# INFLUENCE OF SOIL ORGANIC MATTER ON BULK DENSITY AND AVAILABLE WATER CAPACITY OF SOILS

**Armand Bauer**

**Organic matter is not essential for plant growth, but its presence enhances soil biological, chemical and physical properties. Among the physical properties affected are bulk density and the amount of water held at field capacity and the permanent wilting point. These physical properties affect the available water capacity of soil.**

Bulk density (Bd) is the weight of oven-dry soil per unit bulk volume, including air space. Bulk density will vary with mineral composition of the soil solids, with the manner in which the solid particles pack together, as well as organic matter content. Replacement of any of the solid components with a component of different density will effect a change in bulk density. Likewise, introduction of a substance into soil that can alter the arrangement of the solid particles to effect a change in amount of air space will change bulk density.

Field capacity (FC) is the amount of water remaining in a soil under conditions of free drainage, after excess water has drained away following a rain or irrigation that has wet the soil. Field capacity is expressed as a percentage of oven-dry weight or volume of soil. Field capacity often is estimated in the laboratory by placing water-saturated soil on ceramic plates contained in a pressure chamber, and applying air pressure to remove water from the soil. Water content of medium and fine textured soil retained at equilibrium with a pressure of $\frac{1}{3}$ atmosphere (4.9 psi) and water content of moderately coarse and coarse textured soil retained at equilibrium at 1/10 atmospheres is taken as a measure of field capacity.

Permanent wilting point (PWP) is the water content of soil, expressed on an oven-dry basis, at which plants wilt and do not recover their turgidity when placed in a dark humid atmosphere. Permanent wilting point is estimated in the laboratory in much the same way as the field capacity, except for the air pressure applied. Soil water content at equilibrium with 15 atmospheres pressure is taken as a measure of permanent wilting point.

The available water capacity (AWC) of a soil is the amount of water held to a given depth that is accessible to or can be withdrawn by a crop between the field capacity (FC) and the perma-

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nent wilting point (PWP). The available water capacity (AWC) is calculated as follows:

$$AWC = \frac{[Pw\ (FC) - Pw\ (PWP)] \times \text{Bulk Density} \times \text{Soil Depth}}{100 \times \text{Density of Water}} \quad [1]$$

where *Pw (FC) = Percent water by weight at the field capacity.*

*Pw (PWP) = Percent water by weight at the permanent wilting point.*

*Bulk Density = Weight per unit volume of oven-dry soil.*

*Soil Depth = Depth of soil.*

*Density of Water = Approximated as 1.00.*

Both soil bulk density and density of water are expressed as grams per cubic centimeter. Thus, the units of available water capacity are the same as those used for soil depth.

Soil organic matter content varies among and within soil types. Differences among types are primarily inherited, while differences within types are primarily due to soil management practices. Soil management practices can alter soil organic matter content through the amounts of organic residues that are returned. Usually, the larger the amount of residues returned over a period of several years, the higher the level of organic matter. Amount of residues returned can be affected by the kind of crops grown because of the quantity produced and the crop portion harvested, by the addition of nutrients to increase crop yield, or by addition of residues such as barnyard manure, which may not be a by-product of the soil area to which it is applied.

Soil organic matter is represented by organic residues in various stages of decomposition. Distinction is made between two general groups of soil organic matter on the basis of differences in their properties. One of these, humus, the relatively stable end-product of organic residue decomposition, is sub-microscopic in size (colloidal) and exhibits electrical properties associated wth surface active substances. In the second group are organic materials in all stages of decomposition, and which do not exhibit the properties of humus (for convenience these are referred to as organic materials).

Both humus and organic materials, however, affect soil water relations, but in somewhat different manner. Humus exhibits its primary influence through its effect on bulk density. Bulk density of a given soil can be changed when the packing arrangement of soil aggregates is changed. Packing arrangement is altered by a change in aggregate shape; the packing arrangement can also be changed (but not necessarily) by change in size of aggregates. Humus binds soil particles together and thus changes their shape and size. To a lesser extent, bulk density can change also because organic material of low density replaces inorganic material of higher density. Organic materials exhibit their influence directly by absorbing water and, if on the soil surface, by holding the water in place longer so that runoff is reduced. They also influence indirectly by absorbing the impact energy of rainfall which, if not absorbed, can break down soil aggregates at the surface and so reduce infiltration.

The purpose of this study is to show the extent of change in soil bulk density and available water capacity of soils that could be expected from applications of organic residues and from changes in content and nature of soil organic matter.

