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To the Graduate Council:

I am submitting herewith a thesis written by Benny R. Brasher entitled "Determinations of Bulk Density and Water Retention of Soil Cores, Fragments, and Sieved Samples." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agronomy.

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DETERMINATIONS OF BULK DENSITY AND WATER RETENTION BY SOIL
CORES, FRAGMENTS, AND SIEVED SAMPLES

A Thesis
Presented to
the Graduate Council of
The University of Tennessee

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
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CRANES FOREST

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CHAPTER I

INTRODUCTION

Characterization of the water holding properties of soils has increased in importance. Water in soil is held against gravity by soil suction forces that can be simulated in the laboratory and measured in terms of equivalent negative pressure. The suction force, and measurements of the suction force, have been called the soil moisture tension. When free drainage from a wet soil ceases, moisture tension is usually within the range of 0.06 to 0.33 bar and the water content is called field capacity. Water held at tensions between field capacity and 15 bars is generally considered available for plant growth.

For most purposes water holding properties of soils are usually expressed in terms of the volume of water held per unit volume of soil at specified energy levels. Water retention measurements of sieved samples are on a weight basis and expression on a volume basis is possible only when the bulk density (dry weight per unit volume of undisturbed soil) is known.

Predictions of water holding capacity of soils at specified tensions from measurements with sieved samples and soil cores equilibrated at similar tensions may be erroneous. Crushing and sieving soil may alter the pore size distribution, hence the amount of water held by a sieved sample may differ significantly from the amount held by an undisturbed sample of equal weight. Predictions of water content on a volume

basis from bulk density of undisturbed cores and water content on a weight basis (bulk density x per cent water by weight) may also be inaccurate. The bulk density of cores at the water content at sampling may not be equal to the bulk density of soil at a different water content, i.e. at the predicted tension.

This study was initiated to (1) develop a method to measure water content and volume of undisturbed soil fragments after equilibration to a moisture tension in the field capacity range, (2) to study the relationship between change in the bulk density of soil with a change in water content, and (3) to study the effect of alternation of pore size on water retention by soil samples equilibrated to a moisture tension in the field capacity range.

CHAPTER II

REVIEW OF THE LITERATURE

Methods for measuring soil water content or tension may be included in one of the following categories: (1) biological, (2) electrical, (3) neutron scattering, and (4) gravimetric measurements of samples after equilibration and of samples at field water content. Since the methods presented in this study involve gravimetric measurements similar methods or concepts will be stressed here.

I. MEASUREMENTS AND CONCEPTS OF SOIL WATER

Many methods of measuring soil water are based on concepts held by early workers. Briggs (9,10) visualized soil water as hygroscopic water that is held by attractive forces of soil particles, capillary water held by surface tension forces as a film around particles and in capillary pores, and gravitational water that drains from the soil due to gravity. Buckingham (16) studied the movement of capillary water and suggested that the potential for movement was a function of the amount of water in soil and of the energy which the water was held. He called this relationship capillary potential and defined it as a measure of the attraction of the soil for water at a given point in the profile.

Briggs and McLane (11,12) measured the amount of water held by sieved soil samples against a centrifugal force 1000 times that of gravity. They called the measured value "moisture equivalent" and considered it equal to the amount of water held against gravity in capillary pores and to the maximum amount of water held in the soil that was available for plant use. In further studies to delimit the range of available water Briggs and Shantz (13) measured the moisture content of soil in pots after plants growing in them had wilted permanently. They found that different species of plants growing in the same soil wilted at about the same soil moisture content, which they called the "wilting coefficient". They concluded that differences in the wilting coefficient of soils were insignificant when compared to the range in moisture retentiveness of soils. Since some variation is exhibited by different species and since the term wilting coefficient implies a definite relation to other soil properties, Veihmeyer and Hendrickson (80) proposed the term "permanent wilting percentage" for "wilting coefficient".

Livingston (44) developed an apparatus to maintain a constant water content of soil in pots. Using a rubber tube, he established capillary continuity between a water reservoir and a sealed porous clay cup filled with water and buried in the soil. By changing the elevation of the reservoir, relative to that of the cup, he could adjust suction pressure exerted on water in the cup in capillary continuity with water in the soil. Later Livingston (45) connected a U tube partly filled with mercury to the capillary connecting the cup and

reservoir to obtain greater negative pressures with the apparatus. To study the water supplying power of soils as related to wilting of plants, Livingston and Koketsu (46) calculated the rate of water movement in soils at the wilting coefficient from weight measurements of water absorbed by porous cones buried in the soil.

More recent concepts of the state of soil water are based on quantitative expressions of the attraction forces of soil for water. From freezing point and dilatometer studies, Bouyoucos (7) classified soil water as (1) gravitation water, (2) free water that freezes at -1.5°C . and, (3) unfree water which he considered capillary water that freezes at -4°C . and combined water that is held so tightly in small capillaries or by soil colloids that it does not freeze at -78°C . Keen (38), however, showed that the amount of unfree water varied with moisture content and Parker (50) concluded that the dilatometer method did not measure the physical state of soil water but only measured equilibrium values. Gardner (26) and Veihmeyer and Edlefsen (78) agreed with Buckingham's concept of capillary potential and further suggested that a linear relationship existed between capillary potential and moisture content in the range between field capacity and permanent wilting percentage. Schofield (64) suggested using the logarithm of the capillary potential, designated pF , to express the energy with which water is held by soils. He defined pF as the logarithm of the height in centimeters of a liquid (water) column that is necessary to produce a given suction. This concept permitted graphical expression of the relation between soil moisture content and the suction at a given moisture content. It does

exclude by definition, however, suction due to osmotic effects of the soil solution.

Edlefsen and Anderson (23) studied the thermodynamic concepts of soil moisture and suggested that the capillary potential as defined by Schofield (64) was a mechanical potential that measured only the energy of compression or tension in water. They, and Richards and Weaver (61), preferred to use the concept of thermodynamic potential or free energy in considering soil moisture-energy relationships since it included effects of the absorptive force fields and temperature. Taylor (72), however, has suggested that the free energy concept does not adequately define the free energy of water in soil. He reasoned that at least 3 independent variables were required to define the soil moisture-energy relationship since soil is of at least 3 phases, liquid, solid and gaseous. He suggested total pressure, temperature and the concentration of water in the soil system as independent variables and the activity of soil water as the dependent variable.

Richards (58) reviewed the general aspects of the physics of soil water and proposed adoption of the following terms for describing soil moisture-energy relationships: (1) matric suction for soil moisture tension and capillary potential; (2) solute suction for osmotic pressure of the soil solution; and (3) total suction for total soil moisture stress, that is, the combined effect of matric and solute suction. In discussing suction values he said:

Measured values of matric, solute, and total suction of soil will depend on the water and solute content of the soil, on the temperature and the pressure, and on a host of other variables

related to the physical, chemical, and biological status, and the history of the sample. Suction values, of themselves, have agricultural significance, but satisfactory measuring methods are so new that dependence of suction on even the more easily measured and controlled variables, such as temperature and pressure, is as yet almost completely unexplored.

Richards (60) further pointed out that the concept of field capacity as a moisture constant dependent on soil properties alone was questionable. He stated, as did Nielsen, et al. (49), that cessation of drainage from a wet soil is also affected by the hydraulic gradient and hence it was not possible to predict a time when drainage will become negligible.

Delimitation of the range of available water holding capacity has emerged as one of the more important soil-moisture measurements. The wilting coefficient first determined by Briggs and Shantz (13) was shown by Powers (52), Viehmeyer and Hendrickson (80) and others to be about the same for different species of plants growing in a given soil. Lauritzen (42), Richards, S. J. (62), and Richards, L. A. (54) suggested that the negative pressure limitation of 1 atmosphere common to most suction methods could be overcome by increasing gas pressure in soil air. In accordance with this concept, Richards (55) designed the pressure-membrane extraction apparatus. He used it to study the permanent wilting of sunflowers and found that the moisture content retained against 16 atmospheres pressure was slightly less than the wilting coefficient. Reitemeier and Richards (53), Richards and Weaver (61), Viehmeyer and Hendrickson (82), and the U. S. Salinity Laboratory Staff (77) studied permanent wilting of plants and found that the permanent wilting percent-

age as measured at 15 atmospheres, was a practical index to the permanent wilting point of plants. The pressure membrane apparatus, as modified by Richards and Weaver (61) and Richards (56) is now generally used to measure the permanent wilting percentage of soils.

Field capacity, or the upper end of the range of available water held by soil, was defined by King (40) as the amount of water remaining in small capillaries of the soil under field conditions a few days after saturation. It has generally been measured by collecting soil samples under these conditions and drying them at 105°C. Field capacity has usually been predicted from measurements of moisture content retained against some specified suction or pressure.

Briggs and McLane (11,12) predicted field capacity from moisture equivalent measurements but most predictions have been made from measurements employing the suction principle. Kornev (41), Richards (54), Heath (32), and Heck (33) fitted a porous container filled with water with a mercury manometer and used it to measure the suction force of soil. Richards and Gardner (60) modified the apparatus by substituting a vacuum gauge for the manometer and called it a tensiometer. After appropriate calibration it can be used to measure soil suction below 0.85 atmospheres. Richards (54) also used a porous ceramic plate fitted with a mercury manometer and a water reservoir for measuring the capillary potential and moisture content of soil under selected vacuum pressures. He suggested that the apparatus could be improved by covering it with an airtight case "----so that by supplying air pressure in this soil chamber, the pressure difference between the air in the soil and

the soil solution could be greatly increased." Richards and Weaver (61) and Richards (56) modified the apparatus along these lines. They reasoned that an increase in normal atmospheric pressure on one side of the plate would be equivalent to an equal amount of suction applied to the other side since the wet porous plate was permeable to water but not to air. Therefore, they covered one side of the plate with a rubber backing and provided an outflow tube from the covered side. After saturating the plate and sieved soil samples on the plate they sealed it in a pressure cooker with the tube extending through a hole bored in the side of the cooker. Then by increasing the air pressure in the chamber, water in the soil which was in capillary continuity with water in the plate, was forced through the plate and out the tube until water in the soil was held by a suction equivalent to the increase in pressure in the chamber. The equilibrium moisture content was determined by drying the equilibrated samples at 105°C.

Moisture content of sieved samples determined at 0.33 atmosphere equilibrium by the porous plate method and moisture equivalent values have been positively correlated. Richards and Weaver (61) found a rough correlation between moisture content of sieved samples equilibrated at 0.33 atmospheres. Thorne (74) studied the relationship and found that it was highly significant for a group of Hawaiian soils. From these and similar comparisons Baver (5) concluded that there was a low degree of correlation between moisture retention values obtained by the two methods.

Accurate prediction of field moisture content with either method, however, is questionable. Prediction of field capacity from moisture equivalent measurements was shown (by Alway and McDole, Shaw, Veihmeyer and Hendrickson, and Smith and Browning) to be fairly reliable for medium textured soils, too low for coarse textured soils and too high for fine textured soils (1,66,68,81). Colman (19) found similar relationships when field capacity was predicted from moisture measurements of sieved samples equilibrated at 0.33 atmospheres on porous plates.

Although part of the difference between measured and predicted field capacity may be due to a difference between the total soil suction at field capacity and the equivalent negative pressure used to equilibrate samples, much of the difference can be attributed to alternation of pore size distribution by sieving samples. Richards and Fireman (59), Elrick and Tanner (24), Bartelli and Peters (4), and, Perrier and Evans (51) found that at pressures less than 1 atmosphere the equilibrium moisture content of sieved samples, exceeded that of undisturbed soil cores.

Young (86) found that the moisture content of sieved samples exceeded the moisture content of "undisturbed soil pieces" after equilibration at 0.10 and 0.33 atmospheres on porous plates. In further studies Young and Dixon (87) predicted field capacity from moisture and volume measurements of Saran plastic coated soil fragments after sorption on a 30 cm. capillary column. The column was composed of a mixture of very fine sand and silt. When they compared the total pore volume of

the fragments to the calculated volume of water held by sieved samples after desorption against 0.33 atmospheres they found the pore volume was exceeded in many cases by the volume of water held by the sieved samples. Haines (29) has shown, however, that the amount of water sorbed by a porous medium against a given suction is significantly less than the amount retained after desorption from saturation by the same suction. The difference for a given soil has yet to be predicted or precisely evaluated in terms of soil suction or other soil properties.

II. VOLUME MEASUREMENTS AND BULK DENSITY

Bulk density has been defined by the Committee on Terminology, Soil Science Society of America (20) as "Mass per unit bulk volume of soil that has been dried to constant weight at 105°C.; Symbol-Db.

In determination of bulk density, the main problem has been to obtain a sample or accurate volume measurement of a mass of undisturbed soil. Coillie (18), Kelley, et al. (39), Lutz (48) and others have cut cores of known volume from the soil, presumably without alteration of soil structure. It is difficult or impossible, however, to collect soil cores in stony soils. Furthermore, as pointed out by the U. S. Salinity Laboratory Staff (77), the force required to cut out a soil core may cause alteration of soil structure if the soil is not at an optimum moisture content for sampling.

Others have calculated bulk density from weight measurements of an excavated arbitrary mass of soil and volume measurements of the

excavation. Israelson (35), Beckett (6), and Browning (15) measured the volume of an excavation by filling it with a measured volume of liquid. Frear and Erb (25) suggested the use of sand for the measurement and Lutz (47) suggested making a plaster of paris mold of the excavation and measuring its volume sterometrically or by liquid displacement. Although the excavation method can be advantageously used in stony or other soils difficult to sample by other methods, it is cumbersome and requires an excessive amount of time to make the volume measurement. Furthermore the measured volume may vary from the volume of the sample soil mass in place due to alternation of the excavation walls or difficulties in filling the excavation to a volume that equals the in place volume of the soil removed.

Tortensson and Eriksson (76) calculated volume from the pore volume of the soil cores and clods measured by gas displacement and measured or assumed particle density. Volume determined by this method may vary from the volume of the sample mass prior to sampling if soil structure of the sample was altered or if particle density was assumed rather than measured. In addition rather difficult laboratory measurements are involved in the pore volume determination.

In addition to structure alteration in samples, undetermined volume change with a change in moisture content may result in apparent inconsistencies in calculated bulk density. Woodruff (85) and Hill, et al. (34) used a transit to measure vertical volume change of two soils that ranged from 1.5 to 2.5 inches for the B horizons during wetting and drying. Auchinleck and his associates (2), Tempany (73), Hardy (30),

and Stauffer (70) formed "bricks" of soil and measured the volume sterometrically at different moisture contents. Haines (28) studied shrinkage of puddled samples of three different kinds of clay and found that loss in volume of the samples was equal to loss in volume of water over the wet part of the shrinkage range. He called this unity relationship normal shrinkage. As the samples approached air dryness, however, the loss in soil volume was less than the loss in volume of water and he suggested the change from unity occurred when air begins to enter soil pores. He called the loss in soil volume between this point and oven-dryness, residual shrinkage. Stevenson (71), Brown, et al. (14), Shaw (65), Lauritzen and Stewart (43), Johnson and Hill (37), Russel and Balcerak (63), and Johnston (36) measured the volume of undisturbed soil samples at different moisture contents by liquid displacement after coating them with paraffin. Sideri (67) and Vlasoff (84) used collodion to coat samples for volume measurements in liquid. As noted by Sideri (67) and Johnson and Hill (37), however, both collodion and paraffin coatings may rupture with volume change of a sample.

More recently Dow Saran plastic has been used by Brasher, et al. (8) to coat soil fragments for volume measurements at field moisture content and oven-dryness by water displacement. They pointed out that a Saran coating was very slowly permeable to water and air and sufficiently elastic to cling to fragments that shrink or swell with a change in moisture content. Dixon and Young (21) and Young and Dixon (87) measured

the volume of Saran coated fragments after sorption on a 30 cm. capillary column composed of a mixture of very fine sand and silt.

Most of the presumably undisturbed soil samples that have been coated with paraffin or collodion were called soil clods or natural soil clods. A clod, as defined in the soil survey manual (78), is said to be caused by ". . . disturbance, plowing or digging, that molds the soil to a transient mass that slakes with repeated wetting or drying." The term soil fragment, as defined by the manual should be used for irregularly shaped undisturbed soil samples and will hereinafter be used for these kinds of samples. It is defined in the manual as "a fragment, caused by rupture of the soil mass across natural surfaces of weakness."

CHAPTER III

MATERIALS AND METHODS

I. SOILS AND SAMPLING

To determine the reliability of the methods, three soils with a wide range in chemical and physical properties were selected for study. The soils, and their classification at the great soil group level by the U. S. Soil Survey Staff (3, 75) were Leonardtown silt loam, a Planosol, Iredell silt loam, a Planosol intergrading to Gray Brown Podzolic, and Davidson clay loam, a Reddish-Brown Lateritic soil. Descriptions of the three sampled profiles are given in Appendixes A, B, and C.

A profile of the Leonardtown series was sampled in the Coastal Plain of Maryland. It is a moderately deep somewhat poorly drained soil that developed in unconsolidated marine sediments with a loess overlay. It has a strong fragipan in and below the contact zone between loess and marine sediments. The predominant clay mineral is kaolinite although traces of vermiculite occur in most horizons.* The silt loam A2g, the silty clay loam B2lg, and B'Xlg horizons were sampled.

Profiles of the Davidson and Iredell series were sampled in the Piedmont of Virginia. The epidote greenstone parent rock of Davidson

*Personal communication, Richard V. Vanden Heuvel, Soil Survey Laboratory, Beltsville, Maryland. 1963.

and the gabbro parent rock of Iredell are similar in age, basic, and roughly similar in chemical composition but have weathered to soils that differ greatly in clay mineralogy and morphology. Cady (17) pointed out that the predominant clay mineral is montmorillonite in Iredell and kaolinite in Davidson.

Iredell is a shallow, somewhat poorly drained soil that is sticky and plastic when wet. As it dries in the summer it shrinks considerably and cracks may appear. Numerous slickensides are present in the B horizons. The silt loam A2g and clay B22g and B31g horizons were sampled.

The Davidson is a deep, permeable, and well drained soil. Numerous thick and continuous clay films indicate that considerable amounts of clay have been translocated into the B horizons. The clay loam A3 and clay B22 and B3 horizons were sampled.

