.55

                       AVERAGE WATER CONT. WT. BASIS = 17.93%

                              THE STANDARD DEVIATION IS : 0.40

                           THE COEFFICIENT OF VARIATION IS: 2.26
```

```
SOIL TYPE: SILT CLAY LOAM,UNDIST. SAMPLE

EXTRACTION AT  0.10 ATM.

  A          B          C          D          E          F

50.6      165.1      141.4       90.8       23.7       26.30
49.1      144.0      124.3       75.2       19.7       26.20
48.7      157.1      134.5       85.8       22.6       26.34
48.2      168.7      144.0       95.8       24.7       25.78
51.5      156.6      135.1       83.6       21.5       25.72

               AVERAGE WATER CONT. WT. BASIS = 26.03%

                    THE STANDARD DEVIATION IS : 0.27

               THE COEFFICIENT OF VARIATION IS: 1.03


EXTRACTION AT  0.33 ATM.

  A          B          C          D          E          F

49.1      169.8      147.9       98.8       21.9       22.17
50.2      158.7      138.7       88.5       20.0       22.60
48.8      166.9      145.0       96.2       21.9       22.77
51.0      163.5      142.0       91.0       21.5       23.63
49.8      177.0      153.1      103.3       23.9       23.14

               AVERAGE WATER CONT. WT. BASIS = 22.86%

                    THE STANDARD DEVIATION IS : 0.55

               THE COEFFICIENT OF VARIATION IS: 2.42


EXTRACTION AT  0.40 ATM.

  A          B          C          D          E          F

48.7      130.7      116.0       67.3       14.7       21.84
50.4      166.0      145.4       95.0       20.6       21.68
39.2      163.7      142.3      103.1       21.4       20.76
49.1      162.0      141.7       92.6       20.3       21.92
48.2      166.5      144.5       96.3       22.0       22.85

               AVERAGE WATER CONT. WT. BASIS = 21.81%
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                              THE STANDARD DEVIATION IS : 0.74

                         THE COEFFICIENT OF VARIATION IS: 3.41


  EXTRACTION AT  0.50 ATH.

   A          B          C          D          E          F

  47.7      158.5      139.5       91.8      19.0      20.70
  48.6      157.0      138.4       89.8      18.6      20.71
  49.1      160.7      141.7       92.6      19.0      20.52
  48.2      155.7      137.5       89.3      18.2      20.38
  48.5      165.3      145.3       96.8      20.0      20.66

                        AVERAGE WATER CONT. WT. BASIS = 20.59%

                              THE STANDARD DEVIATION IS : 0.14

                         THE COEFFICIENT OF VARIATION IS: 0.69


  EXTRACTION AT  0.66 ATH.

   A          B          C          D          E          F

  45.5      164.6      145.5      100.0      19.1      19.10
  45.7      153.4      135.6       89.9      17.8      19.80
  47.6      173.1      152.3      104.7      20.8      19.87
  48.6      160.4      142.4       93.8      18.0      19.19
  45.1      162.3      143.3       98.2      19.0      19.35

                        AVERAGE WATER CONT. WT. BASIS = 19.46%

                              THE STANDARD DEVIATION IS : 0.35

                         THE COEFFICIENT OF VARIATION IS: 1.81


  EXTRACTION AT  0.82 ATH.

   A          B          C          D          E          F

  48.6      161.3      144.5       95.9      16.8      17.52
  49.1      160.5      144.1       95.0      16.4      17.26
  49.1      160.5      144.5       95.4      16.0      16.77
  48.5      178.0      159.0      110.5      19.0      17.19
  49.0      157.8      141.4       92.4      16.4      17.75
```

```
                                   AVERAGE WATER CONT. WT. BASIS = 17.30%

                                           THE STANDARD DEVIATION IS : 0.37

                                     THE COEFFICIENT OF VARIATION IS: 2.13


    EXTRACTION AT  3.00 ATH.

