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Evaluation of Some Soil Moisture Characteristics of Iowa Soils

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CONTENTS

SUMMARY

Sampling of a Webster till soil for soil moisture showed significant variability from corn hill to corn hill, with small variability between samples taken 1 foot apart. Variation between hills increased with depth down to 5 feet. Variation between replications was greatest in the surface foot. Spacing was significant at 2 to 3 feet.

The standard error of the mean of six samples taken with a Veihmeyer tube in a 40x40 foot area was estimated to be 0.18, 0.22, 0.31, 0.47 and 0.48 inches for the 0 to 1, 1 to 2, 2 to 3, 3 to 4 and 4 to 5 foot depths.

The 15-atmosphere percentage for samples taken a few feet apart was found to be variable, showing ranges up to 10 percent for a given depth in a Webster soil and 11 percent in an Edina soil. The Ida, Monona and Carrington soils sampled were much less variable. To obtain an accurate wilting point, it must be determined for each plot.

Field capacities determined in the field showed that slowly permeable layers, which cannot be determined visually, have considerable effect on the field capacity.

A bulk density on loess soils of 1.3 can be used with little error for all depths, but on till soils the bulk density changes with depth. The data available averaged 1.21 in the surface 6 inches up to 1.8 from 54 to 60 inches.

Evaluation of Some Soil Moisture Characteristics of Iowa Soils[1]

BY R. H. SHAW, D. R. NIELSEN AND J. R. RUNKLES[2]

The capabilities of a soil for agricultural production are determined by several factors. One of these factors is the water-holding characteristics of the soil. Some soils are able to hold a large amount of plant-available water and are potentially better water reservoirs from which crops can draw their moisture during deficient rainfall periods than are other soils.

To evaluate the differences in available water storage between soils, the determination of the moisture content at wilting point and field capacity must be understood. The determination of the wilting point has been simplified by use of pressure-membrane methods. However, the determination of a field capacity which has a meaning from the farming standpoint has been found to be a complex problem.

In this study, soil moisture characteristics of various Iowa soils have been determined and sampling studies undertaken to obtain a measure of the variability of the wilting coefficient. An evaluation of the sampling errors involved in the use of the soil sampling tube and a comparison of these errors with those obtained by using the neutron meter also were undertaken.

BACKGROUND AND OBJECTIVES

Soil moisture measurements have been made by numerous devices and techniques. These can be classified into three groups: (a) point sample such as that measured by the Bouyoucos blocks, (b) line sample such as that measured by the Veihmeyer or King soil sampling tube where the continuous core represents a line sample with depth and (c) volume sample such as that measured by the neutron moisture meter where approximately a 3-inch radius sphere is measured. The Veihmeyer soil sampling tube and the neutron moisture meter were used in this study.

Onate (13) has summarized a large amount of information on core soil sampling. In his work, he found that experimental and sampling errors decreased with increased depth. As will be shown, this is not always the situation. Onate also suggested that the sites for the individual borings should be selected in some systematic pattern that tends to maximize the gain in efficiency from stratification.

To convert data obtained with a core sampler, such as the Veihmeyer tube, from percent to inches of water, a bulk density must be assumed or measured. Since the neutron moisture meter measures a volume sample, the bulk density does not need to be known. This is a definite advantage of a volume sample.

The neutron moisture meter is a device in which a probe, consisting of a source of fast neutrons, is used in proximity to a detector of slow neutrons. The fast neutrons are slowed down by the hydrogen atoms in soil water, and those slow neutrons returning to the detector are counted and give a direct measure of inches of soil moisture present. Stone, Kirkham and Reed (18) discuss this instrument and also list other references on the subject.

Pipes are installed in the ground and the neutron source inserted into these pipes. The same pipes can be used again, but in the case of a core sampler, a new hole not immediately adjacent to previous borings must be made. This would be expected to increase the variability of the samples since the variability of cores taken within a few feet of each other is large in many soils.

If data are to be expressed in terms of plant-available water, the wilting percent must be known. If data are to be expressed in terms of a deficit of soil moisture from field capacity or some measure of the upper limit of soil moisture, this characteristic must be determined.

The over-all objectives of this particular study were: (a) To obtain an estimate of the sampling errors involved in using either the Veihmeyer tube or neutron moisture meter and to compare results obtained by these methods. (b) To determine the wilting point of representative Iowa soils and the variability of the wilting point within soil types. (c) To determine the field capacity of representative Iowa soils and the variability of the field capacity within soil types.

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AGRONOMY FARM SOIL MOISTURE SAMPLING STUDY, 1954

FALLOW

A 100x300 foot area was kept free of all vegetation throughout the growing season. This area, a fallow plot, was divided into six replications, and three of these were chosen for sampling. Because of time limitations, three locations were chosen at random from each replication and three subsamples taken in the immediate area. Samples were taken with the Veihmeyer tube in 1-foot increments down to 5 feet on four dates—July 9, 15, 21 and 29. Each individual 1-foot increment was placed in a moisture can, weighed, dried for 48 hours at 105°C. and the moisture percentage determined. In converting soil sampling tube readings to inches of water, the following conversion was used:

$$\text{Inches of water} = \frac{\text{Percent moisture} \times 1.3 \times \text{inches of soil represented}}{100}$$

A constant bulk density of 1.3 was used. This was the average of bulk density data available at the time these samples were taken.

The fallow plot provides a measure of the minimum soil moisture variability in a plot where no plant interaction is present. The analyses of variance for the four dates on which the fallow plot was sampled are presented in table 1. Although sampling times were selected by calendar dates, the weather between dates was assumed to be random. On this basis, dates were considered random from the standpoint of the meteorological factors which might affect soil moisture.

As shown in table 1, the variability between subsamples was high in the surface foot, and from 4 to 5 feet. The variability between locations within replications within dates was of the same order of magnitude as subsamples for the surface foot but was much greater for the other depths. The variation of locations several feet apart showed greater variability with increasing depth. This indicated that the size of the uniform area decreased with depth. The dates x replication interaction was not significant for any depth and was combined with the location/within replication/within date term for testing dates and replication significance. At shallow depths, the variability between replications was considerably larger than that between locations in a replication, and it tested significant. From 2 to 4 feet, these terms were of the same magnitude. From 4 to 5 feet, one replication was much wetter than the others, and the variation between replications became very large for this depth.

The mean squares for dates were significantly different only in the top foot. Little loss from evaporation would be expected below this level, and the soil at the lower depths remained near field capacity during the sampling periods.

CORN

An area approximately 100x300 feet which adjoined a large area of corn on a Webster silty clay loam at the Agronomy Farm was selected for sampling. This was divided into six replications. Because of the time involved in sampling, only three of the replications could be sampled in 1 day. Three of the replications were randomly chosen and sampled on July 9, 15, 21, 28, Aug. 6 and Sept. 2. Within each replication, three locations (corn hills) were selected at random. At each location three borings were taken with the Veihmeyer tube—in the hill, 10 inches from the hill and 20 inches from the hill. Each boring consisted of five 1-foot increments taken to a depth of 5 feet. The moisture content of each sample was determined in the laboratory.