The soils were sampled in October 1959, to obtain "moist" samples presumably drier than field capacity and in March 1960, a few days after a snow melt, to obtain "wet" samples presumably at field capacity. In the "moist" sampling, soil fragments ranging in volume from 25 to 75 cc., 1 by 2 inch soil cores, and bulk samples were collected. Soil fragments were either broken from horizons and stored in plastic bags in the field, or they were broken from chunks of horizons that had been placed in plastic bags in the field for storage in the laboratory. Five 1 by 2 inch soil cores were collected from each horizon, with a sampler similar to the one described by the U. S. Salinity Laboratory Staff (77). They

were stored in metal asphalt sample cups. Bulk samples were air dried, passed through a 2 mm. sieve, and stored in pint ice cream cartons. Only soil fragments were obtained from the "wet" sampling. The sampling and storage procedures were identical to those used for the "moist" fragments.

II. LABORATORY PROCEDURE

Saran plastic was used to coat soil fragments and sieved samples for volume measurements by water displacement at 0.33 bar equilibrium and at oven-dryness. Two duplicate sets of fragments were coated with Saran for weight and volume measurements at field water content, at periodic intervals as the fragments swelled while wetting in water or shrank while drying in air, and at oven-dryness. Bulk density and water content of each kind of sample was calculated from volume and weight measurements at each moisture tension and at oven-dryness. Soil cores of known volume at field water content were also equilibrated at 0.33 bar and bulk density and water content at the time of sampling and water content at 0.33 bar were calculated from the known volume and from weight measurements at 0.33 bar and oven-dryness.

The equipment used to equilibrate samples at 0.33 and 15 bars has been described by Richards (57) and Richards and Weaver (61). Particle density was determined following the procedure outlined by the U. S. Salinity Laboratory Staff (77). Preparation of Saran plastic, its use to coat fragments for volume measurements at field water content and

oven-dryness, and subsequent calculations of bulk density have been described by Brasher, et al. (8). Methods of measuring shrinkage and swelling of Saran coated fragments were developed by the Soil Survey Laboratory.* The unpublished methods and modifications of published methods will be described in detail below. The kinds of samples and a summary of laboratory procedures used in this study are given in Table 1.

Equilibrated Fragments

Protruding peaks on duplicate "moist" and duplicate "wet" fragments were cut off and the fragments were coated with Saran plastic and equilibrated at 0.33 bar. Doubled pieces of fine twine, 18 inches long, were looped through holes in identification tags and the tag and twine were weighed (W0). The twine was looped around fragments and the tagged fragments were weighed in air (W1). They were then dipped three times in liquid Saran and weighed in air after the Saran coating had dried (W2). A flat surface was cut on the coated fragments with a sharp knife to establish capillary continuity between fragments and porous ceramic plates. The fragments were "seated" on saturated ceramic plates with the flat surfaces in contact with the plates. The plates with the "seated" fragments were placed in pans and water was added until it just covered the surface of the plates. After the fragments became wet by

*Personal communication, C. E. Simonson and V. Valosois, Soil Survey Laboratory, Beltsville, Maryland. 1962.

Table 1 — Kinds of samples, their field water content, and summary of laboratory procedures used in the study.

Kinds of sample	Water content at sampling	Laboratory procedure
<u>Fragments</u>		
"Moist" 3X	Below field capacity	Apply 3 coats Saran, equilibrate at 0.33 bar, 1 coat Saran, weigh in air and water, oven-dry, and weigh in air and water.
"Wet" 3X	About field capacity	(Same as "moist" 3X fragments.)
"Moist" 4X	Below field capacity	4 coats Saran, weigh periodically in air and water while saturating, oven-dry, and weigh in air and water.
"Wet" 4X	About field capacity	4 coats Saran, weigh periodically in air and water while air-drying, oven-dry, and weigh in air and water.
<u>Sieved samples</u>		
0.33 bar	Below field capacity	Equilibrate at 0.33 bar, 3-5 coats Saran, weigh in air and water, oven-dry, and weigh in air and water.
15 bar	Below field capacity	Equilibrate at 15 bar, weigh in air, oven-dry, and weigh in air.
Particle density	Below field capacity	Determine in water using pycnometers.
<u>"Moist" cores</u>	Below field capacity.	Weigh at field water content, equilibrate at 0.33 bar, weigh in air, oven-dry, and weigh in air.

capillary movement of water, the plates were placed in a pressure cooker and the fragments were equilibrated at 0.33 bar. Following equilibration the fragments were carefully removed from the plates, weighed in air (W3) and the cut surface was dipped three times in Saran. The fragments were then dipped once in Saran. After the coating dried, they were weighed in air (W4) and in water (W5). The fragments were dried to a constant weight at 105°C. (W6) and weighed in water (W7).

To facilitate calculations, the weight of the tag and twine, and the weight of fragments in air and in water, were recorded in adjacent columns on a spread sheet. The weights are identified and listed below in order of occurrence in the coating and equilibration procedure:

W0 = weight of the tag and twine,

W1 = weight of the tag, twine, and fragment prior to coating,

W2 = weight of the tag, twine, and fragment after coating,

W3 = weight of the tag, twine, and cut fragment at 0.33 bar,

W4 = weight of the tag, twine, and fragment after additional coating,

W5 = weight of the coated fragment in water at 0.33 bar,

W6 = weight of the tag, twine, and coated fragment, oven-dry, and

W7 = weight of the coated fragment in water after oven-drying.

The weight in air of the fragments at 0.33 bar and at oven-dryness was corrected for the weight of the coating, tag, and twine at both moisture levels. The weight in water of the fragments at 0.33 bar and at oven-dryness was corrected for the volume of the coating. All weight and volume determinations were in the metric system.

Steps involved in calculation of the weight and volume of a coating are:

WC_o = weight of coating prior to equilibration,

WC_r = weight of coating on fragments after cutting,

WC_e = weight of coating applied after equilibration,

WC_{ad} = weight of air-dry coating used for corrections,

WC_{od} = weight of oven-dry coating used for corrections, and

VC = volume of coating used for corrections.

The air-dry weight of the coating prior to equilibration (WC_o) was equal to:

$$WC_o = W2 - W1 \quad .$$

Part of the coating was lost, however, when a flat surface was cut on the fragments. The weight of the coating remaining on the fragments (WC_r) was estimated as

$$WC_r = WC_o \times C_r \quad ,$$

where C_r was a visual estimate (in tenths) of the fraction of the whole coating remaining on the fragments. The weight of the coating applied after equilibration (WC_e) was given by

$$WC_e = W4 - W3 \quad ,$$

and the total air-dry weight of the coating used for corrections at 0.33 bar (WC_{ad}) was given by

$$WC_{ad} = WC_r + WC_e \quad ,$$

or combining the equations, the total air-dry weight of a coating (WC_{ad}) is equal to

$$WC_{ad} = (W_2 - W_1)C_r + (W_4 - W_3) \quad .$$

The oven-dry weight of the coating (WC_{od}) used for corrections was calculated as

$$WC_{od} = WC_{ad} - (WC_{ad} \times 0.10) \quad ,$$

where 10 per cent (0.10) is the average weight lost by coatings upon oven-drying. The volume of the coating (VC) used for corrections was calculated as

$$VC = \frac{WC_{ad}}{1.3} \quad ,$$

where 1.3 is the average density of Saran coatings on fragments.

The corrected weights and volumes of fragments used to calculate bulk density and moisture content were:

WF_e = weight in air of fragments at 0.33 bar,

WF_{od} = weight in air of fragments at oven-dryness,

VF_e = volume of fragments at 0.33 bar, and

VF_{od} = volume of fragments at oven-dryness.

The weight in air of a fragment at 0.33 bar and at oven-dryness was corrected for the weight of the coating at these moisture levels and the weight of the tag and twine. Thus the corrected weight of a fragment in air at 0.33 bar (WF_e) is equal to

$$WF_e = W_4 - (WC_{ad} + W_0) \quad ,$$

and the corrected weight at oven-dryness (WF_{od}) is

$$WF_{od} = W_6 - (WC_{od} + W_0) \quad .$$

The calculated volume of a fragment at 0.33 bar and at oven-dryness was corrected for the volume of the coating. Thus at 0.33 bar the corrected

volume (VF_e) is equal to

$$VF_e = \frac{(W4 - W5)}{D} - VC ,$$

and at oven-dryness the corrected volume (VF_{od}) is

$$VF_{od} = \frac{(W6 - W7)}{D} - VC ,$$

where D is the density of the water in which the fragment was weighed.

The corrected measurements of fragments were used to calculate the following parameters:

Bulk density (Db) in g./cc. Bulk density at 0.33 bar (Db_e) was calculated by

$$Db_e = \frac{WF_{od}}{VF_e} ,$$

and at oven-dryness (Db_{od}) by

$$Db_{od} = \frac{WF_{od}}{VF_{od}} .$$

Water retention in percent . Water content at 0.33 bar was calculated as percent of oven-dry weight (WW_e) and as percent of volume (VW_e) at 0.33 bar. Thus on a weight basis

$$WW_e = \frac{WF_e - WF_{od}}{WF_{od}} \times 100 ,$$

and on a volume basis

$$VW_e = \frac{WF_e - WF_{od}}{VF_e} \times 100 .$$

Percent water at 0.33 bar on a volume basis (VW_e) can also be calculated as follows:

$$VW_e = Db_e \times WW_e .$$

Shrinking and Swelling Fragments

A duplicate set of fragments was used to determine change in bulk density with change in water content. Protruding peaks on duplicate "moist" and duplicate "wet" fragments were cut off and the fragments were tagged for identification, weighed in air, coated with 4 coats of Saran, and weighed in air and in water after the coating dried. "Moist" fragments were then submerged in water and "wet" fragments were suspended in air. Periodic weight measurements in air and in water were made as "moist" fragments wetted and as the "wet" fragments air-dried. When the fragments reached a constant weight in air (usually in 2 to 6 weeks) they were oven-dried at 105°C. and weighed in air and in water. All weight measurements in air were corrected for the weight of the tag, twine, and plastic and all weight measurements in water were corrected for the volume of the plastic. The air-dry weight of the coating was equal to the difference in the weight of fragments before and after coating. The volume and oven-dry weight of the coating was calculated from the air-dry weight of the coating as described in the section on equilibrated fragments. Bulk density and water content were calculated from the corrected weight measurements at each water content by substituting the corrected measurements into the appropriate equations given in the section on equilibrated fragments.

Sieved Samples

Sieved samples were equilibrated at 0.33 bar and a doubled piece of fine twine was carefully looped around the "caked" sample. The

samples were tagged as described in the section on equilibrated fragments and coated with Saran until they were sufficiently "waterproof" for volume measurements by water displacement. Usually 3 to 5 coats of Saran were required. They were then weighed in air and in water, oven-dried at 105°C., and weighed in air and in water. The air-dry weight of the coating, equal to the difference in the weight of the sample before and after coating, was used to calculate the volume and oven-dry weight of the coating as described in the section on equilibrated fragments. The weight of the samples in air at 0.33 bar and at oven-dryness was corrected for the weight of the tag, twine, and coating. The weights of the samples in water were corrected for the volume of the coating. Bulk density at 0.33 bar and at oven-dryness, and water content at 0.33 bar were calculated by substituting the corrected measurements into the appropriate equations given in the section on equilibrated fragments.

Soil Cores

The bottom end of soil cores, encased in metal rings, was covered with a piece of cheesecloth held in place with a rubber band. The cores were weighed, equilibrated at 0.33 bar, weighed, oven-dried at 105°C. and weighed. The weights were corrected for the weight of the ring, cheesecloth, and rubber band. Bulk density and field water content at the time of sampling and water content at 0.33 bar were calculated by substituting the corrected weight measurements and the known volume of the cores into

the appropriate equations given in the section on equilibrated fragments. Some of the cores were shattered during sampling or were not of full volume, hence, the best 2 of the 5 cores of each horizon were used for determinations.

CHAPTER IV

RESULTS AND DISCUSSION

The results of the study will be presented and discussed in three parts: (1) the precision of determinations obtained with the soil fragment, sieved sample and core methods and differences between the methods, (2) the effect of change in water content on bulk density, and (3) the effect of alteration of soil structure on water holding capacity and prediction of field water content on a volume basis.

Water content as percent of oven-dry weight and moist volume and bulk density of sieved samples and fragments are reported for 9 horizons. Water content as percent of field volume and bulk density of cores are reported for only 7 horizons. Cores of Davidson A3 and B3 horizons were not of full volume. Furthermore volume of cores at 0.33 bar and oven-dryness was not determined. Thus core data on a volume basis was not reported at these moisture levels. For brevity, the terms method or methods will be frequently used for the terms kind of sample or kinds of samples.

I. EVALUATION OF METHODS

Precision of the Determinations

The level of precision with which bulk density and water content were determined by each method was studied by calculating the standard deviation of the difference between duplicate fragments, cores, and

sieved samples of each horizon. As shown in Table 2, determinations of water content and bulk density by sieved samples were considerably more precise than determinations by cores or fragments. Determinations of water content and bulk density by "wet" 3X fragments at 0.33 bar were about twice as precise as determinations of water content and bulk density by "moist" 3X fragments at 0.33 bar, "moist" 4X fragments and cores at field water content, and "wet" 4X fragments at field water content. Determinations of water content at 0.33 bar by cores were least precise. Determinations of bulk density at oven-dryness by undisturbed samples were more precise than determinations at 0.33 bar and field water content. In general the level of precision was similar to the precision usually obtained in determinations of bulk density and water content by gravimetric methods. Although precision by individual horizons was not calculated, differences between duplicates of A horizons probably caused much of the difference in precision between cores and fragments and between "wet" and "moist" samplings. This might be expected, however, since genetic A horizons of these soils are usually thinner and less uniform than the B horizons. The better precision obtained with sieved samples was probably due to grinding, sieving, and mixing operations that resulted in creation of uniform duplicates.

Differences Among Methods

Analysis of variance, as described by Snedecor (68), was used to determine if variance due to methods (kinds of samples) was significant. Soil horizons were used as a source of replication so that variance for

Table 2 — Mean values and standard deviation of the difference between duplicate determinations of bulk density and water content by various kinds of samples.^a

Kind of samples	Water % by weight		Bulk density, g./cc.			
	Mean	SD	Mean	SD	Mean	SD
	<u>0.33 bar</u>		<u>0.33 bar</u>		<u>Oven-dry</u>	
"Moist" 3X	31.1	1.6	1.40	0.04	1.64	0.03
"Wet" 3X	31.8	0.8	1.42	0.02	1.67	0.02
"Moist" cores	30.2	2.3				
Sieved samples	37.5	0.6	1.18	0.01	1.45	0.01
	<u>Field water</u>		<u>Field water</u>		<u>Oven-dry</u>	
"Moist" cores	24.0	1.3	1.48	0.04		
"Moist" 4X	24.7	1.4	1.47	0.03	1.67	0.02
"Wet" 4X	31.5	1.6	1.44	0.04	1.69	0.02

^a"Moist cores" of full volume were not obtained from Davidson A3 and B3 horizons, and volume measurements of all cores at 0.33 bar and oven-dryness were not made.

a given determination would be evaluated over a wide range of soil properties. Variance due to interaction between methods and horizons was used for the F test since it was doubted that the interaction could be eliminated or significantly reduced without changing standard sampling procedure. When variance due to methods was significant, Duncans Multiple Range Test (21,30) was used to determine which of the differences among method means were significant.

Mean values of field water content of duplicate "moist" and "wet" fragments and "moist" cores are given in Table 3 and individual values are given in Table 15. Mean values of water content of duplicate "moist" and "wet" 3X fragments, "moist" cores, and sieved samples at 0.33 bar are given in Table 4 and individual values are given in Table 16. Mean values of particle density and of bulk density of duplicate "moist" and "wet" 3X fragments and sieved samples at 0.33 bar and "moist" and "wet" 4X fragments and "moist" cores at field water content are given in Table 5. Individual values are given in Table 17. Mean values of bulk density of duplicate "moist" and "wet" 3X and 4X fragments and sieved samples are given in Table 6 and individual values are given in Table 18.

Analysis of variance of water content expressed as percent of dry weight of "moist" and "wet" 3X fragments, cores and sieved samples at 0.33 bar, Table 7, revealed that variance due to methods was significant at the 0.05 level of probability. Duncans Multiple Range Test at the 0.05 level of probability, Table 8, showed that the mean of sieved samples was significantly higher than the other method means.

Table 3 — Field water content by various sampling methods of certain horizons of Leonardtown, Davidson, and Iredell soils.^a

Soils and horizons	Field water content at sampling					
	Water, % by weight			Water, % by volume		
	Moist cores	Moist 4X frag-ments	Wet 4X frag-ments	Moist cores	Moist 4X frag-ments	Wet 4X frag-ments
Leonardtown						
A2g	18.9	18.2	26.4	27.1	27.6	40.2
B21g	22.5	22.0	30.0	31.6	33.3	43.0
B'X1g	12.2	12.4	15.5	20.6	22.8	27.9
Davidson						
A3	34.2	29.5	41.0	—	34.1	48.2
B22	31.8	32.6	34.8	39.4	44.6	48.1
B3	27.0	29.2	37.5	—	40.3	50.3
Iredell						
A2g	14.4	17.0	25.6	21.9	27.2	41.5
B22g	32.6	39.5	40.8	44.2	49.0	51.0
B31g	22.2	22.2	32.1	35.8	35.5	44.5
Means: N=7	22.1	23.4	29.3	31.5	34.3	42.3
N=9	24.0	24.7	31.5	—	35.0	43.9

^aEach value is the mean for duplicate samples. "Moist" cores of full volume were not obtained from Davidson A3 and B3 horizons.