      A             B             C             D             E             F
 ---------------------------------------------------------------------------------
    49.0          148.1         135.1          86.1          13.0          15.10
    48.5          152.5         138.1          89.6          14.4          16.07
    48.5          153.0         138.5          90.0          14.5          16.11
    49.0          151.1         137.3          88.3          13.8          15.63
    50.6          149.7         136.2          85.6          13.5          15.77
 ---------------------------------------------------------------------------------
                                   AVERAGE WATER CONT. WT. BASIS = 15.74%

                                           THE STANDARD DEVIATION IS : 0.41

                                     THE COEFFICIENT OF VARIATION IS: 2.60


    EXTRACTION AT  5.00 ATH.

      A             B             C             D             E             F

    48.2          154.6         140.6          92.4          14.0          15.15
    50.5          162.2         148.1          97.6          14.1          14.45
    49.1          156.6         143.2          94.1          13.4          14.24
    48.5          156.6         143.3          94.8          13.3          14.03
    51.5          171.7         157.3         105.8          14.4          13.61

                                   AVERAGE WATER CONT. WT. BASIS = 14.30%

                                           THE STANDARD DEVIATION IS : 0.57

                                     THE COEFFICIENT OF VARIATION IS: 3.99
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```
EXTRACTION AT  7.00 ATM.

  A            B            C            D            E            F

49.1         145.0        133.5         84.4         11.5        13.63
50.2         159.7        146.6         96.4         13.1        13.59
47.7         151.2        139.0         91.3         12.2        13.36
50.5         144.2        133.0         82.5         11.2        13.58
48.5         152.5        140.1         91.6         12.4        13.54

                         AVERAGE WATER CONT. WT. BASIS = 13.54%

                                 THE STANDARD DEVIATION IS : 0.10

                              THE COEFFICIENT OF VARIATION IS: 0.76


EXTRACTION AT 15.00 ATM.

  A            B            C            D            E            F

51.0         151.4        140.1         89.1         11.3        12.68
50.0         159.5        147.2         97.2         12.3        12.65
37.4         151.0        138.5        101.1         12.5        12.36
39.2         140.5        129.1         89.9         11.4        12.68
49.1         160.5        147.6         98.5         12.9        13.10

                         AVERAGE WATER CONT. WT. BASIS = 12.70%

                                 THE STANDARD DEVIATION IS : 0.26

                              THE COEFFICIENT OF VARIATION IS: 2.06


SOIL TYPE: CLAY LOAM. UNDISTURBED SAMPLE

EXTRACTION AT  0.10 ATM.

  A            B            C            D            E            F

49.0         165.5        144.2         95.2         21.3        22.37
48.6         154.5        135.0         86.4         19.5        22.57
48.5         144.0        126.2         77.7         17.8        22.91
49.1         184.0        159.1        110.0         24.9        22.64
50.3         164.6        142.7         92.4         21.9        23.70

                         AVERAGE WATER CONT. WT. BASIS = 22.84%
```

```
                                        THE STANDARD DEVIATION IS : 0.52

                                   THE COEFFICIENT OF VARIATION IS: 2.27


   EXTRACTION AT  0.33 ATM.

    A              B              C              D              E              F

   49.1          164.0          144.5           95.4          19.5          20.44
   50.2          170.2          149.4           99.2          20.8          20.97
   48.5          167.0          147.7           99.2          19.3          19.46
   46.7          198.1          173.1          124.4          25.0          20.10
   46.5          182.4          160.1          111.6          22.3          19.98

                                 AVERAGF WATER CONT. WT. RASIS = 20.19%

                                        THE STANDARD DEVIATION IS : 0.56

                                   THE COEFFICIENT OF VARIATION IS: 2.78


   EXTRACTION AT  0.40 ATM.