To get comparable data with the neutron moisture meter, on July 23 and Nov. 2, the three replications were sampled at the 0- and 20-inch spacing from the hill at the 6-, 18- and 30-inch depths.

In addition to the variation present in a fallow plot, the corn plot had an added factor of soil moisture variability because of plant absorption. The analysis of variance is given in table 2. The sampling error was of the same order of magnitude as the fallow plot and shows rather small variability with depth, except possibly in the top foot. Spacing was significant only at the 2 to 3 foot depth, although it approached the 5-percent level of significance in the top foot. Allmaras and Gardner (1) found the component of variance due to position (ridge, shoulder or furrow) to be small in irrigation experiments. Under nonirrigated conditions, spacing may become significant. Since none of the interactions involving spacing were significant, these were pooled into one error term with 106 degrees of freedom.

Except for the top foot, hills within replications within dates were significant, and the variability increased with depth as in the fallow plot, but the variability was generally greater. One might expect this to be true, as the irregular extraction of moisture by roots should cause greater variability. Since the plots were in nonadjacent areas,

TABLE 1. ANALYSIS OF VARIANCE FOR FALLOW PLOT, 1954 (BASED ON VEIHMEYER SAMPLING TUBE DATA EXPRESSED IN INCHES OF TOTAL WATER PER FOOT).

Source of variation	Degrees of freedom	Mean squares Depth in feet 0-1	1-2	2-3	3-4	4-5
Replication	2	1.128*	1.221*	0.552	0.593	7.551*
Dates	3	0.982**	0.008	0.027	0.128	0.844
D x R	6	0.390	0.114	0.097	0.402	0.281
Location within rep. within date	24	0.230	0.224**	0.352**	0.643**	1.060**
Subsamples within location	72	0.144	0.020	0.050	0.086	0.147

* F value exceeds 5-percent level of probability.
**F value exceeds 1-percent level of probability.

TABLE 2. ANALYSIS OF VARIANCE FOR CORN PLOT, 1954 (BASED ON VEIHMEYER SAMPLING TUBE DATA EXPRESSED IN INCHES OF TOTAL WATER PER FOOT).

Source of variation	Degrees of freedom	Mean squares				
		Depth in feet				
		0-1	1-2	2-3	3-4	4-5
Replication	2	2.302**	1.227	2.101*	0.990	1.054
Dates	5	9.965	8.776**	7.326**	2.247	0.646
R x D	10	0.184	0.659	0.759	0.409	0.892
Hills within reps. within dates	36	0.187	0.302**	0.581**	1.357**	1.438**
Spacing	2	0.417	0.145	0.343*	0.095	0.014
S x R	4	0.062	0.098	0.067	0.051	0.122
S x D	10	0.120	0.113	0.108	0.042	0.102
S x D x R	20	0.149	0.127	0.096	0.112	0.108
S x hills within reps. within dates	72	0.171	0.114	0.066	0.065	0.099
Pooled error	106	0.158	0.114	0.076	0.071	0.102

*F value exceeds 5-percent level of probability.
**F value exceeds 1-percent level of probability.

the greater variability could have been due to the areas sampled.

The R x D interaction was not significant, and a pooled error of 46 degrees was used to test replications and dates. Dates were significantly different in the top three depths. Some moisture was extracted at the lower depths, particularly 3 to 4 feet, but the difference between sampling periods was not great enough to be significant. Replications were significantly different at 0 to 1 foot and 2 to 3 feet. At greater depths the variability between replications was of the same order of magnitude as the variability between hills within replications.

In using the Veihmeyer tube for sampling areas over Iowa, six samples have been taken per plot. Using the data collected at Ames on a Webster soil as an estimate, the standard error of the means on these data for these particular plots would be:

0-1 ft.	0.18 inches
1-2 ft.	0.22 inches
2-3 ft.	0.31 inches
3-4 ft.	0.47 inches
4-5 ft.	0.48 inches
0-5 ft.	1.2 inches

It is believed that, on many of the Iowa soils, particularly loess formed soils, the error will be considerably less because of less variability in the soil. The Webster soil used to determine the estimates was an extremely variable soil at the lower depths. This type of variability was also found by White (21). Data which have been collected on other soils at depths where no change would be expected between sampling dates indicate that, in many of the loess derived soils, a more reasonable standard error to expect would be 0.1 to 0.2 inch per foot increment.

TABLE 3. ANALYSIS OF VARIANCE FOR CORN PLOT, 1954 (NEUTRON MOISTURE METER DATA EXPRESSED IN INCHES OF TOTAL WATER).*

Source of variation	Degrees of freedom	Mean squares		
		Depth in inches		
		6″	18″	30″
Replication	2	0.0782**	0.4257**	0.2593*
Dates	1	0.6468**	5.3770**	9.9459**
R x D	2	0.0047	0.0519	0.0458
Hills within reps.	3	0.0183	0.0634	0.0926
Hills within reps. x dates	3	0.0033	0.0196	0.0285
Pooled error	8	0.0093	0.0441	0.0568
Spacing	1	0.0771	0.1442	0.0040
S x R	2	0.0026	0.0269	0.0178
S x D	1	0.0160	0.0683	0.0126
S x D x R	2	0.0002	0.0095	0.0022
S x hills within reps.	3	0.0172	0.0625	0.0402
S x hills within reps. x dates	3	0.0016	0.0421	0.0055

*Data courtesy J. F. Stone.

The analyses of variance for the two dates on which the neutron moisture meter was used are presented in table 3. The analysis was different since the same hills (pipes) were used for the different dates. The variability with this method was, in most cases, considerably less than for sampling tube data.

Since hills within replications and the R x D interaction were not significant, a pooled error with 8 degrees of freedom was used to test dates and replications. The two dates were widely separated in time so the high significance of dates at all depths is not surprising. Although the mean square for replications was considerably smaller than for the sampling tube method, the error term was proportionally smaller, and the replications were significantly different at all depths.

Spacing was not significant at any of the three depths. The variability between hills within replications x dates increased with depth as previously. The mean square for comparable depths was only a small percentage of that for the sampling tube data. On the basis of these particular data, one neutron meter moisture sample would have a standard error of the mean of approximately the same magnitude as that for six Veihmeyer samples.

SOIL MOISTURE CHARACTERISTICS

WILTING POINT

Plant available water is the amount of water in the soil above the wilting point. The wilting point may be determined by growing the plant under specified conditions as defined by Briggs and Shantz (3) until it has just reached the condition of permanent wilting. This is a tedious procedure. A laboratory approximation to this has been developed by Richards and Weaver (14). The soil samples are dried and passed through a 2-millimeter sieve. The samples are then moistened, placed on a pressure membrane apparatus and allowed to reach an equilibrium with 15 atmospheres of pressure. The resulting moisture content, expressed on an oven-dry basis, is used as an estimate of the wilting percentage. This method was used in this study.

