THE RELATIONSHIP BETWEEN SOIL COMPONENTS AND SOIL PHYSICAL CONSTANTS OF SOME MANITOBA SOILS

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ABSTRACT

The relationships between soil components and soil physical constants were investigated on 94 soil samples varying widely in physical composition. The soil components used were fine sand, very fine sand, silt, clay, organic matter and calcium carbonate content. These were related to apparent density, field capacity, permanent wilting percentage, available moisture (dry weight basis), available moisture (volume fraction) and moisture retained at 1/4, 1/3, 1/2, 1, 3, 7 and 15 atmospheres tension by multiple regression analyses. The relationships were subsequently tested on 18 soil samples from sites not previously investigated.

The results presented show that a highly significant relation exists between soil components and every soil physical constant. A detailed discussion of the extent and nature of each relationship and its usefulness for prediction purposes is given. A comparison of the errors in prediction in the 'test' soils and in the soils used to derive the relations is also given.

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I. INTRODUCTION

It has long been recognized that soil physical constants are related, qualitatively at least, to soil physical components. Field capacity, permanent wilting percentage, and moisture retained at various tensions are known to increase as percentage of fine particles in the soil increases. Apparent density is known to decrease as the percentage of clay and organic matter increase.

The purpose of the present study was to determine; (1) the extent and nature of the relationship of soil components to each soil physical constant; (2) the usefulness of each relationship for prediction purposes.

The soil physical constants measured were apparent density, field capacity, permanent wilting percentage, available moisture (dry weight basis), available moisture (volume fraction) and moisture retained at 1/4, 1/3, 1/2, 1, 3, 7 and 15 atmospheres tension. De Leenheer and Van Ruymbeke (4), working in the Belgian Sea Polder Area found that those components which affect the values of some soil physical constants were silt, clay, organic matter and calcium carbonate. In the present study it was felt that in addition to these, fine sand and very fine sand could possibly have an effect on some of the soil physical constants. Therefore the percentage of fine sand and very fine sand as well as silt, clay, organic matter and calcium carbonate were used as independent variables.

II. REVIEW OF LITERATURE

Apparent Density.

Apparent density may be defined as the weight of oven-dry soil per unit volume. It is also sometimes referred to as "bulk density" or "volume weight".

There are three main methods of determining apparent density. These are (a) by determining the volume and the weight of a soil fragment from the field, (b) determining the volume of a hole from which a weighed amount of soil is taken and (c) weighing the soil taken from a hole of standard dimension. In all cases a correction must be made for the moisture content of the soil. In the first method, determination of volume is usually done by coating the soil fragment with wax and weighing it in air and water. In the second method, the volume of the hole may be determined by measurement, or by filling the hole with some liquid or granular solid of known density. The third method involves the taking of cores of specific dimensions. A wide variety of core samplers varying in diameter and height have been used.

The determination of apparent density is a very time consuming process. If one could predict the apparent density from soil components a considerable amount of time would be saved.

De Leenheer and Van Ruymbeke (4) attempted to relate apparent density to soil components on 114 arable land and 82 meadow samples. As a starting hypothesis they assumed that percent clay ($<$.002mm.), percent silt (.02 to .002mm.), percent coarse silt (.02 to .05 mm.), percent $CaCO_3$, percent organic matter, pH, total cation exchange capacity, percent water at sampling, and all the interactions of the above were related to apparent density.

The first step in their calculations was to determine by correlation analysis the variables which were 'truly independent'. If the correlation coefficient between two variables was greater than 0.70 they assumed that the two variables were dependent on each other, and one of them was excluded from subsequent calculations. The second step was the calculation of the partial correlation coefficient for each of the independent variables versus apparent density. If the result was lower than 0.22 for meadow soils and lower than 0.195 for arable soils, the corresponding independent variable was also eliminated. Finally, the multiple regression equation for apparent density was calculated.

The equations predicting apparent density (A.D.) obtained by De Leenheer and Van Ruymbeke, together with the values of the coefficient of multiple correlation (R) and the standard error of estimate (S_{ee}) are given below:

Meadow Soils (82 samples)

$$A.D.=1.78336 - 0.004239\ (\%clay) - 0.030432\ (\%\ O.M.) - 0.007612\ (\%\ H_2O) \qquad (0.1)$$

$$(R=0.9366,\ S_{ee}=0.0677)$$

Arable Soils (114 samples)

$$A.D.=1.660878 - 0.001386\ (\%clay) - 0.00775\ (CaCO_3) - 0.032113\ (\%\ O.M.) - 0.002443\ (\%\ H_2O) \qquad (0.2)$$

$$(R=0.8249,\ S_{ee}=0.0727)$$

From the relatively high values of the correlation coefficients and the relatively low values of the standard error of estimate one can conclude that the relationship between soil components and apparent density is quite good. The relationship is slightly better in the meadow soils than it is in the arable soils.

Field Capacity.

Veihmeyer and Hendrickson (21) defined field capacity as the amount of water in the soil after the excess water had drained away and the rate of downward movement of water had materially decreased. This condition is usually reached within two or three days after a rain or irrigation in pervious soils of uniform structure and texture.

The most important factors affecting field capacity are soil texture, uniformity and depth (21). If a fine textured soil overlies a coarse soil, the zone immediately above the coarse layer will have a higher field capacity than it would have if it were uniform throughout. Also a shallow soil holds more water per unit depth at field capacity than a deep soil of the same texture.

One can readily see that field capacity is not a well defined soil constant. It is affected by factors other than soil components. Therefore, one would expect that soil components would not be related as closely to field capacity as they would to permanent wilting percentage.

De Leenheer and Van Ruymbeke (4) tried to predict field capacity (F.C.) from soil components. Their equations are as follows:

<u>Meadow Soils</u>

$$F.C.=4.43511 + 0.517699\ (\%\ clay) + 0.172224\ (\%\ coarse\ silt) + 1.635418\ (\%\ O.M.) + 0.147961\ (\%\ CaCO_3) \quad (R=0.9057,\ S_{ee}=5.0665) \qquad (0.3)$$

<u>Arable Soils</u>

$$F.C.=0.290655 + 0.400696\ (\%\ clay) + 0.262886\ (\%\ coarse\ silt) + 3.224689\ (\%\ O.M.) + 0.42686\ (\%\ CaCO_3) \quad (R=0.9155,\ S_{ee}=4.5311) \qquad (0.4)$$

The correlation coefficients show a close relationship between field capacity and soil components. The standard errors of estimate show that there may be considerable error in soils with a low field capacity, however.

Richards and Weaver (19) first suggested the use of the 1/3 atmosphere percentage as an approximation of field capacity. They assumed that the moisture equivalent was close to field capacity and related the 1/3 atmosphere to moisture equivalent. They found that the 1/3 atmosphere percentage was equal to moisture equivalent in most cases.

Haise <u>et al.</u> (5) working with Great Plains soils of Montana found a highly significantly correlation between field capacity and the 1/3 atmosphere percentage. Their equations are given below:

0-12"	$F.C.=7.6 + 0.619\ (1/3\ atm\ \%)$	$(r=0.931^{**})$	(0.5)
12-24"	$F.C.=5.9 + 0.565\ (1/3\ atm\ \%)$	$(r=0.962^{**})$	(0.6)
24-36"	$F.C.=5.4 + 0.531\ (1/3\ atm\ \%)$	$(r=0.943^{**})$	(0.7)
36-48"	$F.C.=5.9 + 0.481\ (1/3\ atm\ \%)$	$(r=0.917^{**})$	(0.8)
48-60"	$F.C.=4.7 + 0.513\ (1/3\ atm\ \%)$	$(r=0.919^{**})$	(0.9)
60-72"	$F.C.=4.6 + 0.518\ (1/3\ atm\ \%)$	$(r=0.886^{**})$	(0.10)

** significant at 1% level

The correlation coefficients indicate that, except for the last depth, there is close relationship between field capacity and the 1/3 atmosphere percentage.

Permanent Wilting Percentage.

Permanent wilting percentage has been defined by Veihmeyer and Hendrickson (22) as the lower limit of readily available moisture. It is the moisture content of a soil when plants permanently wilt. Further extraction of water does not cease. However, the moisture content when plotted against time gives curves that are almost horizontal after permanent wilting percentage has been reached.

Veihmeyer and Hendrickson (21) found that the permanent wilting percentage corresponded quite well to the minimum moisture content attained in a cropped field. Plants reduce the moisture content to a minimum which is slightly below the permanent wilting percentage. However, the difference is very small.

Hendrickson and Veihmeyer (7) showed that the permanent wilting percentages were the same whether the determinations were made using plants with a single leaf or a pair of leaves or whether large or small containers were used. They also found that small changes in temperature had no effect on permanent wilting percentage.

The above statements indicate that permanent wilting percentage is a reasonably well defined constant and is characteristic of the soil irrespective of the test plant or the environmental conditions of the determination. Since this is not true of field capacity, a closer relationship to soil components would be expected from permanent wilting percentage.

The equations predicting permanent wilting percentage (P.W.P.) from soil components obtained by De Leenheer and Van Ruymbeke (4) are as follows:

<u>Meadow Soils</u>

$$P.W.P. = 1.62705 + 0.440577\ (\%\ clay) + 0.116234\ (\%\ CaCO_3) + 1.006603\ (\%\ O.M.) \qquad (0.11)$$

$$(R = 0.9437,\ S_{ee} = 2.7242)$$

<u>Arable Soils</u>

$$P.W.P. = 0.66156 + 0.363627\ (\%\ clay) + 0.044663\ (\%\ coarse\ silt) + 0.199028\ (\%\ CaCO_3) + 0.849308\ (\%\ O.M.) \qquad (0.12)$$

$$(R = 0.9658,\ S_{ee} = 1.6805)$$

As indicated by the higher correlation coefficient and smaller standard error of estimate a closer relationship exists here than in the case of field capacity. However, as in the case of field capacity, the standard error of estimate appears quite large for soils of low permanent wilting percentage.

Hutcheon (9) obtained a correlation of 0.956 between percent clay and permanent wilting percentage, and a correlation of 0.758 between percent organic matter and permanent wilting percentage. The multiple regression equation predicting permanent wilting percentage from clay and organic matter obtained by Hutcheon is as follows:

$$P.W.P. = -0.1 + 0.245\ (\%\ clay) + 0.855\ (\%\ O.M.) \qquad (0.13)$$

For the same soils used to determine the relation, the permanent wilting percentages were calculated from the equation. These were compared with the observed values. In almost all cases the calculated and observed values were found to agree to within 2 percent.

Richards and Weaver (19) studied the tension with which soil moisture was held at permanent wilting percentage. They concluded that on the average the moisture retained at 15 atmospheres tension (F.A.P.) was the best estimate of the permanent wilting percentage.

Since then a number of relationships between permanent wilting percentage and the 15-atmosphere percentage have been determined. Richards and Wadleigh (18) obtained the regression equations relating permanent wilting percentage (P.W.P.) first permanent wilting percentage (F.P.W.P.) and ultimate wilting percentage (U.W.P.) to the 15-atmosphere percentage. The soil was assumed to have reached the first permanent wilting percentage when the lower leaves of the sunflower plant had wilted. The criterion used for the ultimate wilting percentage was the wilting of the upper leaves. The equations obtained are given below:

$$\text{P.W.P.} = 0.85 + 0.96\ (\text{F.A.P.}) \qquad (0.14)$$

$$\text{F.P.W.P.} = 1.50 + 1.022\ (\text{F.A.P.}) \qquad (0.15)$$

$$\text{U.W.P.} = 0.36 + 0.863\ (\text{F.A.P.}) \qquad (0.16)$$

Lehane and Staple (13) determined the ultimate wilting percentage and related it to the 15-atmosphere percentage. Their equation is:

$$\text{U.W.P.} = 0.35 + 0.833\ (\text{F.A.P.}) \qquad (r=0.995) \qquad (0.17)$$

This equation is very similar to the one obtained by Richards and Wadleigh for ultimate wilting percentage.

Heinonen (6) determined the permanent wilting percentage using tomatoes as the test plant. He found that this permanent wilting percentage was related to the 15-atmosphere percentage by the equation:

$$P.W.P.=1.15\ (F.A.P.) + 0.83 \qquad (r=0.99) \qquad (0.18)$$

From this equation Heinon concluded that the permanent wilting percentage as determined by the tomato plant method corresponded quite closely to the first permanent wilting percentage as determined by the sunflower method.

Wilcox (24) showed that the relationship of the first permanent wilting percentage to the 15-atmosphere percentage could be expressed by the following equation:

$$F.P.W.P.=0.662 + 1.016\ (F.A.P.) \qquad (r=0.99,\ S_{ee}=0.50) \qquad (0.19)$$

Haise _et al._ (5) used the 'minimum point' as a measure of permanent wilting percentage. The minimum point was defined as the mean of the lowest moisture percentages at a given depth on a cropped field over a period of years. The regression equations relating the 15-atmosphere percentage to the minimum point (M.P.) are given below:

0-12"	$M.P.=0.9 + 0.631\ (F.A.P.)$	$(r=0.931^{**})$	(0.20)
12-24"	$M.P.=0.2 + 0.758\ (F.A.P.)$	$(r=0.968^{**})$	(0.21)
24-36"	$M.P.=0.2 + 0.791\ (F.A.P.)$	$(r=0.952^{**})$	(0.22)
36-48"	$M.P.=0.8 + 0.804\ (F.A.P.)$	$(r=0.921^{**})$	(0.23)
48-60"	$M.P.=0.2 + 1.01\ (F.A.P.)$	$(r=0.910^{**})$	(0.24)
60-72"	$M.P.=2.5 + 0.886\ (F.A.P.)$	$(r=0.750^{**})$	(0.25)

Haise _et al._ concluded from the above results that the field determined minimum point in the second and third foot corresponded

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**significant at 1%

quite closely to the ultimate wilting percentage. They attributed the lower value of the correlation coefficient in the sixth foot to limited root distribution at this depth.