    A              B              C              D              E              F

   37.3          142.7          126.2           88.9          16.5          18.56
   46.4          173.2          153.4          107.0          19.8          18.50
   46.4          148.7          133.2           86.8          15.5          17.86
   46.6          171.5          152.0          103.4          19.5          18.86
   49.1          161.2          144.1           95.0          17.1          18.00

                                 AVERAGF WATER CONT. WT. RASIS = 18.36%

                                        THE STANDARD DEVIATION IS : 0.42

                                   THE COEFFICIENT OF VARIATION IS: 2.27


   EXTRACTION AT  0.50 ATM.

    A              B              C              D              E              F

   39.1          140.6          125.6           86.5          15.0          17.34
   46.4          192.7          171.3          124.9          21.4          17.13
   46.4          157.6          141.3           94.9          16.3          17.18
   48.6          178.4          159.4          110.8          19.0          17.15
   47.7          158.5          142.0           94.3          16.5          17.50
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```
                              AVERAGE WATER CONT. WT. BASIS = 17.26%

                                    THE STANDARD DEVIATION IS : 0.16

                               THE COEFFICIENT OF VARIATION IS: 0.91


   EXTRACTION AT   0.66 ATM.

    A           B           C           D           E           F

   48.4       183.5       165.6       117.2        17.9       15.27
   48.5       146.7       133.7        85.2        13.0       15.26
   49.2       173.4       156.7       107.5        16.7       15.53
   48.5       169.5       153.4       104.9        16.1       15.35
   48.7       162.0       146.6        97.9        15.4       15.73

                              AVERAGE WATER CONT. WT. BASIS = 15.43%

                                    THE STANDARD DEVIATION IS : 0.20

                               THE COEFFICIENT OF VARIATION IS: 1.30


   EXTRACTION AT   0.82 ATM.

    A           B           C           D           E           F

   47.7       167.5       151.6       103.9        15.9       15.30
   48.7       168.1       152.8       104.1        15.3       14.70
   50.7       163.5       148.7        98.0        14.8       15.10
   46.4       167.5       151.8       105.4        15.7       14.90
   48.6       165.7       150.6       102.0        15.1       14.80
                              AVERAGE WATER CONT. WT. BASIS = 14.96%

                                    THE STANDARD DEVIATION IS : 0.24

                               THE COEFFICIENT OF VARIATION IS: 1.62
```

```
EXTRACTION AT  3.00 ATM.

   A          B          C          D          E          F

  49.0      152.2      139.6       90.6      12.6      13.91
  48.6      146.7      135.2       86.6      11.5      13.28
  48.5      160.2      147.1       98.6      13.1      13.29
  49.0      150.7      138.7       89.7      12.0      13.38
  50.2      166.1      152.6      102.4      13.5      13.18

                  AVERAGE WATER CONT. WT. BASIS = 13.41%

                       THE STANDARD DEVIATION IS : 0.29

                  THE COEFFICIENT OF VARIATION IS: 2.15


EXTRACTION AT  5.00 ATM.

   A          B          C          D          E          F

  49.0      151.3      140.1       91.1      11.2      12.29
  48.6      170.3      157.2      108.6      13.1      12.06
  49.0      153.4      142.1       93.1      11.3      12.14
  49.1      149.4      138.4       89.3      11.0      12.32
  50.2      173.4      159.7      109.5      13.7      12.51

                  AVERAGE WATER CONT. WT. BASIS = 12.26%

                       THE STANDARD DEVIATION IS : 0.17

                  THE COEFFICIENT OF VARIATION IS: 1.42


EXTRACTION AT  7.00 ATM.

   A          B          C          D          E          F

  47.7      162.7      150.5      102.8      12.2      11.87
  48.7      158.7      147.2       98.5      11.5      11.68
  50.5      164.8      152.7      102.2      12.1      11.84
  39.1      146.4      135.0       95.9      11.4      11.89
  48.6      173.6      160.5      111.9      13.1      11.71

                  AVERAGE WATER CONT. WT. BASIS = 11.80%

                       THE STANDARD DEVIATION IS : 0.10

                  THE COEFFICIENT OF VARIATION IS: 0.8
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EXTRACTION AT 15.00 ATM.