To obtain a measure of the variability existing in the wilting percentage over small areas, a detailed study was conducted at the Agronomy Farm, Iowa State College. Three 40x40 foot areas were each divided into nine equal areas. Two of the areas were Webster silty clay loam, and the third was Clarion loam. A 2-inch boring was made near the center of each area and the soil saved by 6-inch increments. Duplicate determinations were made of the moisture percent at 15 atmospheres pressure. This gave nine determinations for each depth in a 40x40 foot area.

The particular Webster silty clay loam sampled was extremely variable as can be seen from fig. 1. Ranges of over 5 percent in the wilting percentage were found at most depths, with about 10 percent from 24 to 54 inches. Another area of Webster soil showed similar wide variability. The Clarion loam (fig. 2) was more uniform, and individual borings were generally within a 5-percent range at all depths. Individual 2-inch diameter borings were also taken over an area of Colo soil approximately 200x200 feet in size near Ames. These showed ranges of from 3 to 5 percent per 6-inch increment. On five soils—Webster, Edina, Ida, Monona and Floyd—3-inch borings were taken 10 feet apart by 3-inch increments. On the coarse textured loess soils, Ida and Monona (fig. 3), the greatest range between the five borings at any depth was only 3½ percent. The Edina (fig. 4) was more variable, having a range of 11 percent at 30 to 33 inches. The glacial till soils (fig. 5) were extremely variable at most depths, with maximum ranges of 10 to 12 percent at many depths. Individual borings would probably show large variability in wilting percentages over small areas in many soils.

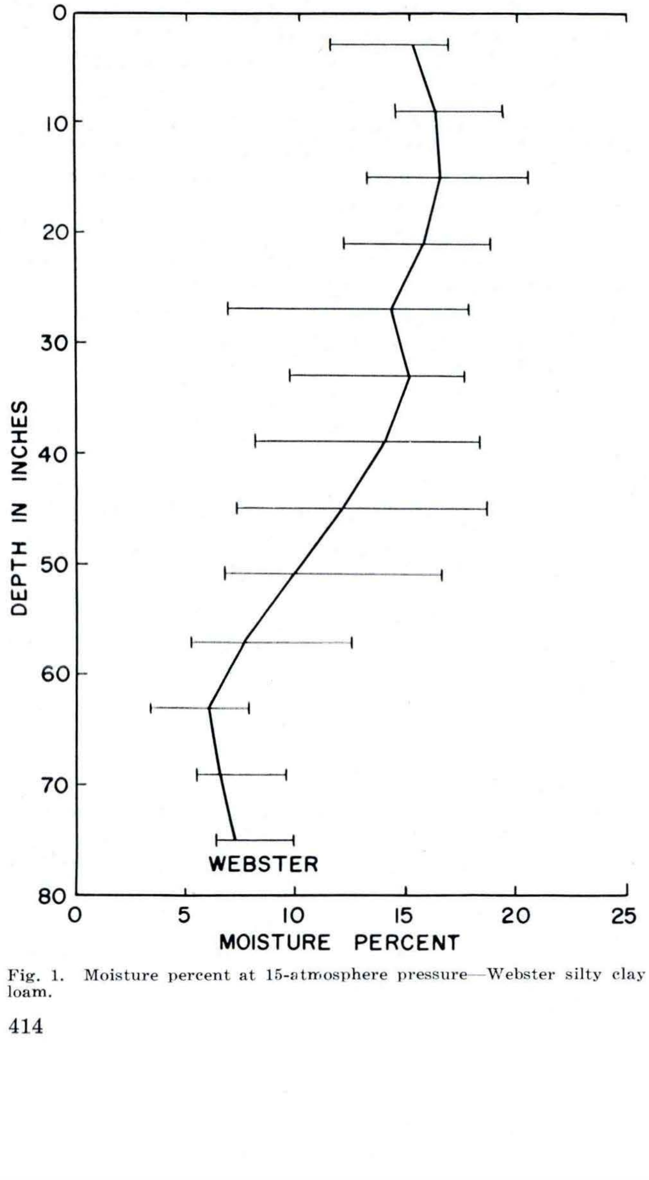

Fig. 1. Moisture percent at 15-atmosphere pressure—Webster silty clay loam.

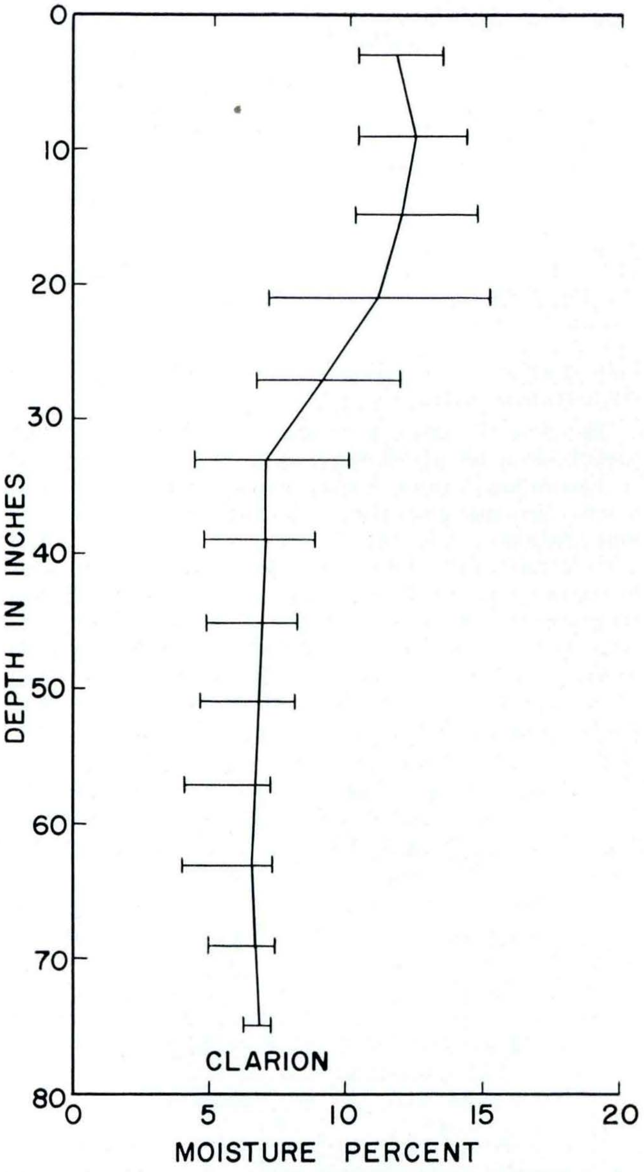

Fig. 2. Moisture percent at 15-atmosphere pressure—Clarion loam.

Mean wilting percentages of small plots on uniform appearing areas were compared to obtain a measure of their variability. On a Carrington soil at Independence, 21 plots, 20x27 feet in size were sampled from an area 450 feet x 325 feet. Seven borings were taken from each plot and composited into one sample for each 6-inch increment of depth. The average wilting point for all plots and the range of wilting points for individual plots are shown in fig. 6. The maximum range on the 21 plots was under 5 percent. Compositing seven borings per plot averaged out some of the extreme variability between individual borings taken short distances apart.