### Effect of Adding Organic Residues

Bouyoucos (1) added partially decomposed horse-cow manure (36.2% organic) to several soils in a laboratory experiment, and determined the effect of several rates on the percent by volume ($P_V$) soil water content. The data are presented in Table 1.

**Table 1. Effect of Organic Residues on the Water-Holding Capacity of Soils. (from G. J. Bouyoucos. 1939. Soil Sci. 43:377)**

| Manure Tons/Acre | Sandy Loam | Silt Loam | Clay Loam | Clay |
|---|---|---|---|---|
| | Soil Texture — Percent Water by Volume (Pv) [1] | | | |
| 0 | 5.5 | 14.1 | 17.1 | 20.9 |
| 20 | 9.1 | 17.8 | 20.0 | 21.6 |
| 40 | 13.2 | 19.5 | 21.2 | 22.5 |
| 60 | 15.7 | 21.0 | 22.2 | 22.6 |

[1] $Pv = \frac{Pw \times Bd}{Dw}$

*Pw = Percent water by weight*
*Bd = Bulk density.*
*Dw = Density of water*

The largest increase in $P_V$ in the silt loam and clay loam resulted from the first 20-ton increment of manure, while the second 20-ton increment produced the largest increase in the sandy loam and clay.

The increase in available water capacity to a given soil depth can be calculated from equation [1]. For example, the increase in $P_V$ from the addition of 20 tons of manure to sandy loam is 3.6 percentage units (9.1 - 5.5). If it is assumed that the 20 tons of manure is incorporated into the upper seven inches of soil and that the manure did not increase the water content at the permanent wilting point, the change in available water capacity is (3.6 ÷ 100) x 7 = 0.25 inches. Making the same assumptions for the other soils, the effect on available water capacity would be 0.25, 0.20 and 0.05 inches for silt loam, clay loam and clay, respectively. If then expressed on a per-ton-of-manure basis, the effect would be an increase of about 0.01 inches on sandy loam, silt loam and clay loam, and 0.003 inch on clay.

Salter and Haworth (11) conducted a field study in which barnyard manure was applied at a rate of 20 tons per acre per crop (160 tons per acre in a six-year period) to a sandy loam. In their literature review, Salter and Haworth reported that several research workers had found no significant increase in available water capacity following incorporation of organic manures on most soils. The effects of the manure on the soil bulk density and available water capacity are shown in Table 2.

**Table 2. Effects of Manure on the Bulk Density and Available Water Capacity of Sandy Loam. (from P. J. Salter and F. Haworth. 1961. J. Soil Sci. 12:335).**

| Soil Depth Inches | Bulk Density[1] Manure Applied — Grams/Cm³ | + [2] | Available Water Capacity[1] Manure Applied — Inches | + |
|---|---|---|---|---|
| 0-6 | 1.79 | 1.67 | .72 | .94 |
| 6-12 | 1.85 | 1.73 | .72 | .87 |
| 12-18 | 1.67 | 1.71 | .64 | .85 |
| Mean | 1.77 | 1.70 | 2.08 | 2.66 |

[1] *Mean of four replications of each of four tillage treatments.*
[2] *"+" manure added; "—" no manure added.*

Bulk density was not decreased at the 12-18 inch depth, but it decreased 0.12 grams per cubic centimeter in the upper 12 inches. Available water capacity was increased 0.22, 0.15 and 0.21 inches, respectively for the three depths measured. The average increase in AWC to 18 inches, per ton manure, was about 0.004 inch (0.54 ÷ 160).

Salter and Haworth suggested that the reason many previous workers failed to detect an increase in AWC was that their methods of determining field capacity (FC) and permanent wilting point (PWP) were not sufficiently accurate. The methods used by Salter and Haworth (10) were direct sampling and the sunflower method, using undisturbed cores for FC and PWP, respectively.

Russell et al. (9) evaluated the effect of applying 0, 10, 20 and 40 tons manure per acre per year for 25 years on physical properties of Sassafras

