WATER PERMEABILITY STUDIES OF THE CARROLL AND HARDING SOIL ASSOCIATIONS IN MANITOBA

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INTRODUCTION

Water erosion in Manitoba has accounted for a considerable loss of soil during the relatively short period of time during which the soil has been cultivated.

Water, as it descends in the form of rain, is intercepted by the vegetation, adsorbed by the soil or runs off the surface. Water erosion is due to the transporting and cutting power of the water as it flows across the surface of the land. If there were no runoff, there would be no erosion.

Severe water erosion has occurred on the Carroll and Harding soil associations in western Manitoba especially in areas where these soils are found on rolling topography. Both soils, when not eroded, are capable of producing excellent yields of cereal crops and as such they have been utilized almost exclusively by farmers practicing a grain-fallow rotation. General observations of the Carroll and Harding soil associations under similar management and in areas where erosion has occurred, indicate that perhaps water erosion has been more severe on the Carroll soil association.

This study was undertaken to observe and measure water permeability relationships of the Carroll and Harding soil associations in an attempt to establish whether differences in water permeability existed and if this was a factor influencing the erodibility of these soils.

LITERATURE REVIEW

Soil Permeability

Uhland and O'Neal (63) define soil permeability as the capacity of a soil to transmit water and air. A knowledge of the rate of movement of water through each significantly different soil horizon has many uses in respect to soil and water conservation. The installation of drainage systems, irrigation projects, dam and reservoir construction and practices for the control of water erosion are based largely on the permeability a soil exhibits in respect to water.

Many terms, such as transmission constant, conductivity, percolation, hydraulic conductivity and permeability have been used to describe the movement of water through soils. The use of so many terms has given rise to some confusion as to exactly what property of the soil is actually being measured or described. In order to clarify the usage of permeability terminology, a committee of the Soil Science Society of America (60) has presented the following recommendations:

1. Define hydraulic conductivity as the physical property which can be measured and expressed in terms of the "Darcy K."

Darcy's Law is expressed as follows:

$$Q/t = K\ A\ (H_1 + d - H_2)\ d$$

Where A equals the cross section, d the thickness, H_1 as the amount of water standing on the upper surface and leaving the lower surface at head H_2, Q equals the amount of water filtering through in time t, and K equals the hydraulic conductivity of the body to the specified fluid.

2. If it is in the author's preference to use the term permeability in connection with the "Darcy K," make it clear at least once in each paper or report that the hydraulic conductivity is the implied quantity.

The flow of a liquid through porous media has been studied by many workers, and the constant "K" of Darcy's Law, as outlined by Childs (14), expresses an interaction between the porous body and the flowing liquid. The "K" value of a soil expresses the readiness of that soil to let a particular fluid flow through it for a given potential gradient.

Factors Affecting Soil Permeability

Downward movement of water in soils must take place through different soil horizons. Since a number of factors are responsible for the formation of various soil horizons it is of value to know what these factors are and what affect they may have in regard to permeability.

The Interaction of Fluid With Porous Medium

The interaction that does occur between water and soil, as described by Reeve *et al.* (53), is dependent largely upon the mineralogical makeup of the soil. Soils which contain considerable quantities of montmorillonitic clays show a much greater physical change upon wetting and drying than soils which contain other types of clay minerals. Such soils therefore may exhibit different rates of water movement through the soil depending upon its moisture content.

Water Quality and Exchangeable Cations

Bodman (5), Fireman (27), Christiansen (15), and Fireman and Bodman (26) have reported that the quality of water that percolates through the soil can have a marked effect upon the permeability, and that the permeability of a soil decreases with time after water is applied.

Bodman (5) states that the "Explanation of the great decrease in the saturated water permeability of all the soils examined seems to lie in the early removal of electrolytes and subsequent gradual dispersion and rearrangement of the clay particles so that the conducting pores are reduced in size more or less permanently." Bodman and Harradine (6), quantitatively evaluated the migration of clay particles within soil columns and showed that permeability was actually reduced by a decrease in pore size due to movement of dispersed clay.

Reeve *et al*. (53), and Brooks (12), showed that soluble sodium in the soil was particularly effective in causing dispersion, swelling, and structural breakdown of soils. Exchangeable magnesium and potassium had little effect.