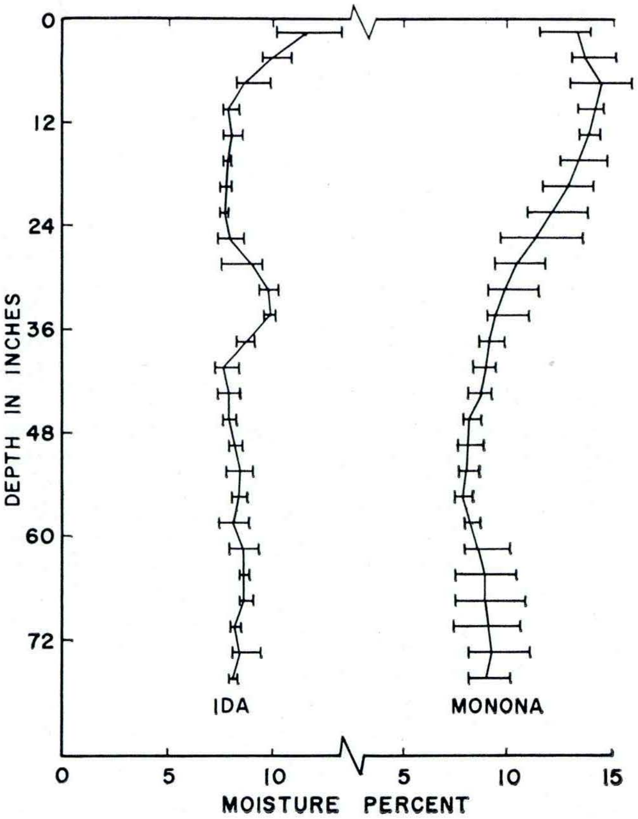

Fig. 3. Moisture percent at 15-atmosphere pressure—Ida and Monona silt loam (mean and range of five borings shown).

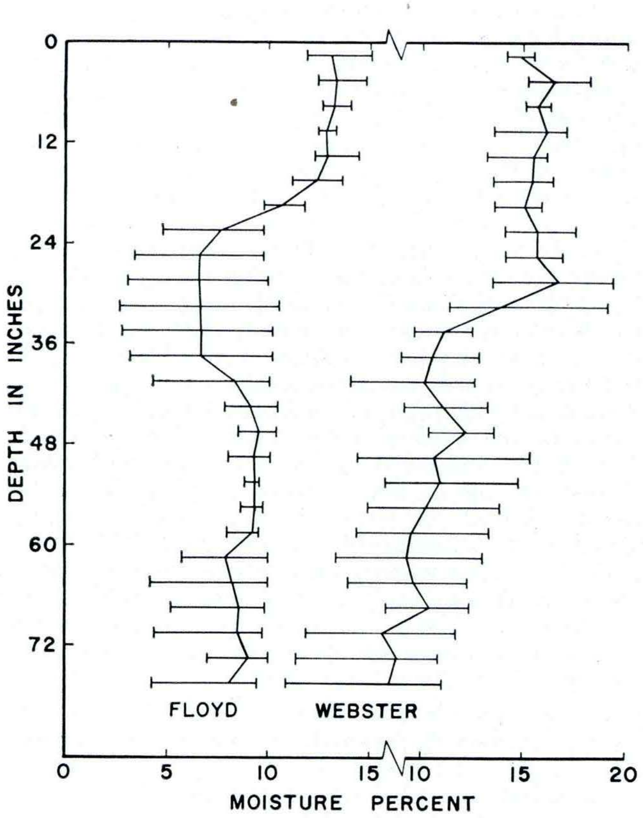

Fig. 5. Moisture percent at 15-atmosphere pressure—Floyd and Webster silty clay loam (mean and range of five borings shown).

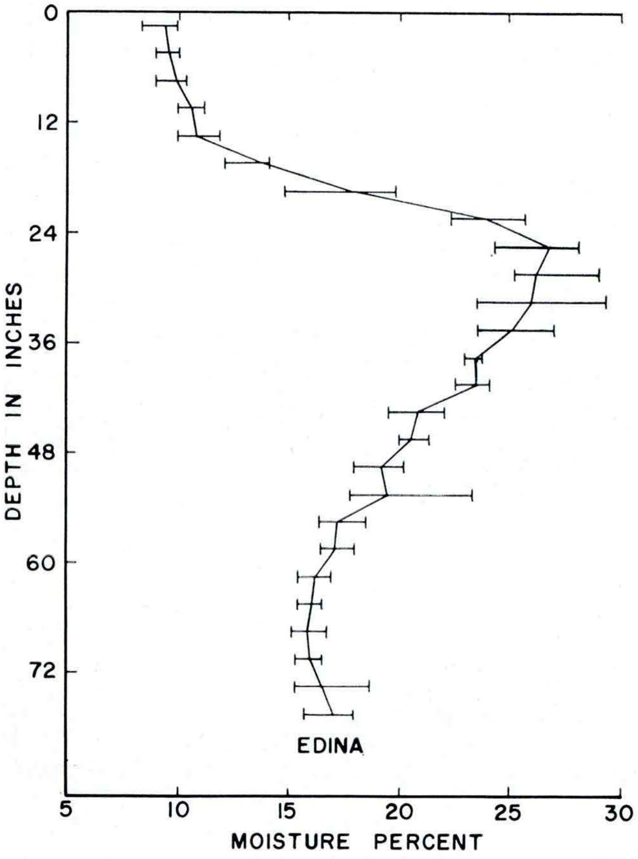

Fig. 4. Moisture percent at 15-atmosphere pressure—Edina silt loam (mean and range of five borings shown).

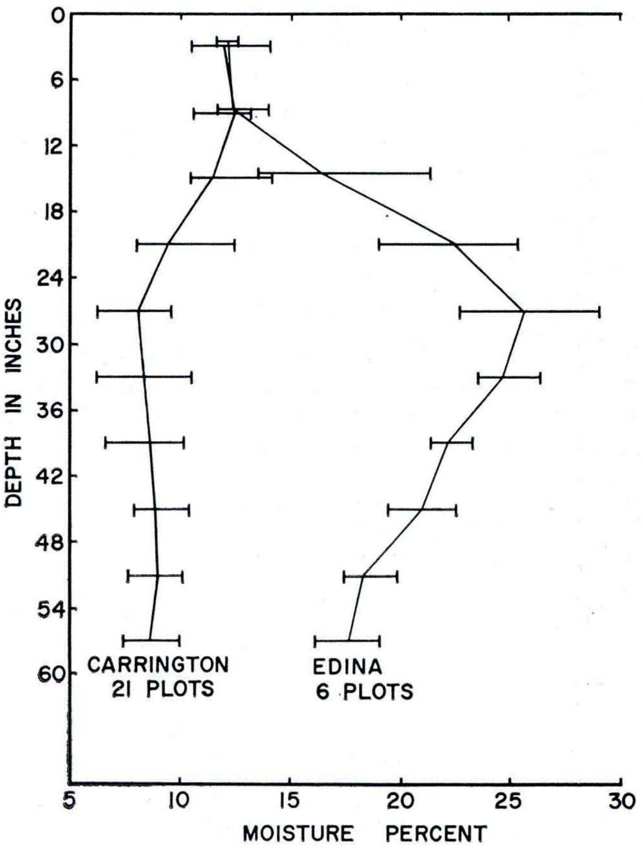

Fig. 6. Moisture percent at 15-atmosphere pressure—Carrington and Edina silt loam.