  A          B          C          D          E          F

48.0       157.3      146.2       98.2       11.1       11.30
49.0       157.4      146.7       97.7       10.7       10.95
50.6       160.4      149.2       98.6       11.2       11.36
46.5       173.5      160.8      114.3       12.7       11.11
48.7       169.8      157.3      108.6       12.5       11.51

                     AVERAGE WATER CONT. WT. BASIS = 11.25%

                          THE STANDARD DEVIATION IS : 0.22

                     THE COEFFICIENT OF VARIATION IS: 1.94


SOIL TYPE: CLAY, DISTURBED SAMPLE

EXTRACTION AT  0.10 ATM.

  A          B          C          D          E          F

48.5       161.4      130.2       81.7       31.2       38.19
49.3       164.5      132.2       82.9       32.3       38.96
50.6       163.7      132.0       81.4       31.7       38.94
48.1       169.4      135.5       87.4       33.9       38.79
49.5       162.7      131.1       81.6       31.6       38.73

                     AVERAGE WATER CONT. WT. BASIS = 38.72%

                          THE STANDARD DEVIATION IS : 0.31

                     THE COEFFICIENT OF VARIATION IS: 0.81


EXTRACTION AT  0.33 ATM.

  A          B          C          D          E          F

49.5       149.7      125.7       76.2       24.0       31.50
48.3       153.3      128.5       80.2       24.8       30.92
49.1       143.1      120.6       71.5       22.5       31.47
48.7       150.0      125.7       77.0       24.3       31.56
50.5       155.2      130.3       79.8       24.9       31.20

                     AVERAGE WATER CONT. WT. BASIS = 31.33%
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                              THE STANDARD DEVIATION IS : 0.27

                         THE COEFFICIENT OF VARIATION IS: 0.85

   EXTRACTION AT  0.50 ATM.

     A          B          C          D          E          F

   50.0       141.8      121.4       71.4       20.4       28.57
   49.6       146.2      124.4       74.8       21.8       29.14
   38.4       140.6      117.4       79.0       23.2       29.37
   47.1       140.2      118.3       71.2       21.9       30.76
   49.1       154.3      130.5       81.4       23.8       29.24

                      AVERAGE WATER CONT. WT. BASIS = 29.423

                              THE STANDARD DEVIATION IS : 0.81

                         THE COEFFICIENT OF VARIATION IS: 2.75

   EXTRACTION AT  0.66 ATM.

     A          B          C          D          E          F

   46.4       159.3      134.5       88.1       24.8       28.15
   47.1       165.0      139.0       91.9       26.0       28.29
   49.2       155.6      131.7       82.5       23.9       28.97
   48.6       156.5      132.5       83.9       24.0       28.61
   50.5       154.2      131.3       80.8       22.9       28.34

                      AVERAGE WATER CONT. WT. BASIS = 28.47%

                              THE STANDARD DEVIATION IS : 0.32

                         THE COEFFICIENT OF VARIATION IS: 1.14

   EXTRACTION AT  0.82 ATM.

     A          B          C          D          E          F

   38.4       150.5      127.1       88.7       23.4       26.38
   47.1       159.1      135.5       88.4       23.6       26.70
   47.7       162.5      138.4       90.7       24.1       26.57
   49.1       150.7      129.1       80.0       21.6       27.00
   50.0       151.0      129.5       79.5       21.5       27.04
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                                   AVERAGE WATER CONT. WT. BASIS = 26.74%

                                          THE STANDARD DEVIATION IS : 0.28

                                   THE COEFFICIENT OF VARIATION IS: 1.06

    EXTRACTION AT  1.50 ATM.

      A             B             C             D             E             F

    39.2          139.2         120.3         81.1          18.9          23.30
    38.3          147.5         127.1         88.8          20.4          22.97
    49.6          150.0         130.7         81.1          19.3          23.80
    47.7          154.7         134.1         86.4          20.6          23.84
    47.4          151.6         131.7         84.3          19.9          23.61

                                   AVERAGE WATER CONT. WT. BASIS = 23.50%

                                          THE STANDARD DEVIATION IS : 0.37

                                   THE COEFFICIENT OF VARIATION IS: 1.55

    EXTRACTION AT  3.00 ATM.