Table 4 — Water content at 0.33 bar by various sampling methods of certain horizons of Leonardtown, Davidson and Iredell soils.^a

Soils and horizons	Water, % by weight. 0.33 bar				Water, % by vol. 0.33 bar		
	Moist 3X		Wet 3X		Moist 3X	Wet 3X	Sieved samples
	Moist cores	frag-ments	frag-ments	Sieved samples	frag-ments	frag-ments	
Leonardtown							
A2g	21.8	23.8	26.9	27.7	35.2	39.9	39.0
B21g	27.9	27.3	30.2	33.7	39.7	42.8	39.8
B'X1g	15.8	14.4	15.0	24.0	26.0	27.4	34.1
Davidson							
A3	38.4	39.5	39.8	36.5	44.8	44.8	34.1
B22	34.2	35.7	35.2	38.2	46.9	48.2	41.2
B3	36.1	36.6	37.4	46.8	49.8	51.2	50.0
Iredell							
A2g	19.2	21.1	21.2	24.7	32.9	35.9	35.3
B22g	45.2	43.3	42.7	53.7	52.1	52.7	54.8
B31g	32.7	38.6	38.1	52.2	49.6	49.3	53.6
Mean N=9	30.2	31.1	31.8	37.5	41.9	43.6	42.4

^aEach value is the mean for duplicate samples.

Table 5 — Particle density and bulk density at 0.33 bar and field water content by various sampling methods of certain horizons of Leonardtown, Davidson, and Iredell soils.^a

Soils and horizons	Part- icle density g./cc.	Bulk density, g./cc.					
		0.33 bar			Field water		
		Moist 3X frag- ments	Wet 3X frag- ments	Sieved samples	Moist 4X frag- ments	Wet 4X frag- ments	Moist cores
Leonardt own							
A2g	2.64	1.48	1.48	1.41	1.52	1.52	1.44
B21g	2.68	1.46	1.42	1.18	1.52	1.44	1.37
B'X1g	2.67	1.80	1.83	1.42	1.84	1.80	1.70
Davidson							
A3	2.70	1.14	1.12	0.94	1.16	1.18	_____
B22	2.92	1.31	1.37	1.08	1.37	1.38	1.34
B3	2.88	1.36	1.37	1.07	1.38	1.34	_____
Iredell							
A2g	2.84	1.56	1.70	1.43	1.60	1.62	1.52
B22g	2.78	1.20	1.24	1.02	1.24	1.25	1.36
B31g	2.84	1.29	1.30	1.03	1.60	1.39	1.62
Means: N=7	2.77	1.44	1.47	1.22	1.52	1.48	1.48
N=9	2.77	1.40	1.42	1.18	1.47	1.44	_____

^aEach value is the mean for duplicate samples. Cores of full volume were not obtained from Davidson A3 and B3 horizons. The unusually high particle densities in Davidson and Iredell horizons are due to the presence of heavy minerals.

Table 6 — Bulk density at oven-dryness by various sampling methods of certain horizons of Leonardtown, Davidson, and Iredell soils.^a

Soils and horizons	Bulk density at oven-dryness, g./cc.				Sieved samples
	Moist 3X frag-ments	Wet 3X frag-ments	Moist 4X frag-ments	Wet 4X frag-ments	
Leonardtown					
A2g	1.51	1.52	1.55	1.60	1.46
B21g	1.62	1.66	1.64	1.65	1.38
B'X1g	1.85	1.86	1.84	1.84	1.52
Davidson					
A3	1.24	1.22	1.24	1.28	1.05
B22	1.44	1.48	1.47	1.52	1.22
B3	1.43	1.46	1.43	1.46	1.20
Iredell					
A2g	1.68	1.80	1.68	1.76	1.52
B22g	2.00	2.04	2.08	2.06	1.89
B31g	2.03	2.02	2.10	2.06	1.81
Mean: N=9	1.64	1.67	1.67	1.69	1.45

^aEach value is the mean for duplicate samples.

Table 7 — Variance among sampling methods of certain horizons of Leonardtown, Davidson, and Iredell soils. Determinations of water retention by "moist" cores, "moist" and "wet" 3X fragments, and sieved samples.^a

Source of variance	Water content at 0.33 bar					
	Water, % by volume			Water, % by weight		
	d.f.	M.S.	F	d.f.	M.S.	F
Total	55	.	.	71		
Horizons	6	388.88	18.48**	8	757.31	46.23**
Methods	3	12.98	0.62	3	202.97	12.39*
Horizons x Methods	18	21.04	18.77**	24	16.38	9.69**
Sampling error	28	1.12		36	1.69	
		<u>Volume</u>			<u>Weight</u>	
Standard error of a method mean		1.08			0.95	

^aThe volume analysis does not include core data.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table 8 — Duncans Multiple Range Test for significant differences among means of water content of "moist" cores, "moist" and "wet" 3X fragments, and sieved samples.

Results: Test for significant differences. Water, % by weight. 0.33 bar

Methods:	Moist cores	Moist 3X fragments	Wet 3X fragments	Sieved samples
Means:	<u>30.2</u>	<u>31.1</u>	<u>31.8</u>	<u>37.5</u>

Any 2 means underscored by the same line are not significantly different at the 0.05 level of probability.

Crushing and sieving soil may alter total pore space, pore size distribution, destroy soil aggregates, and therefore affect water holding capacity at low moisture tensions. Most of the water in soils is held in pore space between particles. Since sieving significantly increased the weight of water per unit dry weight, pore space occupied by water per unit dry weight must also have been increased. This relationship between sieved and undisturbed samples has been reported by Young (85) and Young and Dixon (86). When water content of fragment and sieved samples was expressed as percent of volume at 0.33 bar, Table 7, variance among samples was not significant. There was a rather large F ratio of the sampling error and interaction between horizons and methods. This may indicate the need for a different statistical design to measure the significance of the interaction. Hence caution should be used in forming categorical conclusions from the statistical analysis of water content on a volume basis.

To study pore volume relationships between sieved and fragment samples in greater detail, total pore volume, drained pore volume, and filled pore volume at 0.33 bar were calculated from mean values of water content and bulk density at 0.33 bar and measured particle density. "Moist" 3X fragments were arbitrarily selected to represent undisturbed samples. Thus total pore volume at 0.33 bar in percent is equal to

$$1 - \frac{Db_e}{PD} \times 100,$$

where Db_e is bulk density of "moist" 3X fragments or bulk density of sieved samples at 0.33 bar and PD is measured particle density. Filled

pore volume at 0.33 bar is equivalent to water content expressed as percent of volume of sieved samples or "moist" 3X fragments at 0.33 bar. Drained pore volume at 0.33 bar is the difference between total pore volume and filled pore volume. The water content of sieved samples at 0.33 bar as percent of dry weight was also expressed as percent of volume per unit dry weight of "moist" 3X fragments at 0.33 bar by the following relationship:

(Water, % by weight of sieved samples) x (Db_e of "moist" 3X fragments). As shown in Table 9 the total pore volume per unit volume of sieved samples of each horizon was greater than that of fragments. The differences between sieved and fragment samples ranged from 2.7 to 14.2 percent for Leonardtown A2g and B'Xlg horizons, respectively. Differences between drained pore volume of sieved and fragment samples and differences between filled pore volume of sieved and fragment samples were not as consistent as the total pore volume relationship. Drained pore volume of sieved samples of Leonardtown A2g horizon was slightly less than that of fragments of the horizon. In the other horizons, however, drained pore volume of sieved samples was greater than that of fragments of the other horizons. Filled pore volume of sieved samples of the Iredell profile was greater than that of fragments of the profile, but in the other 2 profiles filled pore volume of sieved samples was not consistently greater than that of fragments.

When the water content of sieved samples per unit dry weight was calculated as percent of volume per unit dry weight of "moist" 3X fragments it exceeded the total pore volume of fragments of Leonardtown

Table 9 — Total, filled, and drained pore volume of "moist" 3X fragments and sieved samples of certain horizons of Leonardtown, Davidson, and Iredell soils.^a

Soils and horizons	Percent pore volume at 0.33 bar						Water, % wt.
	Moist 3X fragments			Sieved samples			x
	Total	Filled	Drained	Total	Filled	Drained	Db _e Moist 3X fragments ^b
Leonardtown							
A2g	43.9	35.2	8.7	46.6	39.0	7.6	41.0
B2lg	45.5	39.7	5.8	56.0	39.9	16.1	49.2
B'Xlg	32.6	26.0	6.6	46.8	34.2	12.6	43.2
Davidson							
A3	57.8	44.8	13.0	65.2	34.1	31.1	41.6
B22	55.1	46.9	8.2	63.0	41.1	21.9	50.0
B3	52.8	49.8	3.0	62.8	50.1	12.7	63.6
Iredell							
A2g	45.1	32.9	12.2	49.6	35.2	14.4	38.5
B22g	56.8	52.1	4.7	63.3	54.8	8.5	64.4
B3lg	54.6	49.6	5.0	63.7	53.8	9.9	67.3
Mean: N=9	49.4	41.9	7.5	57.4	42.5	15.0	51.0

^aPore volume values were calculated from mean values of duplicate determinations of particle density and bulk density and water retention at 0.33 bar.

^bWater, as percent of dry weight of sieved samples at 0.33 bar calculated as percent of volume of a unit dry weight of moist 3X fragments. Db_e is bulk density of moist 3X fragments at 0.33 bar.

B21g and B'X1g, and Iredell B22g and B31g horizons. The inconsistent differences in filled pore volume and in drained pore volume per unit volume of sieved and undisturbed soil cannot be fully explained from the data. Probably the differential effect of sieving on pore size distribution depends mainly on the particular combination of bulk density and soil structure of a sample, which in turn depends on clay mineralogy, texture, nature of cohesive forces, and other variable soil properties.

When the study was planned, it was hypothesized that water content and bulk density of "wet" fragments presumably at field capacity and of "moist" and "wet" 3X fragments equilibrated at 0.33 bar would agree closely. If this were the case, changes of water holding capacity and bulk density of 3X fragments during equilibration could be considered equivalent to changes of the same properties of soil with change in field water content. And furthermore, this would indicate that bulk density and water holding capacity at or near field capacity could be predicted closely by the 3X fragment method using fragments collected at different field water contents. The hypothesis was tested by analysis of variance of the water content and the bulk densities of 3X fragments at 0.33 bar and "wet" 4X fragments at field water content. As shown in Tables 10 and 11 variance due to samples was not significant. Hence the hypothesis of equivalence was accepted.

Core data were not included in the analysis because neither bulk density nor water content (as percent of volume) of cores at 0.33 bar were determined and water content as percent of dry weight was available for only 7 horizons. Water content as percent of dry weight of cores

Table 10 — Variance among sampling methods of certain horizons of Leonardtown, Davidson, and Iredell soils. Determinations of water retention by "moist" and "wet" 3X fragments at 0.33 bar and field water content of "wet" 4X fragments.

Source of variance	Water, % by volume			Water, % by weight		
	d.f.	M.S.	F	d.f.	M.S.	F
Total	53			53		
Horizons	8	377.33	113.65**	8	486.30	71.10**
Methods	2	20.37	3.30	2	2.16	0.32
Horizons x Methods	16	6.18	1.86	16	6.84	2.66*
Error	27	3.32		27	2.58	
		<u>Volume</u>			<u>Weight</u>	
Standard error of a method mean:		0.43			0.62	

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table 11 — Variance among sampling methods of certain horizons of Leonardtown, Davidson, and Iredell soils. Determinations of bulk density of "moist" and "wet" 3X fragments at 0.33 bar and "wet" 4X fragments at field water content.

Source of variance	Bulk density, g./cc.		
	d.f.	M.S.	F
Total	53		
Horizons	8	0.2464	107.13*
Methods	2	0.0068	2.96
Horizons x Methods	16	0.0023	1.77
Error	27	0.0013	

Standard error of a method mean, 0.0086.

*Significant at the 0.05 level of probability.

and 3X fragments at 0.33 bar and "wet" 4X fragments at field water content, however, agreed closely. Hence if the weight of soil per unit volume at 0.33 bar were known, field capacity of these soils could probably be accurately predicted from water retention measurements with cores.

There was more variance among fragment methods when water content was expressed as percent of volume. It was hypothesized that the higher variance associated with the volume component of the data was caused by slight mechanical compaction of "wet" fragments at field water content. Presumably compaction occurred when protruding peaks were cut off "wet" fragments prior to coating with Saran and when a flat side was cut on "wet" 3X fragments prior to equilibration. If compacted the volume of "wet" fragments at field water content would be reduced but the weight would not be changed. Hence water content on a volume basis and bulk density would be increased but water content on a weight basis would not be changed. If uncompacted "moist" 3X fragments at 0.33 bar and compacted "wet" 4X fragments at field water content were at field capacity, then water content on a volume basis and bulk density of "moist" 3X fragments should be less than that of "wet" 4X fragments. Furthermore, cyclic wetting and drying of fragments during equilibration could cause some destruction of soil aggregates that would further increase the difference in bulk density between "moist" 3X and "wet" 4X fragments. Increase in bulk density due to compaction of "wet" 3X fragments, then would be reduced by cyclic wetting and drying. The means of the water content of "moist" 3X and "wet" 3X fragments at 0.33 bar and "wet" 4X fragments at field water content were 41.9, 43.6, 43.9

percent of their volume, respectively, and in the same order, the mean bulk densities were 1.40, 1.42, and 1.44 g./cc. Since the differences among means conformed to the kind of predicted differences due to compaction, the hypothesis that "wet" fragments were slightly compacted was accepted.

Due to interaction the separate effects of compaction and cyclic wetting and drying can not be evaluated accurately from the data. The combined effect can be estimated, however, as the differences between mean values of "moist" 3X fragments at 0.33 bar and "wet" 4X fragments at field water content. The difference in bulk density was 0.04 g./cc. and in water content 2.8 percent on a volume basis.

Mean values of bulk density of sieved samples and "moist" and "wet" 3X and 4X fragments at oven-dryness are given in Table 6. Analysis of variance among fragment sampling methods, Table 12, showed that variance between samplings and among sampling methods was significant at the 0.05 level of probability. Duncans Multiple Range Test at the 0.05 level of probability, Table 13, revealed that only the means of "moist" 3X and "wet" 4X samples were significantly different. The significant variance between samplings and among sampling methods could probably be attributed to the net effect of compaction and cyclic wetting and drying. There was no change in the array of means of "moist" and "wet" 3X and "wet" 4X fragments at "field capacity" upon oven-drying. Bulk density values of sieved samples were consistently much lower than those of fragments and were not included in the analysis.

Table 12 — Variance among sampling methods of certain horizons of Leonardtown, Davidson, and Iredell soils. Determinations of bulk density of "moist" and "wet" 3X and 4X fragments at oven-dryness.

Source of variance	Bulk density at oven-dryness, g./cc.		
	d.f.	M.S.	F
Total	71		
Horizons	8	0.6068	379.25**
Samplings ("moist" and "wet")	1	0.0120	7.50*
Methods	1	0.0110	7.08*
Samplings x Horizons ^a	8	0.0021	3.00*
Methods x Horizons ^a	8	0.0018	2.57*
Samplings x Methods	1	0.0003	0.43
Samplings x Methods x Horizons ^a	8	0.0007	1.00
Error	36	0.0007	
Standard error of a method mean		0.0091	

^aThe pooled mean square (0.0016 and 24 d.f.) of these interactions was used for the F test of methods, samplings, and horizons.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table 13 — Duncans Multiple Range Test of the means of bulk density of "moist" 3X and 4X fragments and "wet" 3X and 4X fragments at oven-dryness.

Results: Test for significant differences. Bulk density, g./cc. oven-dry

Methods:	"Moist" 3X fragments	"Moist" 4X fragments	"Wet" 3X fragments	"Wet" 4X fragments
Means	1.64	1.67	1.67	1.69

Any 2 means underscored by the same line are not significantly different at the 0.05 level of probability.

II. CHANGE IN BULK DENSITY WITH CHANGE IN WATER CONTENT

Theoretical Considerations

The magnitude of change in bulk density with a given change in water content of soil depends mainly on the kind and amount of clay and organic matter present and to the nature of cohesive forces between soil particles. As cited previously, the predominant clay minerals in Davidson, Leonardtown, and Iredell soils are kaolinite, kaolinite with traces of vermiculite, and montmorillinite, respectively. According to Grim (26) kaolinite with 1 silica and 1 alumina sheet per unit layer has a fixed or non-expanding crystal lattice structure due to strong hydrogen bonding between unit layers. Thus change in bulk density of kaolinite with change in water content is small and depends mainly on addition or removal of water molecules adsorbed at the edges of broken unit layers. Vermiculite with a silica-alumina-silica unit layer has a restricted expanding lattice, with expansion limited to 4.98 A. or about the thickness of two layers of water molecules. Montmorillinite with a silica-alumina-silica unit layer structure and a weak bond between unit layers has an expanding lattice which readily permits entrance of water molecules between unit layers. To quote Grim:

The c-axis dimension of montmorillinite. . .varies from about 9.6 A., when no dipolar molecules are between unit layers, to substantially complete separation of the individual layers in some cases.

Thus large changes in bulk density with change in water content are closely related to the presence and amount of expanding-lattice clay. In coarse textured, eluviated, or kaolinitic horizons with little or no

expanding lattice clay, change in bulk density is small and depends mainly on (1) change in the water content of organic matter, and (2) change in the thickness of adsorbed layers of water around individual soil particles or aggregates. Both changes result in a net change in the amount of soil per unit volume. Cemented or fragipan horizons change little in bulk density except at or near saturation when they slake down. The mechanism of cementation is not clearly understood.

In this study Saran plastic was used to coat "moist" and "wet" 4X fragments to determine periodic change in bulk density as "moist" fragments wetted between field water content and saturation and as "wet" fragments dried between field water content and air-dryness. Change in bulk density of fragments of a subsurface horizon, in the absence of the constrictive force of the soil mass, may not be equivalent to change in the bulk density of the horizon. Thus fragments may swell more and shrink less than the horizon with a given change in water content. Although the plastic coating is sufficiently elastic to cling to fragments as they shrink or swell, the constrictive force of the coating is undoubtedly less than that of the soil. Nevertheless, the coating prevents disintegration of fragments with change in water content and since it is very slowly permeable to water, it should prevent destruction of aggregates due to rapid expulsion of air entrapped in pores by sudden wetting.