Available Moisture.

Available moisture expressed on a dry weight basis is the difference in the moisture contents at field capacity and permanent wilting percentage. When this figure is multiplied by the apparent density the percentage available moisture on a volume basis is obtained.

Hill (8), working with soils ranging from loamy sand to silty clay loam in texture, found a highly significant correlation between the available moisture holding capacity by volume percent (AMHC) and the silt content. The following regression equation was obtained:

$$AMHC = 6.5 + 0.26\ (\%\ silt) \qquad (r = 0.73) \qquad (0.26)$$

This relationship was linear indicating that AMHC is a linear function of the silt content.

Hill found that capillary porosity as well as silt content was significantly related to AMHC. The regression equation is:

$$AMHC = -3.41 + 0.12\ (\%\ silt) + 0.41\ (\%\ capillary\ porosity) \qquad (0.27)$$
$$(r = 0.81)$$

Hill tested the regression equations that he obtained on soils other than the ones upon which the regression was based. He found that the largest error was about 5 percent while most errors were about 2 percent.

Wilcox and Spilsbury (25) found that the available moisture holding capacity was significantly correlated with the silt and clay content. Soils showed an increase in available moisture up to a colloid concentration of 60 percent (colloids included all particles less than 0.02 mm. in size). Soils with a colloid concentration greater than 60 percent showed no further increase in available moisture. This was due to the fact that as a soils became finer in texture, the field capacity increased at a decreasing rate, whereas the permanent wilting percentage increased at an increasing rate. When a colloid concentration of 60 percent was reached the permanent wilting percentage was increasing just as rapidly as the field capacity, so that the difference between them tended to remain constant or even to decrease.

Wilcox and Spilsbury also found a highly significant negative correlation ($r=-0.855$) between available moisture and the sand content.

Jamison (10) and Jamison and Kroth (11) found that the available moisture holding capacities of some silty soils of Missouri was primarily related to the total silt content. Their results showed that this capacity actually decreased as the clay percentage increased. Organic matter increased the available moisture holding capacity only on very sandy soils.

Jamison and Kroth (11) found that coarse silt (0.05 to 0.02 mm.) increased the available moisture holding capacity more than fine silt (0.02 to 0.002 mm.). Available moisture increased generally with organic matter content. However, in the soils used, organic matter increased with coarse silt and decreased with clay. Therefore, the effect of organic matter was masked by textural changes. Only in a grouping of soils between 13 and 20 percent clay was there evidence that organic matter increased the available moisture. It was suggested that in these soils, silt-sized micro-aggregates formed the clay and organic matter.

Lund (14) and Bartelli and Peters (2) also found that available moisture was correlated with silt content but not with the clay content. Lund found that organic matter increased the available moisture only in sandy soils.

Soil Moisture Retention and Soil Components.

The relation of soil components to moisture retained at various tensions in the range of available moisture has not been studied as such, however, many investigators have related the 15-atmosphere percentage to soil components.

Nielsen and Shaw (15) related particle size distribution data obtained by the hydrometer method to moisture retained at 15-atmosphere tension. They found a highly significant correlation (r=0.808) between percent clay and the 15-atmosphere percentage. When the percent silt, sand and clay were related to the 15-atmosphere percentage the coefficient of multiple correlation was 0.815. This was not significantly different from the simple correlation coefficient between the 15-atmosphere percentage and percent clay. Nielsen and Shaw also found a highly significant negative relationship between percent sand and the 15-atmosphere percentage, r=-0.537. Lund (14) found a highly significant correlation, r=0.932, between the clay content and the 15-atmosphere percentage.

III. MATERIALS AND METHODS

Apparent Density.

Apparent densities were determined by boring a hole approximately 4 3/8 inches in diameter and 5-7 inches deep with a post hole auger and by weighing the soil removed from the hole. To obtain the volume of the hole the depth and diameter were measured with a ruler and caliper, respectively. From the soil removed from the hole a representative sample was taken for moisture determination. Using the moisture content of this sample the dry weight of the soil taken from the hole was calculated. The dry weight divided by the volume of the hole yielded the apparent density.[1]

Four replicates of the apparent density were determined in each of three horizons at each site.

Field Capacity.

For this determination a five-foot-square area was flooded with enough water to thoroughly wet the soil to a depth of four feet. After all the water had infiltrated, the plot was covered with polethylene to prevent evaporation. Three days later four soil samples from each of three previously determined horizons were taken from a three-foot-square area in the centre of the plot.[2] The soil samples were dried

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[1]This method was tested against the sand cone method (ASTM, Procedures for Testing Soils. 1958. pp 422-425.). Analysis of the data showed there was no difference between the "auger" method described above, and the sand cone method.

[2]In the first two years of the experiment, samples were taken, at 3 6 and 9 days after flooding. Analysis of variance of the data showed that there was no significant difference in moisture content at the three sampling dates. Therefore, in 1963, samples for field capacity were taken only once, 3 or 4 days after flooding.

at 110°C and the moisture content was calculated on an oven-dry basis.

Permanent Wilting Percentage Determinations.

Wilting percentages were determined by the sunflower method as outlined by Lehane and Staple (13). The wilting of the upper leaves of the sunflower plant was used as the criterion of wilting.

Determination of Available Moisture.

The percent available moisture on a dry weight basis was obtained by subtracting the moisture content at permanent wilting percentage from that at field capacity. Available moisture on a volume basis was calculated by multiplying the percent available moisture (dry weight basis) by the apparent density.

Moisture Retention Data.

Moisture retention data were obtained by using the pressure plate and the pressure membrane apparatus as outlined by Richards (17).

Particle Size Analysis.

Particle size analysis was determined by the method outlined by Kilmer and Alexander (12).

Organic Matter.

Organic matter was determined by the chromic acid oxidation method outlined by Peech *et al.* (16).

Calcium Carbonate Determinations.

The method used was a modification of the methods given by Adams (1) and by Weynick (23). A .5 gm. sample air dry soil ($<$2mm) was digested for 10 minutes in 100 ml. of 1:0 HCl solution. The carbon dioxide evolved was drawn by suction through a drying and absorption train consisting of concentrated H_2SO_4, a tube of Dehydrite and $CaCl_2$. The carbon dioxide was adsorbed by the Ascarite in a Nesbitt tube. The weight of carbon dioxide multiplied by 2.27, i.e. $\frac{(\text{formula weight } CaCO_3)}{(\text{formula weight } CO_2)}$ gave the weight of $CaCO_3$ equivalent in the sample.

Statistical Analysis of the Data.

In this study, percent fine sand (.25 to .1 mm.), percent very fine sand (0.1 to 0.05 mm.), percent silt (.05 to .002 mm.), percent clay (less than 0.002 mm.), percent organic matter, percent $CaCO_3$ and percent fine plus percent very fine sand were used as independent variables.

The first step in the calculations was to determine which of the independently variables had a high mutual correlation coefficient. If the correlation coefficient between any two variables was greater than 0.70 it was assumed that they were not 'truly independent' and one of them was eliminated. By multiple regression analysis the 'truly independent' variables were then related to the dependent variables. (See Table 1 for list of independent and dependent variables).

The 't' value of each regression coefficient was calculated and compared with the critical 't' values at the 5 and 1 percent levels of probability. Independent variables which did not make a significant contribution to the relationship at the 5 percent level were deleted. Only those variables which contributed significantly to the relationship were included in the final multiple regression analysis.

TABLE 1

LIST OF INDEPENDENT AND DEPENDENT VARIABLES

Dependent Variables	Abbreviations
Apparent density	A.D.
Field Capacity	F.C.
Permanent wilting percentage	P.W.P.
Available moisture - dry weight percentage	A.M.P.W.
Available moisture - volume fraction	A.M.V.F.
1/4 atmosphere percentage	1/4 - atm %
1/3 atmosphere percentage	1/3 - atm %
1/2 atmosphere percentage	1/2 - atm %
1 atmosphere percentage	1 - atm %
3 atmosphere percentage	3 - atm %
7 atmosphere percentage	7 - atm %
15 atmosphere percentage	15 - atm %

Independent Variables	Abbreviations
percent fine sand	% F.S.
percent very fine sand	% V.F.S.
percent silt	% silt
percent clay	% clay
percent organic matter	% O.M.
percent $CaCO_3$	% $CaCO_3$

The data for 94 soil samples used in this study were divided on a profile basis[1] into five textural groups. In each textural group, an equation including all those independent variables significant in all soils was derived for each dependent variable. The five textural groups are similar to those outlined by the U.S.D.A. soil survey staff (20) and are as follows:

Coarse textured - sand, loamy sand.
Moderately coarse textured - sandy loam.
Medium textured - loam, silt loam, silt.
Moderately fine textured - clay loam, sandy clay loam, silty clay loam.
Fine textured - sandy clay, silty clay, clay

In the case of apparent density a separate regression equation was derived for each of the A, B and C horizons.

Simple regression analyses were carried out relating field capacity to the 1/3 atmosphere percentage, and permanent wilting percentage to the 15-atmosphere percentage. The relationship of the 1/3 atmosphere percentage and its square to field capacity was also determined. Likewise, an equation relating the 1/3 atmosphere percentage and total porosity to field capacity was calculated.

Testing of Equations.

In 1964, six sites were selected in the Dauphin area, an area that had not previously been investigated. The determinations made on these soils were the same as those outlined for the soil samples on

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[1]The profile was placed in the textural group in which the majority of its horizons occured.

which the regression equations were based.

For the purpose of prediction the "ALL SOILS COMBINED" equations containing only those variables which contributed significantly to the regression were used. A comparison between predicted and actual values was made. Then, the average error of the prediction for each dependent variable was calculated in order to evaluate its precision.

IV. RESULTS AND DISCUSSION

Correlation Analysis.

The results of correlation analysis are presented in the form of a correlation matrix in Table 2. Examination of the table shows that correlation coefficients greater than 0.70 were obtained between % F.S. + % V.F.S. and % V.F.S., and between % F.S. + % V.F.S. and % silt. Therefore % F.S. + % V.F.S. was considered dependent on % V.F.S. and % silt. As it was not a 'truly independent' variable it was not used in subsequent regression analysis.

TABLE 2

CORRELATION MATRIX OF INDEPENDENT VARIABLES

	% F.S.	% V.F.S.	% Silt	% Clay	% O.M.	% $CaCO_3$	% F.S.+ % V.F.S.
% F.S.		-.126	-.391	-.483	-.240	.098	.533
% V.F.S.			-.615	-.436	-.094	-.307	.772*
% Silt				.326	.175	.327	-.775*
% Clay					.308	-.035	-.681
% O.M.						-.181	-.235
% $CaCO_3$							-.198
% F.S.+% V.F.S.							

*greater than 0.70

APPARENT DENSITY

Equation (1.1), Table 3, shows the relationship between apparent density and the independent variables fine sand, very fine sand, silt, clay, $CaCO_3$ and organic matter. Since the 't' value of the regression coefficient of fine sand was not significant, fine sand was eliminated as an independent variable. The remaining independent variables were used to derive regression equation (1.2). The 't' values of the regression coefficients in equation (1.2) show that all the variables contributed significantly to the regression. Equation (1.3) illustrates the effect of the inclusion of the interactions (%silt)(% O.M.), (% clay)(% $CaCO_3$) and (% clay)(% O.M.) on the significance of the variables used in equation (1.2). In equation (1.3) it can be seen that the regression coefficients of (% V.F.S.), (% silt), (% $CaCO_3$), (% silt)(% O.M.) and (% clay)(% $CaCO_3$) do not make significant contributions to the regression.

Equation (1.7) was obtained by progressive elimination of variables not contributing significantly to the regression in equations (1.4) to (1.6). The independent variables used in equation (1.7) were (% clay), (% O.M.) and (% clay)(% O.M.).

In equations (1.2) and (1.7) the coefficients of determination are 0.626 and 0.616, respectively. Thus by deleting three variables from equation (1.2) and adding the interaction (% clay)(% O.M.) there was a reduction of only one percent of the total sum of squares attributable to regression. The standard error of estimate is the

TABLE

REGRESSION EQUATIONS

Eqn. no.	EQUATION	S_{ee}	R^2
(1.1)	A.D.= 1.82034 - 0.0019696(%F.S.) - 0.0028252(%V.F.S.) - 0.0036426(%silt) - 0.00383696(%clay) - 0.037586(%O.M.)+0.00172477(%$CaCO_3$)	0.105	0.640
(1.2)	A.D.= 1.69776 - 0.00166417(%V.F.S.) - 0.00240901(%silt) - 0.00256326(%clay) - 0.0377287(%O.M.) + 0.00162833(%$CaCO_3$)	0.106	0.626
(1.3)	A.D.= -9.28179 + 10.94586(%V.F.S.) - 0.0000654(%silt) - 0.00472193(%clay) - 0.0615163(%O.M.) + 0.00121549($CaCO_3$) - 0.00041064(%silt)(%O.M.) + 0.00106106(%clay)(%O.M.) + 0.000002505(%clay)(%$CaCO_3$)	0.105	0.641
(1.4)	A.D.= -9.3399 + 11.02126(%V.F.S.) - 0.0009478(%silt) - 0.0042589(%clay) -0.07206599(%O.M.) + 0.00127168($CaCO_3$) + 0.00092902(%clay)(%O.M.)	0.105	0.635
(1.5)	A.D.= 1.68130 - 0.000947817(%silt) - 0.0042585(%clay) - 0.07206249(%O.M.) + 0.00127174(%$CaCO_3$) + 0.0009283(%clay)(%O.M.)	0.105	0.634
(1.6)	A.D.= 1.671378 - 0.0047375(%clay) - 0.0758084(%O.M.) + 0.00101254(%clay)(%O.M.) + 0.00099286(%$CaCO_3$)	0.105	0.625
(1.7)	A.D.= 1.69687 - 0.004861597(%clay) - 0.0800295(%O.M.) + 0.0010921(%clay)(%O.M.)	0.106	0.616

FOR APPARENT DENSITY

t values for regression coefficients								
% F.S.	% V.F.S.	%silt	% clay	% O.M.	%CaCO$_3$	(%silt) x (%O.M.)	(%clay) x (%O.M.)	(% clay) x (%CaCO$_3$)
1.84	3.20**	3.62**	3.72**	8.47**	2.55**			
	2.65**	3.18**	3.32**	8.40**	2.36**			
	0.11	0.07	3.62**	4.07**	0.94	1.18	3.20**	0.07
	0.10	1.48	4.00**	6.10**	1.83		3.04**	
		1.49	4.01**	6.15**	1.84		3.06**	
			4.66**	6.57**	1.48		3.36**	
			4.75**	7.10**			3.64**	

**significant at 1%

same for equations (1.2) and (1.7). It was felt that the increased simplicity of equation (1.7) was well worth the sacrifice of one percent in the sum of squares due to regression. Also, equation (1.7) allowed a study of the relation between apparent density and aggregation (represented by the interaction of (% clay)(% O.M.)). For these reasons equation (1.7) was given preference and it is the one which is subsequently discussed.