Texture

The texture of a soil can also affect permeability. Soils which have a high sand content usually exhibit high permeability due to the large macro pore space and interconnected conducting pores. Soils with a high percentage of silt and clay usually exhibit low permeability even though the total pore space may be fairly large. In such soils, the pores are small and good conducting pores are usually not present.

Structure

The structure of a soil is a highly important characteristic affecting permeability. Uhland and O'Neal (63), have recognized ten types of soil structure: prismatic, columnar, cubical blocky, fragmental, nuciform, granular, crumb, laminar, phylliform, and squamose. Prismatic and columnar structures are characterized by aggregates which have a long vertical axis as compared to their horizontal axis and these types of structures in soil are usually an indication that permeability will be fairly good. Cubical blocky and fragmental structures are characterized by aggregates with horizontal and vertical axes more or less equal. Soils exhibiting these types of structures usually have good permeability. Nuciform, granular and crumb structures are characterized by aggregates that are more or less rounded. Soils with these types of structures usually have good permeability in that the shape of the aggregates does not permit close packing and as such a relatively good porosity is maintained. Soils exhibiting the laminar, phylliform and squamose types of structures usually have lower permeability rates. These types of structures are also called platy and are characterized by aggregates which have a long horizontal axis relative to their vertical axis.

Aggregate Stability

The stability of the structural units and aggregates has a direct bearing upon the permeability of a soil. The durability or stability of the aggregates and their ease of separation as set out by Nikiforoff (1941) and contained in Baver (9), classifies the grades of soil structure as poorly developed, weakly developed, moderately developed, well developed, and strongly developed.

Micro-organisms

Peele and Beale (48) have shown that microbes and fungi in the soil are important in binding soil particles together. Martin (41) and McCalla (42) have indicated in their work that gelatinous organic materials, and gums and resins which occur in the soil act as cementing agents and therefore aid in aggregation. Kroth and Page (34), using an electron microscope, were not able to prove conclusively that the gelatinous organic materials are important in aggregate formulation. In some cases, micro-organisms may also be detrimental to good permeability. Allison (1) has shown that in soils under long periods of submergence, the microbial bodies and slimes produced in the decomposition of organic matter plug the pores of the soils so that permeability is greatly reduced.

Natural Agencies, Clay and Organic Matter Content.

McHenry and Russell (43) have shown that clay particles play an important role in aggregate formation and stability because of their cohesive properties. Clay minerals may enclose soil particles or even form bridges between soil particles. Soils which have little or no clay content exhibit little or no structure, but with the addition of small amounts of clay minerals, aggregates soon appear. Clay minerals, because of their small size and large surface area, are perhaps the most active material in the soil in respect to aggregate formation.

Baver (9) indicates that soil cracks, such as may be caused by shrinking and swelling or freezing and thawing, and holes caused by roots, worms, and animals also have an affect upon the permeability of the soil.

The organic matter content of the soil is recognized as being very important in the stabilizing of soil structure. Soils which have a low organic matter content disperse much more readily than do soils having higher amounts of organic matter. Baver (9) also indicates the specific role played by organic matter tends to develop a type of structure conducive to good permeability.

Non-homogeneity of Porous Material

One of the basic assumptions that is usually involved in the theory of the flow of a liquid through a porous medium is that the medium is homogeneous. Such is rarely, if ever, the case in soils. In most soils there are several horizons in the soil profile which may differ in texture and structure and thus possess different permeability.

Soil can exhibit anisotropic properties in regards to permeability. The horizontal permeability may be as great or even greater than the vertical permeability and this may well be the case especially where soils were formed under large glacial lakes where sedimentation was not uniform. Soils with layers of sand between layers of silt or clay may show greater horizontal than vertical permeability.

Direct Methods of Determining Soil Permeability

Direct measurements of soil permeability can be carried out in the field or on soil core samples in a laboratory.