Absence of constrictive force should have the same effect on shrinkage of cores as on shrinkage of fragments. The effect on cores, however, would not be the same as on fragments if swelling is considered. Since

a soil core is encased in a metal ring, lateral swelling is prohibited but vertical swelling is unrestricted. Absence of constrictive force of the soil mass should have the least effect on change in bulk density of samples of kaolinitic horizons and the greatest effect on change in bulk density of samples of montmorillinitic horizons. The extent to which the constrictive force of the plastic coating on fragments and the metal ring around cores would substitute for the constrictive force of the soil mass could not be determined from this study.

Experimental Data

As described in the methods chapter in the section on shrinking and swelling fragments, duplicate "moist" 4X fragments and duplicate "wet" 4X fragments of each horizon were used to determine bulk density at different water contents. The bulk density of each fragment at different water contents is given in Tables 19 and 20 and shown as points on graphs in Figures 1 through 9. The points were connected by lines to show the approximate curvilinear relationship between change in bulk density and change in water content of each fragment. The means of bulk density of duplicate "moist" cores at field water content and duplicate "moist" 3X and "wet" 4X fragments and sieved samples at 0.33 bar and oven-dryness are also shown on the graphs.

Bulk density of "wet" 4X fragments of A horizons was greater than that of "moist" 4X fragments of A horizons at a given water content. As previously discussed, the difference was probably due to compaction of "wet" fragments. Differences were less obvious between

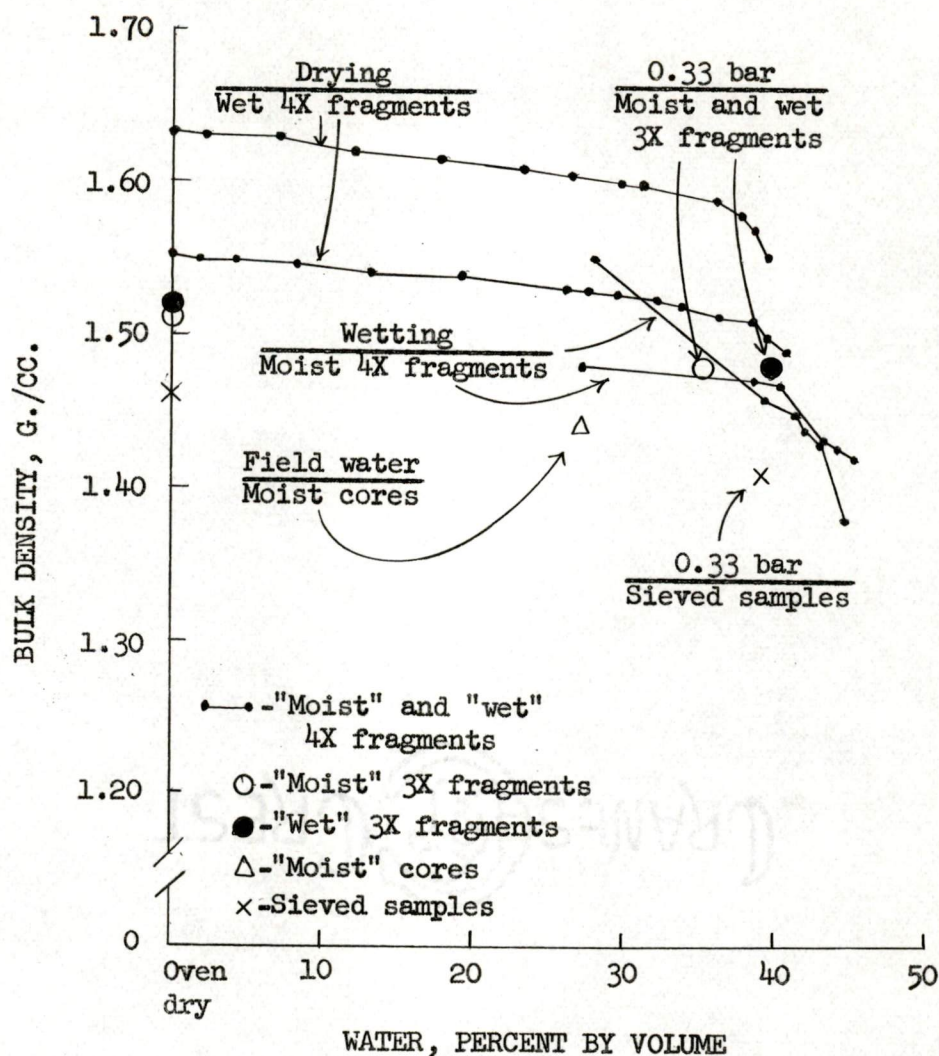


Figure 1 — Change in bulk density with change in water content. Leonardtown A2g horizon. The lines connect bulk density values of "moist" 4X fragments wetting from field water content and "wet" 4X fragments air-drying from field water content (over a 2-6 week period). Symbolic points locate mean bulk density values of duplicate "moist" 3X fragments, "wet" 3X fragments, and sieved samples at 0.33 bar and oven-dryness and "moist" cores at field water content.

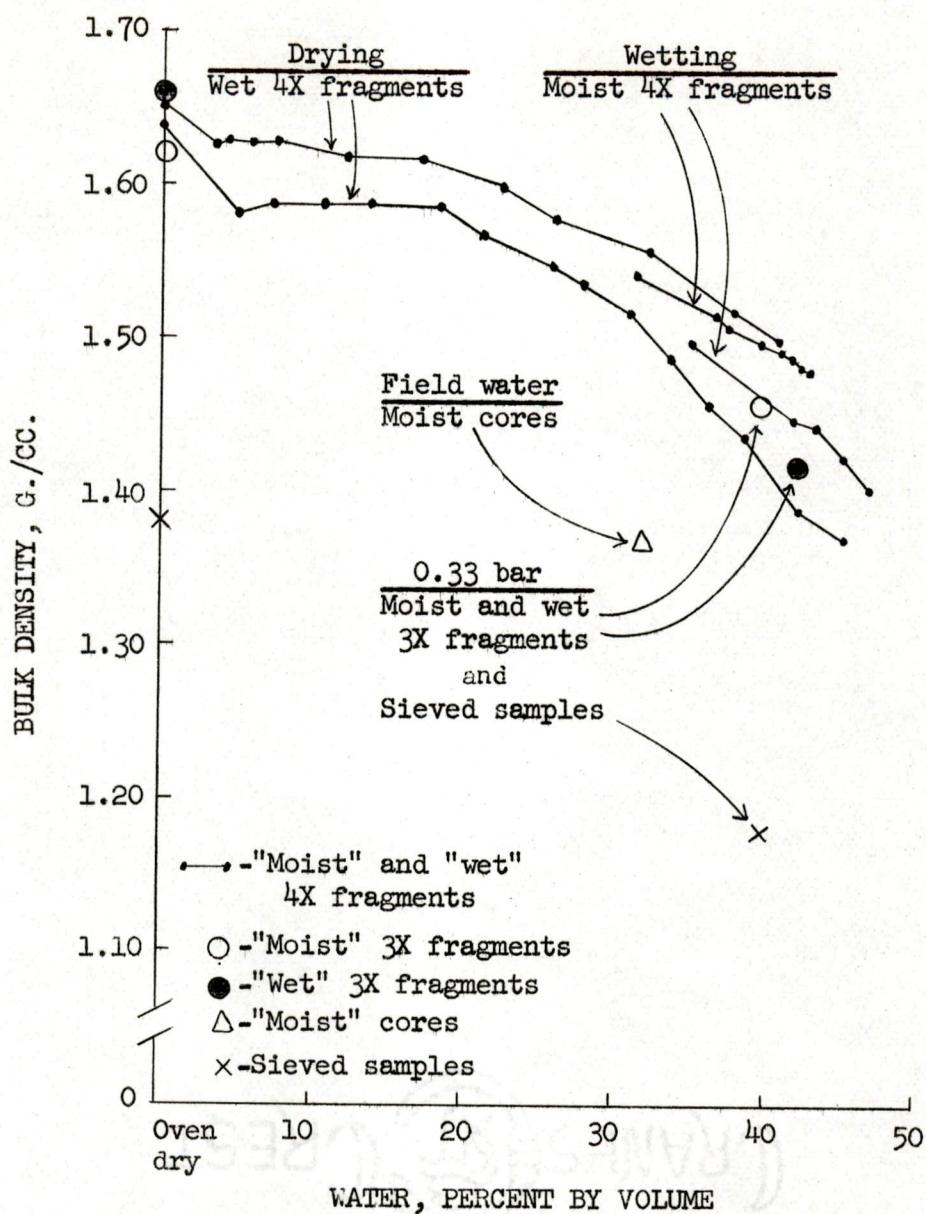


Figure 2 — Change in bulk density with change in water content. Leonardtown B2lg horizon. The lines connect bulk density values of "moist" 4X fragments wetting from field water content and "wet" 4X fragments air-drying from field water content (over a 2-6 week period). Symbolic points locate mean bulk density values of duplicate "moist" 3X fragments, "wet" 3X fragments, and sieved samples at 0.33 bar and oven-dryness and "moist" cores at field water content.

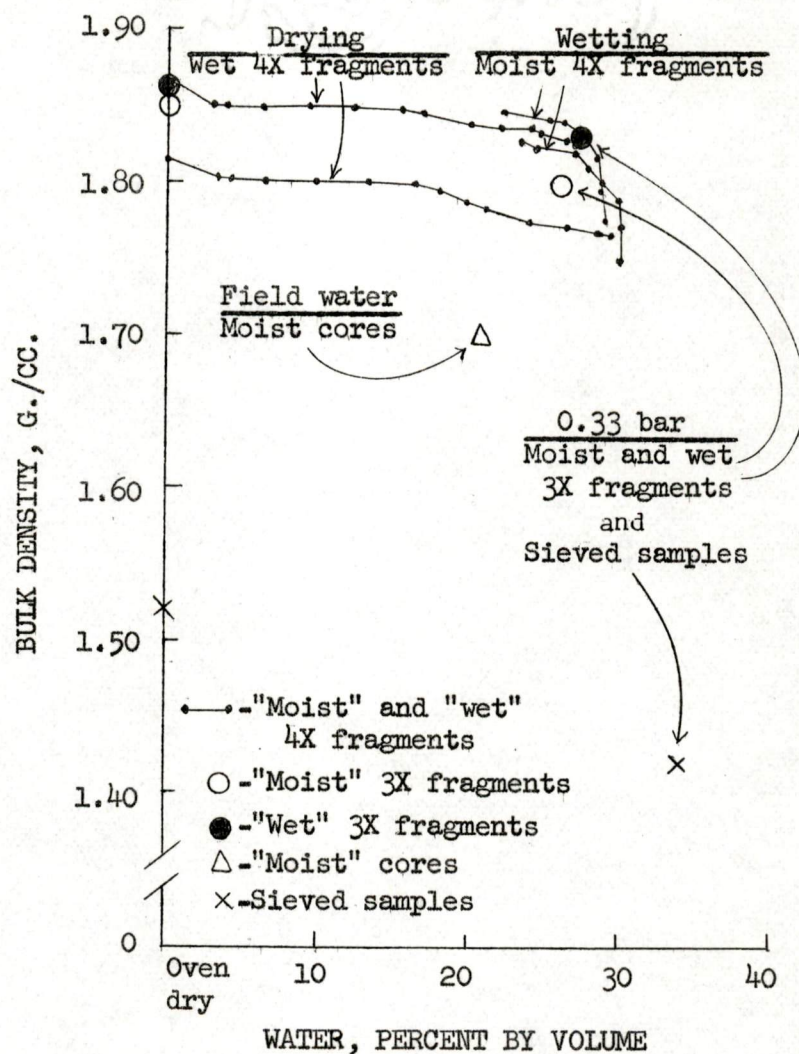


Figure 3 — Change in bulk density with change in water content. Leonardtown B'Xlg horizon. The lines connect bulk density values of "moist" 4X fragments wetting from field water content and "wet" 4X fragments air-drying from field water content (over a 2-6 week period). Symbolic points locate mean bulk density values of duplicate "moist" 3X fragments, "wet" 3X fragments, and sieved samples at 0.33 bar and oven-dryness and "moist" cores at field water content.

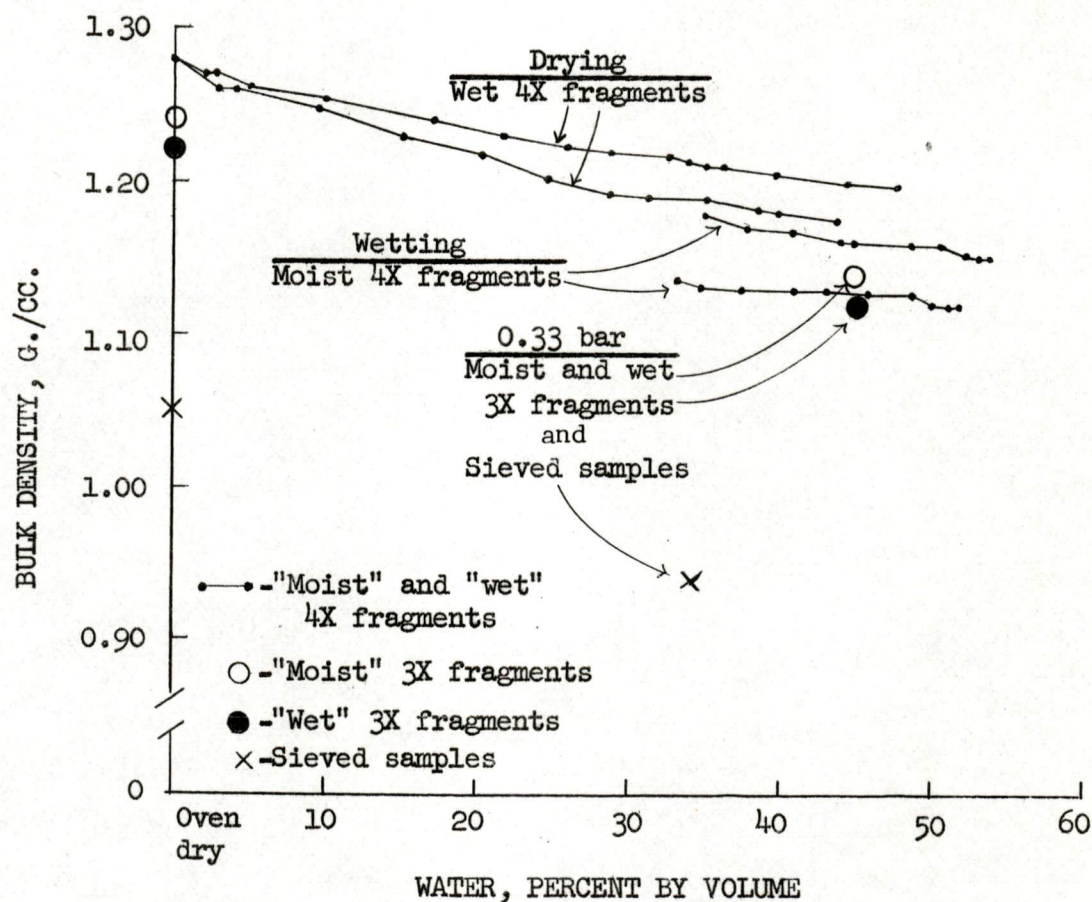


Figure 4 — Change in bulk density with change in water content. Davidson A3 horizon. The lines connect bulk density values of "moist" 4X fragments wetting from field water content and "wet" 4X fragments air-drying from field water content (over a 2-6 week period). Symbolic points locate mean bulk density values of duplicate "moist" 3X fragments, "wet" 3X fragments, and sieved samples at 0.33 bar and oven-dryness and "moist" cores at field water content.

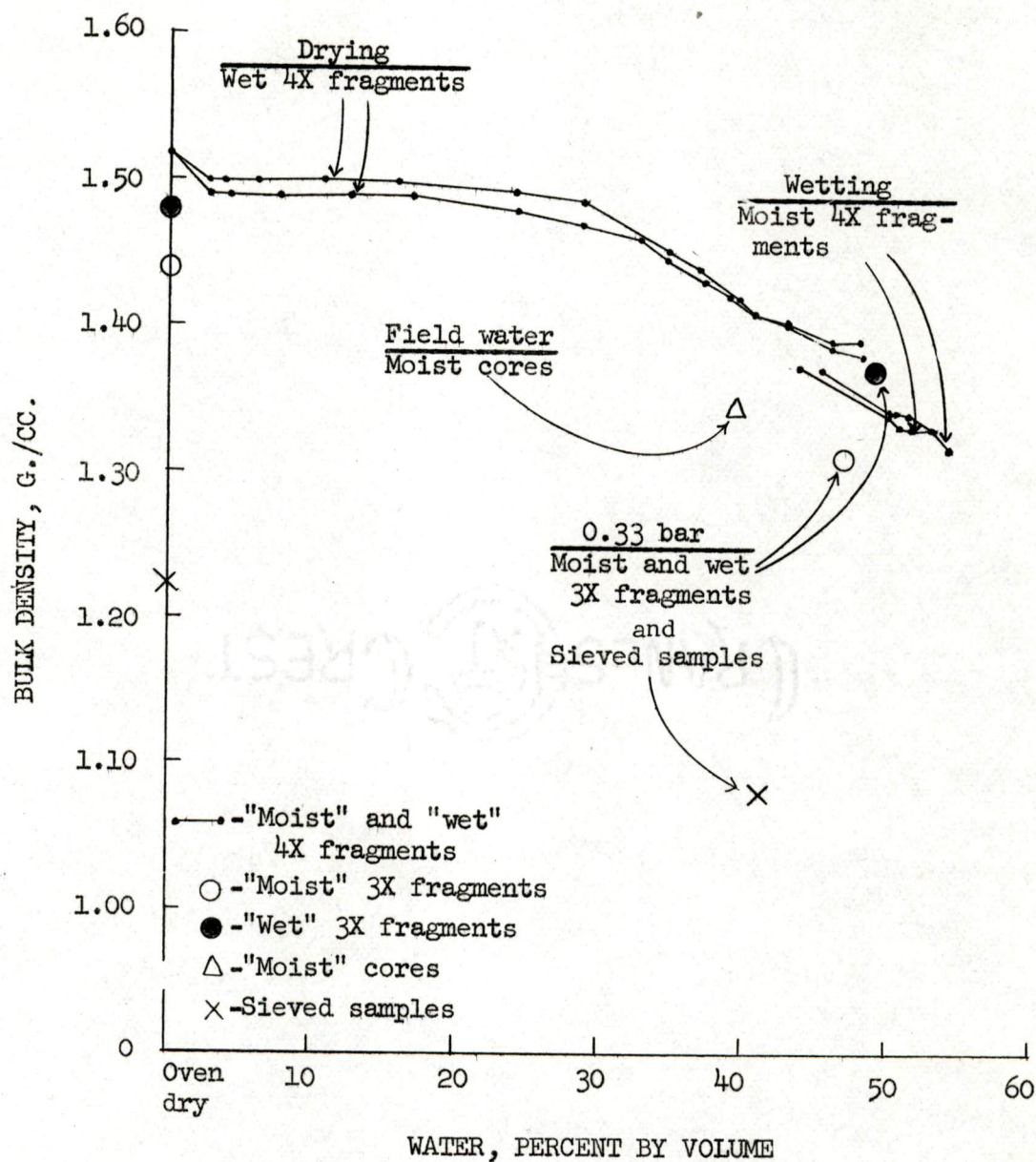


Figure 5 — Change in bulk density with change in water content. Davidson B22 horizon. The lines connect bulk density values of "moist" 4X fragments wetting from field water content and "wet" 4X fragments air-drying from field water content (over a 2-6 week period). Symbolic points locate mean bulk density values of duplicate "moist" 3X fragments, "wet" 3X fragments, and sieved samples at 0.33 bar and oven dryness and "moist" cores at field water content.