Equation (1.7) is as follows:

$$A.D.=1.69687 - 0.004861597^{**}(\%\ clay) - 0.0800295^{**}(\%\ O.M.) + 0.0010902^{**}(\%\ clay)(\%\ O.M.) \quad (1.7)$$

$$(R=0.794^{**},\ S_{ee}=0.106)$$

According to the equation a soil having no clay or organic matter would have a density of 1.69687. The coarse-textured soils having an average clay of about 10 percent used in the present study have an average apparent density of 1.59 (Appendix I, p. 76). When the clay content is accounted for, this value is not too far from the value of the constant. Thus, the value of the constant appears to be quite reasonable for soils in which the sand fraction predominates. When the effect of clay is accounted for in medium textured soils, their mean density is close to that of the constant. This shows that the constant is also acceptable in soils in which the silt fraction predominates.

Perhaps the most interesting feature of equation (1.7) is the

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**significant at 1%

relatively high value of the regression coefficient of organic matter (-0.0800295). This means that if the organic matter content were increased from zero to 10 percent, the apparent density would decrease by 0.8. This is a rather large reduction. The regression coefficient of organic matter is about twenty times that of clay and about eighty times that of the interaction of clay and organic matter. The 't' values of the regression coefficients of organic matter, clay and the interaction of clay and organic matter are 7.10, 4.75 and 3.64, respectively and indicate that all the coefficients are significant at the 1 percent level. One can conclude, therefore, that organic matter is by far the most important factor governing the apparent density of soils.

Probably one reason why apparent density is affected so greatly by organic matter is that the density of organic matter is considerably lower than that of other soil components.

Equation (1.7) shows that the regression coefficients of clay and organic matter are negative. This is to be expected since the densities of both clay and organic matter are lower than those of other soil components. However, it is interesting to note that the coefficient of the interaction of clay and organic matter is positive. This interaction probably represents the formation of aggregates of clay and organic matter. It appears, therefore, that for the soils used, the formation of aggregates increased the apparent density. This is contrary to the common belief that aggregation increases porosity and therefore, of necessity decreases the apparent density.

The standard error of estimate of equation (1.7) is 0.106. This means that 67 percent of the time the real value of the apparent density will be in the range of ± 0.106 of the predicted value. This error does not appear to be excessively large when one considers that the standard deviation of density measurements by the auger method was about 0.058[1].

The equations obtained when the data was separated into textural groups are presented in Table 4. The equation for moderately coarse textured soils is different from those of all the other textural groups. However, with the exception of this group, the table shows the following general trends:

1. The standard error of estimate increases as the percentage of finer separates in the soil increases. Thus the prediction of apparent density becomes less accurate as the percentage of finer separates increases.

2. The interaction of clay and organic matter has the greatest effect on density in coarse-textured soils. In medium, moderately fine and fine textured soils the effect of this interaction is approximately the same.

3. The statements made about the interaction of clay and organic matter also apply to clay.

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[1]This was the mean standard deviation of the density measurements taken in 1964. It is probably a good estimate of the standard deviation of density measurements taken in the other three years of the experiment.

TABLE 4

REGRESSION EQUATIONS FOR APPARENT DENSITY (TEXTURAL GROUPS)

Textural Group	No. of samples	EQUATION	R	S_{ee}	t values b_1	t values b_2	t values b_3
Coarse textured	12	A.D.= 1.941068 - 0.0282063(% clay) - 0.146252(% O.M.) + 0.00673449(% clay)(% O.M.)	0.929**	0.076	2.71*	2.03	1.04
Moderately coarse textured	12	A.D.= 1.43227 + 0.0032879(% clay) + 0.0362757(% O.M.) - 0.003229386(% clay)(% O.M.)	0.553	0.075	0.39	0.51	0.77
Medium textured	17	A.D.= 1.682 - 0.0070868(% clay) - 0.088030(% O.M.) + 0.0017353(% clay)(% O.M.)	0.888**	0.071	1.55	2.91*	1.28
Moderately fine textured	33	A.D.= 1.8104 - 0.00830245(% clay) - 0.094216(% O.M.) + 0.001436(% clay)(% O.M.)	0.760**	0.121	1.97	2.10*	1.02
Fine textured	20	A.D.= 1.8502 - 0.00728537(% clay) - 0.113583(% O.M.) + 0.001835(% clay)(% O.M.)	0.790**	0.108	2.28*	2.47*	1.82
All soils combined	94	A.D.= 1.69687 - 0.0048616(% clay) - 0.0800295(% O.M.) + 0.0010902(% clay)(% O.M.)	0.794**	0.106	4.75**	7.10**	3.64**

*significant at 5% level
**significant at 1% level

4. The regression coefficients of organic matter do not vary as much as the regression coefficients of the other two independent variables. The influence of organic matter on apparent density does not vary greatly with texture.

The 't' values of clay and organic matter in fine textured soils are 2.28 and 2.47 respectively. This indicates that the closeness of the relationship of each of organic matter and clay to apparent density is approximately the same in this textural group. This is also true of moderately fine textured soils, except that the 't' value of clay is not significant. In the other textural groups, one of the components is more closely related to apparent density than the other.

The 't' values of the clay-organic matter interaction (of which none are significant) seem to indicate an increasing importance of the interaction from coarse to fine textured soils.

Table 5 shows the equations obtained when the data were grouped according to horizons. Equation (1.13), predicting the apparent density of the A horizon has the highest correlation coefficient and all three regression coefficients in the equation are significant. This result indicates a very close relationship between soil components and apparent density in this horizon.

Equation (1.14) used in predicting the apparent density in the B horizon, has a highly significant correlation coefficient and significant regression coefficients for clay and organic matter. The regression coefficient of the interaction of clay and organic matter,

TABLE 5

REGRESSION EQUATIONS FOR APPARENT DENSITY (HORIZONS)

Horizon	No. of samples	EQUATION	R	S_{ee}	t values b_1	t values b_2	t values b_3
(1.13) A	33	A.D. = 1.76191 − 0.006636(%clay) − 0.086445(%O.M.) + 0.0012706(%clay)(% O.M.)	0.780**	0.098	2.56*	4.48**	2.82**
(1.14) B	33	A.D. = 1.74659 − 0.0093688(%clay) − 0.118328(%O.M.) + 0.00290057(%clay)(%O.M.)	0.633**	0.118	2.64*	2.83**	2.18
(1.15) C	28	A.D. = 1.72407 − 0.0026051(%clay) − 0.14475(%O.M.) + 0.001010495(%clay)(%O.M.)	0.657**	0.094	0.96	2.05	0.62
(1.7) All Horizons	94	A.D. = 1.69687 − 0.0048616(% clay) − 0.0800295(% O.M.) + 0.0010902(% clay)(% O.M.)	0.794**	0.106	4.75**	7.10**	3.64**

* significant at 5%
** significant at 1%

however, does not make a significant contribution to the regression. This can probably be attributed to the low organic matter in the B horizon, resulting in the lack of appreciable aggregation.

Equation (1.15), predicting apparent density of the C horizon, has a highly significant correlation coefficient. However, none of the regression coefficients are significant. There appears to be no apparent explanation for this.

On comparing the regression coefficients of organic matter it is seen that there is a greater decrease in apparent density for a comparable increase in organic matter on going from the A to the C horizon. No explanation can be offered for this either.

To facilitate comparison of the equation obtained in the present investigations to that obtained by De Leenheer and Van Ruymbeke (4), these equations are given below.

$$A.D.=1.69687-0.004861597\ (\%\ clay) -0.0800295\ (\%\ O.M.)+0.0010902\ (\%\ clay)(\%\ O.M.) \quad (R=0.794,\ S_{ee}=0.106) \tag{1.7}$$

$$A.D.=1.660878-0.001386\ (\%\ clay)-0.0032113\ (\%\ O.M.) -0.00775\ (\%\ CaCO_3)-0.002443\ (\%\ H_2O) \quad (R=0.8249,\ S_{ee}=0.0727) \tag{0.2}$$

The ways in which equation (0.2) (De Leenheer and Van Ruymbeke) and equation (1.7) (present study) differ are:

1. The percentage moisture at sampling was not included in regression analysis in the present study and therefore the ($\%\ H_2O$) term is not present in equation (1.7).

2. In equation (1.7), the interaction of clay and organic

matter contributed significantly to the regression. This was not the case in equation (0.2) derived by De Leenheer and Van Ruymbeke.

3. De Leenheer and Van Ruymbeke found that $CaCO_3$ was significantly related to apparent density. This was not the case in the present study.

As indicated above, the relationship of soil components to apparent density is different in the two groups of soils.

FIELD CAPACITY

a) Relation to Soil Components.

The independent variables found to be contributing significantly to the regression equation predicting field capacity were silt, clay and organic matter. The regression equation is:

$$F.C.=11.47807 + 0.11703^{**}(\%\ silt) + 0.25400^{**}(\%\ clay) + 1.16457^{**}(\%\ O.M.) \quad (R=0.879^{**},\ S_{ee}=3.73) \qquad (2.1)$$

The relatively high value of the correlation coefficient significant at the one percent level of probability indicates that a close relationship exists between field capacity and the soil components (silt, clay and organic matter).

The standard error of estimate in equation (2.1) is 3.73. This means that 67 percent of the determined values of field capacity fall in a range of $\pm$ 3.73 from the predicted value. For most purposes, then, the equation gives a sufficiently good estimate of field capacity.

The 't' values of the regression coefficients of silt, clay and organic matter are 5.42, 9.95 and 7.64, respectively. The 't' values indicate that all the coefficients are significant at the one percent level of probability. Since the 't' values of the regression coefficients are not very different, the extent of the association of each of the three soil components with field capacity is about the same. No one component stands out as being much more or less important

**significant at 1%

than the others in its relation to field capacity.

The nature of the relationship between soil components and field capacity is revealed by a further consideration of equation (2.1).

1. A soil containing no silt, clay or organic matter, according to the equation, would have a field capacity of 11.47807. Soils closest to this composition are those in the coarse textured group. The average field capacity of these soils is 13.72 (Appendix I, p 76). This is quite close to the value of the constant in equation (2.1) when one considers that the coarse textured soils have a small amount of each of silt, clay and organic matter.

2. The numerical values of the regression coefficients differ considerably. Table 6 points out how the differences in the regression coefficients of silt and clay affect the predicted values of field capacity. In Table 6a the sand content is held constant at 30 percent and the silt and clay contents vary from 10 to 60 percent and 60 to 10 percent, respectively. The prediction values of field capacity for these soils show that, at constant sand content, no great changes occur in the value of field capacity when the silt and clay contents are varied. Field capacity is decreased only 6.85 percent when the clay content is decreased from 60 to 10 percent.

Table 6b shows how a change in the sand content at the expense of the clay content affects the predicted value of field capacity. At a constant silt content of 30 percent, field capacity is decreased 12.71 percent when the clay content is decreased from 60 to 10 percent.

TABLE 6

PREDICTION VALUES FOR FIELD CAPACITIES OF ORGANIC MATTER FREE SOILS VARYING IN MECHANICAL COMPOSITION

	% sand	% silt	% clay	F.C. %
a)				
	30	10	60	27.89
	30	20	50	26.52
	30	30	40	25.05
	30	40	30	23.78
	30	50	20	22.41
	30	60	10	21.04
b)	10	30	60	30.24
	20	30	50	27.69
	30	30	40	25.15
	40	30	30	22.61
	50	30	20	20.08
	60	30	10	17.53
c)	10	60	30	26.12
	20	50	30	24.95
	30	40	30	23.78
	40	30	30	22.61
	50	20	30	21.43
	60	10	30	20.27

Table 6c shows how a decrease in silt at a constant clay content of 30 percent affects field capacity. The predicted field capacity is decreased 5.85 percent when the silt content is decreased from 60 to 10 percent.

From Table 6 one can conclude that:a) approximately equal increases occur in field capacity when sand is replaced by silt and when silt is replaced by clay; and b) when clay replaces sand the increase in field capacity is approximately twice that when either silt replaces sand or clay replaces silt.

3. Considering the relation of organic matter to field capacity it can be seen from equation (2.1) that the regression coefficient of organic matter is more than four times that of clay and almost ten times that of silt. Thus on a weight basis organic matter holds more than four times as much water as clay and almost ten times as much water as silt. This is in accordance with present beliefs concerning the water holding capacity of organic matter (3).

Separation of the data into textural groups yielded the equations in Table 7 . Final equations using only those variables contributing significantly to the regression were not calculated as it was felt that the number of observations in some of the groups was too small.