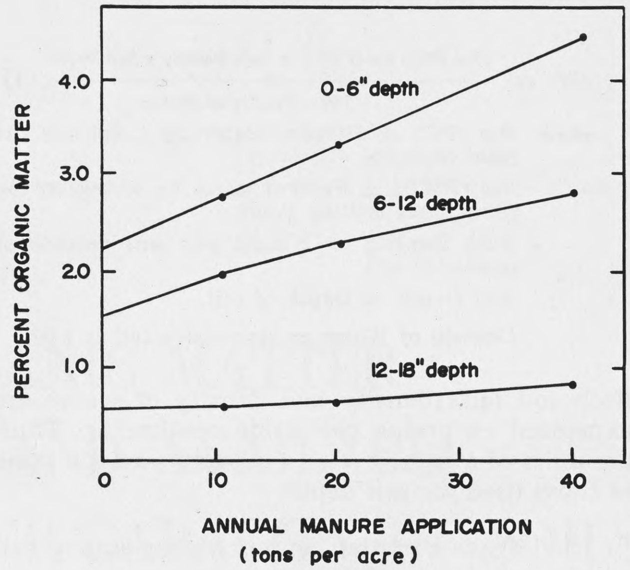


**Figure 1. Percent Organic Matter of Sassafras Silt Loam After Differential Manure Applications for 25 Years (from M. B. Russell, A. Klute and W.C. Jacob. 1952. Soil Sci. Amer. Proc. 16:156).**

silt loam. Applications were terminated in 1947 and the soil samples were taken in 1949. The effects of the manure on the percent organic matter and bulk density are presented in Figures 1 and 2, respectively. Data of the effect of the manure additions on the soil water content at the moisture equivalent (may be used to approximate field

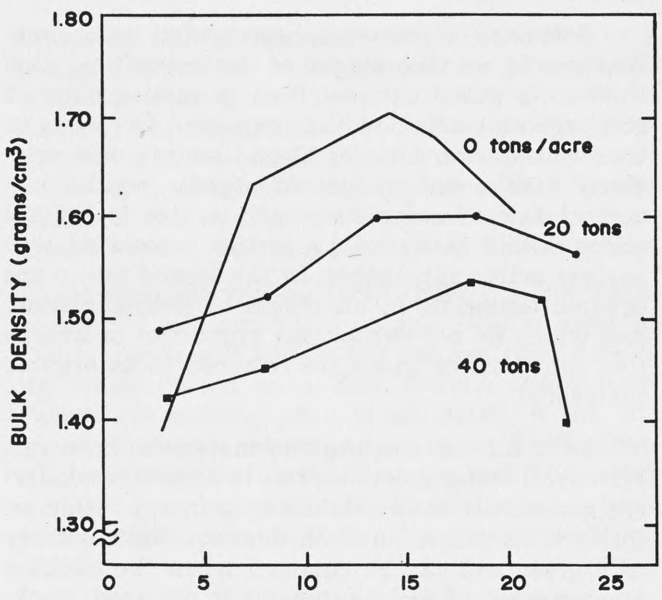


**Figure 2. Effects of Manure Applications on Susceptibility of Compaction of Sassafras Silt Loam (from M. B. Russell, A. Klute and W. C. Jacob. 1952. Soil Sci. Soc. Amer. Proc. 16:156).**

capacity [a]) and at permanent wilting point (15-atmosphere percentage) are given in Table 3.

Percent water by weight (Pw) was increased by manure at both the moisture equivalent and 15-atmosphere percentage (Table 3). Organic matter was increased about 2.4 percentage units (Figure 1) at the 0-6 inch depth from the application of 40 tons of manure over the 25-year period. Bulk density was decreased about 0.17 grams per cubic centimeter by 40 tons manure, considering the maximum bulk density (compaction) for the 0 and 40-ton rates (Figure 2). In this study, a one percentage unit increase in organic matter decreased bulk density about 0.07 grams per cubic centimeter.

While not specifically related to the discussion, the data in Figure 2 illustrate that the maximum bulk density that can be achieved in a given soil is related to organic matter. These data show that the higher the organic matter content the lower the maximum bulk density, and the larger the organic matter content the larger the soil water content when maximum bulk density occurred. Davidson et al. (3) observed the same in a study comparing soil organic matter levels under continuous cotton and continuous lezpedeza.

The effect of the manure on the available water capacity of the 0 to 6-inch depth can be approximated from Figures 1 and 2, and from Table 3. The difference between the moisture equivalent and 15-atmosphere percentage at the 0 to 6-inch depth for the 0 and 40 ton manure rate is 8.7 percentage units and 11.0 percentage units, respectively (Table 3). The maximum bulk density (Figure 1) for the 0-manure rate is about 1.67 grams per cubic centimeter and about 1.50 grams per cubic centimeter for the 40-ton rate. Available water capacity, calculated with equation [1], is 0.87 inches and 0.99 inches, respectively, for the upper six inches of soil supplied with no manure and 40 tons manure per acre. Thus, the 40-ton manure rate increased the available water capacity of the upper six inches of soil by 0.12 inches. When the field capacity values, as estimated by the regression of Peale and Beale (8), are used in place of the moisture equivalent, the calculated increase in available water capacity from the 40-ton manure treatment is 0.05-inch water in the upper six inches of soil.