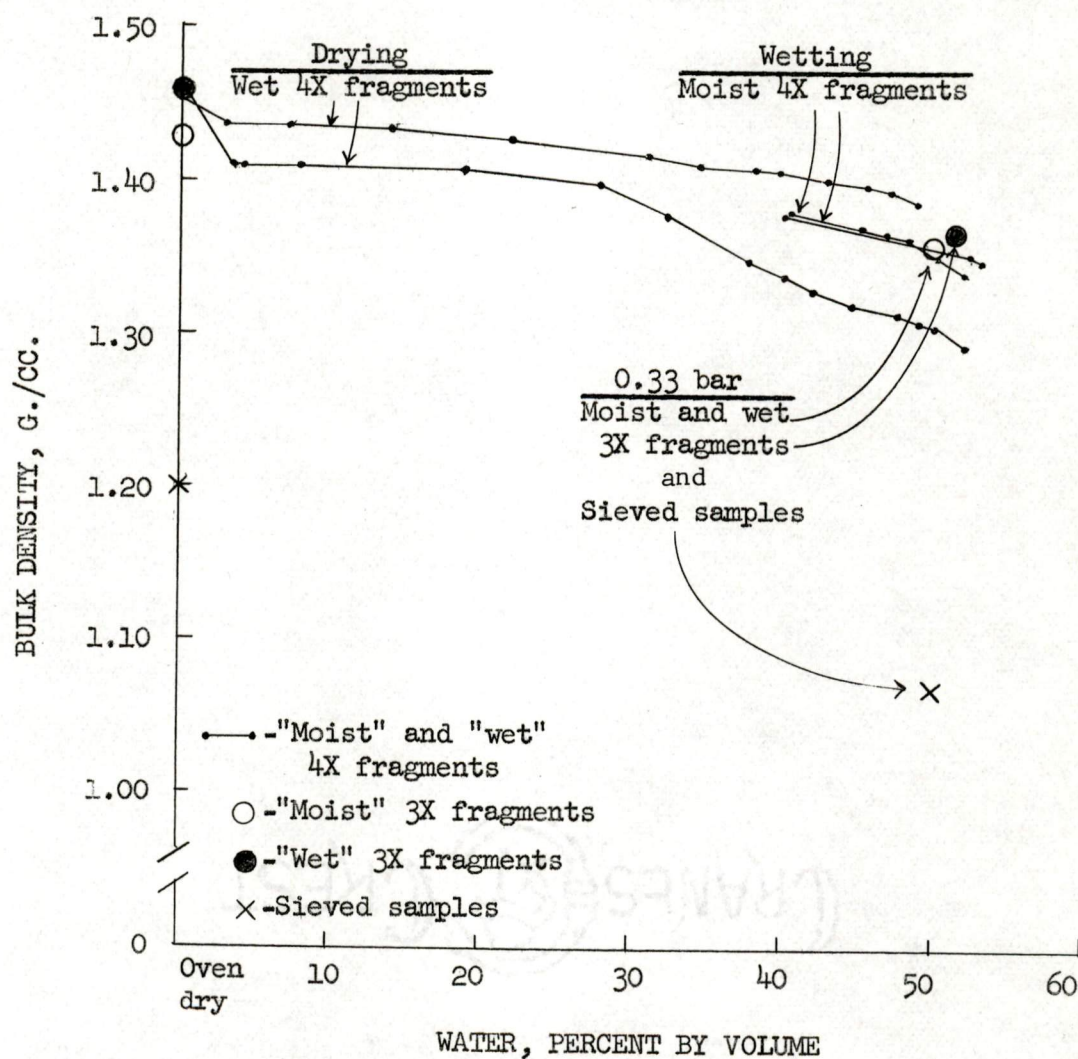


Figure 6 — Change in bulk density with change in water content. Davidson B3 horizon. The lines connect bulk density values of "moist" 4X fragments wetting from field water content and "wet" 4X fragments air-drying from field water content (over a 2-6 week period). Symbolic points locate mean bulk density values of duplicate "moist" 3X fragments, "wet" 3X fragments, and sieved samples at 0.33 bar and oven-dryness and "moist" cores at field water content.

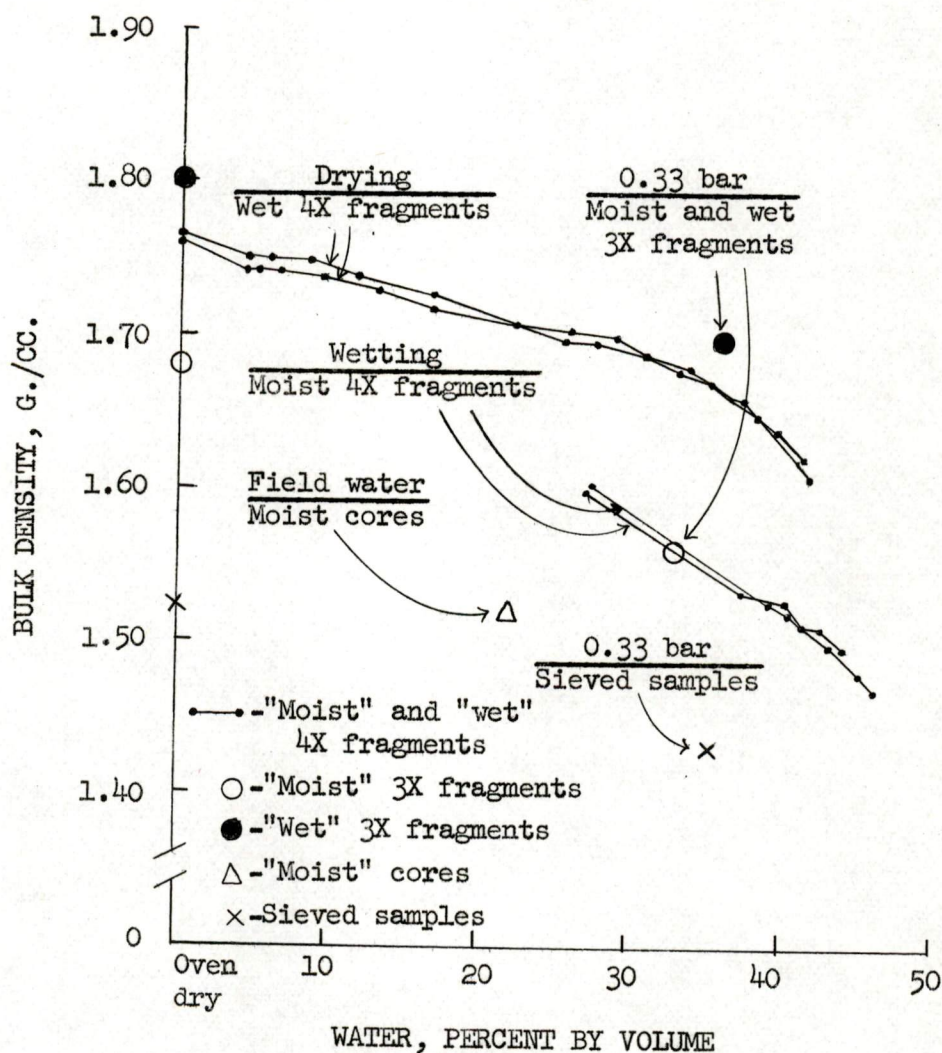


Figure 7 — Change in bulk density with change in water content. Iredell A2g horizon. The lines connect bulk density values of "moist" 4X fragments wetting from field water content and "wet" 4X fragments air-drying from field water content (over a 2-6 week period). Symbolic points locate mean bulk density values of duplicate "moist" 3X fragments, "wet" 3X fragments, and sieved samples at 0.33 bar and oven-dryness and "moist" cores at field water content.

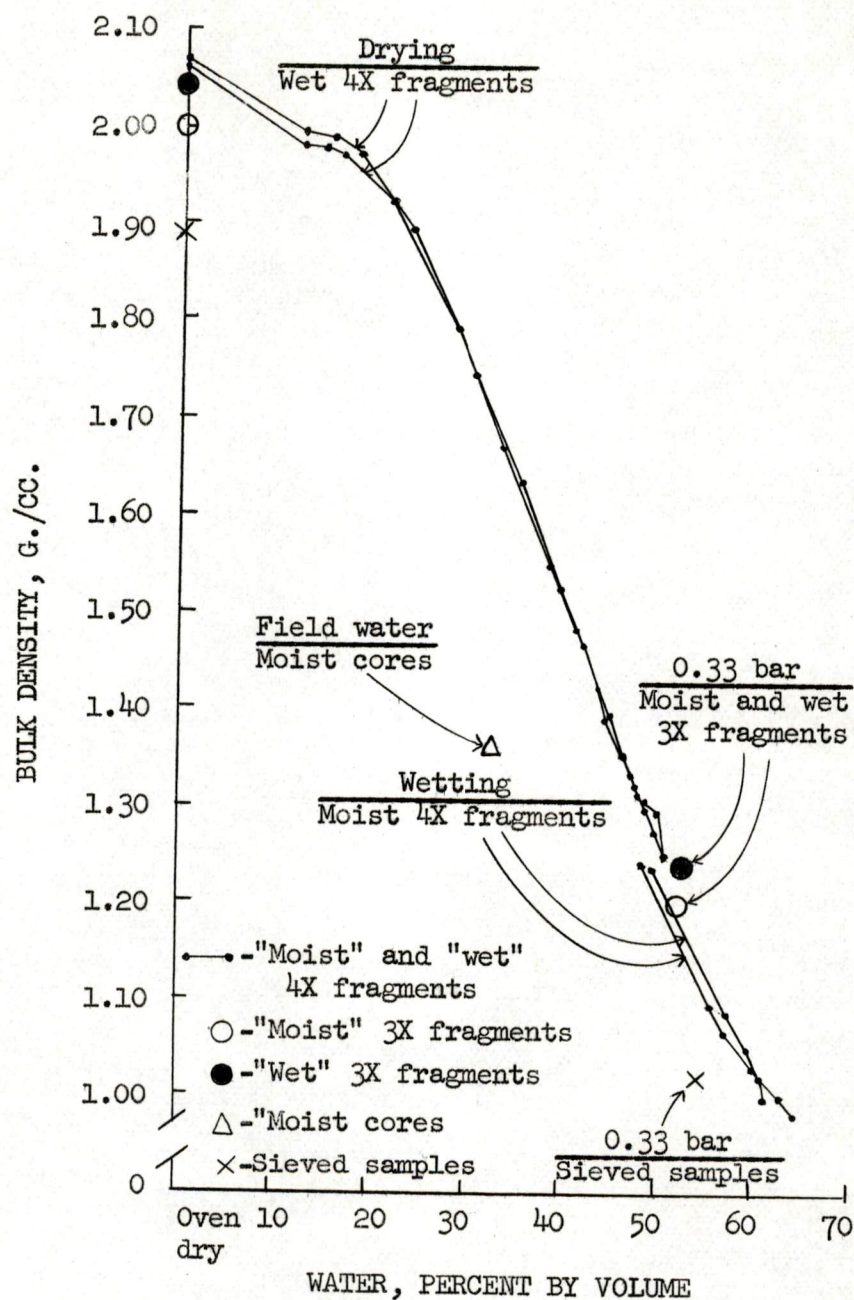


Figure 8 — Change in bulk density with change in water content. Iredell B22g horizon. The lines connect bulk density values of "moist" 4X fragments wetting from field water content and "wet" 4X fragments air-drying from field water content (over a 2-6 week period). Symbolic points locate mean bulk density values of duplicate "moist" 3X fragments, "wet" 3X fragments, and sieved samples at 0.33 bar and oven-dryness and "moist" cores at field water content.

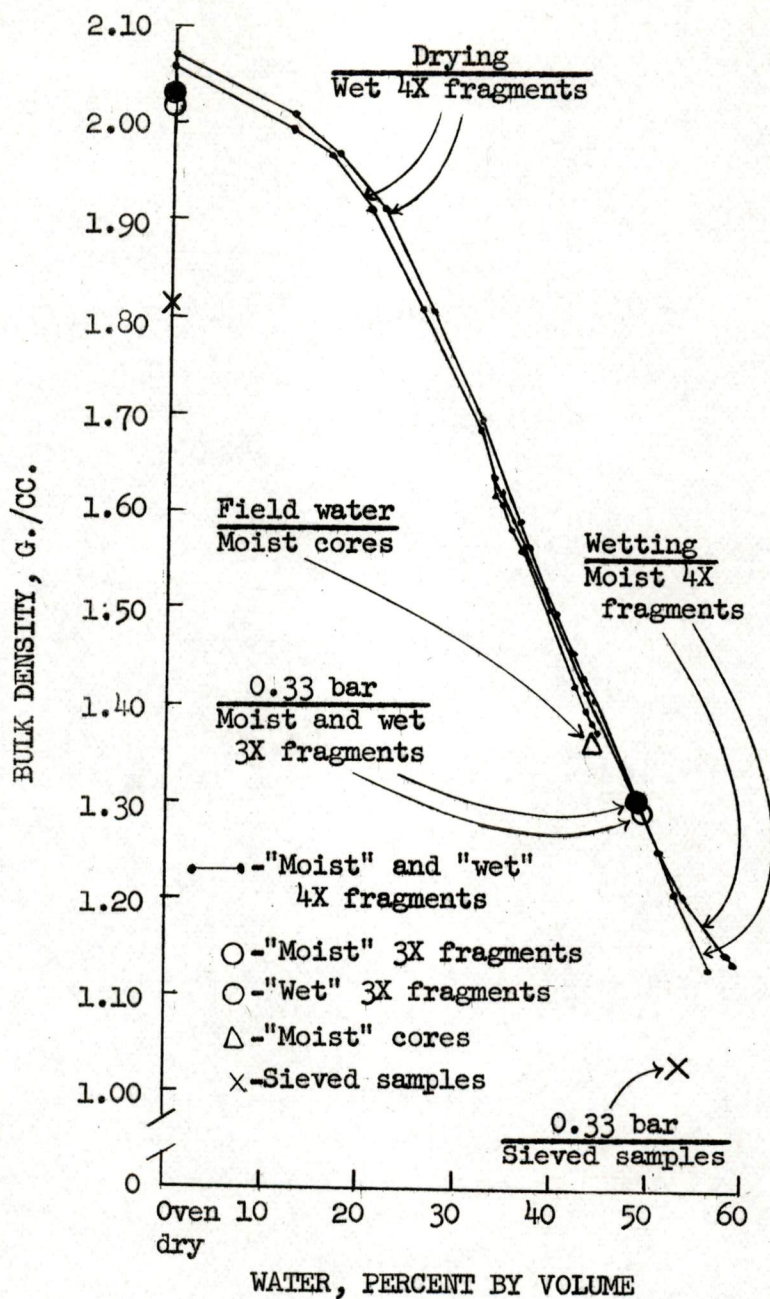


Figure 9 — Change in bulk density with change in water content. Iredell B3lg horizon. The lines connect bulk density values of "moist" 4X fragments wetting from field water content and "wet" 4X fragments air-drying from field water content (over a 2-6 week period). Symbolic points locate mean bulk density values of duplicate "moist" 3X fragments, "wet" 3X fragments, and sieved samples at 0.33 bar and oven-dryness and "moist" cores at field water content.

"moist" and "wet" 4X fragments of B horizons at a given water content and would probably be attributed to sample variability rather than to compaction if compared exclusive of differences between A horizons.

If allowances are made for the differences among fragments, obvious in some of the horizons, the bulk density values connected by lines could be thought of as showing average change in bulk density of fragments of Leonardtown B'Xlg horizon between saturation and oven-dryness was about 0.10 g./cc. and less than that of fragments of other horizons. Most of the change occurred when the cemented fragments slaked down at or near saturation (28-30 percent water). Change in bulk density of fragments of the clay Iredell B horizons was about 1.00 g./cc. and greatly exceeded change in bulk density of fragments of the other horizons. Change in bulk density of fragments of the silt loam Iredell A2g horizon was about 0.25 g./cc. and slightly exceeded change in bulk density of fragments of Davidson clay loam A3, clay B22, and clay B3 horizons. Change in bulk density of fragments of Leonardtown silt loam A2g and silty clay loam B2lg horizons was about equal to change in bulk density of fragments of Iredell A2g horizon. Thus the greatest change in bulk density was apparently due to the predominance of montmorillinite in fragments of the Iredell B horizons. The least change in bulk density was apparently due to cementation of soil particles in fragments of Leonardtown B'Xlg horizon. Change in bulk density of fragments of non-cemented kaolinitic horizons was about 25 percent of change in bulk density of fragments of montmorillinitic B horizons and about twice as great as change in bulk density of fragments of the cemented B'Xlg horizon.