Field Measurements

Methods of measuring the permeability of a soil in situ are described by Luthin (38). He describes the use of the single auger hole method for homogeneous soils, the single auger hole method for layered soil, the four-well method and the piezometer method for the determination of soil permeability. In these methods a hole is made in the soil with an auger to a depth well below the water table. After first determining the elevation of the water table by allowing the water surface in the hole to reach an equilibrium with the soil water, the hole is then pumped out to a new water level elevation and the rate of rise of the water in the hole is then measured. The permeability of the soil is then calculated from this measurement.

Winger (65) outlined a method of measuring the permeability or hydraulic conductivity of a soil above a water table. This method involves the use of two different sized cylinders which are driven into the soil. The smaller cylinder is placed inside the larger one and water is poured into the outside ring until the soil in this area becomes saturated. Water is then placed in the inner cylinder and a constant head of six inches maintained. The permeability of the soil is then determined by the amount of water which moves through the soil in a given period of time.

Laboratory Measurements

Determination of soil permeability may be carried out in the laboratory by measuring the flow of water through soil cores. Core sampling equipment, as designed by Lutz *et al.* (39) and modified by Bower and Peterson (10), has been used quite extensively. Yoder (64) and Coile (18) also designed soil core sampling equipment and this type of equipment, remodelled by Uhland and O'Neal (62), is extensively used in obtaining core samples of soil for laboratory studies of permeability. A power driven core sampler, first designed by Kelly *et al.* (33), is used to obtain soil cores to a depth of ten feet or more.

Soil cores of the various soil horizons upon which permeability measurements are to be conducted are obtained in the field and then transported to a laboratory. The laboratory method of determining permeability of soil cores as outlined by Uhland and O'Neal (62) is the method generally accepted.

Indirect Methods of Assessing Soil Permeability

The permeability of soils can be assessed by measuring in the laboratory some of the properties of a soil related to permeability, or by observation of the characteristics of the soil profile.

Laboratory Measurements

The soil porosity, particle size, and pore and particle size distribution are the soil properties most commonly determined in the laboratory as an indication of permeability.

The pore size distribution has been correlated with permeability by Baver (8), Bendixen and Slater (4), Lutz and Leamer (39), and Nelson and Baver (46). The non-capillary and capillary pores together constitute the total porosity of the soil. The determination of the non-capillary pore space is of greater significance for it is these pores which contribute to the more rapid movement of water through the soil. Baver (9), (10), Richards (54), (55), Richards and Gardner (56), Richards and Weaver (57), Peele (49), and Bendixen and Slater (4) have done considerable work with respect to the tension under which soil cores should be drained in order to separate the non-capillary and capillary pore space.

A tension of sixty centimeters is generally recognized as most suitable for the separation of the non-capillary and capillary pore space. Childs and Collis-George (13) have presented a method of calculating permeability to air and water flow in a porous medium at all fluid contents based upon the moisture characteristic curve which is representative of the pore size distribution.

Field Observation

The permeability of a soil can also be assessed by studying certain soil characteristics of the soil profile in the field. Uhland and O'Neal (63) list the following soil characteristics that can be used as field clues for the evaluation of permeability: type of structure, stability of aggregates, relative length of the horizontal and vertical axes of structural aggregates, the amount of overlap of the structural aggregates, the texture, comparative ease and direction of natural breakage, size and number of visible pores, cracks and channels visible under a hand lens, character of clay minerals, compaction, size and shape of sand grains, mottling, organic material, and soluble salt. They also indicate that these soil characteristics are more meaningful when applied to the sub-surface than to the surface or cultivated layer of the soil. Some soil characteristics are more important than others in assessing soil permeability, but the movement of water through the soil cannot be based on any one characteristic.

Evaluation of the Various Methods of Determining Soil Permeability

The direct measurements of soil permeability as described by Luthin (38) and Winger (65) are quite costly and time consuming. The auger hole method is applicable to soils with a water table that is not too deep, and the use of the method outlined by Winger (65) can be best applied in soils in which the soil horizon below the one upon which permeability measurements are being conducted, has a greater permeability. The use of these two methods is therefore limited to certain soils with specific characteristics.

The values of soil permeability obtained by these methods are quite reliable and the use of such methods has a place in permeability studies where the permeability of a particular soil may be critical in view of the use to which the land may be put. These direct measurements of soil permeability in situ are usually only used after the less costly and faster laboratory methods for direct permeability determinations have been carried out in which the critical zones of a soil profile are identified.