*a/Peale and Beale (8) reported that field capacity could be estimated from the moisture equivalent by the equation $y = 0.86\,x + 2.6$, where $y$ = field capacity and $x$ = moisture equivalent.*

#### Effect of Differences in Soil Organic Matter (Humus)

Tabatabai and Hanway (16) in Iowa determined the bulk density of natural aggregates of seven surface and seven subsoils representing a wide range in chemical and physical properties. Texture of the aggregates ranged from loam to clay. The relationship between aggregate bulk density and percent organic carbon is shown in Figure 3.

A one percentage unit change in organic carbon altered the bulk density of the aggregates 0.25 grams per cubic centimeter (Figure 3). Expressed in terms of soil organic matter, one percentage unit increase in organic matter decreased bulk density 0.14 grams per cubic centimeter (organic carbon x 1.72 is an estimate of organic matter).

Shaykewich and Zwarich (13) evaluated the relationship of bulk density, field capacity, permanent wilting point and available water on a weight and volume basis to sand, silt, clay, organic matter and calcium carbonate content of soils. Of the 112 soils, 12 were coarse textured, nine moderately coarse, 29 medium, 36 moderately fine, and 26 fine. The effects of changes in clay and organic matter content on bulk density are shown in Figure 4. At low organic matter content (2 percent), an increase in clay content effected a greater decrease in bulk density than at high organic matter content (5 percent).

Regression equations from the study by Shaykewich and Zwarich are shown in Table 4.

Bulk density decreased 0.07 grams per cubic centimeter with a one percentage unit increase in organic matter, considering the effect over all soils (Table 4). However, as shown in Figure 4,

**Table 3. Mean Moisture Equivalent and 15-Atmosphere Percentage at Three Depths as Affected by Manure Additions. (from M. B. Russell, A. Klute and W. C. Jacob. 1952. Soil Sci. Soc. Amer. Proc. 16:156)**

| Soil Depth Inches | Moisture Equivalent Tons/Acre 0 | 10 | 20 | 40 | 15 Atmosphere Percentage Tons/Acre 0 | 10 | 20 | 40 |
|---|---|---|---|---|---|---|---|---|
| | Percent by Weight (Pw) | | | | | | | |
| 0-6 | 13.3 | 15.6 | 15.2 | 18.0 | 4.6 | 5.9 | 5.3 | 7.0 |
| 6-12 | 12.8 | 15.4 | 13.5 | 16.5 | 4.7 | 5.9 | 5.1 | 6.6 |
| 12-18 | 12.3 | 14.4 | 11.0 | 15.2 | 4.6 | 5.4 | 5.0 | 5.7 |
| Mean | 12.8 | 15.1 | 13.2 | 16.6 | 4.7 | 5.7 | 5.1 | 6.4 |