A general trend which may be observed in Table 7 is that of an increasing standard error of estimate with increasing percentage of fine particles. This means that one cannot obtain as accurate an

TABLE 7

REGRESSION EQUATIONS FOR FIELD CAPACITY

Textural Group	No. of samples	EQUATION	R	S_{ee}	t values		
					b_1	b_2	b_3
Coarse textured	12	F.C.= 10.5816 + 0.30881(% silt) + 0.817197(% clay) + 0.660903(% O.M.)	0.892*	2.16	1.97	3.70**	1.14
Moderately coarse textured	12	F.C.= 9.0751 + 0.026267(% silt) + 0.450808(% clay) + 1.32293(% O.M.)	0.990*	1.78	0.63	10.90**	15.00**
Medium textured	17	F.C.= 11.2508 + 0.07924(% silt) + 0.34504(% clay) + 1.136177(% O.M.)	0.844*	3.74	0.81	1.94	2.50*
Moderately fine textured	33	F.C.= 14.3744 + 0.13425(% silt) + 0.10448(clay) + 1.46674(% O.M.)	0.750*	3.49	2.54*	1.10	5.81**
Fine textured	20	F.C.= 12.1226 + 0.04439(% silt) + 0.29523(% clay) + 0.97815(% O.M.)	0.725	5.58	0.45	3.20**	2.77*
All soils combined	94	F.C.= 11.47807 + 0.11703(% silt) + 0.25400(% clay) + 1.16457(% O.M.)	0.879**	3.73	5.42**	9.95**	7.64**

* significant at 5%
** significant at 1%

estimate of field capacity in fine textured soils as in coarse textured soils.

Inspection of Table 7 reveals no trends in the values of the regression coefficients of silt, clay and organic matter with increasing percentages of fine particles.

The equation predicting field capacity from soil components obtained by De Leenheer and Van Ruymbeke (4) is:

$$F.C.=0.290655 + 0.400696\ (\%\ clay) + 0.262886\ (\%\ coarse\ silt) + 0.42686\ (\%\ CaCO_3) + 3.224689\ (\ O.M.) \quad (R=0.9155,\ S_{ee}=4.5311) \tag{0.4}$$

To facilitate comparison to the above equation, the equation obtained in the present study is given below:

$$F.C.=11.47807 + 0.11703\ (\%silt) + 0.25400\ (\%\ clay) + 1.16457\ (\%O.M.) \quad (R=0.879,\ S_{ee}=3.73) \tag{2.1}$$

The differences between equations (0.4) (De Leenheer and Van Ruymbeke) and equation (2.1) (present study) are outlined below:

L. De Leenheer and Van Ruymbeke found that $CaCO_3$ was significantly related to field capacity. This was not the case in the present study.

2. The value of the constant in equation (0.4) appears to be different from the constant in equation (2.1). This difference seems to imply that the entire relationship is different.

3. The two equations appear to differ with respect to the regression coefficients. Taking the regression coefficients of clay as an example, equation (0.4) gives a value of 0.400696 while

equation (2.1) gives a value of 0.25400. The variance of the clay coefficient in equation (2.1) was very small (0.0006501). If the variance of the clay coefficient in equation (0.4) were of similar magnitude, a 't' test comparing the coefficients would show that they are significantly different. Similar comments appear to be applicable to the coefficients of silt and organic matter.

These differences seem to indicate that the relation of soil components to field capacity varies with geographical location. Therefore, in order to obtain a reasonable degree of accuracy, the relation should be determined experimentally on soils similar to those for which it is to be used.

b) Relation of Field Capacity to the 1/3 Atmosphere Percentage.

The regression equation obtained when the 1/3 atmosphere percentage (1/3 atm %) was related to field capacity is as follows:

$$F.C.=8.2803 + 0.65421\ (1/3\ atm\ \%). \qquad (2.7)$$
$$(r=0.917^{**},\ S_{ee}=3.07)$$

The standard error of estimate in equation (2.7), 3.07, is smaller than that in equation (2.1), 3.73. Thus the use of the 1/3 atmosphere percentage gives a more accurate estimate of field capacity.

Equation (2.7) is quite similar to the equations obtained by Haise *et al.* (5) on soils of the Great Plains of Montana. Equation (2.7) shows the greatest similarity to the equation Haise *et al.* obtained for the 0-12 inch depth. Their equation was:

$$F.C.=7.6 + 0.619\ (1/3\ atm\ \%) \qquad (r=0.931^{**}) \qquad (0.5)$$

** significant at 1%

It can be seen that both the constant and the regression coefficient are larger in equation (2.7) than in equation (0.5). These differences, however, do not appear to be very great. Therefore it appears that the relation of field capacity to the 1/3 atmosphere percentage in the soils used in the present study is not too different from that obtained by Haise et al. on the surface soils of Montana.

The possibility that field capacity was a quadratic function of the 1/3 atmosphere percentage was investigated. (If the quadratic term were significant a better estimate of field capacity than given by equation (2.7) would be obtained). The equation of the form

$$F.C. = a + b_1(1/3 \text{ atm } \%) + b_2(1/3 \text{ atm}\%)^2$$

was calculated. The 't' value of b_2, 1.29, was not significant. Thus the quadratic term did not improve the relationship.

Finally, a combination of field and laboratory data was related to field capacity. The 1/3 atmosphere percentage and the percentage total porosity, as calculated from density measurements, were used. The prediction equation obtained is as follows:

$$F.C. = 0.73917 + 0.6005996^{**}(1/3 \text{ atm } \%) + 0.192102^{**}(\% \text{ total porosity}) \quad (r = 0.929^{**},\ S_{ee} = 2.82) \qquad (2.8)$$

The 't' value of the regression coefficient of percentage total porosity was highly significant indicating that field capacity was truly dependent upon the total porosity. The standard error of

** significant at 1%

estimate in equation (2.8) was 2.82, while that obtained by using the 1/3 atmosphere percentage alone, equation (2.7), was 3.07. Therefore the accuracy of field capacity prediction was increased by the inclusion of total porosity data. The disadvantage in using equation (2.3) is that density determinations, which are quite time consuming, must be made.

PERMANENT WILTING PERCENTAGE

a) Relation to Soil Components.

The soil components found to be significantly related to permanent wilting percentage were silt, clay and organic matter. The calculated regression equation is as follows:

$$\begin{aligned} P.W.P. &= 1.1231 + 0.03563^{**}(\%\ \text{silt}) \\ &+ 0.24197^{**}(\%\ \text{clay}) + 0.6212^{**}(\%\ \text{O.M.}) \\ &(R = 0.934^{**},\ S_{ee} = 1.92) \end{aligned} \tag{3.1}$$

The highly significant correlation coefficient indicates that a real relationship exists between permanent wilting percentage and the soil components silt, clay and organic matter.

The standard error of estimate in equation (3.1) is 1.92 indicating that 67 percent of the determined values of permanent wilting percentage fall within $\pm$ 1.92 of the predicted values. Considering the fact that the standard deviation of permanent wilting percentage as determined by the sunflower method has been found to be about 0.54 (13), it seems fairly reasonable to assume, that for prediction purposes, equation (3.1) is quite good.

The 't' values of the regression coefficients of silt, clay and organic matter are 3.30, 18.50 and 7.95, respectively. The 't' value of the regression coefficient of clay is considerably larger than that of the other two variables. This indicates that there is a closer relationship between clay and permanent wilting percentage than between the other soil components and permanent wilting percentage.

**significant at 1%

A further consideration of equation (3.1) reveals some interesting features of the nature of the relationship between soil components and permanent wilting percentage. These are as follows:

1. A soil having no silt, clay or organic matter would have, according to the equation, a permanent wilting percentage of 1.1231. This permanent wilting percentage value is lower than the mean value of 4.65 obtained for the coarse textured soils in the present investigation (Appendix I, p 76). However, when the proper corrections for the silt, clay and organic matter content of this group are made, a value similar to the constant is obtained.

2. The regression coefficients indicate that the greatest contribution to the value of the permanent wilting percentage is made by organic matter. Organic matter contributes about two and one-half times as much per unit weight as clay and about twenty times as much as silt.

3. Permanent wilting percentage is not increased very much by increasing the silt content. The permanent wilting percentage of a pure sand would be, according to the equation, 1.1231, while that of a pure silt would be 4.7921. This is a small increase considering the marked change in the size of the soil separates.

The coefficient of organic matter in equation (3.1) is approximately one-half its value in equation (2.1). This means that an appreciable amount of the available moisture is extracted from organic matter. Lund (14) and Jamison and Kroth (11) also found this to be true in certain cases.

The regression coefficient of silt in equation (3.1) has been reduced to one-half its value in equation (2.1) indicating that a considerable amount of available water is held in the silt fraction.

In contrast to the above differences in the regression coefficients of silt and organic matter, there is virtually no difference in the regression coefficients of clay in the two equations. This means that very little, if any, available moisture is extracted from the clay fraction.

From the above comparison of equations (2.1) and (3.1) one must conclude that available water is probably related to silt and organic matter content but not to clay content. This will be shown to be true in the next section of this thesis.

Separation of the data into textural groups yielded the equations in Table 8. Because of the small number of observations in some of the groups, the final equations, using only those variables contributing significantly to the regression were not derived. However, the following trends can be observed in Table 8.

With the exception of coarse textured soils, there is a general increase in the standard error of estimate as soils become finer in texture. This indicates that the accuracy of the prediction decreases as the percentage of fine particles in the soil increases.

2. The 't' values of the regression coefficients of clay and organic matter increase as soils become finer in texture. This

TABLE 8

REGRESSION EQUATIONS PREDICTING PERMANENT WILTING PERCENTAGE

Textural Group	No. of samples	EQUATION	R	See	t values b_1	t values b_2	t values b_3
Coarse textured	12	P.W.P.= 0.50128 + 0.3104(% Silt) + 0.14807(% clay) + 0.26232(% O.M.)	0.740*	1.77	2.41*	0.82	0.55
Moderately coarse textured	12	P.W.P.= 0.83169 + 0.08975(% silt) + 0.1808(% clay) + 0.8515(% OM.)	0.951**	0.85	1.42	2.88*	2.02
Medium textured	17	P.W.P.= 1.6704 + 0.003362(% silt) + 0.29828(% clay) + 0.30545(% O.M.)	0.846**	0.93	0.21	3.18**	1.27
Moderately fine textured	33	P.W.P.= 1.6714 + 0.05140(% silt) + 0.1906(% clay) + 0.6458(% O.M.)	0.729**	2.04	1.66	3.33**	4.32**
Fine textured	20	P.W.P.= 0.6316 + 0.04533(% silt) + 0.2475(% clay) + 0.6923(% O.M.)	0.900**	2.19	1.17	6.76**	4.95**
All Soils combined	94	P.W.P.= 1.1231 + 0.03569(% silt) + 0.24197(% clay) + 0.6212(% O.M.)	0.934**	1.92	3.30**	18.50**	7.95**

** significant at the 1% level of probability
* significant at the 5% level of probability

indicates an increasing dependence of permanent wilting percentage on these components.

In conclusion, one can say that the data in Table 8 show that the factors affecting permanent wilting percentage vary with texture. Therefore, for precise prediction a different equation should be derived for each textural group.

The general equation obtained in the present study, equation (3.1), and that obtained by De Leenheer and Van Ruymbeke (4), equation (0.12), are given below:

$$\text{P.W.P.} = 1.1231 + 0.03569\ (\%\ \text{silt}) + 0.24197\ (\%\ \text{clay}) + 0.621200\ (\%\ \text{O.M.}) \quad (R=0.934,\ S_{ee}=1.92) \tag{3.1}$$

$$\text{P.W.P.} = -0.666156 + 0.36327\ (\%\ \text{clay}) + 0.044663\ (\%\ \text{coarse silt}) + 0.19908\ (\%\ CaCO_3) + 0.849308\ (\%\ \text{O.M.}) \quad (R=0.9658,\ S_{ee}=1.6805) \tag{0.12}$$

The differences between equations (3.1) and (0.12) can be summarized as follows:

1. De Leenheer and Van Ruymbeke found that the $CaCO_3$ content was significantly related to permanent wilting percentage. Such was not the case in the present study.

2. The regression coefficient of clay in equation (3.1) is 0.24197 while that in equation (0.12) is 0.36327. The variance of the regression coefficient of clay in equation (3.1) is 0.0001704. If the variance of the regression coefficient of clay in equation (0.12) were of similar magnitude, a 't' test of the regression coefficients would show them to be different.

3. Similar remarks can be made in the case of the constants and the regression coefficients of silt and organic matter.

The results of De Leenheer and Van Ruymbeke and those of the present investigations indicate that a close relationship exists between soil components and the permanent wilting percentage. The factors involved in this relationship and the extent to which they contribute vary. Therefore, if such a relationship is to be used to predict permanent wilting percentage, it must be determined on soils similar to those for which it is to be used.

b) Relation of Permanent Wilting Percentage to the 15-atmosphere Percentage.

The relation between permanent wilting percentage and the 15-atmosphere percentage (F.A.P.) is as follows:

$$P.W.P. = 0.0207 + 0.77468\ (F.A.P.) \qquad (r = 0.970^{**},\ S_{ee} = 1.32) \qquad (3.2)$$

The standard error of estimate of this equation is 1.32. The standard error of estimate of the equation used in predicting permanent wilting percentage from soil components (equation (3.1)) is 1.92. Thus a more accurate estimate of permanent wilting percentage is obtained when equation (3.2) is used.

A test of the constant in equation (3.2) shows that it is not significantly different from zero. This means that the constant can be deleted from equation (3.2) and that a simple ratio between permanent wilting percentage and the 15-atmosphere percentage can be used.