On an Edina soil at the Southern Iowa Experimental Farm, six plots 20x50 feet were sampled within an area 200x500 feet. Seven borings were composited from each plot. These data are also presented in fig. 6. The range in wilting percentage from 12 to 30 inches reached 8 percent. Because of the rapid change in wilting percentage with depth from a mean of 12½ percent in the surface 6 inches to a mean of over 25½ percent from 24 to 30 inches, it is not surprising that a relatively large range of wilting percentages was found at these depths. If sampling had been done by horizons, variability would have been much smaller. At shallower depths and greater depths the range of wilting percentages was small. Within a small plot area, as represented by fig. 4, the range of the wilting percent was relatively small. The range of the wilting percent of the plot means shown in fig. 6 was considerably larger. This indicated that for experimental plots covering a large area, considerable difference would be expected in mean wilting percentage on this type of soil, even though on small plots individual borings would be relatively uniform. The larger change in plot means is probably due to a gradual change in the soil over the large area.

On a variable soil such as the Webster, the range between different locations is large. In fig. 7, the mean and range of wilting percentages for 21 locations sampled at Ames and Kanawha are given. This variability from plot to plot shows the problem involved in defining a wilting percentage for a particular soil type. It should be measured for specific locations. Any one soil type has a range of wilting percentages.

TABLE 4. CORRELATION BETWEEN WILTING PERCENT AND CLAY CONTENT OF A CARRINGTON SOIL.

Depth (inches)	Correlation coefficient
0- 6	0.206
6-12	—0.011
12-18	0.757**
18-24	0.786**
24-30	0.809**
30-36	0.871**
36-42	0.848**
42-48	0.799**
48-54	0.817**
54-60	0.811**
All depths	0.706**

**Significant at 99-percent level of probability.

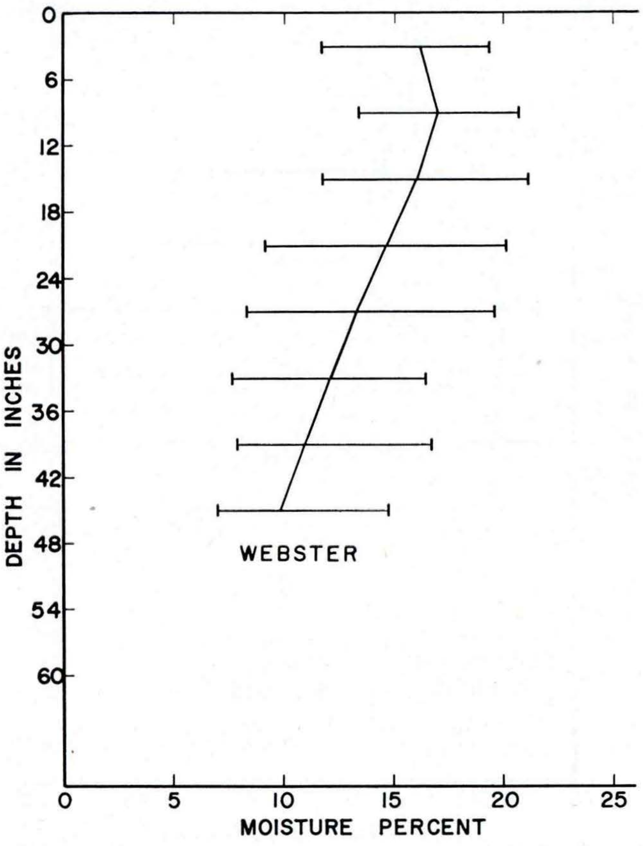

Fig. 7. Moisture percent at 15-atmosphere pressure—21 locations of Webster soil sampled at Ames and Kanawha.

Differences in texture between individual soil samples were believed to account for much of the range in wilting percent at any given depth. A study was made on the Carrington soil to determine how well the wilting percentage correlated with the clay content. Particle size distributions were determined by the hydrometer method. The correlation coefficients of the wilting percentage and the clay content, as determined by this method, for each 6-inch increment to 5 feet, and also for the entire profile are given in table 4. The lack of correlation in the 0 to 6 and 6 to 12 inch depths is attributed partially to the influence of crop rotation and management practices on the organic matter content of the soil, which would affect the wilting point and also lessen the accuracy of the clay determination by the hydrometer method, and to the presence of a relatively narrow range of clay content. All other depths were highly correlated. It was later found that, for a range of Iowa soils, the clay content was highly correlated with the wilting percent in the 0 to 6 and 6 to 12 inch depths. This study was later extended to cover most of the major soils of Iowa, and it has been summarized by Nielsen and Shaw (12).

The range of the wilting point data for each soil type during the course of the study is summarized in table 5. The mean, and the high and low value for each depth are given. The soil texture given was determined by the hydrometer method. This method tends to place soils in a slightly heavier textural class: For example, a heavy silt loam, as determined by the pipette method would probably be determined as a silty clay loam by this method.

FIELD CAPACITY

The upper limit of the amount of water capable of being stored in well drained soils is known as the field capacity. Veihmeyer and Hendrickson (20) first defined the concept of field capacity as being that water in a soil after its downward movement had materially decreased. For most soils, the time required to reach this approximate equilibrium after a soil has been thoroughly wet is from 2 to 4 days. Coarse textured soils may reach field capacity in less than a day while some fine textured soils may require a week or more.

TABLE 5. 15-ATMOSPHERE PERCENTAGE ON IOWA SOILS.

Depth	Belinda (5) * silt loam	Carrington (30) silt loam	Castana (1) silt loam	Clarion (3) clay loam
	Low Av. High	Low Av. High	Single value	Low Av. High
0- 6	7.5- 8.1- 8.7	10.6-12.2-15.4	11.1	12.0-13.8-15.9
6-12	7.4- 7.9- 8.6	10.3-12.5-13.8		13.3-14.5-16.4
12-18	7.8-12.2-16.8	9.7-11.8-14.3	13.1	13.0-14.5-15.2
18-24	16.9-19.9-23.1	8.0-10.1-12.6		13.1-13.7-14.4
24-30	22.2-23.8-24.5	6.2- 9.0-12.4	10.6	10.8-11.7-12.6
30-36	22.1-22.6-23.4	6.1- 8.9-11.5		8.3-10.0-12.1
36-42	20.1-20.8-22.6	6.5- 8.8-10.0	10.0	7.8- 8.3- 9.6
42-48	18.3-19.8-21.1	7.7- 9.2-10.5		7.3- 8.3- 9.7
48-54	17.5-19.0-20.0	7.5- 9.1-10.1	9.5	8.4- 9.3-10.4
54-60	15.8-17.3-18.8	7.2- 8.9-10.0		6.9- 8.5- 9.3