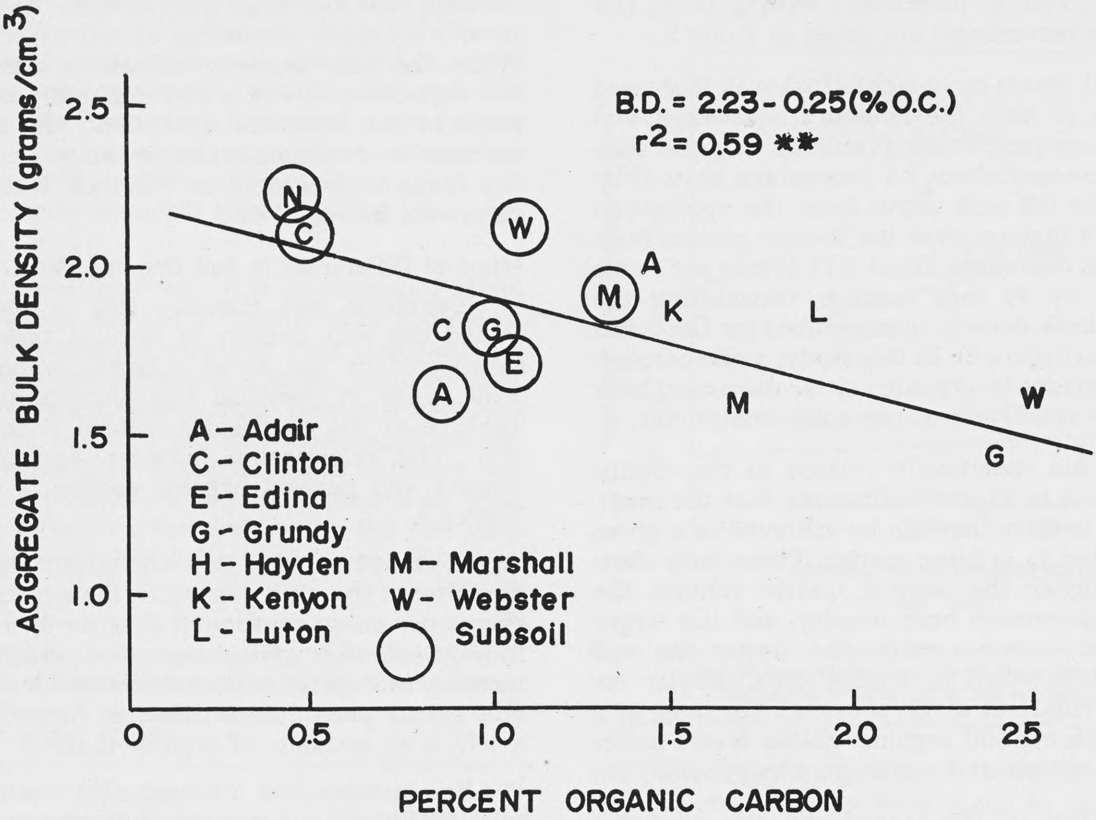


**Figure 3. Effect of Percent Organic Carbon on Bulk Density of Soil Aggregates (from M. S. Tabatabai and J. J. Hanway. 1968. Soil Sci. Soc. Amer. Proc. 32:588).**

this would vary with clay fraction. The data in Table 4 show too that a one percentage unit increase in organic matter effected an increase of about 1.27 and 0.66 percentage units at the FC and PWP, respectively, over all soil.

Jameson (4) showed that increases in organic matter increased the AWC of coarse textured soils, but even in these soils the amount of increase of AWC in relation to amount of organic matter increase was very small (5).

Jameson and Kroth (6) evaluated the effect of organic matter content of profiles of predominantly medium textured Missouri soils on the AWC. They found that organic matter increase

**Table 4. Regression Equations for Soil Physical Constants (from C. F. Shaykewich and M. A. Zwarich. 1968. Canad. J. Soil Sci. 48:199).[1]**

| | Regression Equation [2] | R |
|---|---|---|
| BD | = 1.77 — 0.0016 (VFS) — 0.0017 (Si) — 0.0047 (C) — 0.07 (OM) + 0.0008 (C) (OM) | 0.805 |
| FC | = 9.87 + 0.12 (Si) + 0.27 (C) + 1.27 (OM) | 0.878 |
| PWP | = 3.80 — 0.038 (FS) — 0.033 (VFS) + 0.22 (C) + 0.66 (OM) | 0.943 |
| AMw | = — 0.34 + 0.11 (FS) + 0.11 (VFS) + 0.18 (Si) + 0.12 (C) + 0.65 (OM) | 0.751 |
| AMv | = 1.99 + 0.16 (FS) + 0.16 (VFS) + 0.24 (Si) + 0.19 (C) | 0.592 |

[1] *The coefficients were rounded off.*
[2] *BD - bulk density*
*FC - field capacity*
*PWP - permanent wilting point*
*AMw - available water capacity, weight basis*
*AMv - available water capacity, volume basis*
*VFS - % very fine sand*
*Si - % silt*
*C - % clay*
*OM - % organic matter*
*FS - % fine sand*

may improve the water storage capacity of soils having 13 to 20 percent clay.

Laboratory data are available for a large number of North Dakota soils sampled by horizons (2, 7, 12, 14, 15). Laboratory analyses include percent organic carbon and water content at field capacity and the permanent wilting point. Data of the A and B horizons, separated on the basis of texture, were subjected to regression analyses to determine the effect of change of percent organic carbon on percent water by weight at field capacity and permanent wilting point. Field capacity was taken as 1/10-atmosphere pressure for the coarse and moderately coarse soils and $\frac{1}{3}$-atmosphere for the others.

Results of regression analyses of organic carbon and percent water by weight are presented in Table 5, and data in Table 6 and Figure 5 show the change in water capacity, percent by weight, with change in soil organic matter.

The effect of a one percentage unit increase in organic matter on the available water capacity differed with textural class (Table 6). The least change occurred in fine textured and the greatest in coarse textured soil; in the B horizon the trend was reversed.

