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

A Thesis
Submitted to
the Faculty of Graduate Studies and Research
The University of Manitoba

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

by
Carl Francis Shaykewich
February 1965

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to:

Dr. M. A. Zwarich, Assistant Professor, Department of Soil Science, under whose immediate supervision the investigation was conducted, for his guidance and criticism of the manuscript;

Dr. M. H. Yeh and N. Longmuir of the Department of Agricultural Economics for assistance with statistical analysis of the data;

Dr. R. A. Hedlin, Professor and Head, Department of Soil Science, for arranging financial assistance.

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.

TABLE OF CONTENTS

PAGE

I. INTRODUCTION 1

II. REVIEW OF LITERATURE 2

Apparent Density 2

Field Capacity 4

Permanent Wilting Percentage 6

Available Moisture 10

Soil Moisture Retention and Soil Components. 12

III. MATERIALS AND METHODS. 14

Apparent Density 14

Field Capacity 14

Permanent Wilting Percentage 15

Available Moisture 15

Moisture Retention Data. 15

Particle Size Analysis 15

Organic Matter 15

Calcium Carbonate. 15

Statistical Analysis of the Data 16

Testing of Equations 18

IV. RESULTS AND DISCUSSION 20

Correlation Analysis 20

Apparent Density 22

IV. RESULTS AND DISCUSSION--cont. PAGE

Field Capacity 32

a) Relation to Soil Components 32

b) Relation of Field Capacity to the 1/3-atmosphere. . 38

Percentage. . . . .

Permanent Wilting Percentage 41

a) Relation to Soil Components 41

b) Relation of Permanent Wilting Percentage to the . . 46

15-atmosphere Percentage. . . . .

Available Moisture 48

a) Percent Weight Basis. 48

b) Volume Fraction 50

Soil Moisture Retention Data 53

Testing of Equations 68

V. SUMMARY AND CONCLUSIONS. 71

VI. BIBLIOGRAPHY 73

VII. APPENDIX I - Summary of Soils Data used to Derive Equations. 76

VIII. APPENDIX II- Summary of 1964 Soils Data. 80

LIST OF TABLES

PAGE

TABLE 1 - List of Independent and Dependent Variables 17

TABLE 2 - Correlation Matrix of Independent Variables 21

TABLE 3 - Regression Equations for Apparent Density 23

TABLE 4 - Regression Equations for Apparent Density (Textural Groups) 27

TABLE 5 - Regression Equations for Apparent Density (Horizons) 29

TABLE 6 - Prediction Values for Field Capacities of Organic Matter Free Soils Varying in Mechanical Composition 34

TABLE 7 - Regression Equations for Field Capacity 36

TABLE 8 - Regression Equations Predicting Permanent Wilting Percentage 44

TABLE 9 - Regression Equations for % Available Moisture (weight basis) 49

TABLE 10 - Regression Equations for Available Moisture (volume fraction) 52

TABLE 11 - Regression Equations for Moisture Retention 54

TABLE 12 - The 't' Values from Tests of Significance of the Difference Between Regression Coefficients at Successive Tensions 56

TABLE 13 - Regression Equations for 1/4 atmosphere Percentage 60

TABLE 14 - Regression Equations for 1/3 atmosphere Percentage 61

TABLE 15 - Regression Equations for 1/2 atmosphere Percentage 62

LIST OF TABLES--cont. PAGE

TABLE 16 - Regression Equations for 1 atmosphere Percentage 63

TABLE 17 - Regression Equations for 3 atmosphere Percentage 64

TABLE 18 - Regression Equations for 7 atmosphere Percentage 65

TABLE 19 - Regression Equations for 15 atmosphere Percentage 66

TABLE 20 - Root Mean Square Difference and Standard Error of Estimate for Each Dependent Variable 69

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)

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

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

Arable Soils (114 samples)

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

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

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:

Meadow Soils

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

Arable Soils

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

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

$$\text{P.W.P.}=1.62705 + 0.440577\,(\%\ \text{clay}) + 0.116234\,(\%\ \text{CaCO}_3) + 1.006603\,(\%\ \text{O.M.}) \qquad (0.11)$$

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

<u>Arable Soils</u>

$$\text{P.W.P.}=0.66156 + 0.363627\,(\%\ \text{clay}) + 0.044663\,(\%\ \text{coarse silt}) + 0.199028\,(\%\ \text{CaCO}_3) + 0.849308\,(\%\ \text{O.M.}) \qquad (0.12)$$

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

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:

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

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:

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

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:

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

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

Haise <u>et al.</u> concluded from the above results that the field determined minimum point in the second and third foot corresponded

---

**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:

$$\mathrm{AMHC}=6.5 + 0.26\ (\%\ \text{silt}) \qquad (r=0.73) \qquad (0.26)$$

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:

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

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

---

[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 Waynick (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

---

[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.