Depth	Clarion (10) loam	Clarion (1) sandy loam	Clyde (1) silty clay loam	Colo (26) silty clay loam
	Low Av. High	Single value	Single value	Low Av. High
0- 6	10.5-11.8-13.6	9.6	15.5	11.4-17.3-22.3
6-12	9.5-12.3-14.5	9.9		12.6-18.4-25.4
12-18	9.4-12.0-14.8	9.9	19.0	15.2-18.9-24.4
18-24	7.2-11.1-15.3	8.1		16.1-19.4-23.9
24-30	6.6- 9.4-12.1	8.5	11.0	16.3-19.2-23.0
30-36	4.6- 7.5-10.2	8.6		14.8-17.9-23.1
36-42	4.8- 6.5- 9.0	7.5	9.7	14.0-17.0-20.9
42-48	5.2- 6.5- 8.3	7.2		12.2-15.5-20.7
48-54	4.7- 6.5- 8.2	6.3	9.9	11.1-13.8-18.8
54-60	4.1- 6.5- 7.3	5.3		8.9-13.0-18.9

Depth	Cresco (3) silt loam	Edina (26) silt loam	Fayette (5) silt loam	Floyd (6) silt loam
	Low Av. High	Low Av. High	Low Av. High	Low Av. High
0- 6	11.6-12.2-13.4	9.3-12.0-14.8	7.0- 8.1- 9.9	13.1-14.8-18.3
6-12	11.3-12.0-12.7	9.0-12.5-14.8	9.0-10.4-12.3	12.9-13.7-15.9
12-18	11.0-11.1-11.2	9.1-14.1-19.8	10.8-13.8-12.9	12.5-12.8-13.9
18-24	10.3-11.0-11.5	14.5-19.1-24.2	11.4-12.7-14.1	9.0-10.0-12.3
24-30	11.5-11.8-12.1	20.4-24.2-26.7	12.0-13.5-15.0	6.4- 8.3-12.6
30-36	11.0-11.7-12.3	21.0-24.6-31.4	11.9-13.1-14.3	6.6- 8.4-12.9
36-42	10.6-11.0-11.8	18.9-22.8-30.0	11.8-13.1-14.4	7.4- 8.0-11.4
42-48	11.1-11.2-11.2	19.1-21.1-27.3	12.1-13.0-13.9	9.3- 9.4- 9.6
48-54	10.2-11.0-11.4	17.3-17.7-22.7	11.3-12.4-13.4	9.1- 9.2- 9.4
54-60	11.1-11.4-11.5	16.4-18.1-20.1	10.6-11.9-13.2	9.1- 9.2- 9.4

Depth	Galva (4) silt loam	Grundy (7) si. cl. loam	Ida (13) silt loam	Luton clay
	Low Av. High	Low Av. High	Low Av. High	Single value
0- 6	15.0-16.2-17.4	10.9-14.1-19.2	8.5-11.1-14.1	19.6
6-12	16.6-17.3-18.0	15.0-16.7-22.2	7.5-10.1-12.1	
12-18	14.5-16.0-17.6	15.2-17.8-22.4	6.8- 9.8-13.2	19.0
18-24	13.2-15.5-17.0	15.5-17.8-20.4	6.0- 9.7-13.2	
24-30	12.5-14.9-16.2	14.4-17.4-19.4	5.6- 9.1-12.6	18.3
30-36	12.4-14.4-15.2	12.9-16.2-18.7	5.5- 9.2-12.6	
36-42	12.6-13.9-14.4	13.1-15.5-17.5	6.5- 9.4-11.2	19.2
42-48	12.4-13.4-14.4	11.6-14.7-16.5	7.8- 9.7-11.2	
48-54	11.4-12.8-14.1	11.1-14.6-17.1	7.6- 9.5-11.2	19.7
54-60	10.7-11.9-13.2	11.3-15.2-17.8	7.7- 9.5-11.2	

Depth	Mahaska-Taintor si. cl. loam (3)	Mahaska (1) silt loam	Marshall (9) silt loam	Monona (14) silt loam
	Low Av. High	Single value	Low Av. High	Low Av. High
0- 6	13.7-15.2-16.3	12.1	13.1-15.0-17.6	10.9-13.4-15.8
6-12		12.0	15.6-17.2-20.4	9.9-12.7-14.2
12-18	16.1-18.4-19.6	13.5	12.5-17.1-20.4	11.0-12.6-14.0
18-24		18.9	12.9-15.9-18.8	10.4-12.5-13.7
24-30	19.2-19.4-19.5	19.7	11.9-14.0-17.4	10.1-11.8-13.1
30-36		19.6	12.0-13.9-17.1	9.8-11.2-12.7
36-42	16.6-17.3-18.2	18.3	11.3-13.3-17.0	8.9-10.9-12.3
42-48		17.5	11.3-13.2-15.7	8.8-10.9-13.0
48-54	15.1-15.8-17.2	16.4	10.4-12.4-15.1	8.2-10.8-13.2
54-60		15.8	10.0-12.2-15.0	8.5-10.9-12.7

Depth	Moody (6) si. cl. loam	Muscatine (5) silt loam	Nicollet (4) si. cl. loam	Primgar (1) silt loam
	Low Av. High	Low Av. High	Low Av. High	Single value
0- 6	13.2-14.2-15.6	11.6-13.5-14.3	12.0-14.8-17.0	20.5
6-12	13.6-14.9-16.4	11.6-14.1-17.0	12.2-14.9-17.3	21.6
12-18	13.8-14.4-15.7	12.6-15.0-17.3	12.5-14.8-17.2	20.3
18-24	13.0-13.9-14.3	12.6-15.4-17.9	13.4-14.1-15.3	18.3
24-30	11.5-12.9-13.9	15.0-15.9-18.6	9.4-12.7-14.4	13.4
30-36	11.3-12.2-13.5	14.5-15.3-16.0	8.7-12.3-15.3	14.5
36-42	10.8-11.7-12.7	8.3-13.6-15.5	8.4-11.0-12.9	12.8
42-48	10.4-11.0-12.0	8.7-13.6-15.0	8.2-10.9-12.5	11.5
48-54	10.2-11.8-14.5	8.8-12.2-14.3	8.8-10.3-11.2	7.9
54-60	9.6-10.4-11.2	8.9-12.0-13.6	7.3-10.8-12.7	6.8

Depth	Seymour(2)	Sharpsburg (10) silt loam	Shelby (1) loam	Taintor (3) si. cl. loam
	Low Av. High	Low Av. High	single value	Low Av. High
0- 6	13.6-14.3-15.0	12.2-15.1-19.6	11.9	13.0-13.6-14.5
6-12		14.2-15.4-17.8	13.7	
12-18	20.9-21.9-22.9	14.5-17.7-19.7	17.0	15.7-16.7-17.5
18-24		15.2-17.2-19.9	15.9	
24-30	19.4-20.2-21.1	16.3-18.7-20.1	14.5	18.4-19.4-21.4
30-36		16.4-17.4-19.7	13.9	
36-42	16.9-17.2-17.4	14.4-17.4-20.2	12.6	16.4-17.3-17.7
42-48		15.2-17.3-20.2	12.0	
48-54	12.9-14.2-15.4	14.8-17.5-19.6	11.6	13.8-14.5-15.2
54-60		14.3-16.6-18.9	11.3	

Depth	Webster (38) si. cl. loam, clay loam	Winterset (2) silt loam
	Low Av. High	Low Av. High
0- 6	12.5-16.1-19.5	14.4-15.2-16.0
6-12	12.8-16.4-19.5	16.8-17.2-17.6
12-18	11.8-15.5-18.3	14.9-17.6-20.4
18-24	9.2-14.4-17.0	16.4-18.5-20.6
24-30	8.3-13.3-17.6	20.8-21.8-22.8
30-36	7.6-11.8-16.4	20.8-21.7-22.6
36-42	7.9-10.6-16.8	20.4-20.6-20.9
42-48	7.7- 9.9-14.8	19.9-20.3-20.7
48-54	7.7- 9.6-12.4	18.5-19.0-19.6
54-60	7.4- 9.2-13.1	15.2-16.8-18.4

* Number of samples of each soil type.