Figure 5 data show that:

1. The water content, percent by weight, increased at both the field capacity and permanent wilting point as soil organic carbon increased.

2. The percent water by weight at the field capacity and permanent wilting point increased as soil clay content increased.

3. The difference in percent water by weight between field capacity and permanent wilting point increased in all textural groups as percent organic carbon increased; the change was greatest in coarse textured soils and diminished as clay content increased.

Bulk density was not determined on the North Dakota soil samples, but when results of studies by others (Russell et al, Shaykewich and Zwarich, Tabatabai and Hanway) are applied, estimates can be obtained of the effect of a change in one percentage organic matter on the available water capacity of the A horizon of North Dakota soil.

The effect of a one percentage unit change of soil organic matter on bulk density ranged from 0.07 to 0.14 grams per cubic centimeter in studies reported. If this change were the same on all tex-

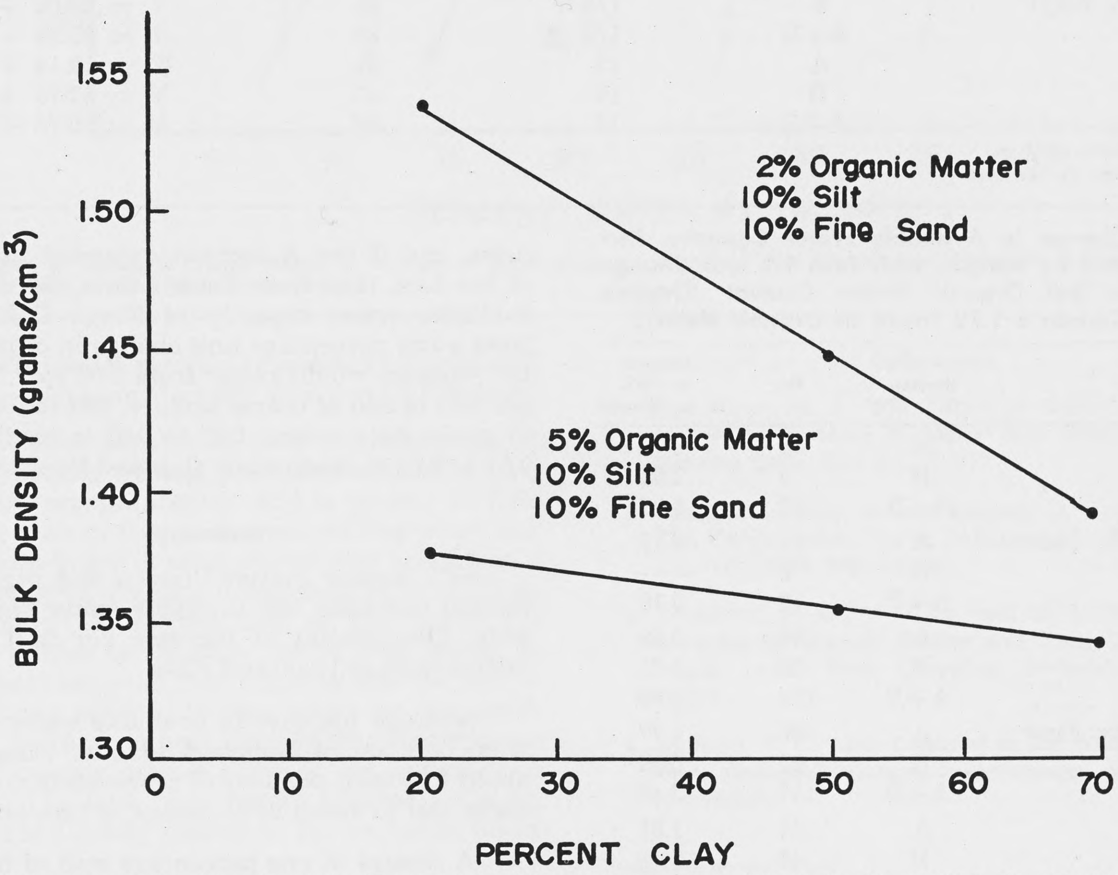


**Figure 4. Bulk Density as Affected by Changes in Clay and Organic Matter Content (from C. F. Shaykewich and M. A. Zwarich. 1968. Canad. J. Soil Sci. 48:199).**