Points representing 3X fragments, sieved samples, and cores were plotted on the graphs for visual comparisons of water content and bulk density with that of 4X fragments. Except for bulk density of cores and sieved samples, differences among the samples were statistically evaluated, and further comparison would be redundant. Differences between bulk density of "moist" cores at field water content and bulk density of 4X fragments at an equivalent water content ranged from about 0.30 g./cc. lower for cores of Iredell B22g horizon to no difference for cores of Iredell B31g horizon. The average difference was about 0.10 g./cc. Since cores would contain some pore space (including cracks) that would be lost when fragments were broken along natural surfaces of weakness, cores might be expected to have lower bulk density than fragments at a given water content. Furthermore, cores were taken when the soil was below field capacity, and in the non-plastic Davidson and Leonardtown horizons (see profile descriptions), some shattering would be expected. Cores of Davidson B3 horizon were not obtained for that reason. Bulk density of sieved samples was much less than that of other samples. Differences between bulk density of sieved samples and undisturbed samples provided one measure of the effect of crushing and sieving on soil structure of these horizons.

To study change in the volume component of bulk density, volume of soil per unit dry weight of 4X fragments at each level of hydration was calculated as follows:

$$\frac{\text{Volume of soil (cc.)}}{\text{Per unit dry weight (g.)}} = \frac{1}{\text{Bulk density at a given water content}}$$

Individual values were given in Tables 19 and 20. Values for fragments of Davidson B22 and Iredell B22g horizons were chosen to represent kaolinitic and montmorillinitic horizons, respectively, and are plotted as points on graphs connected by lines in Figures 10 and 11. Water, as percent of dry weight and volume of soil per unit dry weight are the y-and x-axis, respectively.

Change in volume per unit dry weight of 4X fragments of Iredell B22g horizon between saturation and oven-dryness was about 0.50 cc./g. Over much of the volume-change range loss in volume of soil and water per unit dry weight was near unity. As the fragments approached air-dryness (about 10 percent water) loss in water greatly exceeded loss in volume of soil per unit dry-weight. According to Haines (27) the inflection point is where air begins to enter soil pores and residual shrinkage begins. Loss in volume of soil and water per unit dry weight of Davidson fragments was for from unity over all of the volume-change range. Between saturation (about 41 percent water) and the apparent inflection point (about 20 percent water) change in volume of soil was about 0.08 cc./g. with a change in water content of about 0.20 cc./g. Between the inflection point and air-dryness (about 2 percent water) there was no change in the volume of fragments with change in water content.

III. PREDICTION OF AVAILABLE WATER HOLDING CAPACITY

Available water holding capacity of soil is defined as the difference between water content at field capacity and water content at

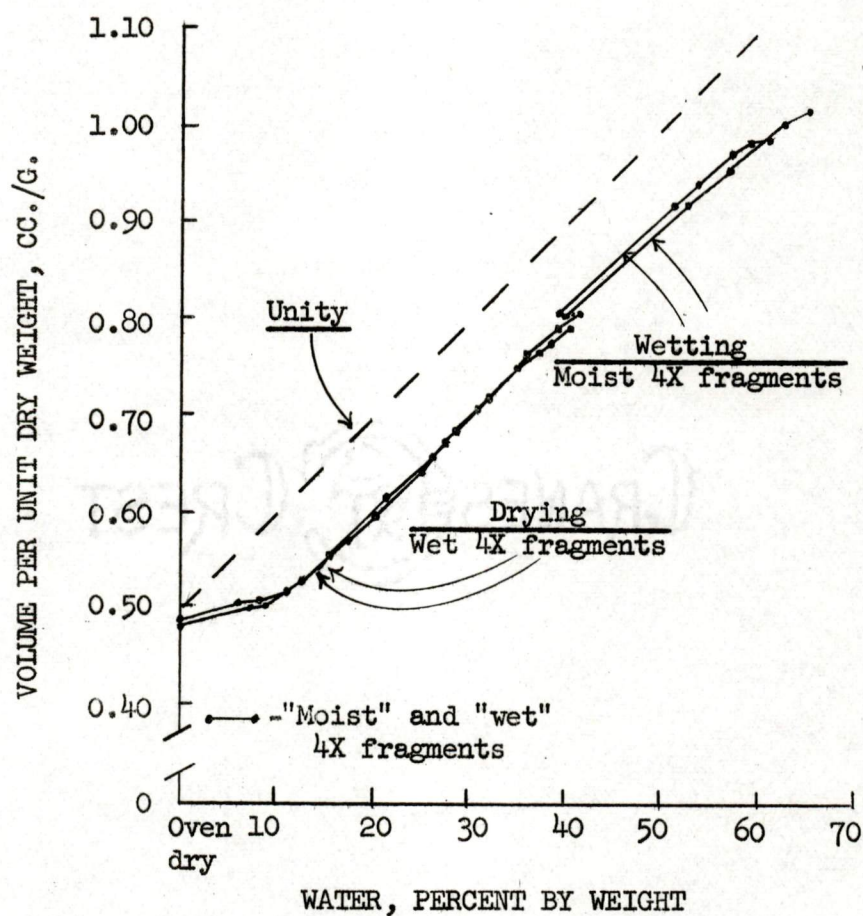


Figure 10 — Change in volume per unit dry weight with change in water content. Iredell B22g horizon. The lines connect volume per unit dry weight values of "moist" 4X fragments wetting from field water content and "wet" 4X fragments drying from field water content (over a 2-6 week period). The unity line would represent an equal change in volume of soil and water per unit dry weight of soil.

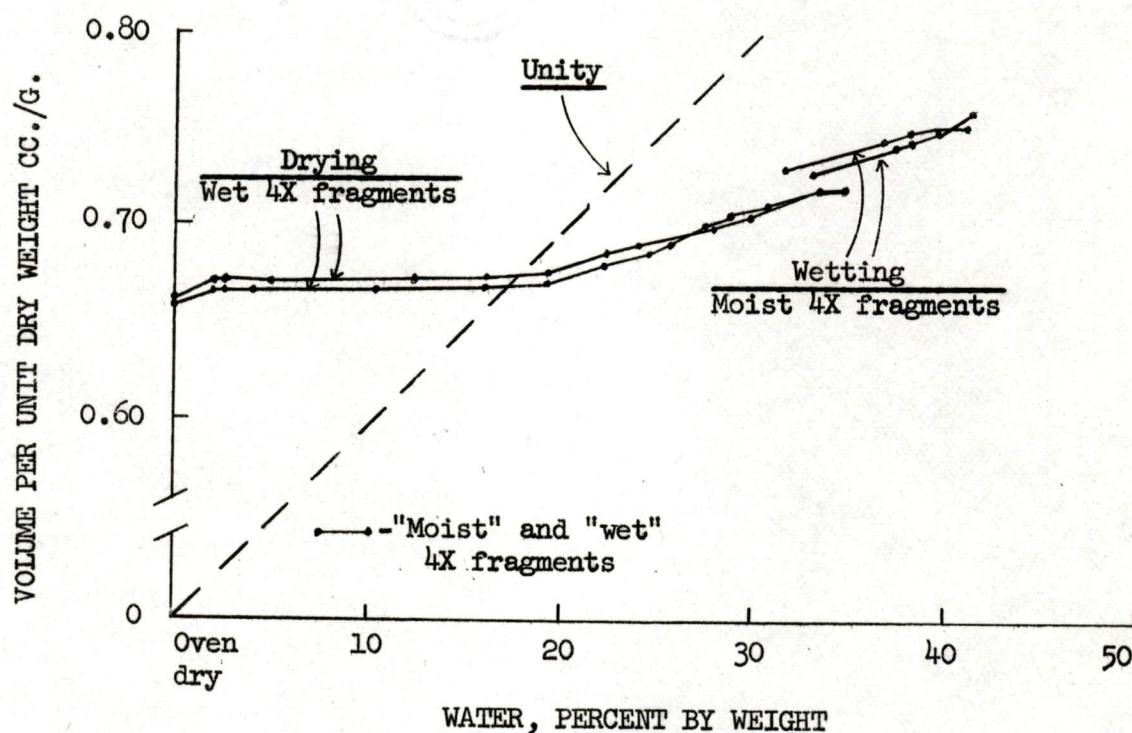


Figure 11 — Change in volume per unit dry weight with change in water content. Davidson B22 horizon. The lines connect volume per unit dry weight values of "moist" 4X fragments wetting from field water content and "wet" 4X fragments drying from field water content (over a 2-6 week period). The unity would represent an equal change in volume of soil and water per unit dry weight of soil.

which plants permanently wilt. Predictions of the permanent wilting point of plants from water retention measurements at 15 bar are very reliable. Predictions of field capacity, however, from water retention measurements at pressures presumably equivalent to total soil suction at field capacity are less reliable. Usually both measurements of water retention are expressed as percent of dry weight and available water holding capacity is predicted by multiplying the difference between measurements by bulk density of undisturbed samples at field water content. As shown in this study bulk density changes with change in water content, especially in montmorilinitic horizons. Hence, predictions of available water holding capacity involving bulk density at field water content may be imprecise. Furthermore, prediction of available water holding capacity that involves water retention measurements by sieved samples at 0.33 bar may also be imprecise. As shown by Young and Dixon (86) and in this study, water retention by sieved samples at 0.33 bar exceeded that of undisturbed samples when expressed as percent of dry weight of the sample.

It was suggested previously that increase in water retention caused by sieving was caused mainly by alteration of soil structure and that the magnitude of the increase varies with degree of aggregation, clay mineralogy, and texture of samples of the horizons. The following equation was used to make predictions of available water holding capacity for determining the effect of differences in water retention between sieved and undisturbed samples on the predictions. Thus

$$AWHC = (WW_e - WW_{15 \text{ bar}}) \times Db \times L$$

where AWHC is available water in inches per horizon, WW_e is water content as percent of dry weight of sieved samples, "moist" 3X fragments, or cores at 0.33 bar, $WW_{15 \text{ bar}}$ is permanent wilting percentage, Db is bulk density of cores or "moist" 3X fragments at field water content and 0.33 bar, respectively, and L is thickness of a horizon in inches. Bulk density of fragments was arbitrarily used for predictions with sieved samples.

As shown in Table 14, there was less difference among predictions by sieved and undisturbed samples of A horizons. There was little or no aggregation of particles in A horizons and, as indicated by bulk density and consistence, no cementation or field compaction. Hence sieving did not result in creation of many additional water holding pores. Predictions by sieved samples of Leonardtown B'Xlg and Iredell B horizons, however, were respectively about 3 and 2 times as high as predictions by fragments. The structure of the horizons is massive but the Leonardtown horizon is cemented and dense while the Iredell horizons are plastic and swell with increase in water content. Crushing and sieving samples results in creation and random arrangement of less than 2mm. fragments that increases both filled and drained pores at 0.33 bar. In addition, sieved samples of the Iredell montmorillinitic B horizons swell without restriction during equilibration which, probably, further increases the amount of both filled and drained pores at 0.33 bar. Predictions by sieved samples of Leonardtown B21 g and Davidson B horizons were also higher than predictions by fragments. Soil peds were well developed in these horizons and the main effect of sieving was to break the peds into a mixture of less than 2mm. aggregates or fragments of

Table 14 — Inches of available water predicted by various sampling methods of certain horizons of Leonardtown, Davidson, and Iredell soils.^a

Soils and horizons	Thickness in inches	Water, % by weight 15 bar	Available water, inches		
			Moist cores	Moist 3X fragments	Sieved samples
Leonardtwn					
A2g	4	5.6	0.9	1.1	1.3
B21g	5	15.7	0.8	0.8	1.3
B'X1g	6	9.5	0.6	0.5	1.6
Davidson					
A3	3	14.1	—	0.9	0.8
B22	25	24.8	3.1	3.6	4.4
B3	16	20.5	—	3.5	5.7
Iredell					
A2g	4	10.0	0.6	0.7	0.9
B22g	9	27.1	2.2	1.7	2.9
B31g	3	24.1	0.4	0.5	1.1

^aEach value at 15 bar is the mean for duplicate sieved samples. Other values were calculated from mean values of duplicate samples.

aggregates which increased both filled and drained pores at 0.33 bar.

Predictions of available water holding capacity involving bulk density of cores at field water content and water content of cores at 0.33 bar were quite similar to predictions involving bulk density and water content of fragments at 0.33 bar. Differences between predictions ranged from 0.5 inch more for cores of Iredell B22g horizon to 0.5 inch less for cores of Davidson B22g horizon. Lack of difference, however, does not necessarily mean that bulk density and water content of cores was equal to bulk density and water content of fragments.

In the predicting equation, water as percent of weight is converted to water as percent of volume by multiplying weight percent water by bulk density. The other values in the equation are constant. Since bulk density and water content vary inversely, however, their net effect may be mutual compensation. Thus the product of a low bulk density and high water content obtained with one kind of samples may or may not equal the product of a higher bulk density and lower water content obtained with the other kind of samples. Hence differences between prediction by cores and fragments may be non-existent, small, or large depending on difference between bulk densities and differences between water contents of the samples.

CHAPTER V

SUMMARY AND CONCLUSIONS

"Moist" soil fragments, cores, and bulk samples were collected from selected horizons of 3 widely different soils at water contents below field capacity; "wet" fragments were collected when the soils were presumably at field capacity. Four "moist" and four "wet" fragments of each horizon were coated with Saran plastic to "waterproof" them for volume measurements by water displacement. Duplicate "moist" and "wet" fragments of each horizon were used to determine bulk density and water retention at 0.33 bar. The remaining "moist" and "wet" fragments were used to measure shrinkage and swelling. Field bulk density and water content of duplicate "moist" cores was determined. Water content of the cores and water content and bulk density of sieved samples at 0.33 bar were also determined. Certain determinations by each kind of duplicate samples were compared statistically. Available water holding capacity of each horizon was predicted to determine differences in the predictions due to differences in water retention by cores, fragments, and sieved samples at 0.33 bar. The main findings are outlined below.

1. Variance due to methods among determinations of water content as percent of dry weight of cores, "moist" and "wet" 3X fragments, and sieved samples at 0.33 bar was significant at the 0.05 level of probability. Duncans Multiple Range Test of means at the 0.05 level of probability showed that the mean of sieved sample values was significantly higher than

the other means. Variance was not significant when water content was expressed as percent of volume of the samples at 0.33 bar.

2. Variance due to methods was not significant among determinations of bulk density and water content of "moist" and "wet" 3X fragments at 0.33 bar and "wet" 4X fragments presumably at field capacity. This indicates that bulk density and water content of fragments at 0.33 bar could be used to accurately predict bulk density and water content of fragments at field capacity.

3. Some small consistent differences in bulk density of "moist" and "wet" 3X and 4X fragments were not significant at 0.33 bar but were significant at oven-dryness at the 0.05 level of probability. The differences were attributed to the net effect of compaction of "wet" fragments and cyclic wetting and drying of equilibrated fragments.

4. Change in bulk density with change in water content of fragments of montmorillinitic B horizons greatly exceeded change in bulk density of fragments of other horizons. Change in bulk density of fragments of subsurface horizons in the absence of the constrictive force of the soil mass may not be equivalent to change in bulk density of the horizons in the field. To an unknown extent, however, the constrictive force of the plastic coating may partially substitute for that of the soil mass.

5. Predictions of available water holding capacity by sieved samples of B horizons were much higher than predictions by cores or fragments of B horizons. There was less difference between predictions by sieved and undisturbed samples of A horizons. Differences between

predictions in both kinds of horizons by cores and fragments were small and inconsistent.

The fragment method has advantages over the core method for determining bulk density and water retention because:

1. Fragments can be collected from stony soils and over a wide range of field water content without alteration of soil structure, and
2. Bulk density of fragments can be simply and precisely determined after adjustment of the water content of fragments. Available water holding capacities of medium and fine textured soils should be predicted using determinations of bulk density and water retention of undisturbed samples equilibrated at "field capacity" in the predicting equation.

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LITERATURE CITED

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APPENDIXES

CRANES  CREST

APPENDIX A Profile description of Leonardtown silt loam.

Soil survey numbers: S58Md.-16-1-(1-11)

Location: Prince Georges County, Maryland. One-half mile south-southwest from TB, Maryland on east side Route 373. Along telephone cable right-of-way 490 feet east side of pole No. 171 and 40 feet to left of right-of-way.

Physiography and Relief: Undissected flat area of Brandywine terrace; slope 0-1 per cent.

Vegetation: Second growth white and red oak, red and black gum, maple, Virginia scrub pine with an understory mostly of blueberry and wild azalea.

Described by: W. Holton, M. Bailey, R. Kirby, and R. Grossman
September 25, 1958.

Remarks: Loess has evidently influenced the upper portion of the solum, particularly the first 15 inches. Scattered quartzite gravel observed below A'2g-B'22g. Profile is on wet side of Leonardtown, grading toward Elkton.

<u>Horizon</u>	<u>Depth-inches</u>	<u>Description</u>
A00	2-1	Undecomposed forest litter.
A0	1-0	Black (10YR 2/1) decomposed forest litter. Abundant roots largely removed in sampling.
A1	0-1	Dark gray (5Y 4/1); silt loam; weak medium crumb; friable; roots common; abrupt and wavy.
A2g	1-5	Light brownish-gray (2.5Y 6/3) with distinct common medium light gray and light olive brown mottles; silt loam; massive to weak fine platy; friable; roots abundant; clear and smooth.