Many laboratory methods have been used to attempt to measure the field capacity of soils. Colman (5) introduced the one-third atmosphere pressure method. The resulting moisture after the samples have come to equilibrium with a one-third atmosphere pressure is the estimate of field capacity. Laboratory methods have failed to give an accurate measure of field capacity owing to the inability of the method to evaluate the field conditions which influence the water movement in the soil *in situ*. Measurement of soil water in the field still remains as the only reliable method of determining field capacity.

Field capacity measurements on well drained or well tiled soils can be determined without too much difficulty. On these soils the greatest error in field capacity measurement is probably the incomplete wetting of the entire profile. The neutron moisture meter is an excellent apparatus to be used in moisture movement studies. The same volume of soil sample is measured for its water content time after time without introducing further soil sampling error. Using this apparatus, it is very easy to follow moisture movement in soil.

On poorly drained or poorly tiled soils it is difficult to obtain an accurate estimation of field capacity. Presence of a water table certainly results in an increase in stored water in a soil profile over that when no water table is present. Such is the case in many Iowa soils in the spring when water is being removed by tile drainage. If the field capacities of Webster silty clay loam and Ida silt loam are measured when no water tables occur, the Ida soil may have more plant-available moisture. However, the reverse may occur when the Webster soil exhibits a water table.

Slowly permeable layers occuring within the soil profile influence the rate at which soils can be wetted to field capacity. In some years, soils having very slowly permeable layers might not reach field capacity under normal weather conditions. Therefore, using a soil moisture deficit relative to field capacity at the beginning of a growing season might well be meaningless.

Available water for plant growth is sometimes defined as that water between the permanent wilting percentage and field capacity. An exception to this definition has to be taken when dealing with soils possessing water tables just below a reasonable root zone. Plants growing on these

TABLE 6. FIELD CAPACITY ON SIX IOWA SOILS (VALUES GIVEN IN PERCENT BY VOLUME).

Depth in inches*	Ida silt loam	Monona silt loam	Marshall silt loam	Floyd clay loam	Webster clay loam	Thurman sand
6	28.3	31.8	31.0	39.6	45.1	25.5
12	26.1	28.9	30.5	37.1	38.7	22.0
18	25.9	26.4	34.0	32.8	37.8	23.8
24	27.4	26.1	34.0	28.4	37.8	16.2
30	30.2	25.5	34.0	29.4	35.2	19.5
36	30.0	24.6	33.8	29.2	33.8	......
42	29.6	24.8	33.5	32.1	37.4	......
48	29.2	25.5	35.5	32.2	40.0	21.0
54	28.0	24.5	36.5	31.9	43.9	18.0
60	28.4	23.1	......	31.8	43.3	18.0

*Depth at which source element of neutron meter centered.

soils may utilize some of this water, particularly if the water table is present for any length of time.

Data collected by Burrows (4) are given in table 6 for Marshall silt loam and Thurman sand. Data collected by Nielsen (11) for four Iowa soils—Ida, Monona, Floyd and Webster—are also given in table 6. Both of these sets of data were collected using the neutron moisture meter, and the field capacity is expressed in percent by volume. To obtain the inches of water present in the soil, multiply these values by the depth of sample divided by 100.

BULK DENSITY

To convert gravimetric data in percent over to inches of water, it is necessary to know the bulk density. The conversion is:

$$\text{Inches of water} = \frac{\text{percent water} \times \text{inches represented in sample} \times \text{bulk density}}{100}$$

Bulk densities were determined by digging a pit and sampling the center of each depth with a 3-inch core sampler. Each value represents the average of four samples per depth. These data are summarized in table 7.

The bulk density data presented here supplement other data available. Bulk density would be expected to vary some within the same soil type and also with soil moisture content at the same location. Other data on loess derived soils show relatively small variation: Anderson and Browning (2)—Edina, Grundy, Ida, Marshall; Ulrich (19)—Edina, Haig, Winterset; Scholtes (15)—Fayette, Tama; McCracken (10)—Marshall, Tama; Hunter (9)—Grundy, Mahaska, Tama; Foth (8)—Galva, Moody; Diaz (7)—Ida, Grundy, Sharpsburg; and Shaeffer (16)—Garwin, Haig, Taintor. Most of these data have been collected by horizons, but for simplification average bulk densities, by 6-inch increments, are presented in table 8. Very few samples deviated more than ±0.1 from these means.

TABLE 7. BULK DENSITY DATA COLLECTED ON IOWA SOILS.

Depth in inches	Clarion loam Story County	Colo silty clay loam Story Co.	Lagonda-Clarinda Ringgold County	Webster silty clay loam Story County
		—Bulk density, gms/c.c.—		
0- 6	1.34	1.38	1.13	1.25
6-12	1.24	1.33	1.23	1.55
12-18	1.27	1.39	1.29	1.55
18-24	1.36	1.44	1.29	1.61
24-30	1.46	1.49	1.40	1.63
30-36	1.46	1.52	1.40	1.62
36-42	1.57	1.71	1.50	1.67
42-48	1.60	1.70	......	1.69
48-54	1.66	1.71	......	1.68
54-60	1.68	1.82		1.76

Depth	Floyd clay loam Buchanan Co.	Webster clay loam Story Co.	Monona silt loam Monona Co.	Ida silt loam Monona Co.
3- 9	1.29	1.20	1.32	1.31
9-15	1.33	1.28	1.22	1.22
15-21	1.46	1.40	1.17	1.23
21-27	1.66	1.46	1.15	1.24
27-33	1.80	1.51	1.17	1.23
33-39	1.85	......	1.16	1.27
39-45	1.86	......	1.17	1.31
45-51	1.79	......	1.20	1.25
51-57	1.86	......	1.24	1.26
57-63	1.91	......	1.22	1.26

TABLE 8. AVERAGE BULK DENSITY OF LOESS DERIVED SOILS.

Depth	Bulk density gms/c.c.	Depth	Bulk density gms/c.c.
0- 6	1.24	30-36	1.30
6-12	1.23	36-42	1.32
12-18	1.24	42-48	1.33
18-24	1.28	48-54	1.32
24-30	1.29	54-60	1.29

TABLE 9. AVERAGE BULK DENSITY OF GLACIAL TILL SOILS.