**Table 5. Summary of Regression Analyses of Organic Carbon and Soil Water Content at Field Capacity and Permanent Wilting Point of Textural Groups of North Dakota Soils.**

| Textural Group | Soil Horizon | Pressure Atmospheres | No. Samples | Regression |
|---|---|---|---|---|
| Coarse | A | 1/10 | 28 | Y = 5.87 + 5.57 x |
| (loamy sand, sand) | B | 1/10 | 5 | Y = 10.50 + 1.99 x |
| | A+B | 1/10 | 33 | Y = 6.66 + 5.20 x |
| | A | 15 | 28 | Y = 2.65 + 1.65 x |
| | B | 15 | 5 | Y = 3.27 + 0.24 x |
| | A+B | 15 | 33 | Y = 2.62 + 1.67 x |
| Moderately Coarse | A | 1/10 | 11 | Y = 23.19 + 2.56 x |
| (sandy loam, | B | 1/10 | 8 | Y = 44.89 — 29.24 x |
| fine sandy loam) | A+B | 1/10 | 19 | Y = 26.59 + 0.99 x |
| | A | 15 | 11 | Y = 4.52 + 1.32 x |
| | B | 15 | 8 | Y = 4.84 + 3.03 x |
| | A+B | 15 | 19 | Y = 5.57 + 0.93 x |
| Medium | A | 1/3 | 108 | Y = 12.93 + 4.57 x |
| (Loam, silt loam, | B | 1/3 | 66 | Y = 14.77 + 4.99 x |
| very fine sandy | A+B | 1/3 | 174 | Y = 14.71 + 4.07 x |
| loam) | A | 15 | 108 | Y = 5.70 + 2.31 x |
| | B | 15 | 66 | Y = 6.53 + 3.10 x |
| | A+B | 15 | 174 | Y = 6.90 + 1.98 x |
| Moderately Fine | A | 1/3 | 66 | Y = 23.69 + 3.07 x |
| (clay, loam, | B | 1/3 | 51 | Y = 21.30 — 5.90 x |
| silty clay loam) | A+B | 1/3 | 117 | Y = 23.73 + 3.11 x |
| | A | 15 | 66 | Y = 10.85 + 2.04 x |
| | B | 15 | 51 | Y = 11.95 + 2.65 x |
| | A+B | 15 | 117 | Y = 12.32 + 1.68 x |
| Fine | A | 1/3 | 41 | Y = 32.85 + 2.26 x |
| (clay, silty clay) | B | 1/3 | 45 | Y = 26.68 + 7.97 x |
| | A+B | 1/3 | 86 | Y = 33.26 + 2.41 x |
| | A | 15 | 41 | Y = 19.14 + 1.38 x |
| | B | 15 | 45 | Y = 17.76 + 3.90 x |
| | A+B | 15 | 86 | Y = 20.76 + 1.13 x |

*x = % organic carbon*
*Y = % water by weight*

**Table 6. Change in Available Water Capacity, Percent by Weight, with Each 1% Unit Change in Soil Organic Matter Content (Organic Carbon x 1.72 Taken as Organic Matter).**

| Textural Group | Horizon | No. | Increase in AWC % by Weight |
|---|---|---|---|
| Coarse | A | 28 | 6.74 |
| | B | 5 | 3.01 |
| | A+B | 33 | 6.07 |
| Moderately Coarse | A | 11 | 2.13 |
| | B | 8 | —— |
| | A+B | 19 | 0.10 |
| Medium | A | 108 | 5.59 |
| | B | 66 | 3.25 |
| | A+B | 174 | 3.59 |
| Moderately Fine | A | 66 | 1.77 |
| | B | 51 | 5.59 |
| | A+B | 117 | 2.46 |
| Fine | A | 41 | 1.51 |
| | B | 45 | 7.00 |
| | A+B | 86 | 2.20 |

tures, and if the A horizon extended to a depth of one foot, then from Table 6 data, the change in available water capacity of North Dakota soils from a one percentage unit change in organic matter (humus) would range from 0.06 to 0.11 inches per foot of soil of coarse texture, 0.02 to 0.04 inches in moderately coarse, 0.05 to 0.09 in medium, and 0.01 to 0.03 in moderately fine and fine texture.

### Summary

Soil organic matter (humus and organic materials) increases the available water capacity of soils. The amount of increase per unit of each differs with soil textural class.

Average increase in available water capacity from one ton of barnyard manure ranged from about 0.01 inch per foot of moderately coarse textured soil to about 0.003 inches in fine texture.