**significant at 1%

Richards and Wadleigh (18) and Lehane and Staple (13) obtained equations (0.16) and (0.17), respectively. These equations are as follows:

$$U.W.P. = 0.36 + 0.863\ (F.A.P.) \qquad (S_{ee} = 0.67) \qquad (0.16)$$

$$U.W.P. = 0.35 + 0.833\ (F.A.P.) \qquad (r = 0.995) \qquad (0.17)$$

For a 15-atmosphere percentage of 20, equations (3.2), (0.16), and (0.17) predict a permanent wilting percentages of 15.42, 17.62 and 17.01, respectively. Therefore equations (0.16) and (0.17) give relatively similar results. Equation (3.2), however, gives slightly lower permanent wilting percentages than the other two equations. This indicates a slightly different relationship between permanent wilting percentage and the 15-atmosphere percentage for the soils used in the present study.

AVAILABLE MOISTURE

a) Percent Weight Basis.

Silt and organic matter were found to be significantly related to available moisture on a percent weight basis (A.M.P.W.). The equation is as follows:

$$A.M.P.W. = 10.25815 + 0.0863604^{**} (\%\ silt) + 0.683927^{**} (\%\ O.M.) \quad (R=0.672^{**},\ S_{ee}=2.89) \tag{4.1}$$

The correlation coefficient in equation (4.1) is 0.672. The correlation coefficients for field capacity and permanent wilting percentage were 0.879 and 0.934, respectively. In view of this fact, a correlation coefficient of 0.672 for available moisture (the difference between field capacity and permanent wilting percentage) appears to be in order.

The standard error of estimate in equation (4.1) is 2.89. This means that in a soil with an apparent density of 1.40 the error in calculating the available moisture in a one foot depth is approximately one-half inch. An error of this magnitude appears to limit the usefulness of this equation for prediction purposes, particularly for coarse textured soil which have a low available moisture content.

Separation of the data into textural groups yielded the equations in Table 9. In these equations the correlation coefficients of the coarse, moderately coarse and medium textured soils range from 0.705 to 0.745, whereas those for the moderately fine and fine

**significant at 1%

TABLE 9

REGRESSION EQUATIONS FOR % AVAILABLE MOISTURE (WEIGHT BASIS)

Textural Group	No. of samples	EQUATION	R	S_{ee}	t values b_1	t values b_2
Coarse textured	12	A.M.P.W.=13.547317 - 0.5326958(% silt) + 1.44091(% O.M.)	0.705*	3.14	2.36	2.08
Moderately coarse textured	12	A.M.P.W.= 6.30618 + 0.367132(% silt) + 0.614758(% O.M.)	0.746*	2.92	2.06	1.35
Medium textured	17	A.M.P.W.= 9.768256 + 0.094587(% silt) + 0.870986(% O.M.)	0.718**	2.72	1.95	2.80*
Moderately fine textured	33	A.M.P.W.= 9.21865 + 0.1037598(% silt) + 0.8255887(% O.M.)	0.596**	3.06	2.47	3.67**
Fine textured	20	A.M.P.W.=13.21696 + 0.027528568(% silt) + 0.469152(% O.M.)	0.555*	2.86	0.58	2.78
All soils combined	94	A.M.P.W.=10.25815 + 0.0863604(% silt) + 0.683927(% O.M.)	0.672**	2.89	5.50**	6.01**

* significant at 5%
** significant at 1%

textured are 0.596 and 0.555, respectively. This result indicates that a closer relationship exists between soil components and available moisture in the coarse, moderately coarse and medium textured soils than in moderately fine and fine textured soils.

b) Volume Fraction.

Silt was found to be the only soil component related to available moisture by volume fraction (A.M.V.F.). Similar results were obtained by Jamison (10), Jamison and Kroth (11), Lund (14), Bartelli and Peters (2) and Hill (8). The equation obtained in the present investigations is as follows:

$$A.M.V.F.=0.1773 + 0.0011289\ (\%\ \text{silt}) \qquad (4.2)$$
$$(r=0.419^{**},\ S_{ee}=0.0457)$$

The correlation coefficient, although highly significant, is relatively small. Only 18.5% of the total variation in available moisture can be explained by a relationship to silt. Therefore, the equation probably should not be used for prediction purposes.

Organic matter is significantly related to available moisture on a percent weight basis (equation (4.1)), but not on a volume basis (equation (4.2)). An increase in organic matter decreases apparent density (equation (1.7)) and increases available moisture on a percent weight basis. Available moisture on a volume basis is the product of apparent density and available moisture on a percent weight basis. In the data used in the present investigation the effects of organic matter on apparent density and available moisture on a weight

**significant at 1%

basis appear to cancel each other.

Hill (8) found that available moisture holding capacity on a percent volume basis (A.M.H.C.) was related to silt content as shown in the following equation:

$$A.M.H.C.=6.5 + 0.26 \text{ (\% silt)} \qquad (r=0.730^{**}) \qquad (0.27)$$

This equation converted to volume fraction available moisture reads as follows:

$$A.M.V.F.=0.065 + 0.0026 \text{ (\% silt)} \qquad (0.27a)$$

There is very little similarity between the equation calculated by Hill and the one calculated in the present study. The regression coefficient in equation (0.027a) is approximately two times as large as the one in equation (4.2). The constants of the two equations are also of different magnitude.

A comparison of the correlation coefficients in equations (4.2) and (0.27), indicates that there was a much closer relationship between silt content and available moisture in the soils Hill used than in the soils used in the present investigation.

Table 10 shows the regression equations for the five textural groups used. The low correlation coefficients and the high standard errors of estimate indicate that the equations are unsatisfactory for prediction purposes.

** significant at 1%

TABLE 10

REGRESSION EQUATIONS FOR AVAILABLE MOISTURE (VOLUME FRACTION)

Textural Group	No. of samples	EQUATION	r	S_{ee}
Coarse textured	12	A.M.V.F. = 0.2335 - 0.00725575(% silt)	-0.561	.0566
Moderately coarse textured	12	A.M.V.F. = 0.09954 + 0.00167777(% silt)	0.336	.0226
Medium textured	17	A.M.V.F. = 0.17665 + 0.001126(% silt)	0.381	.0129
Moderately fine textured	33	A.M.V.F. = 0.1646 + 0.001435(% silt)	0.363*	.0496
Fine textured	20	A.M.V.F. = 0.2272 - 0.0001383(% silt)	-0.0501	.0488
All soils combined	94	A.M.V.F. = 0.1773 + 0.0011289(% silt)	0.419**	.0457

* significant at 5% level
** significant at 1% level

SOIL MOISTURE RETENTION DATA

The equations predicting soil moisture retention at various tensions are presented in Table 11. The variables contributing significantly to the regressions were silt, clay and organic matter.

Table 11 shows that the correlation coefficients are highly significant in all the equations and are of similar magnitude. The correlation coefficients range from 0.934 to 0.951. This indicates that the closeness of the relation of soil components to moisture retained is about the same for all tensions.

As the tension increases the constant terms in the equations and the regression coefficients for each independent variable decrease. This indicates that the relationship between moisture retention and soil components changes with tension. To determine if the change in the value of the regression coefficients of each variable with each increment of tension was significant, a 't' test was applied. An example of the calculations, using the regression coefficients of silt at the 1/4- and 1/3-atmosphere percentages is given below:

1. The pooled variance of two successive tensions.

$$S_p^2 = \frac{\text{Residual sum } S_{q.\frac{1}{4}atm} + \text{Residual sum } S_{q.1/3\ atm}}{(n-k-1)_{\frac{1}{4}atm} + (n-k-1)_{1/3atm}}$$

$$= \frac{1291.066 + 1397.701}{180}$$

$$= 15.837$$

TABLE 11.

REGRESSION EQUATIONS FOR MOISTURE RETENTION DATA

No. of samples	EQUATION	R	S_{ee}	t values b_1	t values b_2	t values b_3
94	1/4 atm % = 5.77301 + 0.23129(% silt) + 0.44447(% clay) + 1.205976(% O.M.)	0.936**	4.01	9.97**	16.25**	7.49**
94	1/3 atm % = 5.044858 + 0.221189(% silt) + 0.4264122(% clay) + 1.056421(% O.M.)	0.934**	3.94	9.73**	15.90**	6.68**
94	1/2 atm % = 3.19943 + 0.189539(% silt) + 0.42529(% clay) + 1.0028998(% O.M.)	0.950**	3.14	10.46**	19.90**	7.95**
94	1 atm % = 2.83107 + 0.181248(% silt) + 0.365037(% clay) + 0.8701245(% O.M.)	0.950**	2.82	11.09**	18.90**	7.55**
92	3 atm % = 1.44769 + 0.1090625(% silt) + 0.365156(% clay) + 0.729685(% O.M.)	0.945**	2.60	7.18**	20.58**	6.95**
94	7 atm % = 1.22798 + 0.07766(% silt) + 0.323676(% clay) + 0.659386(% O.M.	0.951**	2.12	6.34**	22.40**	7.75**
94	15 atm % = 0.90329 + 0.0722346(% silt) + 0.31049(% clay) + 0.6532076(% O.M.)	0.945**	2.20	5.69**	20.75**	7.39**

** significant at 1% level of probability

2. The varience of the difference between the regression coefficients.

a) The varience of silt at the two tensions.

$$\sum(X_{\frac{1}{4}} - \overline{X}_{\frac{1}{4}})^2 = \frac{S^2}{S^2_{b\frac{1}{4}}} = \frac{S^2}{S^2_{?}} = 16.1443 = 30133.0691$$

$$\overline{\sum(X_{\frac{1}{4}} - \overline{X}_{\frac{1}{4}})^2}$$

$$\sum(X_{1/3} - \overline{X}_{1/3})^2 = \frac{15.530011}{0.000515381} = 30133.0691$$

b) The variance of the difference of the regression coefficients.

$$S^2(b_{1/4} - b_{1/3}) = S_p^2\left(\frac{1}{\sum(X_{1/4} - \overline{X}_{1/4})^2} \neq \frac{1}{\sum(X_{1/3} - \overline{X}_{1/3})^2}\right)$$

or $S(b_{1/4} - b_{1/3}) = 0.03242$

3. The 't' value.

$$t = \frac{b_{1/4} - b_{1/3}}{S(b_{1/4} - b_{1/3})} = \frac{.23120 - .22118885}{0.03242} = 0.31$$

The 't' value obtained in this way was compared with the significant 't' for 180 degrees of freedom at the 5 and 1 percent levels.

The 't' values from tests of significance of the difference between regression coefficients at successive tensions obtained are shown in Table 12. For several tension increments the 't' values for the difference in regression coefficients for all three soil components are not statistically significant. In this case one can conclude that the greatest portion of the moisture extracted came from the soil

TABLE 12

THE 't' VALUES FROM TESTS OF SIGNIFICANCE OF THE DIFFERENCE BETWEEN REGRESSION COEFFICIENTS AT SUCCESSIVE TENSIONS

Tension range	t values		
	silt	clay	Organic matter
1/4 - 1/3 atm	0.31	0.47	0.66
1/3 - 1/2 atm	1.09	0.03	0.27
1/2 - 1 atm	0.34	2.10*	0.78
1 - 3 atm	3.24**	-0.01	0.91
3 - 7 atm	1.62	1.88	0.52
7 - 15 atm	0.31	0.64	0.05

* significant at 5%
** significant at 1%

component for which the 't' value is largest.

The 't' values in Table 12 indicate from which soil component the greatest portion of water is extracted at each tension increment. Extraction of water for each tension increment can be summarized as follows:

1. 1/4 - 1/3 atmosphere -- equal amounts of water are extracted from the silt and clay components. A slightly larger amount is extracted from organic matter.

2. 1/3 - 1/2 atmosphere -- the greatest portion of the moisture is extracted from the silt fraction. A small amount of water is extracted from organic matter, while virtually no water is extracted from clay.

3. 1/2 - 1 atmosphere -- the greatest part of the water is extracted from clay. (The 't' value for clay is significant in this tension increment). Some moisture is extracted from organic matter and a smaller amount from silt.

4. 1 - 3 atmospheres -- most of the moisture is extracted from silt. (The 't' value for silt is highly significant for this tension increment). A small amount of water is extracted from organic matter but none from clay.

5. 3 - 7 atmospheres -- approximately equal amounts are extracted from silt and clay; a smaller amount is extracted from organic matter.

6. 7 - 15 atmospheres -- most of the water is extracted

from clay, some is extracted from silt, and almost none is extracted from organic matter.

The tension ranges in which the greatest extractions of water from each soil component occur are as follows:

1. Silt -- the largest amount of water is extracted between 1 and 3 atmospheres. Smaller but approximately equal extractions occur between 1/3 and 1/2 atmosphere, and between 3 and 7 atmospheres.

2. Clay -- approximately equal amounts of water are extracted between 1/2 and 1 atmosphere, and between 3 and 7 atmospheres. Smaller amounts are extracted between 1/4 and 1/3 atmosphere and between 7 and 15 atmospheres.

3. Organic Matter -- approximately equal amounts of water are extracted in each tension increment up to 7 atmospheres. From 7 to 15 atmospheres very little water is extracted from organic matter.

The limitations to the above discussions are as follows:

1. As the tension increases, the constant in the equations decrease (Table 11). This decrease in the constant contributes to the moisture extracted in that tension increment. This constant amount of water is extracted from one or more of the soil components, however, it is not possible to determine its source. Therefore, the 't' values in Table 12 show only from which fraction it is most probably that extraction of moisture occurs when the tension is increased.

2. The variances of the differences of the regression coefficients of organic matter are much larger than those of silt and

clay. For example, in the tension increment 1/4 to 1/3 atmosphere, the variance of the differences of silt, clay and organic matter coefficients are 0.03242, 0.03824 and 0.2255, respectively. Therefore, the difference of the regression coefficients of organic matter for a particular tension increment can be quite large numerically and yet statistically can be quite small.