      A             B             C             D             E             F

    49.3          150.0         133.2         83.9          16.8          20.02
    49.1          144.1         128.1         79.0          16.0          20.25
    49.1          153.2         135.2         86.1          18.0          20.91
    50.2          132.1         118.0         67.8          14.1          20.80
    48.2          141.2         125.2         77.0          16.0          20.78

                                   AVERAGE WATER CONT. WT. BASIS = 20.55%

                                          THE STANDARD DEVIATION IS : 0.39

                                   THE COEFFICIENT OF VARIATION IS: 1.89
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EXTRACTION AT  5.00 ATM.

  A          B          C          D          E          F
-----------------------------------------------------------------
 49.3      154.3      137.7       88.4       16.6       18.78
 49.1      148.4      132.5       83.4       15.9       19.06
 50.6      147.1      131.2       80.6       15.9       19.73
 49.5      145.8      130.2       80.7       15.6       19.33
 48.3      138.6      124.3       76.0       14.3       18.82
-----------------------------------------------------------------
                AVERAGE WATER CONT. WT. BASIS = 19.14%
-----------------------------------------------------------------
                      THE STANDARD DEVIATION IS : 0.39
-----------------------------------------------------------------
                  THE COEFFICIENT OF VARIATION IS: 2.06

-----------------------------------------------------------------
EXTRACTION AT 10.00 ATM.
-----------------------------------------------------------------
  A          B          C          D          E          F

 38.3      136.4      122.6       84.3       13.8       16.37
 47.1      141.5      127.0       79.9       14.5       18.15
 47.7      142.5      127.6       79.9       14.9       18.65
 47.4      126.1      114.1       66.7       12.0       17.99
 49.1      133.2      120.3       71.2       12.9       18.12

                AVERAGE WATER CONT. WT. BASIS = 17.86%
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                      THE STANDARD DEVIATION IS : 0.87
-----------------------------------------------------------------
                  THE COEFFICIENT OF VARIATION IS: 4.86

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EXTRACTION AT 15.00 ATM.
-----------------------------------------------------------------
  A          B          C          D          E          F

 50.0      149.6      135.2       85.2       14.4       16.90
 48.8      141.6      128.1       79.3       13.5       17.02
 50.2      145.8      131.8       81.6       14.0       17.16
 51.6      141.4      128.2       76.6       13.2       17.23
 49.8      142.6      129.3       79.5       13.3       16.73

-----------------------------------------------------------------
                AVERAGE WATER CONT. WT. BASIS = 17.01%

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                      THE STANDARD DEVIATION IS : 0.20

                  THE COEFFICIENT OF VARIATION IS: 1.18
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                        EFFECT OF SAMPLE DISTURBANCE ON

                        WATER RETENSION IN THREE SOILS


      RESEARCH DATA ANALYSIS

      LEGEND INFORMATION:
                              A = CAN WEIGHT (GRAMS)
                              B = WEIGHT OF WET SOIL + CAN (GRAMS)
                              C = WEIGHT OF DRY SOIL + CAN (GRAMS)
                              D = WEIGHT OF DRY SOIL (GRAMS)
                              E = WEIGHT OF WATER (GRAMS)
                              F = WATER CONTENT ON WEIGHT BASIS (%)

    SOIL TYPE: SILT CLAY LOAM, DIST. SAMPLE

    EXTRACTION AT  0.10 ATM.

     A          B          C          D          E          F

    49.5      165.0      135.0      85.5       30.0       35.09
    48.3      164.3      134.1      85.8       30.2       35.20
    49.1      171.5      139.3      90.2       32.2       35.70
    50.7      165.2      135.4      84.7       29.8       35.18
    49.6      166.0      135.7      86.1       30.3       35.19

                     AVERAGE WATER CONT. WT. BASIS = 35.27%

                           THE STANDARD DEVIATION IS : 0.24

                      THE COEFFICIENT OF VARIATION IS: 0.69


    EXTRACTION AT  0.33 ATM.