A change of one percentage unit of humus altered the available water capacity in the range of

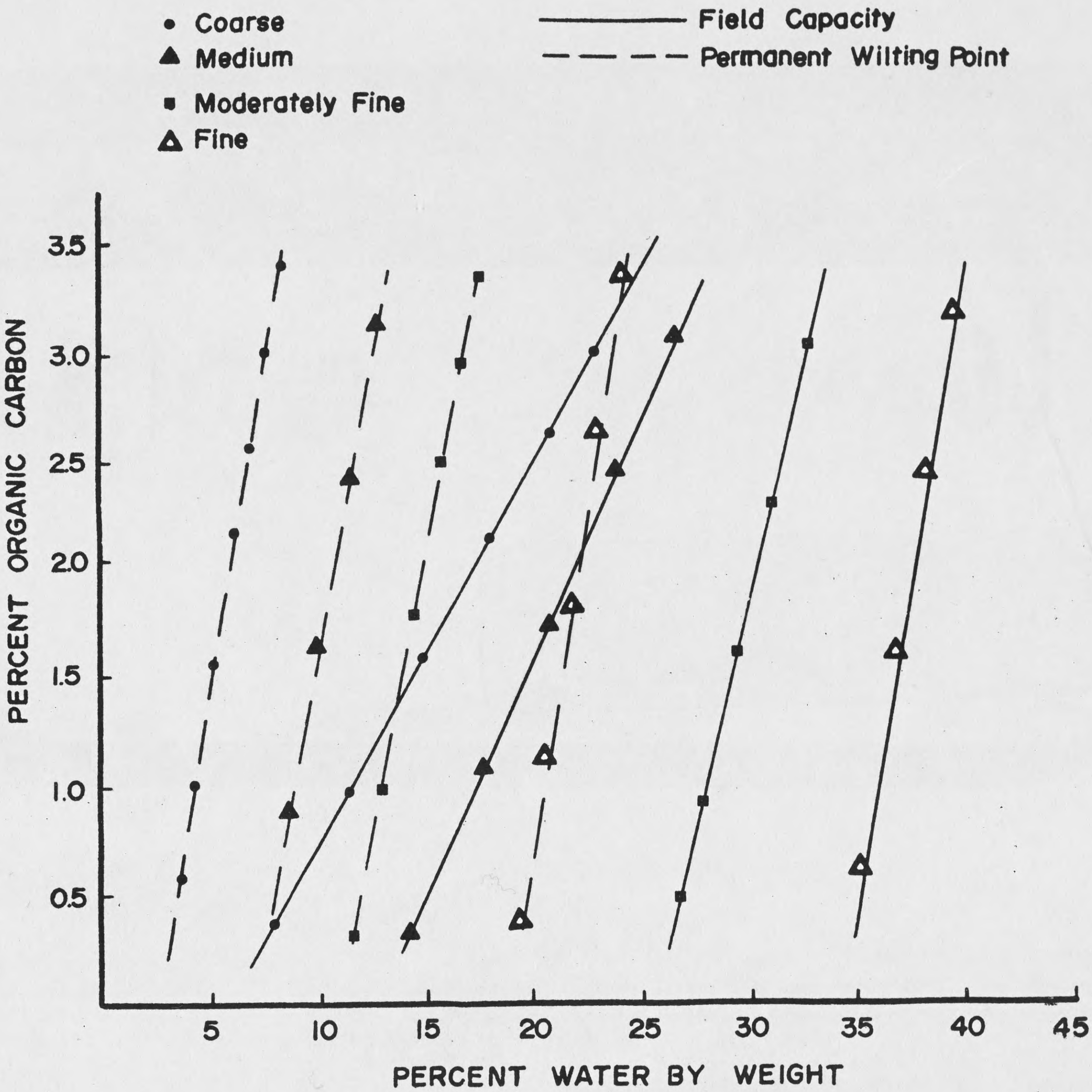


**Figure 5. Effect of Change in Organic Carbon on Change in Percent Water by Weight at Field Capacity and Permanent Wilting Point of the "A" Horizon of Four Soil Textural Groups.**

0.06 to 0.11 inches per foot of coarse textured soils to 0.01 to 0.03 in moderately fine and fine texture.

Soil water content at both the field capacity and permanent wilting point increase with additional soil organic matter, and is greater at field capacity than at the permanent wilting point. But an increase in soil organic matter also brings about a simultaneous decrease in soil bulk density. Thus, any benefit that accrues from an increase in soil organic matter to increase the percent water by weight held between field capacity and the permanent wilting point is largely offset by the simultaneous decrease in bulk density that accompanies the soil organic matter increase. As indicated in equation [1], bulk density and percent water by weight are directly related to the available water capacity.

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