Depth	Bulk density gms/c.c.	Depth	Bulk density gms/c.c.
0- 6	1.21	30-36	1.46
6-12	1.28	36-42	1.59
12-18	1.33	42-48	1.63
18-24	1.38	48-54	1.75
24-30	1.45	54-60	1.80

Data on glacial till soils show greater variability. In table 9 averages of bulk density are presented for the till soils in table 6 in addition to the following: Anderson and Browning (2)—Carrington, Webster; McCracken (10)—Clarion, Nicollet, Shelby, Webster; and Ulrich (19)—Kenyon.

Very few samples deviated more than ±0.2 from these means.

DISCUSSION

In sampling for soil moisture, variation both in a horizontal direction and with depth must be expected. Sampling of a fallow Webster glacial till soil for soil moisture showed large variability in soil moisture from one location to another only a few feet distant. When sampling corn, considerable variability was found from hill to hill. Variation increased with depth. Samples taken within a foot of each other had small variability. Under conditions when the soil was not completely wet or dry, different spacings from the hill had significant mean squares. On most loess derived soils the variability would be expected to be smaller because of greater textural uniformity.

On the basis of this information, soil moisture sampling over the state has been designed to take six borings in a 40x40 foot area, three borings from each half of the area. On corn these are taken at 0, 10 and 20 inches from different hills systematically located across the plot. In meadow, these borings are taken in a systematic pattern across the plot. The standard error of these means, based on a variable Webster glacial till soil are:

0-1 foot	0.18 inches
1-2	0.22
2-3	0.31

3-4	0.47
4-5	0.48
0-5 foot	1.2 inches

This is believed to represent an upper limit of variability. Most Iowa soils would be expected to have smaller standard errors because of less textural variability.

A comparison of data collected using the Veihmeyer tube and the neutron moisture meter showed the standard error of the mean for comparable numbers of samples was about six times greater for the Veihmeyer tube samples.

Wilting percentages of soils, as measured by 15-atmosphere pressure, have been found to be extremely variable on certain soils. Within a small area, a Webster soil had a variability of 10 percent in the wilting point at a given depth, and an Edina soil had a range up to 11 percent. On the particular Ida, Monona and Carrington soils sampled, the range was only a few percent. When sampling the same soil over large areas and at different locations, all soils showed considerable variation in the wilting point. A soil type does not have a wilting point but a range of wilting points, depending upon the characteristics of the particular location sampled. The wilting point was found to be significantly correlated with the clay content as determined by the hydrometer method.

Laboratory methods fail to give an accurate measure of field capacity owing to the inability of the method to evaluate the field conditions which influence the water movement of the soil *in situ.* Field capacities determined in the field on well drained or well tiled soils show that slowly permeable layers, which cannot be determined visually have considerable effect on the field capacity. The determination of field capacity must be defined on a time basis, because the water held by a soil is not in a static condition. The inability to define a field capacity on poorly drained soils is due to the continual changing of the soil moisture.

When gravimetric samples are taken, the bulk density of the soil must be known if the soil moisture is to be expressed in inches of water. On loess soils an average bulk density of 1.3 can be used for all depths with little error. In contrast to this, on glacial till soils, the bulk density increases with depth, and a constant value cannot be used.

LITERATURE CITED

1. Allmaras, R. R. and Gardner, C. O. Soil sampling for moisture determination in irrigation experiments. Agron. Jour. 48:15-17. 1956.
2. Anderson, M. A. and Browning, G. M. Some physical and chemical properties of six virgin and six cultivated Iowa soils. Soil Sci. Soc. Amer. Proc. 14: 370-374. 1949.
3. Briggs, L. J. and Shantz, H. L. The wilting coefficient for different plants and its indirect determination. U. S. Dept. Agric., Bur. Plant Ind. Bul. 230. 1912.
4. Burrows, Wm. Field capacity of some Iowa soils as determined by a neutron scattering moisture meter. Unpublished M.S. thesis. Iowa State College Library, Ames, Iowa. 1957.
5. Colman, E. A. A laboratory procedure for determining the field capacity of soils. Soil Sci. 63: 277-283. 1947.
6. Coultas, L. C. Properties of some profiles of the O'Neill series. Unpublished M.S. thesis. Iowa State College Library, Ames, Iowa, 1951.
7. Diaz, C. V. Profile characteristics of three Iowa soils in relation to soil and water conservation problems. Unpublished M.S. thesis. Iowa State College Library, Ames, Iowa. 1946.
8. Foth, H. D. Profile properties of the Galva Moody soil sequence of northwest Iowa. Unpublished PhD thesis. Iowa State College Library, Ames, Iowa. 1952.
9. Hunter, Ray. Physical properties of some loess-derived prairie soils of southeastern Iowa. Unpublished M.S. thesis. Iowa State College Library, Ames, Iowa. 1950.
10. McCracken, R. J. Soil classification in Polk County, Iowa. Unpublished PhD thesis. Iowa State College Library, Ames, Iowa. 1956.
11. Nielsen, D. R. Unpublished research. Iowa Agr. Exp. Sta. 1957.
12. Nielsen, D. R. and Shaw, R. H. Estimation of the wilting point of a soil from the mechanical analysis. Soil Sci. 86: 103-105. 1958.
13. Onate, B. T. Methods for sampling soil from replicated field experiments. Unpublished PhD thesis. Iowa State College Library, Ames, Iowa. 1952.
14. Richards, L. A. and Weaver, L. R. The relation between the 15 atmosphere percentage and the permanent wilting percentage. Soil Sci. 56: 331-339. 1943.
15. Scholtes, W. H. Properties and classification of the paha loess-derived soils in northeastern Iowa. Unpublished PhD thesis. Iowa State College Library, Ames, Iowa. 1951.
16. Schafer, G. M. Profile properties of a loess-derived wiesenboden sequence of southeastern Iowa. Unpublished PhD thesis. Iowa State College Library, Ames, Iowa. 1954.
17. Shaw, R. H. and Runkles, J. R. Soil moisture and water utilization in Iowa. Agron. Jour. 48: 313-318. 1956.

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18. Stone, J. F., Kirkham, D. and Read, A. A. Soil moisture determination by a portable neutron scattering moisture meter. Soil Sci. Soc. Amer. Proc. 19: 419-423. 1955.

19. Ulrich, R. Some physical changes accompanying soil profile development. Soil Sci. Soc. Amer. Proc. 14: 287-295. 1949.

20. Veihmeyer, F. J. and Hendrickson. A. H. The permanent wilting point as a reference for the measurement of soil moisture. Trans. Amer. Geoph. Union 29: 887-896. 1948.

21. White, E. M. Subsoil textural variation on the Clarion-Webster Experimental Farm as related to Mankato Glacial Deposit. Ia. Acad. Sci. 60: 438-441. 1953.

22. White, E. M. Profile properties of some variants of the Carrington series in Iowa. Unpublished M.S. thesis. Iowa State College Library, Ames, Iowa. 1950.