The use of soil cores for laboratory determinations of soil permeability has a definite place in permeability studies. Such methods are relatively simple to carry out and do not require as much time as field measurements, thus permitting a greater number of determinations to be carried out in any given period of time. Luthin (38) reports that permeability values obtained in the laboratory are usually higher than those obtained under field measurement. Such measurements, however, do tend to characterize the permeability relationships of the various horizons within the soil and between soils.

There are several factors which affect the laboratory measurements of soil permeability. The non-homogeneity of the soil presents one of the first problems in the determination of soil permeability. Small soil samples, such as those contained in cores, are more homogeneous than the soil being studied and therefore one has to be careful in relating values obtained from a small core sample to the large soil masses which may be more heterogeneous. The number of replicates that have to be taken then becomes very important in order to obtain values which can be considered as being realistic. Uhland and O'Neal (63), found that six replicates were not sufficient to obtain reliable permeability information. Toogood (61), working with fine-textured soils in Alberta, found that a number of replicates were required to give reliable permeability data.

Soil cracks and holes in cores may be a problem in the laboratory determinations of permeability. In establishing standards for laboratory measurements of permeability, Smith and Browning (59) have recommended that cores having obvious cracks and holes, which permit the free flow of water, be discarded due to the fact that this is not truly representative of field conditions.

Obtaining complete saturation of soil cores in the laboratory presents another problem in permeability determinations. Several workers, (51), (7), (28), (29), (16), (50), (17), (52), (65), (59), have investigated the problems of obtaining complete saturation of soil cores and the effect of confined and entrapped air upon permeability determinations. Soil cores are usually wetted from the bottom in order to obtain complete saturation. Results of the above workers indicate that complete saturation is not achieved by the method due to the blocking of soil pores with confined air and the actual explosion of soil particles due to entrapped air. A method of passing CO_2 through the soil first, which displaces all the air, and then allowing saturation with free water has been used successfully to obtain complete saturation of the soil core. This method is quite time consuming and since it requires special laboratory apparatus, it is not often used, except for very critical permeability determinations.

The use of indirect laboratory determination of permeability has the same advantages, the same limitations, as the direct laboratory methods of evaluating permeability. Baver (9) has been able to correlate the pore size distribution of some soils with the permeability of that soil, but this is not the case in every soil, therefore, the pore size distribution of any soil is not necessarily a good measure of its permeability. Pore size, particle size, and the pore and particle size distribution values obtained in the laboratory therefore can only be used as an indicator of permeability and not as absolute values.

The use of soil characteristics observed in the field in assessing the permeability of the soil is the least costly method and perhaps the most rapid of all methods. The value of such determinations depends heavily upon the person carrying out the investigation. Uhland and O'Neal (63) have been able to correlate permeability values obtained in the laboratory with certain soil characteristics. The human factor is the greatest deterrant to using this method to obtain absolute values of permeability. Even well trained soils men may give the same soil a different permeability value. The human factor cannot be standardized and therefore comparison of soil permeability data so obtained in various areas is, in most cases, not as meaningful as direct measurements of soil permeability.

MATERIALS AND METHODS

Experimental Design and Location of Soil Sampling Sites

The Carroll and Harding soil associations selected for this study are located in the Alexander-Harding area some twenty-five miles west of Brandon, Manitoba. In this area the two soil associations are found on rolling topography under similar climatic conditions. The land use is similar on both soil associations in that farmers have generally practised a grain-fallow rotation.

Water erosion has caused severe loss of soil from both soil associations as can be observed by the numerous gullies and extensive areas of exposed subsoil on the knolls and slopes (Figures 1 and 2). General observations of the area would seem to indicate that water erosion has been more severe on the Carroll soil association than on the Harding soil association.

Six soil sampling sites were located in each of the two soil associations. Within each soil association, three sites were located on virgin soil and three on adjacent cultivated land. The design adopted in this study permits one to compare the permeabilities under virgin and cultivated conditions within each association as well as to compare results obtained from the two different associations.

The location of the soil sampling sites in each soil association are shown in Figure 3.