<u>Horizon</u>	<u>Depth-inches</u>	<u>Description</u>
A3g	5-9	Light olive brown (2.5Y 5/3) with distinct many medium light brownish-gray and olive-yellow mottles; silt loam; weak coarse subangular blocky; friable to firm; roots common; clear and smooth.
Blg	9-12	Light olive brown (2.5Y 5/3) with prominent many medium yellowish-brown and light brownish-gray mottles, and with grayish-brown (2.5Y 5/2) ped surfaces showing no evidence of current clay illuviation; fine silt loam; moderate medium subangular blocky; friable to firm; roots common; clear and smooth.
B2lg	12-17	Ped interiors grayish-brown (2.5Y 5/2) with prominent many medium strong brown and gray mottles, and with grayish brown (2.5Y 5/2) ped surfaces showing no evidence of current clay illuviation; silty clay loam; strong medium to coarse subangular blocky breaking apart into very coarse plates; roots common; firm; clear and smooth.
A'2g-B'22g	17-22	Discontinuous bands of strong brown (7.5YR 5/6) and gray (2.5Y 5/0), with many of the peds having gray peripheries and strong brown central portions; silty clay loam; moderate coarse platy; firm; few roots; abrupt and smooth.
B'Xlg	21-31	Gray (2.5Y 5/1) with prominent many medium yellowish-brown and gray mottles; and with one-inch wide, gray (2.5Y 5/0), clay-rich wedges having strong brown peripheries, these wedges extending with decreasing width and expression to a depth of 55 inches and outlining polygons roughly 8 inches in diameter; silty clay loam (wedges silty clay or clay); massive with tendency to platiness in upper 6 inches; very firm; moderately vesicular; weak clay flow surface along numerous discontinuous horizontal and a few vertical cleavage planes, and around vesicles; few roots restricted to gray planes; diffuse.

<u>Horizon</u>	<u>Depth-inches</u>	<u>Description</u>
B'X2g	31-49	Gray (5Y 5/1) with prominent many coarse strong brown and gray mottles; silty clay loam; massive; very firm to firm; weakly vesicular; scattered clay flow surface along void walls (less common than in horizon above); few roots restricted to gray wedges; diffuse.
Clg	49-70+	Gray (2.5Y 5/0) with prominent many coarse strong brown mottles; silty clay loam; massive; firm; wet vesicular; a little active clay flow along discontinuous cleavage planes; a few roots extending into upper portion following along the gray wedges.

CRANES CREST

APPENDIX B Profile description of Iredell silt loam.

Soil survey numbers: S58Va.-24-1-(1-10)

Location: Culpepper County, Virginia. Six-tenths of a mile north-northeast of Winston, Virginia on state route 615 and 50 feet west of Southern Railroad cut.

Physiography and relief: Undissected flat area of Piedmont of Virginia; slope 0-1 per cent.

Vegetation: Second growth, red and white oak, post oak, and Virginia scrub pine. Thick understory of wild azalea and blueberry and blackberry.

Described by: R. Grossman, K. Flach, and R. Vanden Heuvel

Remarks: Occasionally, separation of the B3g horizon into B31g and B32g horizons may be justified.

<u>Horizon</u>	<u>Depth-inches</u>	<u>Description</u>
A00 and A0	1-0	Mixed partly decayed and fresh forest litter.
A11g	0-2	Very dark gray (10YR 3/1) moist, though at sampling moisture, on intermingling of black and light gray, silt-rich concentrations are apparent; fine silt loam; weak medium to fine granular; friable; numerous roots; abrupt and smooth boundary.
A2g-A12g	2-6	Very dark grayish-brown (2.5Y 3/1) with faint common medium to fine light olive gray and yellowish-brown mottles and with light brownish-gray silt-rich concentrations plentiful throughout that disappear on moistening; fine silt loam; weak coarse subangular to massive; firm; numerous spherical Fe-Mn concretions; roots are common; weakly vesicular; abrupt and smooth boundary.

<u>Horizon</u>	<u>Depth-inches</u>	<u>Description</u>
B1g	6-10	Dark grayish-brown (2.5Y 4/3) with very dark grayish-brown (2.5Y 3/2) along weak cleavage planes, with scattered light brownish-gray silt-rich concentrations that disappear on moistening and with distinct common fine yellowish-red mottles; clay loam ?; weak coarse subangular blocky to massive; extremely firm; roots are few to common; Fe-Mn spherical concretions (1/2 - 2mm. in diameter) are extremely abundant; clear and smooth boundary.
B21g	10-16	Very dark grayish-brown (2.5Y 3/2) clay; massive breaking apart under careful manipulation into angular, highly triclinic structural elements; with prominent slickenside on the larger planes; slightly sticky and plastic; numerous spherical Fe-Mn concretions 1/2 - 2 mm. in diameter); few roots distributed in no relation to the fracture pattern; gradual and smooth boundary.
B22g	16-25	Dark grayish-brown 2.5Y 4/3) with some of the larger fracture surfaces (2.5Y 4/2) clay; massive breaking apart under careful manipulation into angular, highly triclinic structural elements, and with prominent slickensides on some of the larger cleavage faces; sticky to slightly sticky and plastic; few roots at random to fracture planes; numerous small (less than 1/2 mm.) spherical Fe-Mn concretions; a few primary ferro-magnesium minerals observable; abrupt and wavy boundary.
B3g	25-30	Olive brown (2.5Y 4/4 to 10YR 5/4) silty clay loam; massive; firm, breaking to plastic and slightly sticky; numerous pockets of very dark grayish-brown clay; primary ferro-magnesium minerals common; abrupt and irregular boundary.
C1	30-37	Olive(5Y 5/3) loamy fine sand with irregularly shaped inclusions (3/4" diameter) of brown (10YR 4/3) clay; massive; firm; lower boundary gradual and irregular. In this horizon the feldspars are strongly weathered and hornblende and augite are weakly weathered; this horizon is dissected by cracks that continue into the underlying horizons. Most commonly these

<u>Horizon</u>	<u>Depth-inches</u>	<u>Description</u>
		cracks occur at an angle of about 30° to the vertical. Two types of cracks with two types of cracked-soil mass interfaces were observed. They are: (1) cracks not followed by roots. The interfaces are yellowish-brown (10YR 5/6) with many fine and distinct pale brown (10YR 6/3) areas, which do not appear to be drainage mottles and common fine and prominent black (10YR 2/1) manganese? concretions. The brown interface material is very thin (less than 1 mm.) but distinct; it does not show evidence of clay flow and (2) cracks followed by roots. These cracks possess distinct accretive surfaces at their interfaces with the soil mass. They are dark yellowish-brown (10YR 4/4 to 3/4) clay and are partially coated by free calcium carbonate in a conspicuous root hair pattern.
C2	37-45	This horizon is similar to the C1 but the feldspars are less strongly weathered and lighter in color than in the C1 horizon. The feldspars are pale olive (5Y 6/3).
C3	45-61	This horizon is similar to the C2 but the feldspars are light gray (2.5Y 7/2). The streaks many of which have a tendency to be parallel to each other, decrease in frequency with depth. The lowest streak of type 2 (filled with calcium carbonate and clay skins) terminate at a depth of about 61 inches.
C4	61-79	Similar to the C3 but the clay-filled streaks are lacking; weakly developed streaks of type 1 are still observed and continue through this horizon. The lower boundary is taken arbitrarily.

APPENDIX C Profile description of Davidson clay loam.

Soil survey numbers: S59Va.-69-1-(1-7)

Location: Orange County, Virginia. Two miles south-southeast of Orange, Virginia and 0.7 mile along a private lane that intersects state route 647 from the east. Site located on a broad ridge.

Physiography and relief: Piedmont of Virginia. Local relief from 50 to 200 feet. Slopes range from 2 - 30 per cent.

Vegetation: Old second growth mixed hardwoods with some Virginia scrub pine. Sparse understory.

Described by: J. B. Carter, C. Simonson, and B. Brasher.

<u>Horizon</u>	<u>Depth-inches</u>	<u>Description</u>
A00, A0	1-0	Mixed partly decayed and fresh forest litter.
A1	0-1	Thin and discontinuous. Mixed organic residue and mineral material.
A3	1-4	Dark reddish-brown (5YR 3/4) clay loam; weak medium granular structure; very friable; many fine and medium roots; clear smooth and boundary.
B3	4-9	Dark reddish-brown (2.5YR 3/4) clay loam; moderate medium subangular blocky structure; friable; many medium roots; few quartz fragments; gradual wavy boundary.
B22	9-34	Dark red (10R 3/6) clay; strong medium to fine subangular blocky structure; firm to very firm, few medium and large roots; some yellowish-brown weathered basic rock fragments; common prominent clay skins; gradual wavy boundary.
B23	34-49	Dark red (10R 3/6) clay; strong medium angular blocky structure; firm to very firm; few roots; common prominent clay skins; gradual wavy boundary.

<u>Horizon</u>	<u>Depth-inches</u>	<u>Description</u>
B3	49-65	Mottled light red (2.5YR 6/8) and reddish-brown (5YR 5/4) dark red (2.5YR 3/6) clay; moderate medium subangular blocky structure; firm; few prominent clay skins; clear smooth boundary.
C1	65-92+	Reddish-brown and yellowish-red silty clay loam strongly weathered parent material; no definite structure; friable; light in weight; some fragments of slightly weathered basic parent material.

Table 15 — Field water content of duplicate samples of various sampling methods of certain horizons of Leonardtown, Davidson, and Iredell soils.

Soils and horizons	Field water content at sampling					
	Water, % by weight			Water, % by volume		
	Moist cores	Moist 4X frag- ments	Wet 4X frag- ments	Moist cores	Moist 4X frag- ments	Wet 4X frag- ments
Leonardtown						
A2g	19.24	17.96	25.46	27.44	27.92	39.51
	18.61	18.35	27.45	26.75	27.23	40.94
B21g	22.63	23.37	32.96	32.30	35.01	45.30
	22.35	20.50	27.08	30.92	31.52	40.76
B'X1g	12.31	11.90	14.67	21.08	22.00	26.49
	12.00	12.87	16.61	20.06	23.52	29.35
Davidson						
A3	33.75	29.81	39.92	—	35.03	47.78
	34.75	29.18	42.01	—	35.12	48.72
B22	31.40	31.96	34.88	36.94	43.68	48.22
	32.18	33.25	34.62	41.83	45.50	47.98
B3	26.82	28.93	34.97	—	39.96	48.57
	27.16	29.45	40.02	—	40.59	51.98
Iredell						
A2g	14.62	17.11	25.98	21.18	27.44	41.90
	14.13	16.84	25.28	22.59	26.97	41.05
B22g	32.83	38.66	41.58	44.58	48.07	51.46
	32.33	40.30	40.08	43.88	49.94	50.56
B31g	21.63	23.82	32.72	35.49	37.31	44.91
	22.71	20.66	31.42	36.16	33.62	44.17

Table 16 — Water content of duplicate samples at 0.33 bar by various sampling methods of certain horizons of Leonardtown, Davidson, and Iredell soils.

Soils and horizons	Water, % by weight 0.33 bar				Water, % by vol. 0.33 bar		
	Moist 3X		Wet 3X		Moist 3X	Wet 3X	Sieved samples
	Moist cores	frag-ments	frag-ments	Sieved samples	frag-ments	frag-ments	
Leonardt own							
A2g	22.14	22.45	27.36	28.02	33.97	40.41	39.28
	21.46	25.09	26.47	27.32	36.46	39.31	38.74
B21g	27.95	26.83	29.79	33.79	39.73	42.38	39.74
	27.85	27.84	30.64	33.63	39.74	43.16	39.88
B'X1g	15.59	14.20	15.02	23.96	25.46	27.62	34.14
	16.07	14.64	14.99	24.03	26.53	27.22	34.00
Davidson							
A3	38.24	39.00	40.15	36.23	45.63	44.50	34.09
	38.59	40.02	39.47	36.68	44.02	45.02	34.08
B22	33.93	36.69	36.49	38.18	47.00	49.18	40.97
	34.45	34.75	33.92	38.20	46.74	47.17	41.45
B3	35.16	38.51	37.95	46.61	51.68	51.90	49.92
	37.06	34.61	36.86	46.95	47.87	50.56	50.19
Iredell							
A2g	19.71	19.17	20.59	24.24	30.86	35.22	34.76
	18.70	23.00	21.75	35.10	34.88	36.45	35.78
B22g	42.26	43.55	42.82	53.34	52.89	52.78	53.74
	48.24	43.01	42.58	54.06	51.40	52.62	55.90
B31g	30.66	38.12	39.33	52.19	49.94	49.81	53.70
	34.75	39.08	36.81	52.17	49.24	48.73	53.60

Table 17 — Particle density, bulk density at 0.33 bar, and field water content of duplicate samples of certain horizons of Leonardtown, Davidson, and Iredell soils.

Soils and horizons	Part- icle density g./cc.	Bulk density, g./cc.					
		0.33 bar			Field water		
		Moist 3X frag- ments	Wet 3X frag- ments	Sieved samples	Moist 4X frag- ments	Wet 4X frag- ments	Moist cores
Leonardtown							
A2g	2.64	1.51	1.48	1.40	1.55	1.55	1.42
	2.63	1.45	1.48	1.42	1.48	1.49	1.46
B21g	2.68	1.48	1.42	1.18	1.54	1.37	1.36
	2.68	1.43	1.41	1.19	1.50	1.50	1.38
B'X1g	2.68	1.79	1.84	1.43	1.85	1.83	1.71
	2.66	1.81	1.82	1.42	1.83	1.77	1.70
Davidson							
A3	2.71	1.17	1.11	0.94	1.18	1.20	—
	2.70	1.10	1.14	0.93	1.14	1.16	—
B22	2.91	1.28	1.35	1.07	1.37	1.38	1.37
	2.93	1.34	1.39	1.08	1.37	1.39	1.30
B3	2.88	1.34	1.37	1.07	1.38	1.39	—
	2.87	1.38	1.37	1.07	1.38	1.30	—
Iredell							
A2g	2.84	1.61	1.71	1.43	1.60	1.61	1.45
	2.83	1.51	1.68	1.42	1.60	1.62	1.60
B22g	2.78	1.26	1.23	1.01	1.24	1.24	1.36
	2.77	1.18	1.24	1.03	1.24	1.26	1.36
B31g	2.84	1.31	1.27	1.03	1.56	1.37	1.64
	2.84	1.26	1.32	1.03	1.63	1.41	1.59

Table 18 — Bulk density of duplicate samples at oven-dryness by various sampling methods of certain horizons of Leonardtown, Davidson, and Iredell soils.

Soils and horizons	Bulk density at oven-dryness, g./cc.				Sieved samples
	Moist 3X frag-ments	Wet 3X frag-ments	Moist 4X frag-ments	Wet 4X frag-ments	
Leonardtown					
A2g	1.54	1.52	1.57	1.63	1.45
	1.48	1.51	1.53	1.56	1.47
B21g	1.62	1.62	1.64	1.64	1.38
	1.61	1.70	1.64	1.66	1.39
B ¹ X1g	1.83	1.87	1.85	1.87	1.54
	1.87	1.86	1.84	1.82	1.51
Davidson					
A3	1.27	1.21	1.27	1.28	1.06
	1.20	1.24	1.22	1.28	1.04
B22	1.41	1.46	1.47	1.52	1.21
	1.46	1.50	1.48	1.52	1.22
B3	1.41	1.46	1.44	1.45	1.19
	1.45	1.46	1.42	1.46	1.21
Iredell					
A2g	1.71	1.82	1.69	1.77	1.53
	1.66	1.78	1.68	1.76	1.52
B22g	2.01	2.03	2.10	2.06	1.89
	1.98	2.04	2.06	2.07	1.89
B31g	2.05	2.00	2.13	2.06	1.80
	2.01	2.03	2.06	2.07	1.82

Table 19 — Determinations of water content, bulk density, and volume per unit dry weight of duplicate "wet" 4X fragments at different levels of hydration.^a

Bulk density g./cc.		Vol. per unit weight, cc./g.		Water, % by weight		Water, % by volume	
A	B	A	B	A	B	A	B
Leonardtown, A2g horizon							
1.55	1.49	0.64	0.67	25.5	27.4	39.5	40.9
1.56	1.50	0.64	0.67	25.1	27.0	39.2	40.4
1.57	1.50	0.64	0.67	24.5	26.2	38.5	39.4
1.58	1.50	0.63	0.66	24.1	25.7	37.9	38.7
1.58	1.51	0.63	0.66	23.3	24.9	36.9	37.6
1.59	1.52	0.63	0.66	23.0	24.2	36.5	36.7
1.59	1.52	0.63	0.66	21.8	22.3	24.8	33.9
1.60	1.52	0.63	0.66	20.7	21.0	33.0	32.0
1.60	1.53	0.62	0.66	19.5	19.4	31.2	29.6
1.60	1.53	0.62	0.65	18.6	18.1	29.8	27.7
1.60	1.53	0.62	0.65	16.7	15.4	26.8	23.6
1.61	1.54	0.62	0.65	14.5	12.6	23.4	19.3
1.62	1.54	0.62	0.65	11.0	8.6	17.7	13.2
1.62	1.54	0.62	0.65	7.4	5.4	12.0	8.4
1.63	1.55	0.61	0.65	4.4	2.9	7.2	4.4
1.63	1.55	0.61	0.65	1.3	1.2	2.1	1.8
1.63	1.56	0.61	0.64	—	—	—	—
Leonardtown, B2lg horizon							
1.37	1.50	0.73	0.66	33.0	27.1	45.3	40.8
1.39	1.52	0.72	0.66	30.6	24.9	42.4	37.8
1.44	1.56	0.70	0.64	26.9	20.8	38.6	32.4
1.47	1.58	0.68	0.64	24.7	18.2	36.1	28.5
1.49	1.59	0.67	0.63	22.6	15.9	33.7	25.3
1.52	1.60	0.66	0.62	20.4	14.0	31.0	22.5
1.54	1.62	0.65	0.62	18.1	10.6	27.8	17.2
1.55	1.62	0.64	0.62	16.6	10.4	25.8	16.9
1.57	1.62	0.64	0.62	13.5	7.5	21.2	12.2
1.59	1.64	0.63	0.61	11.6	6.3	18.4	10.3
1.59	1.63	0.63	0.62	8.6	4.6	13.7	7.5
1.59	1.63	0.63	0.61	6.6	3.6	10.6	5.9
1.59	1.63	0.63	0.61	4.5	2.6	7.1	4.2
1.58	1.62	0.63	0.62	3.7	2.1	5.9	3.5
1.58	1.62	0.63	0.62	3.4	2.4	5.3	3.9
1.58	1.62	0.63	0.62	3.3	2.3	5.2	3.8
1.64	1.66	0.61	0.60	—	—	—	—

Table 19 — (Continued)