     A          B          C          D          E          F

    48.7      141.8      122.7      74.0       19.1       25.81
    48.8      137.2      119.2      70.4       18.0       25.57
    46.5      139.8      120.8      74.3       19.0       25.57
    48.3      153.3      132.0      83.7       21.3       25.45
    47.2      134.0      116.5      69.3       17.5       25.25

                     AVERAGE WATER CONT. WT. BASIS = 25.53%

                           THE STANDARD DEVIATION IS : 0.20

                      THE COEFFICIENT OF VARIATION IS: 0.80
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EXTRACTION AT  0.50 ATM.

  A          B          C          D          E          F

47.7       126.7      112.3      64.6       14.4       22.29
50.4       145.2      126.6      76.2       18.6       24.41
39.1       126.5      110.4      71.3       16.1       22.58
46.4       128.2      113.0      66.6       15.2       22.82
46.4       130.3      115.2      68.8       15.1       21.95

                   AVERAGE WATER CONT. WT. BASIS = 22.81%

                        THE STANDARD DEVIATION IS : 0.95

                   THE COEFFICIENT OF VARIATION IS: 4.17


EXTRACTION AT  0.66 ATM.

  A          B          C          D          E          F

49.1       137.6      122.2      73.1       15.4       21.07
49.1       136.6      121.3      72.2       15.3       21.19
49.2       127.4      113.4      64.2       14.0       21.81
39.2       121.6      107.1      67.9       14.5       21.35
37.3       115.8      102.0      64.7       13.8       21.33

                   AVERAGE WATER CONT. WT. BASIS = 21.35%

                        THE STANDARD DEVIATION IS : 0.28

                   THE COEFFICIENT OF VARIATION IS: 1.31


EXTRACTION AT  0.82 ATM.

  A          B          C          D          E          F

47.5       127.2      114.0      66.5       13.2       19.85
46.2       131.5      117.4      71.2       14.1       19.80
46.1       128.2      114.6      68.5       13.6       19.85
46.4       128.7      115.2      68.8       13.5       19.62
46.1       130.1      116.2      70.1       13.9       19.83

                   AVERAGE WATER CONT. WT. BASIS = 19.79%

                        THE STANDARD DEVIATION IS : 0.10

                   THE COEFFICIENT OF VARIATION IS: 0.49
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EXTRACTION AT  1.50 ATM.

  A           B           C           D           E           F

47.7        131.6       119.4       71.7        12.2        17.02
47.5        133.3       120.5       73.0        12.8        17.53
46.4        134.3       121.3       74.9        13.0        17.36
48.5        138.3       125.2       76.7        13.1        17.08
48.6        129.6       117.6       69.0        12.0        17.39

                      AVERAGE WATER CONT. WT. BASIS = 17.28%

                             THE STANDARD DEVIATION IS : 0.22

                        THE COEFFICIENT OF VARIATION IS: 1.27


EXTRACTION AT  3.00 ATM.

  A           B           C           D           E           F

51.2        125.2       115.5       64.3         9.7        15.09
49.1        123.6       114.0       64.9         9.6        14.79
48.6        130.2       119.5       70.9        10.7        15.09
50.5        132.4       122.0       71.5        10.4        14.55
49.2        130.0       119.3       70.1        10.7        15.26

                      AVERAGE WATER CONT. WT. BASIS = 14.96%

                             THE STANDARD DEVIATION IS : 0.29

                        THE COEFFICIENT OF VARIATION IS: 1.91


EXTRACTION AT  5.00 ATM.