Equations obtained for each textural group are presented in Tables 13, 14, 15, 16, 17, 18 and 19. Similar variations due texture are present at most tensions. Therefore a detailed study of these variations at each tension was not undertaken. Only the general trends are outlined below:

1. The correlation coefficients are significant at the 5 percent level and all but one (medium textured - 1/3-atm) are significant at the 1 percent level. This seems to indicate a close relationship between soil components and moisture retained at various tensions, regardless of texture.

2. In general, the standard error of estimate for a given tension increases as the percentage of fine separates increases. This means that the accuracy of the prediction decreases as the amount of fine separates increases. An exception to this general rule occurs in moderately fine textured soils. Here the standard error of estimate is always lower than that of either fine textured or medium textured soils. This affect, however, can probably be attributed to the larger number of observations in this textural group.

TABLE 13

REGRESSION EQUATIONS FOR 1/4 ATMOSPHERE PERCENTAGE

Textural group	No. of samples	EQUATION	R	S_{ee}	t values b_1	t values b_2	t values b_3
Coarse textured	12	1/4 atm % = 3.45284 + 0.3073688(% silt) + 0.539298(% clay) + 0.815737(% O.M.)	0.936**	1.43	2.94*	3.67**	2.10
Moderately coarse textured	12	1/4 atm % = 2.651211 + 0.3505823(% silt) + 0.8659668(% clay) + 0.8532174(% O.M.)	0.906**	2.64	1.94	4.48**	2.49*
Medium textured	17	1/4 atm % = 13.73370 + 0.1741449(% silt) + 0.296522(% clay) + 1.2233709(% O.M.)	0.853**	4.16	1.60	1.50	2.42*
Moderately fine textured	33	1/4 atm % = 7.280003 + 0.214753(% silt) + 0.379400(% clay) + 1.6468804(% O.M.)	0.840**	3.24	4.35**	4.30**	6.90**
Fine textured	20	1/4 atm % = 10.186428 + 0.0717137(% silt) + 0.455574(% clay) + 1.1285226(% O.M.)	0.849**	5.08	.80	5.40**	3.50**
All soils combined	94	1/4 atm % = 5.77301 + 0.23129(% silt) + 0.44447(% clay) + 1.205976(% O.M.)	0.936**	4.01	9.97**	16.25**	7.49**

* significant at 5%
** significant at 1%

TABLE 14

REGRESSION EQUATIONS FOR 1/3 ATMOSPHERE PERCENTAGE

Textural group	No. of samples	EQUATION	R	S_{ee}	t values b_1	t values b_2	t values b_3
Coarse textured	12	1/3 atm % = 3.9614896 + 0.251958(% silt) + 0.451487(% clay) + 0.687057(% O.M.)	0.904**	1.51	2.29	2.92*	1.68
Moderately coarse textured	12	1/3 atm % = 1.88905 + 0.267471(% silt) + 0.786840(% clay) + 0.890138(% O.M.)	0.915**	2.28	1.71	4.71**	3.00*
Medium textured	17	1/3 atm % = 12.46015 + 0.08867317(% silt) + 0.449085(% O.M.) + 0.9150327(% O.M.)	0.790*	5.07	.68	1.86	1.49
Moderately fine textured	33	1/3 atm % + 5.803204 + 0.212233(% silt) + 0.373994(% clay) + 1.415556(% O.M.)	0.860**	2.73	5.11**	5.03**	7.05**
Fine textured	20	1/3 atm % = 5.9603604 + 0.1476498(% silt) + 0.453982(% clay) + 0.9779338(% O.M.)	0.810**	5.59	1.50	4.89**	2.76*
All soils combined	94	1/3 atm % = 5.044858 + 0.22118885(% silt) + 0.4264212(%clay) + 1.056421(% O.M.)	0.934**	3.94	9.73**	15.90**	6.68**

* significant at 5%
** significant at 1%

TABLE 15

REGRESSION EQUATIONS FOR 1/2 ATMOSPHERE PERCENTAGE

Textural group	No. of samples	EQUATION	R	S_{ee}	t values b_1	t values b_2	t values b_3
Coarse textured	12	1/2 atm % = 1.307614 + 0.4001025(% silt) + 0.403406(% clay) + 0.685047(% O.M.)	0.930**	1.37	4.05**	2.88*	1.85
Moderately coarse textured	12	1/2 atm % = -1.93637 + 0.235125(% silt) + 0.72273(% clay) + 0.758791(% O.M.)	0.930**	1.83	1.87	5.38**	3.18*
Medium textured	17	1/2 atm % = 7.78726 + 0.1452265(% silt) + 0.3725660(% clay) + 0.890208(% O.M.)	0.870**	3.68	1.51	2.13	1.99
Moderately fine textured	33	1/2 atm % = 5.14487 + 0.176427(% silt) + 0.351324(% clay) + 1.2418449(% O.M.)	0.836**	2.68	4.33**	4.80**	6.30**
Fine textured	20	1/2 atm % = 4.759138 + 0.126990(% silt) + 0.433975(% clay) + 0.995096(% O.M.)	0.858**	4.53	1.60	5.80**	3.47**
All soils combined	94	1/2 atm % = 3.19943 + 0.189539(% silt) + 0.42539(% clay) + 1.0028998(% O.M.)	0.950**	3.14	10.46**	19.90**	7.95**

* significant at 5%
** significant at 1%

TABLE 16

REGRESSION EQUATIONS FOR 1 ATMOSPHERE PERCENTAGE

Textural group	No. of samples	EQUATION	R	See	t values b_1	t values b_2	t values b_3
Coarse textures	12	1 atm % = 0.278303 + 0.459242(% silt) + 0.439134(% clay) + 0.5189167(% O.M.)	0.952**	1.17	5.36**	3.64**	1.62
Moderately coarse textured	12	1 atm % = 0.1876913 + 0.043797(% silt) + 0.5813159(% clay) + 0.9282625(% O.M.)	0.975**	0.90	.66	8.75**	6.57**
Medium textured	17	1 atm % = 4.523774 + 0.145128(% silt) + 0.379658(% clay) + 0.745249(% O.M.)	0.880**	3.56	1.57	2.22*	1.73
Moderately fine textured	33	1 atm % = 2.26718 + 0.18283366(% silt) + 0.373846(% clay) + 1.015916(% O.M.)	0.795**	2.90	4.15**	4.73**	4.77**
Fine textured	20	1 atm % = 6.485719 + 0.1206896(% silt) + 0.333429(% clay) + 0.834612(% O.M.)	0.842**	3.82	1.80	5.27**	3.45**
All soils combined	94	1 atm % + 2.83107 + 0.181248(% silt) + 0.365037(% clay) + 0.8701245(% O.M.)	0.950**	2.82	11.09**	18.90**	7.55**

*significant at 5%

**significant at 1%

TABLE 17

REGRESSION EQUATIONS FOR 3 ATMOSPHERE PERCENTAGE

Textural group	No. of samples	EQUATION	R	S_{ee}	t values b_1	b_2	b_3
Coarse textured	11	3 atm % = 0.114859 + 0.388313(% silt) + 0.327403(% clay) + 0.390394(% O.M.)	0.940**	1.11	4.37**	2.17	1.00
Moderately coarse textured	12	3 atm % = 2.055188 + 0.2057406(% silt) + 0.4972919(% clay) + 0.6776498(% O.M.)	0.914**	1.56	1.93	4.35**	3.33*
Medium textured	17	3 atm % = 2.5943276 + 0.0593276(% silt) + 0.458813(% clay) + 0.440545(% O.M.	0.835**	3.60	0.63	2.68*	1.01
Moderately fine textured	32	3 atm % = 1.144890 + 0.137516(% silt) + 0.388677(% clay) + 0.8765004(% O.M.)	0.824**	2.48	3.65**	5.71**	4.80**
Fine textured	20	3 atm % = 3.2631707 + 0.0718521(% silt) + 0.351319(% clay) + 0.776937(% O.M.)	0.879**	3.44	1.23	6.41**	3.70**
All soils combined	92	3 atm % = 0.44769 + 0.1090625(% silt) + 0.365156(% clay) + 0.729685(% O.M.)	0.945**	2.60	7.18**	20.58**	6.95**

* significant at 5%
** significant at 1%

TABLE 18

REGRESSION EQUATIONS FOR 7 ATMOSPHERE PERCENTAGE

Textural group	No. of samples	EQUATION	R	See	t values b1	t values b2	t values b3
Coarse textured	12	7 atm % = -0.320089 + 0.32708(% silt) + 0.33482(% clay) + 0.44899(% O.M.)	.915**	1.22	3.68**	2.68*	1.35
Moderately coarse textured	12	7 atm % = -1.244137 + 0.1568238(% silt) + 0.41898(% clay) + 0.610442(% O.M.	.909**	1.36	1.68	4.20**	3.43**
Medium textured	17	7 atm % = 2.064835 + 0.087843(% silt) + 0.294803(% clay) + 0.33899(% O.M.)	.875**	2.34	1.44	2.66*	1.19
Moderately fine textured	33	7 atm % = 0.759399 + 0.075446(% silt) + 0.33385(% clay) + 0.7420388(% O.M.)	.810**	2.22	2.24*	5.62**	4.55**
Fine textured	20	7 atm % = 1.383213 + 0.097822(% silt) + 0.308144(% clay) + 0.7072325(% O.M.)	.885**	2.72	1.98	6.50**	3.96**
All soils combined	94	7 atm % = 1.22798 + 0.077665(% silt) + 0.323676(% clay) + 0.659386(% O.M.)	0.951**	2.12	6.34**	20.75**	7.39**

* significant at 5%
** significant at 1%

TABLE 19

REGRESSION EQUATIONS FOR 15 ATMOSPHERE PERCENTAGE

Textural group	No. of samples	EQUATION	R	S_{ee}	t values b_1	t values b_2	t values b_3
Coarse textured	12	15 atm % = -0.206378 + 0.3198299(% silt) + 0.2740739(% clay) + 0.2559068(% O.M.)	0.894**	1.19	3.68**	2.24	0.82
Moderately coarse textured	12	15 atm % = -1.0672413 + 0.2048772(% silt) + 0.3474211(% clay) + 0.63079126(% O.M.)	0.900**	1.40	2.12	3.38**	3.44**
Medium textured	17	15 atm % = 2.5985536 + 0.0125694(% silt) + 0.344675(% O.M.) + 0.6463655(% O.M.)	0.873**	2.36	.20	3.08**	2.26*
Moderately fine textured	33	15 atm % = -0.1250587 + 0.10501685(% silt) + 0.25935747(% clay) + 0.87198356(% O.M.)	0.798**	2.20	3.14*	4.32**	5.40**
Fine textured	20	15 atm % = 0.0741061 + 0.0964584(% silt) + 0.3272002(% clay) + 0.5414719(% O.M.	0.876**	2.91	1.89	6.79**	2.94**
All soils combined	94	15 atm % = 0.90329 + 0.072234(% silt) + 0.31049(% clay) + 0.6532076(% O.M.)	0.945**	2.20	5.69**	20.75**	7.33**

* significant at 5%
** significant at 1%

3. The regression coefficients for silt, clay and organic matter are significant at all tensions in moderately fine textured soils. This is probably due to the large number of observations in this group.

4. For fine textured and moderately coarse textured soils, the regression coefficients for clay and organic matter are significant at all tensions. Fine textured soils contain a relatively high percentage of clay and therefore one would expect clay to be closely related to moisture retained. It is not evident, however, why clay should be closely related to moisture retained in moderately coarse textured soils. There appears to be no obvious explanation as to why organic matter is significantly related to soil moisture retention at every tension in these two textural groups and not in the others.

TESTING OF EQUATIONS

The equation for each soil physical constant was tested on 18 'test' soil samples. The procedure used is as follows:

1. The predicted values for each dependent variable were calculated from the derived prediction equations.

2. The difference between the actual and predicted values for each variable were calculated and designated as 'd'.

3. The root mean square difference was defined as

$$\sqrt{\frac{\sum d^2}{n-k-1}}$$

where n = the total number of samples in the test soils
and k = the number of independent variables used in the prediction equation

4. The root mean square difference and the standard error of estimate from the prediction equation were compared by means of an F ratio. This was obtained by dividing the root mean square difference by the standard error of estimate and squaring the quotient.

5. The F ratios were compared to the critical F values at the 10, 5 and 1 percent levels.

Table 20 shows the root mean square difference and the standard error of estimate of each dependent variable. In every case the root mean square difference is larger than the standard error of estimate. This was to be expected since only 18 samples were used to test equations derived from 94 samples.

There is some general similarity between the root mean square difference and the standard error of estimate. For permanent wilting

TABLE 20

ROOT MEAN SQUARE DIFFERENCE AND STANDARD ERROR

OF ESTIMATE FOR EACH DEPENDENT VARIABLE

Dependent Variable	Root Mean Square Difference	See	F Ratio
Apparent density	.139	.106	1.72*
Permanent wilting percentage	2.16	1.92	1.28
Field capacity	6.41	3.73	2.96***
Available moisture (percent by weight)	5.01	2.89	2.99***
Available moisture (volume fraction)	.0758	.0457	2.63***
1/4-atmosphere percentage	6.04	4.01	2.25**
1/3-atmosphere percentage	5.98	3.94	2.31**
1/2-atmosphere percentage	3.90	3.14	1.54
1-atmosphere percentage	3.00	2.82	1.12
3-atmosphere percentage	2.67	2.60	1.06
7-atmosphere percentage	2.71	2.12	1.64*
15-atmosphere percentage	3.24	2.20	2.16**

*significant at 10%
**significant at 5%
***significant at 1%

percentage, $\frac{1}{2}$-, 1-, and 3-atmosphere percentages the standard error of estimate and the root mean square difference are quite similar. Thus the expected average errors in prediction of these dependent variables in the 'test' soils are similar to the standard errors of estimate in the prediction equations. This indicates that the derived equations are applicable to the 'test' soils as well as to the soils from which they were derived.