Bulk density g./cc.		Vol. per unit weight, cc./g.		Water, % by weight		Water, % by volume	
A	B	A	B	A	B	A	B
Leonardtown, B'Xlg horizon							
1.83	1.77	0.55	0.57	14.5	16.6	26.5	29.4
1.83	1.77	0.55	0.56	14.1	16.2	25.9	28.6
1.84	1.77	0.54	0.56	13.4	15.3	24.6	27.2
1.84	1.77	0.54	0.56	13.0	14.8	23.8	26.2
1.84	1.78	0.54	0.56	12.3	14.3	22.6	25.4
1.84	1.78	0.54	0.56	11.9	13.5	21.8	24.1
1.84	1.79	0.54	0.56	10.9	11.9	20.1	21.2
1.84	1.79	0.54	0.56	10.1	10.9	18.6	19.6
1.85	1.80	0.54	0.56	9.1	10.0	16.8	18.0
1.85	1.80	0.54	0.56	8.2	9.0	15.3	16.2
1.85	1.80	0.54	0.55	6.6	7.2	12.3	13.0
1.86	1.80	0.54	0.55	5.1	5.4	9.4	9.8
1.85	1.80	0.54	0.55	3.3	3.5	6.1	6.3
1.85	1.80	0.54	0.55	2.0	2.3	3.8	4.0
1.85	1.81	0.54	0.55	1.6	1.8	2.9	3.3
1.85	1.81	0.54	0.55	1.3	1.6	2.4	2.8
1.87	1.82	0.54	0.55	—	—	—	—
Davidson, A3 horizon							
1.20	1.16	0.82	0.86	39.9	42.0	47.8	48.7
1.20	1.18	0.83	0.85	37.0	41.2	44.4	48.4
1.20	1.18	0.83	0.85	32.9	37.1	39.7	43.7
1.21	1.18	0.83	0.85	30.0	34.0	36.3	40.0
1.21	1.18	0.82	0.84	29.1	32.4	35.3	38.4
1.22	1.19	0.82	0.84	26.8	29.7	32.6	35.2
1.22	1.19	0.82	0.84	23.4	26.3	28.6	31.4
1.22	1.20	0.82	0.84	21.1	24.2	25.8	28.9
1.23	1.20	0.81	0.83	17.6	20.4	21.6	24.5
1.24	1.21	0.80	0.82	13.9	16.7	17.2	20.3
1.26	1.23	0.80	0.81	7.9	12.2	9.9	15.0
1.26	1.23	0.79	0.80	4.0	7.7	5.0	9.6
1.27	1.26	0.79	0.79	2.1	3.4	2.7	4.3
1.26	1.26	0.79	0.79	1.7	2.4	2.2	3.0
1.27	1.27	0.79	0.79	2.0	2.4	2.5	3.1
1.27	1.26	0.79	0.79	1.8	2.2	2.3	2.8
1.28	1.28	0.78	0.78	—	—	—	—

Table 19 — (Continued)

Bulk density g./cc.		Vol. per unit weight, cc./g.		Water, % by weight		Water, % by volume	
A	B	A	B	A	B	A	B
Davidson, B22 horizon							
1.38	1.39	0.72	0.72	34.9	34.6	48.2	48.0
1.39	1.39	0.72	0.72	33.2	33.1	46.0	46.0
1.40	1.40	0.71	0.71	30.7	30.7	43.0	43.2
1.41	1.41	0.71	0.71	28.8	29.0	40.6	41.0
1.42	1.42	0.70	0.70	27.5	27.9	39.2	39.6
1.44	1.43	0.69	0.70	25.7	26.0	37.0	37.3
1.46	1.45	0.69	0.69	23.7	23.8	34.5	34.5
1.47	1.46	0.68	0.69	22.1	22.4	32.5	32.6
1.48	1.47	0.67	0.68	19.4	19.5	38.9	28.7
1.49	1.48	0.67	0.68	16.1	16.3	24.0	24.1
1.50	1.49	0.67	0.67	10.5	11.4	15.7	17.0
1.50	1.49	0.67	0.67	7.2	8.4	10.8	12.5
1.50	1.49	0.67	0.67	4.1	5.1	6.2	7.6
1.50	1.49	0.67	0.67	2.6	2.9	3.9	4.4
1.50	1.49	0.67	0.67	2.1	2.5	3.2	3.8
1.50	1.49	0.67	0.67	1.9	1.9	2.8	2.9
1.52	1.52	0.66	0.66				
Davidson, B3 horizon							
1.39	1.30	0.72	0.77	35.0	40.0	48.6	52.0
1.39	1.30	0.72	0.77	34.5	39.4	48.0	51.2
1.40	1.31	0.72	0.76	33.7	38.3	47.0	50.0
1.40	1.31	0.72	0.76	33.2	37.6	47.0	49.3
1.40	1.32	0.71	0.76	32.4	36.8	45.4	48.4
1.40	1.32	0.71	0.76	32.0	36.0	44.8	47.4
1.40	1.32	0.71	0.76	30.4	33.6	42.7	44.5
1.41	1.33	0.71	0.75	29.6	31.8	41.6	42.2
1.41	1.34	0.71	0.75	28.0	29.7	39.5	39.8
1.41	1.35	0.71	0.74	26.9	27.8	38.0	37.6
1.41	1.38	0.71	0.72	24.2	23.3	34.2	32.2
1.42	1.40	0.71	0.71	21.7	19.7	30.8	27.7
1.43	1.41	0.70	0.71	15.3	13.0	21.8	18.4
1.44	1.41	0.70	0.71	9.5	7.8	13.6	11.0
1.44	1.41	0.70	0.71	5.0	4.2	7.2	6.0
1.44	1.41	0.70	0.71	2.1	2.4	3.0	3.4
1.45	1.46	0.69	0.69				

Table 19 — (Continued)

Bulk density g./cc.		Vol. per unit weight, cc./g.		Water, % by weight		Water, % by volume	
A	B	A	B	A	B	A	B
Iredell, A2g horizon							
1.61	1.62	0.62	0.62	26.0	25.1	41.9	41.0
1.62	1.64	0.62	0.61	25.0	24.2	40.8	39.6
1.65	1.66	0.61	0.60	23.2	22.4	38.4	37.1
1.66	1.67	0.60	0.60	22.0	21.2	36.6	35.4
1.67	1.68	0.60	0.60	21.2	20.1	35.5	33.7
1.68	1.69	0.59	0.59	19.8	18.3	33.2	30.8
1.69	1.70	0.59	0.59	18.2	16.3	30.7	27.6
1.60	1.60	0.59	0.59	17.1	15.1	29.0	25.6
1.70	1.70	0.59	0.59	15.2	13.0	25.8	22.1
1.71	1.72	0.58	0.58	13.0	9.8	22.4	16.8
1.73	1.73	0.58	0.58	9.8	7.6	16.9	13.2
1.74	1.74	0.58	0.58	6.7	5.6	11.7	9.7
1.75	1.74	0.57	0.58	4.9	5.8	8.6	6.6
1.75	1.74	0.57	0.57	3.4	2.9	6.0	5.0
1.75	1.75	0.57	0.57	3.0	2.8	5.3	5.0
1.75	1.74	0.57	0.57	2.5	2.5	4.4	4.4
1.77	1.76	0.57	0.57	—	—	—	—
Iredell, B22 g horizon							
1.24	1.26	0.81	0.79	41.6	40.1	51.5	50.6
1.25	1.27	0.80	0.79	40.5	39.4	50.9	50.0
1.30	1.30	0.77	0.77	38.6	37.7	50.1	48.9
1.31	1.31	0.76	0.76	37.1	36.5	48.5	48.0
1.32	1.33	0.76	0.75	36.1	35.6	47.7	47.4
1.36	1.36	0.74	0.73	34.0	33.9	46.1	46.1
1.39	1.39	0.72	0.72	32.1	32.3	44.7	45.0
1.42	1.42	0.70	0.70	38.0	31.0	43.8	44.0
1.48	1.47	0.67	0.68	27.7	28.7	41.2	42.1
1.55	1.52	0.64	0.66	25.0	26.2	38.8	40.0
1.67	1.63	0.60	0.61	20.1	21.7	33.6	35.5
1.80	1.75	0.56	0.57	15.8	17.6	28.5	30.8
1.93	1.90	0.52	0.53	11.2	12.6	21.6	23.7
1.97	1.97	0.51	0.51	8.4	9.2	16.5	18.2
1.98	1.99	0.50	0.50	7.5	7.8	14.9	15.6
1.98	1.99	0.51	0.50	6.2	6.1	12.3	12.2
2.06	2.07	0.48	0.48	—	—	—	—

Table 19 — (Continued)

Bulk density g./cc.		Vol. per unit weight, cc./g.		Water, % by weight		Water, % by volume	
A	B	A	B	A	B	A	B
Iredell, B3lg horizon							
1.37	1.41	0.73	0.71	32.7	31.4	44.9	44.2
1.38	1.41	0.72	0.71	32.2	30.9	44.4	43.7
1.40	1.43	0.72	0.70	31.4	30.3	43.8	43.2
1.40	1.43	0.71	0.70	30.9	29.9	43.4	42.8
1.42	1.45	0.70	0.69	30.1	29.0	42.7	42.2
1.43	1.46	0.70	0.68	29.4	28.4	42.2	41.6
1.46	1.49	0.68	0.67	28.0	27.0	40.9	40.4
1.49	1.52	0.67	0.66	26.7	25.8	39.8	39.2
1.53	1.56	0.65	0.64	25.0	24.2	38.3	37.8
1.56	1.59	0.64	0.63	23.6	23.0	36.9	36.6
1.62	1.61	0.62	0.62	21.3	20.8	34.6	33.6
1.69	1.70	0.59	0.59	19.3	19.2	32.6	32.6
1.81	1.80	0.56	0.55	14.6	15.2	26.4	27.4
1.91	1.91	0.52	0.52	10.9	11.6	20.9	22.1
1.97	1.97	0.51	0.51	8.4	8.9	16.6	17.4
1.99	2.01	0.50	0.50	6.2	6.2	12.4	12.5
2.06	2.07	0.49	0.48	—	—	—	—

^aThe first value in each column for each horizon is at field water content, the value next to the last value is at air-dryness, and the last value is at oven-dryness. The other values were obtained as the fragments air-dried over a 2-6 weeks period.

Table 20 — Determinations of water content, bulk density, and volume per unit dry weight of duplicate "moist" 4X fragments at different levels of hydration.^a

Bulk density g./cc.		Vol. per unit weight, cc./g.		Water, % by weight		Water, % by volume	
A	B	A	B	A	B	A	B
Leonardtown, A2g horizon							
1.55	1.48	0.64	0.67	18.0	18.4	27.9	27.2
1.46	1.47	0.68	0.68	27.0	26.3	39.4	38.7
1.46	1.47	0.69	0.68	28.0	27.5	41.3	40.3
1.44	1.46	0.70	0.68	29.2	27.8	42.1	40.7
1.43	1.43	0.70	0.70	30.1	30.1	43.0	43.1
1.38	1.43	0.72	0.70	32.3	30.1	44.7	43.0
1.57	1.43	0.64	0.70	—	31.0	—	44.2
	1.42		0.70		31.5		44.9
	1.43		0.70		31.7		45.3
	1.53		0.65		—		—
Leonardtown, B2lg horizon							
1.50	1.54	0.67	0.65	23.4	20.5	35.0	31.5
1.45	1.52	0.69	0.66	28.9	22.6	42.0	34.3
1.44	1.51	0.69	0.66	30.1	24.8	43.5	37.5
1.44	1.50	0.69	0.67	30.5	26.4	43.9	39.6
1.44	1.50	0.69	0.67	30.8	27.3	44.4	40.9
1.42	1.49	0.70	0.67	31.8	28.0	45.3	41.8
1.42	1.49	0.70	0.67	31.8	28.1	45.6	41.9
1.42	1.49	0.70	0.67	32.7	38.5	46.4	42.4
1.41	1.48	0.71	0.67	33.4	29.0	47.0	43.0
1.41	1.49	0.71	0.67	33.3	29.0	47.1	42.9
1.64	1.64	0.61	0.61	—	—	—	—
Leonardtown, B'Xlg horizon							
1.85	1.83	0.54	0.55	11.9	12.9	22.0	23.5
1.84	1.83	0.54	0.55	13.8	13.5	25.4	24.6
1.84	1.82	0.54	0.55	14.3	14.8	26.3	27.0
1.84	1.81	0.54	0.55	14.5	15.3	26.7	27.6
1.84	1.80	0.54	0.55	14.7	15.9	27.0	28.7
1.83	1.79	0.54	0.56	15.1	16.6	27.6	29.8
1.83	1.77	0.55	0.56	15.3	16.9	27.9	30.1
1.82	1.75	0.55	0.57	15.6	17.2	28.4	30.2
1.80	1.75	0.56	0.57	15.9	17.3	28.6	30.2
1.78	1.75	0.56	0.57	15.9	17.3	28.3	30.3
1.85	1.84	0.54	0.54	—	—	—	—

Table 20 — (Continued)

Bulk density g./cc.		Vol. per unit weight, cc./g.		Water, % by weight		Water, % by volume	
A	B	A	B	A	B	A	B
Davidson, A3 horizon							
1.18	1.14	0.85	0.88	29.8	29.2	35.0	33.1
1.17	1.13	0.86	0.88	32.7	30.9	38.2	35.0
1.17	1.13	0.86	0.88	35.1	33.2	41.0	37.5
1.17	1.13	0.86	0.88	37.8	36.2	44.1	40.9
1.16	1.13	0.86	0.89	40.9	38.3	47.5	43.2
1.16	1.12	0.86	0.89	43.7	41.0	50.7	46.1
1.16	1.12	0.86	0.89	44.2	43.1	51.2	48.4
1.15	1.12	0.87	0.89	45.4	45.0	52.3	50.3
1.15	1.12	0.87	0.89	46.0	45.7	53.1	51.3
1.15	1.12	0.87	0.89	46.6	46.4	53.7	52.0
1.27	1.22	0.79	0.82	—	—	—	—
Davidson, B22 horizon							
1.37	1.37	0.73	0.73	32.0	33.2	43.7	45.5
1.34	1.34	0.75	0.74	37.4	37.5	50.0	50.4
1.33	1.34	0.75	0.75	38.1	38.3	50.8	51.4
1.34	1.34	0.75	0.75	38.2	38.6	51.0	51.7
1.34	1.34	0.74	0.75	38.4	38.8	51.2	52.0
1.33	1.33	0.75	0.75	39.0	39.7	51.9	52.9
1.33	1.33	0.75	0.75	39.0	40.0	51.9	52.9
1.33	1.32	0.75	0.76	39.5	40.3	52.4	53.3
1.33	1.32	0.75	0.76	40.2	41.4	53.3	54.4
1.32	1.31	0.76	0.76	41.2	41.4	53.2	54.4
1.47	1.48	0.67	0.68	—	—	—	—
Davidson, B3 horizon							
1.38	1.38	0.72	0.72	28.9	29.4	40.0	40.6
1.36	1.37	0.74	0.73	37.2	32.8	50.6	45.0
1.36	1.37	0.74	0.73	37.9	34.2	51.5	46.8
1.36	1.37	0.74	0.73	38.1	35.2	51.7	48.1
1.36	1.37	0.74	0.74	38.1	35.0	51.7	47.6
1.36	1.35	0.74	0.74	38.6	37.3	52.5	50.4
1.35	1.35	0.74	0.74	38.6	37.5	52.3	50.6
1.35	1.35	0.74	0.74	38.9	38.2	52.3	51.4
1.35	1.34	0.74	0.74	39.3	38.7	53.0	51.9
1.35	1.34	0.74	0.74	39.2	38.7	52.8	51.9
1.42	1.44	0.71	0.70	—	—	—	—

Table 20 — (Continued)

Bulk density g./cc.		Vol. per unit weight, cc./g.		Water, % by weight		Water, % by volume	
A	B	A	B	A	B	A	B
Iredell, A2g horizon							
1.60	1.60	0.62	0.62	17.1	16.8	27.5	27.0
1.53	1.54	0.66	0.65	25.6	24.2	39.1	37.4
1.52	1.53	0.66	0.65	26.7	26.4	40.6	40.3
1.50	1.52	0.67	0.66	29.0	26.8	43.4	40.7
1.49	1.51	0.67	0.66	29.3	27.4	43.6	41.4
1.48	1.51	0.68	0.66	30.4	28.3	45.1	42.7
1.47	1.50	0.68	0.67	31.4	29.5	46.2	44.1
1.47	1.50	0.68	0.67	31.0	29.3	45.6	43.7
1.69	1.68	0.59	0.60	—	—	—	—
Iredell, B22g horizon							
1.24	1.24	0.80	0.81	38.7	40.3	48.1	50.0
1.10	1.09	0.92	0.92	51.0	52.8	55.8	57.4
1.07	1.05	0.94	0.96	53.8	56.9	57.4	59.6
1.03	1.00	0.97	1.00	58.4	62.8	60.1	62.6
1.02	0.99	0.98	1.00	59.2	63.2	60.3	62.8
1.02	0.99	0.99	1.01	60.1	64.2	61.0	63.5
1.00	0.98	1.00	1.02	61.1	65.4	61.3	64.1
1.00	1.00	1.00	1.00	61.1	64.2	61.3	63.9
2.10	2.06	0.48	0.48	—	—	—	—
Iredell, B31g horizon							
1.57	1.63	0.64	0.62	23.8	20.7	37.3	33.6
1.20	1.62	0.83	0.62	44.6	20.7	53.7	33.6
1.16	1.62	0.87	0.62	49.5	20.8	57.2	33.8
1.15	1.62	0.87	0.62	50.2	21.1	57.6	34.1
1.14	1.61	0.88	0.62	51.3	21.3	58.5	34.3
1.13	1.58	0.88	0.62	52.1	22.3	59.0	35.3
1.15	1.41	0.87	0.71	51.2	30.9	58.9	43.6
2.13	1.25	0.47	0.80	—	41.0	—	51.2
	1.13		0.87		50.3		56.8
	2.06		0.49		—		—

^aThe first value in each column for each horizon is at field water content, the value next to the last value is at or near saturation, and the last value in each column is at oven-dryness. The other values were determined as the fragments wetted over a 2-6 weeks period.