  A           B           C           D           E           F

49.2        134.2       124.2       75.0        10.0        13.33
51.2        136.3       126.4       75.2         9.9        13.16
49.1        131.0       121.3       72.2         9.7        13.43
50.2        136.6       126.4       76.2        10.2        13.39
48.2        132.5       122.5       74.3        10.0        13.46

                      AVERAGE WATER CONT. WT. BASIS = 13.36%

                             THE STANDARD DEVIATION IS : 0.12
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                                  THE COEFFICIENT OF VARIATION IS: 0.88

     EXTRACTION AT 10.00 ATM.

        A            B            C            D            E            F

       48.3        121.5        113.4        65.1         8.1         12.44
       50.2        129.3        120.5        70.3         8.8         12.52
       48.2        128.0        119.0        70.8         9.0         12.71
       50.7        129.9        121.3        70.6         8.6         12.18
       49.6        128.1        119.4        69.8         8.7         12.46

                                  AVERAGE WATER CONT. WT. BASIS = 12.46%

                                       THE STANDARD DEVIATION IS : 0.19

                                  THE COEFFICIENT OF VARIATION IS: 1.53

     EXTRACTION AT 15.00 ATM.

        A            B            C            D            E            F

       48.6        119.6        112.3        63.7         7.3         11.46
       49.0        118.3        111.2        62.2         7.1         11.41
       48.3        117.1        110.0        61.7         7.1         11.51
       48.7        117.0        110.0        61.3         7.0         11.42
       48.8        115.0        108.2        59.4         6.8         11.45

                                  AVERAGE WATER CONT. WT. BASIS = 11.45%

                                       THE STANDARD DEVIATION IS : 0.04

                                  THE COEFFICIENT OF VARIATION IS: 0.33

     SOIL TYPE: CLAY LOAM. DISTURBED SAMPLE

     EXTRACTION AT  0.10 ATM.

        A            B            C            D            E            F

       50.2        152.6        130.6        80.4        22.0         27.36
       50.2        151.6        129.6        79.4        22.0         27.71
       48.2        150.5        128.3        80.1        22.2         27.72
       51.5        161.5        137.3        85.8        24.2         28.21
       50.0        151.3        129.3        79.3        22.0         27.74
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                           AVERAGE WATER CONT. WT. BASIS = 27.75%

                                THE STANDARD DEVIATION IS : 0.30

                           THE COEFFICIENT OF VARIATION IS: 1.08


   EXTRACTION AT  0.33 ATM.

     A         B          C          D          E          F

   48.1      134.7      118.6       70.5       16.1       22.84
   51.5      146.3      129.1       77.6       17.2       22.16
   49.0      142.6      125.1       76.1       17.5       23.00
   48.4      145.1      127.1       78.7       18.0       22.87
   49.2      142.4      125.2       76.0       17.2       22.63

                           AVERAGE WATER CONT. WT. BASIS = 22.70%
                                THE STANDARD DEVIATION IS : 0.33

                           THE COEFFICIENT OF VARIATION IS: 1.44


   EXTRACTION AT  0.40 ATM.

     A         B          C          D          E          F

   39.2      140.1      123.1       83.9       17.0       20.26
   38.6      140.4      123.1       84.5       17.3       20.47
   38.4      142.8      125.2       86.8       17.6       20.28
   49.1      142.2      126.3       77.2       15.9       20.60
   49.2      149.0      131.6       82.4       17.4       21.12