For apparent density, and the 7-atmosphere percentage the standare error of estimate and the root mean square difference are significantly different at the 10 percent level of probability. This means that 90 percent of the time the deviation of the predicted from the actual values was greater than the standard error of estimate. Thus the equations appear applicable to soils similar to the 'test' soils only for purposes where this larger variation can be tolerated.

For the other dependent variables the root mean square difference and the standard error of estimate are significantly different at either the 5 percent or 1 percent level of probability. This indicates that the prediction equations for these variables are not applicable to soils similar to the 'test' soils.

As can be seen from Table 20, the prediction equations for moisture retention are applicable to the 'test' soils at some tensions and not at others. One would have expected that the equations for all tensions would have been uniform with respect to applicability. There is no apparent reason for this lack of uniformity.

V SUMMARY AND CONCLUSIONS

A study of the relationships between soil components and some soil physical constants was conducted on 94 samples from some of the major soil types in Manitoba. The equation obtained for each soil physical constant was subsequently tested on 18 'test' samples from an area not previously investigated. The conclusions resulting from these investigations are as follows:

1. Apparent density is closely related to clay, organic matter and the interaction of clay and organic matter. This relationship is significant at the 1 percent level ($R = .794$). The standard error of estimate is 0.106.

2. Field Capacity is related to silt, clay and organic matter. The relationship is significant at the 1 percent level ($R = .879$). The standard error of estimate is 3.73. A closer relationship ($r = .917$), and a smaller error in prediction ($S_{ee} = 3.07$) is obtained when the 1/3-atmosphere percentage is related to field capacity.

3. Permanent wilting percentage, like field capacity, is related to silt, clay and organic matter. However, the relationship is closer ($R = .934$) than in the case of field capacity. The standard error of estimate is 1.92. A better relationship ($r = .970$), and a smaller error in prediction ($S_{ee} = 1.32$) is obtained when the 15-atmosphere percentage is related to the permanent wilting percentage.

4. Silt and organic matter are related to available moisture on a percent by weight basis. The relationship is highly significant

(R = .672), and the standard error of estimate is 2.89.

5. Silt is the only soil component related to available moisture on a volume fraction basis. The relationship is significant at the 1 percent level (r = .419). The standard error of estimate is 0.0457.

6. Silt, clay and organic matter are the soil components related to moisture retention data. The relationships between soil components and the moisture retained at various tensions are closer than for the other soil physical constants. This is shown by the values of the coefficients of multiple correlation which range from .934 to .951. The standard errors of estimate for the various tensions appear to be directly proportional to the amount of moisture retained at each tension.

7. Testing of equations on the 'test' soils showed that the equations predicting permanent wilting percentage, 1/2-, 1-, and 3-atmosphere percentage are applicable to these soils. The equations for apparent density and the 7-atmosphere percentage are applicable to soils similar to the 'test' soils only if a variation slightly larger than the standard error of estimate can be tolerated. For the remaining soil physical constants the prediction equations do not appear to be applicable to the 'test' soils.

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SUMMARY OF SOILS DATA

Association	Depth: ins.	Mechanical Analysis % F.S.	% V.F.S.	% Total sand	% silt	% clay	% O.M.	% $CaCO_3$	Apparent density	F.C. %
Coarse Textured										
Altona	0-10	2.8	77.7	81.6	7.7	10.7	3.37	5.21	1.34	20.33
	10-24	1.0	80.7	82.4	5.4	12.2	1.07	8.49	1.52	19.53
Almasippi	0-18	60.1	5.0	88.7	6.4	4.9	1.50	18.77	1.66	10.60
	18-30	37.5	12.1	84.0	8.7	7.3	.90	16.82	1.77	11.67
	30-36	80.9	4.7	87.2	9.3	3.5	.06	36.27	1.80	14.53
Miniota	0-11	4.4	1.0	65.8	19.4	14.8	2.69	0.0	1.44	18.35
	11-24	4.8	0.9	84.5	10.5	5.0	0.28	21.70	1.80	11.75
	24-36	8.5	1.2	83.3	11.5	5.2	0.21	18.00	1.81	10.91
Almasippi	0-6	45.8	32.4	81.8	6.0	12.20	4.21	4.95	1.32	22.61
	6-16	47.8	34.2	83.2	5.0	11.80	1.40	12.70	1.58	18.68
Almasippi	0-8	55.1	31.6	87.8	5.3	6.9	1.93	0.36	1.56	14.95
	8-16	51.7	36.3	89.7	3.7	6.6	0.55	0.20	1.55	16.46
Moderately coarse textured										
Altona	0-10	1.60	74.2	77.4	9.5	13.0	3.24	0.18	1.38	18.86
	10-22	8.2	68.8	78.7	8.3	13.0	1.42	6.02	1.36	18.23
	22-36	2.9	75.3	81.0	5.7	13.3	0.68	11.62	1.48	16.47
Altona	0-8	0.7	65.9	68.3	13.7	17.9	7.07	3.11	1.32	26.93
	8-16	0.7	68.3	70.8	6.7	22.5	2.05	14.05	1.44	21.67
	16-36	0.7	84.6	86.3	5.6	8.1	0.44	12.53	1.48	12.87
Altona	0-10	1.1	63.8	67.1	14.8	18.1	5.71	2.04	1.38	25.33
	10-20	1.5	66.5	69.8	8.2	22.0	1.97	10.60	1.41	21.93
	20-36	0.8	59.9	62.3	17.0	20.7	1.02	25.06	1.45	20.13
Altona	0-9	1.0	68.7	70.9	15.2	13.8	4.88	0.81	1.50	22.13
	9-17	1.4	64.0	66.4	17.4	16.2	2.23	0.52	1.44	19.77
	17-36	1.4	66.2	68.7	15.8	15.6	1.40	2.73	1.61	18.23
Medium textured										
Holland	10-12	13.5	27.0	41.3	36.2	22.5	7.31	15.32	1.10	31.82
	12-24	39.0	9.5	49.5	31.6	19.9	3.38	32.48	1.41	25.71
	24-36	49.2	8.6	59.5	24.8	15.7	0.90	25.60	1.56	22.86

DIX I

USED TO DERIVE EQUATIONS

P.W.P. %	Available moisture % by wt.	Available moisture % by volume	1/4	1/3	1/2	1	3	7	15
			Moisture retained at various tensions (atmospheres)						
6.59	13.74	18.4	14.90	13.63	12.40	10.18	9.45	7.96	7.55
4.21	15.32	23.2	11.67	10.60	9.75	8.57	6.91	6.02	5.74
1.67	8.93	14.8	7.90	6.90	5.65	4.54	3.51	2.66	2.28
2.34	9.33	16.5	10.15	9.04	7.11	6.15	4.65	3.20	2.79
2.57	11.96	21.5	11.36	11.00	9.11	7.98	5.47	3.41	4.64
8.50	9.85	14.2	19.62	17.23	16.30	17.10	13.01	11.90	10.33
5.58	6.17	11.1	8.17	7.96	6.87	6.85	6.19	5.56	4.40
8.16	2.75	5.0	9.48	9.24	8.63	8.57	7.51	7.01	6.35
5.84	16.77	22.1	15.89	14.66	11.82	11.40	7.96	7.66	6.02
3.82	14.86	23.5	12.26	11.59	8.24	7.88	6.38	5.34	4.44
3.51	11.44	17.8	10.05	9.77	6.62	7.01	4.93	5.47	3.74
3.33	13.13	20.4	8.69	8.10	5.13	5.71	3.92	3.76	3.08
6.41	12.45	17.2	15.60	14.62	12.69	10.63	9.19	8.25	8.30
5.50	12.73	17.3	14.60	14.16	12.48	10.50	8.21	7.32	6.88
5.46	11.01	16.3	12.63	12.64	11.07	9.45	7.36	6.76	6.30
11.96	14.97	19.7	26.06	24.47	21.69	18.37	16.27	14.39	14.01
7.17	14.50	20.9	19.08	18.17	16.64	14.10	11.65	10.23	9.08
2.94	9.93	14.7	8.19	7.24	6.19	5.21	4.17	3.87	3.64
10.76	14.57	20.1	25.91	23.38	20.34	16.94	15.13	12.91	12.70
6.01	15.92	22.4	22.33	19.98	18.02	15.56	12.44	11.07	10.40
7.96	12.17	17.7	22.49	20.36	17.53	14.84	11.50	9.90	8.93
7.98	14.15	21.2	18.53	17.22	15.36	12.89	11.36	10.29	10.11
6.95	12.82	18.5	16.20	14.73	13.58	11.50	9.84	8.39	8.76
5.71	12.52	20.3	15.70	14.08	12.96	11.00	9.07	8.02	7.95
10.19	21.63	25.7	36.69	31.93	28.51	24.40	19.07	16.14	12.26
9.80	15.91	22.4	30.94	30.44	25.56	19.70	15.39	10.39	12.79
6.56	16.30	25.4	20.79	29.61	10.30	14.33	11.82	8.74	9.36

APPENDIX I cont.

Association	Depth: ins.	Mechanical Analysis % F.S.	% V.F.S.	% Total sand	% silt	% clay	% O.M.	% $CaCO_3$	Apparent density	F.C. %
Medium textured										
Wellwood	0-10	22.4	5.3	35.1	41.0	23.9	4.55	28.91	1.33	27.42
	10-21	24.3	11.5	38.7	37.1	24.3	1.24	26.48	1.48	22.86
	21-36	31.0	10.0	43.7	40.6	15.7	0.76	22.88	1.53	22.10
Portage	0-10	23.2	5.3	36.4	42.5	21.1	6.00	30.10	1.31	25.93
	10-20	73.4	7.2	83.1	10.1	6.8	1.10	37.29	1.48	22.64
	20-36	43.0	8.3	64.4	20.0	15.6	0.55	44.62	1.64	18.65
Portage	0-10	2.30	1.6	7.0	53.3	39.7	5.31	24.48	1.29	38.80
	10-21	1.60	1.2	6.1	54.1	39.8	2.89	22.79	1.41	32.19
Carroll	0-12	22.7	21.7	48.1	34.0	17.9	4.69	1.59	1.31	23.19
	12-18	23.8	24.4	50.8	30.7	18.5	1.86	0.48	1.38	16.67
	18-36	28.5	28.0	59.4	25.7	14.9	0.73	1.84	1.56	11.86
Carroll	0-10	8.6	14.7	25.9	49.4	24.7	5.52	1.68	1.20	30.04
	10-18	6.8	11.2	21.4	54.5	28.8	1.66	6.75	1.30	27.12
	18-36	0.6	8.8	10.2	67.8	22.0	0.41	27.89	1.43	26.98
Moderately fine textured										
Altona	0-11	1.6	43.7	49.4	20.7	29.8	6.30	3.84	1.37	29.47
	11-22	1.9	47.2	52.4	14.6	33.0	2.66	17.43	1.45	23.00
	22-36	1.2	43.9	46.7	26.6	26.6	1.02	34.25	1.52	21.87
Balmoral	0-9	1.80	31.1	34.4	36.9	28.7	6.95	33.26	1.28	33.37
	9-16	0.70	18.5	19.7	51.2	29.0	0.83	61.01	1.61	21.53
	16-36	1.0	14.8	15.6	69.1	16.3	0.76	57.95	1.76	19.67
Rathwell	0-12	24.0	3.1	29.1	38.3	32.6	5.10	13.39	1.36	28.70
	12-24	5.2	1.4	8.6	85.5	5.9	2.00	9.15	1.55	27.47
	24-36	12.4	3.7	16.3	53.4	30.3	1.20	25.49	1.62	27.84
Wellwood	0-8	10.8	9.8	23.0	53.8	23.2	5.45	24.83	1.17	30.25
	8-18	9.0	2.8	12.2	53.7	34.1	2.34	39.40	1.48	24.13
	18-36	2.7	0.6	4.0	55.6	40.4	1.04	40.86	1.45	21.17
Portage	0-13	8.4	1.5	10.6	49.7	39.7	8.97	17.20	1.15	39.04
	13-26	17.7	5.7	24.2	43.1	32.7	3.59	22.70	1.34	31.45
	26-36	1.9	1.2	26.4	48.5	25.2	0.55	34.61	1.65	31.36

P.W.P. %	Available moisture % by wt.	Available moisture % by volume	Moisture retained at various tensions (atmospheres) 1/4	1/3	1/2	1	3	7	15
8.29	19.13	25.4	31.96	31.52	23.27	19.40	13.08	13.18	11.88
7.23	15.63	23.2	27.32	26.16	21.47	17.70	13.53	10.53	10.51
7.75	14.35	21.9	30.35	29.36	23.45	19.37	15.71	11.75	11.86
9.02	16.91	22.2	35.48	32.95	26.71	23.42	18.02	14.53	14.90
8.63	14.01	20.7	25.47	24.70	20.70	18.17	14.69	11.09	10.53
4.45	14.20	23.2	16.00	14.70	12.92	10.63	7.92	7.70	6.40
17.50	21.30	27.5	42.48	41.89	38.18	33.54	29.45	23.54	22.40
16.04	16.15	22.8	42.47	41.74	35.50	33.36	29.07	20.43	21.12
7.94	15.25	20.0	27.25	23.59	21.20	18.30	13.34	12.00	10.66
6.57	10.10	13.9	23.43	19.61	17.4	14.13	10.96	8.86	8.39
5.41	6.45	10.1	18.28	15.43	13.22	11.03	8.54	6.85	6.32
11.90	18.14	21.8	35.01	30.61	28.57	25.40	18.80	16.41	14.31
9.59	17.53	22.8	30.90	27.69	25.91	22.71	16.95	15.10	12.31
9.55	17.43	24.9	33.46	29.51	27.71	24.62	18.64	15.31	12.24

13.68	15.79	21.7	32.15	30.55	27.61	23.45	21.31	17.73	17.31
9.62	13.38	19.4	26.56	25.58	23.08	19.71	16.03	14.15	13.10
8.34	13.53	20.6	25.75	23.58	20.60	17.45	13.55	11.50	10.76
12.45	20.92	26.7	32.32	30.10	27.07	23.00	19.33	16.98	14.19
9.32	12.21	19.7	23.22	22.91	20.60	18.76	15.49	14.60	12.98
4.46	15.21	26.7	20.25	19.26	15.65	11.39	7.68	5.86	5.69
13.41	15.29	20.8	36.66	36.07	32.81	27.56	21.71	14.77	18.33
11.61	15.86	24.6	33.87	34.27	30.39	27.53	20.95	13.48	17.45
16.43	11.41	18.5	35.17	31.16	28.63	27.51	20.71	14.30	17.10
9.36	20.89	24.4	37.64	33.76	30.68	24.55	19.14	11.93	15.95
10.09	14.04	20.7	31.74	31.45	27.50	29.96	20.90	15.85	15.01
10.97	10.20	14.7	33.91	34.30	29.80	26.13	21.75	17.43	17.16
16.85	22.19	25.5	47.15	44.45	37.75	33.43	27.97	25.97	24.05
13.61	17.84	23.9	36.04	35.47	29.08	27.34	21.77	19.71	18.60
9.11	22.25	36.7	29.60	29.30	25.52	22.83	16.80	13.75	13.04

APPENDIX I cont.

Association	Depth: ins.	% F.S.	% V.F.S.	% Total sand	% silt	% clay	% O.M.	% CaCO3	Apparent density	F.C. %
		Mechanical Analysis								
Moderately fine textured										
Carroll	0-7	4.3	12.4	18.7	51.6	29.7	7.38	2.18	1.22	37.66
	7-21	3.8	13.3	17.2	52.0	30.8	2.42	3.75	1.56	32.97
	21-36	2.4	12.9	15.5	51.1	33.4	1.10	4.16	1.60	31.51
Newdale	0-8	7.5	5.3	19.8	44.1	36.2	6.35	1.43	1.18	30.10
	8-20	4.2	3.4	12.1	45.0	42.9	1.59	10.25	1.08	27.84
	20-36	2.3	3.7	7.8	48.5	43.7	1.04	24.73	1.54	27.16
Newdale	0-8	11.1	8.7	31.2	38.4	30.4	5.59	0.86	1.25	25.98
	8-20	14.2	9.5	39.7	29.2	31.1	1.45	0.25	1.34	20.73
	20-36	13.0	9.5	37.1	31.3	31.6	0.48	16.07	1.66	18.58
Portage	0-11	9.1	9.7	23.3	47.5	29.2	5.59	3.57	1.19	33.23
	11-22	3.2	12.1	17.3	52.6	30.1	2.21	13.55	1.18	29.57
	22-36	8.2	11.2	12.7	64.6	22.7	0.69	26.66	1.50	28.27
Portage	0-9	7.5	15.7	23.8	45.1	31.1	4.28	11.05	1.36	33.68
	9-17	5.1	14.2	21.9	48.9	29.2	1.31	19.68	1.38	30.09
	17-36	4.6	23.0	29.5	49.5	21.0	0.55	19.73	1.48	23.73
Portage	0-8	10.4	8.7	30.3	47.1	22.6	5.73	1.27	1.32	32.81
	8-14	8.4	6.9	26.3	48.4	25.3	1.93	16.27	1.39	28.71
	14-36	4.3	4.2	23.1	47.2	29.7	0.76	20.73	1.66	27.49
Fine textured										
Morden	0-10	3.3	15.7	29.2	30.7	40.1	11.00	1.37	0.99	36.83
	10-20	1.4	12.0	15.9	38.2	45.9	2.80	10.24	1.28	29.47
	20-36	2.0	12.5	17.6	41.7	40.6	1.75	14.33	1.43	27.07
Morden	0-10	1.9	18.3	20.3	35.2	41.6	6.87	0.08	1.22	34.23
	10-20	1.1	4.5	7.8	46.1	46.1	3.01	9.83	1.36	28.77
	20-36	0.0	3.9	5.4	49.6	45.0	1.89	13.82	1.43	28.37
Balmoral	0-5	1.3	7.2	9.7	39.5	50.8	15.20	39.71	1.21	44.00
	5-12	0.6	4.8	5.5	41.5	52.6	3.47	34.22	1.40	34.10
	12-36	0.3	1.3	2.2	38.9	58.8	1.00	33.50	1.51	25.33
Riverdale	0-10	0.8	3.4	5.6	43.4	51.8	6.75	0.78	1.18	39.72
	10-24	0.5	3.4	4.0	44.4	51.5	2.47	0.23	1.28	36.73
	24-36	0.1	1.0	1.2	40.0	58.8	1.52	8.29	1.36	36.75

P.W.P. %	Available moisture % by wt.	Available moisture % by volume	Moisture retained at various tensions (atmospheres)						
			1/4	1/3	1/2	1	3	7	15
16.53	21.13	25.8	44.52	38.63	34.57	30.49	25.05	20.58	20.03
10.90	22.07	34.4	39.08	34.87	30.67	26.94	20.32	17.21	15.82
13.54	17.97	28.8	36.74	33.78	29.80	26.99	20.59	17.48	15.43
14.70	15.40	18.2	40.30	37.06	33.54	29.87	24.58	19.83	18.59
14.17	13.67	14.8	37.38	34.90	32.67	29.74	23.40	20.93	18.68
13.40	13.76	21.2	35.02	31.93	30.16	27.64	26.65	19.61	17.07
10.91	15.07	18.8	35.17	30.58	27.85	24.78	18.57	15.91	13.54
9.99	10.74	14.4	26.21	24.27	21.79	19.97	15.58	13.75	11.13
8.80	9.78	16.2	26.76	25.72	21.80	21.03	15.12	14.85	11.19
13.92	19.31	23.0	36.92	35.14	30.10	28.54	19.90	19.76	15.32
10.12	19.45	23.0	33.11	30.82	25.59	25.10	17.17	16.56	12.65
6.72	21.55	32.3	28.49	26.83	22.04	20.51	14.23	13.49	10.03
13.67	20.01	27.2	39.06	32.65	28.89	28.95	23.14	19.61	16.57
12.90	17.19	23.7	33.66	29.21	26.77	24.82	20.49	17.46	14.89
8.27	15.46	22.9	28.48	24.43	21.28	18.97	13.15	12.12	10.12
13.30	19.51	25.8	35.86	31.47	28.57	27.81	19.00	18.87	16.29
11.01	17.70	24.6	35.28	30.34	27.38	25.52	20.00	17.53	14.86
12.47	15.02	24.9	31.19	29.67	27.90	24.60	19.42	17.72	14.85
21.96	14.87	14.7	44.18	41.47	37.79	33.47	29.61	26.60	24.47
15.05	14.42	18.4	34.77	32.91	30.59	27.05	23.54	20.72	20.50
13.01	14.06	20.0	34.02	31.41	29.56	26.15	22.03	19.00	18.71
16.94	17.29	21.1	37.91	34.71	32.51	28.55	25.36	21.78	19.88
15.45	13.32	18.1	34.70	33.28	30.81	27.18	23.12	20.56	21.33
14.62	13.75	19.7	35.95	33.61	31.74	27.82	23.59	20.88	20.64
22.88	21.12	25.6	49.46	44.09	93.88	38.62	32.81	28.96	25.55
14.77	19.33	27.1	33.33	31.82	29.34	25.99	22.40	19.87	19.20
13.69	11.64	17.6	28.19	26.09	24.94	23.15	19.78	17.49	16.18
22.30	17.42	20.6	48.85	46.55	42.87	35.53	32.77	27.63	26.32
21.40	15.33	19.6	45.46	43.05	39.57	33.94	31.10	26.88	26.49
21.24	15.51	21.1	48.92	45.88	43.18	36.43	32.79	28.06	27.99

APPENDIX I cont.

Association	Depth ins.	Mechanical Analysis % F.S.	% V.F.S.	% Total sand	% silt	% clay	% O.M.	% $CaCO_3$	Apparent density	F.C. %
Fine textured										
Red River	0-10	4.1	10.1	15.8	20.1	64.1	5.55	0.90	1.25	44.06
	10-21	0.4	3.0	3.6	8.7	87.6	3.18	2.20	1.35	42.17
	21-36	0.4	2.4	2.9	11.5	85.6	2.07	4.62	1.38	39.30
Portage	0-11	2.3	2.3	5.0	46.6	48.4	6.48	20.77	1.35	40.52
	11-20	1.2	1.0	3.3	53.0	43.7	2.14	31.91	1.49	35.20
Gretna	0-13	13.4	28.9	46.1	14.7	39.2	2.48	0.0	1.69	26.53
	13-19	12.1	24.6	39.1	15.9	45.0	1.31	1.39	1.58	22.56
	19-36	19.7	36.1	60.4	14.6	25.0	0.97	11.82	1.60	22.58

P.W.P. %	Available moisture % by wt.	Available moisture % by volume	Moisture retained at various tensions (atmospheres) 1/4	1/3	1/2	1	3	7	15
22.74	21.30	26.7	50.75	46.25	42.09	35.56	34.19	28.86	27.51
25.42	16.75	22.6	56.47	53.59	50.02	42.05	38.87	33.26	33.16
22.83	16.47	31.5	50.52	47.43	44.35	37.52	34.40	29.58	29.46
19.27	21.25	28.7	46.57	49.37	42.86	39.77	29.59	27.30	26.01
15.78	19.42	28.9	40.63	42.44	37.18	35.02	26.49	24.63	20.70
11.92	14.61	24.7	31.94	27.79	25.86	23.51	19.41	15.28	14.74
13.50	9.06	14.3	33.88	29.45	26.83	24.57	19.88	16.80	15.52
8.17	14.41	23.1	23.71	21.94	19.96	18.41	14.74	12.40	10.98

VIII APPEN

SUMMARY OF

Association	Depth: ins.	% F.S.	% V.F.S.	%Total sand	% silt	% clay	% O.M.	% $CaCO_3$	Apparent density	F.C. %
		Mechanical Analysis								
Gilbert	0-10	29.9	38.6	81.6	8.8	9.6	4.26	6.37	1.46	15.77
	10-16	31.4	33.3	79.4	6.9	13.7	1.75	13.18	1.48	14.09
	16-36	34.8	47.0	93.9	3.3	2.8	1.24	13.43	1.44	7.48
Gilbert	0-8	56.4	8.8	89.3	4.0	6.7	1.45	0.0	1.71	7.71
	8-18	43.2	6.6	86.7	6.8	6.5	0.87	0.0	1.74	5.80
	18-36	31.5	4.6	83.4	8.8	7.6	0.73	1.13	1.75	5.76
Dutton	0-12	14.9	11.2	34.4	33.1	32.5	3.79	4.82	1.40	26.78
	12-30	5.9	5.4	18.7	48.1	33.2	1.61	27.90	1.41	22.48
	30-36	2.3	4.7	13.2	51.2	35.6	1.24	28.35	1.52	20.03
Plainview	0-8	9.8	11.1	22.5	34.7	42.8	6.73	0.48	1.17	32.53
	8-16	9.8	11.4	22.2	40.7	37.1	1.76	6.57	1.24	26.33
	6-36	3.3	0.5	3.8	58.0	38.2	1.13	22.33	1.52	23.19
Plainview	0-12	1.6	2.2	6.8	40.8	52.4	7.00	0.0	1.27	37.37
	12-20	2.1	1.4	4.7	41.0	54.3	2.11	0.0	1.35	34.87
	20-36	1.2	1.0	2.9	48.9	48.2	1.78	3.63	1.64	32.28
Lakeland	0-6	10.0	40.6	54.7	26.0	19.3	6.51	2.83	1.18	23.12
	6-18	3.6	10.1	14.9	54.6	30.5	0.66	20.17	1.45	17.54
	18-36	1.3	2.1	4.8	65.0	30.2	0.41	28.63	1.56	20.91

DIX II

1964 SOILS DATA

P.W.P. %	Available moisture % by wt.	Available moisture% by volume	Moisture retained at various tensions (atmospheres) 1/4	1/3	1/2	1	3	7	15
6.06	9.71	14.2	13.92	12.33	12.59	11.19	8.36	7.30	6.54
4.71	9.38	13.9	13.40	11.88	11.85	10.60	8.20	7.20	6.37
1.78	5.70	8.2	5.22	4.23	4.28	3.34	2.57	2.17	1.86
2.60	5.11	8.7	7.11	6.10	6.22	5.27	4.09	3.47	3.10
2.71	3.09	5.4	6.07	5.26	5.43	4.42	3.11	2.65	2.42
2.53	3.23	5.7	6.92	5.96	6.13	4.94	3.37	2.98	2.63
11.66	15.12	21.2	26.35	23.68	23.14	20.60	16.78	14.93	12.96
9.49	12.99	18.3	28.45	25.08	24.68	21.97	17.67	14.66	11.79
9.80	10.23	15.5	27.24	24.99	23.91	21.42	17.91	14.43	11.88
16.44	16.09	18.8	31.97	30.78	29.42	28.75	22.88	20.63	17.97
11.87	14.46	17.9	27.29	25.23	23.83	22.85	18.07	16.35	13.96
11.34	11.85	18.0	27.81	25.94	24.35	23.01	17.56	15.19	12.95
19.80	17.58	22.3	40.01	38.44	37.33	35.65	29.25	26.60	23.26
19.83	15.04	20.3	40.58	37.59	36.77	35.41	28.68	26.11	21.88
18.10	14.18	23.3	38.83	37.36	35.16	33.82	26.64	23.67	20.40
11.52	11.6	13.7	25.48	23.66	21.76	21.63	15.35	13.83	11.85
8.62	8.92	12.9	25.77	25.30	22.73	21.25	15.36	12.25	10.48
7.72	13.19	20.6	31.61	30.12	28.22	26.72	18.16	12.07	9.75