                           AVERAGE WATER CONT. WT. BASIS = 20.54%

                                THE STANDARD DEVIATION IS : 0.35

                           THE COEFFICIENT OF VARIATION IS: 1.70
```

EXTRACTION AT 0.50 ATM.

A	B	C	D	E	F
48.5	137.6	123.1	74.6	14.5	19.44
49.0	154.3	137.3	88.3	17.0	19.25
48.2	154.4	137.3	89.1	17.1	19.19
48.5	139.2	124.5	76.0	14.7	19.34
48.6	151.2	134.4	85.8	16.8	19.58

AVERAGE WATER CONT. WT. BASIS = 19.36%

THE STANDARD DEVIATION IS : 0.15

THE COEFFICIENT OF VARIATION IS: 0.79

EXTRACTION AT 0.66 ATM.

A	B	C	D	E	F
39.2	138.7	123.4	84.2	15.3	18.17
49.1	143.7	129.0	79.9	14.7	18.40
49.2	140.0	125.6	76.4	14.4	18.85
48.7	142.5	128.0	79.3	14.5	18.28
50.4	149.0	133.7	83.3	15.3	18.37

AVERAGE WATER CONT. WT. BASIS = 18.41%

THE STANDARD DEVIATION IS : 0.26

THE COEFFICIENT OF VARIATION IS: 1.40

EXTRACTION AT 0.82 ATM.

A	B	C	D	E	F
48.5	145.3	130.7	82.2	14.6	17.76
49.0	143.5	129.6	80.6	13.9	17.25
49.0	144.2	130.2	81.2	14.0	17.24
48.2	146.2	131.7	83.5	14.5	17.37
48.6	156.0	140.4	91.8	15.6	16.99

AVERAGE WATER CONT. WT. BASIS = 17.32%

THE STANDARD DEVIATION IS : 0.28

THE COEFFICIENT OF VARIATION IS: 1.62

EXTRACTION AT 1.16 ATM.

A	B	C	D	E	F
50.4	139.3	127.1	76.7	12.2	15.91
39.1	132.3	119.6	80.5	12.7	15.78
49.0	146.0	132.2	83.2	13.8	16.59
48.2	144.2	130.2	82.0	14.0	17.07
49.1	140.5	127.5	78.4	13.0	16.58

AVERAGE WATER CONT. WT. BASIS = 16.38%

THE STANDARD DEVIATION IS : 0.54

THE COEFFICIENT OF VARIATION IS: 3.28

EXTRACTION AT 3.00 ATM.

A	B	C	D	E	F
48.2	133.4	123.5	75.3	9.9	13.15
50.6	140.8	130.2	79.6	10.6	13.32
49.5	143.1	131.7	82.2	11.4	13.87
48.3	135.1	125.0	76.7	10.1	13.17
49.1	134.2	124.2	75.1	10.0	13.32

AVERAGE WATER CONT. WT. BASIS = 13.36%

THE STANDARD DEVIATION IS : 0.29

THE COEFFICIENT OF VARIATION IS: 2.20

EXTRACTION AT 5.00 ATM.

A	B	C	D	E	F
48.5	131.2	122.3	73.8	8.9	12.06
49.3	136.5	127.3	78.0	9.2	11.79
50.6	138.2	128.5	77.9	9.7	12.45
49.5	134.1	125.0	75.5	9.1	12.05
48.3	129.5	120.7	72.4	8.8	12.15

AVERAGE WATER CONT. WT. BASIS = 12.10%

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                                    THE STANDARD DEVIATION IS : 0.24

                               THE COEFFICIENT OF VARIATION IS: 1.95


   EXTRACTION AT 10.00 ATM.

    A           B           C           D           E           F

   51.5       138.0       129.1        77.6        8.9        11.47
   50.0       134.5       126.1        76.1        8.4        11.04
   48.7       148.1       138.1        89.4       10.0        11.19
   50.4       146.7       137.1        86.7        9.6        11.07
   37.3       126.7       117.6        80.3        9.1        11.33

                              AVERAGE WATER CONT. WT. BASIS = 11.22%

                                    THE STANDARD DEVIATION IS : 0.18

                               THE COEFFICIENT OF VARIATION IS: 1.61


   EXTRACTION AT 15.00 ATM.

    A           B           C           D           E           F

   49.1       132.2       124.0        74.9        8.2        10.95
   48.6       141.4       132.3        83.7        9.1        10.87
   50.6       136.1       127.8        77.2        8.3        10.75
   37.4       123.5       115.2        77.8        8.3        10.67
   49.6       136.8       128.2        78.6        8.6        10.94

                              AVERAGE WATER CONT. WT. BASIS = 10.84%

                                    THE STANDARD DEVIATION IS : 0.12

                               THE COEFFICIENT OF VARIATION IS: 1.13
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