Generalized Description and Schematic Diagram of Virgin and Cultivated Carroll and Harding Soil Profiles

A generalized description and schematic diagram of virgin and

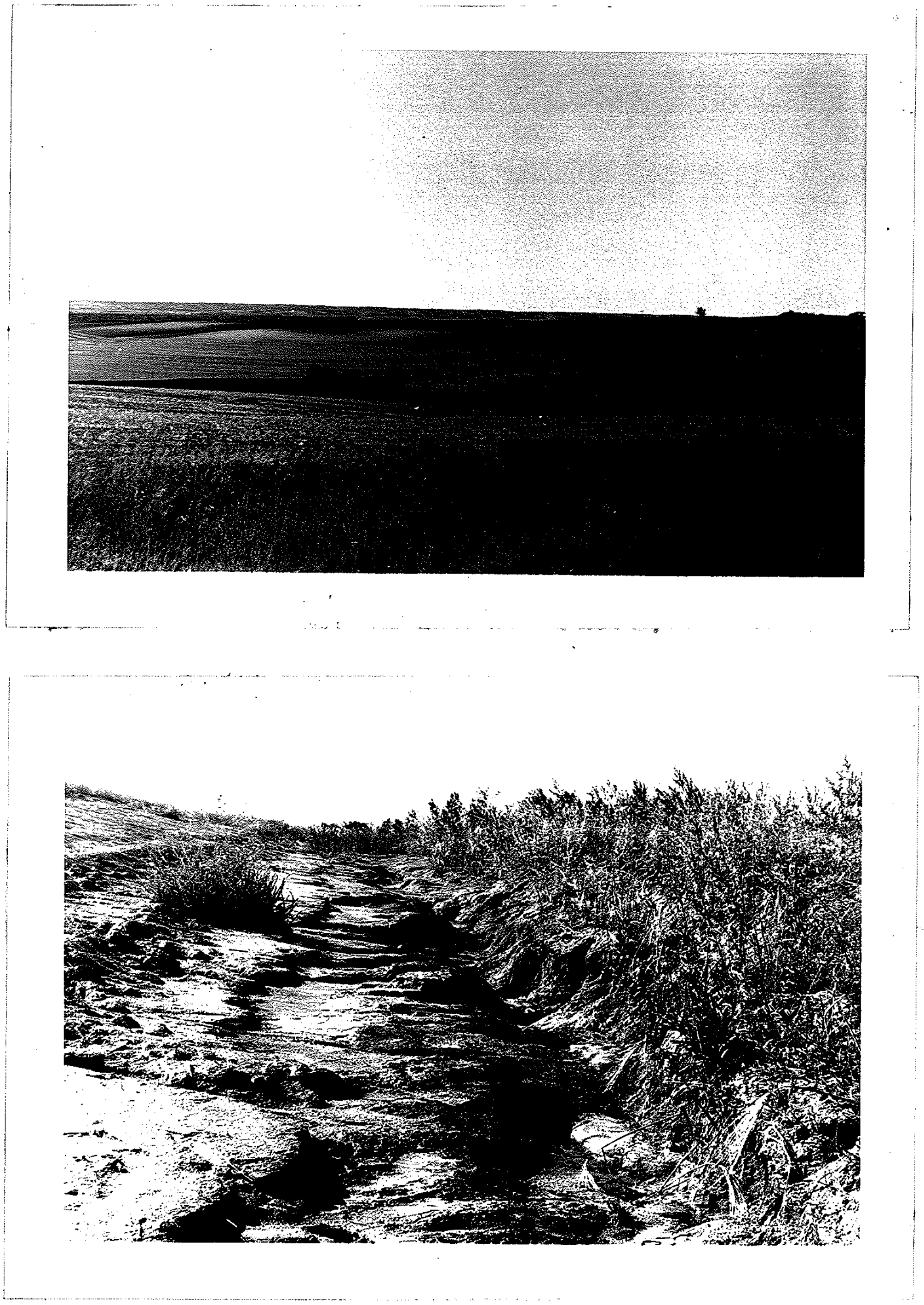


Figure 1.

Landscape and water erosion of the Carroll Soil Association - Alexander, Manitoba

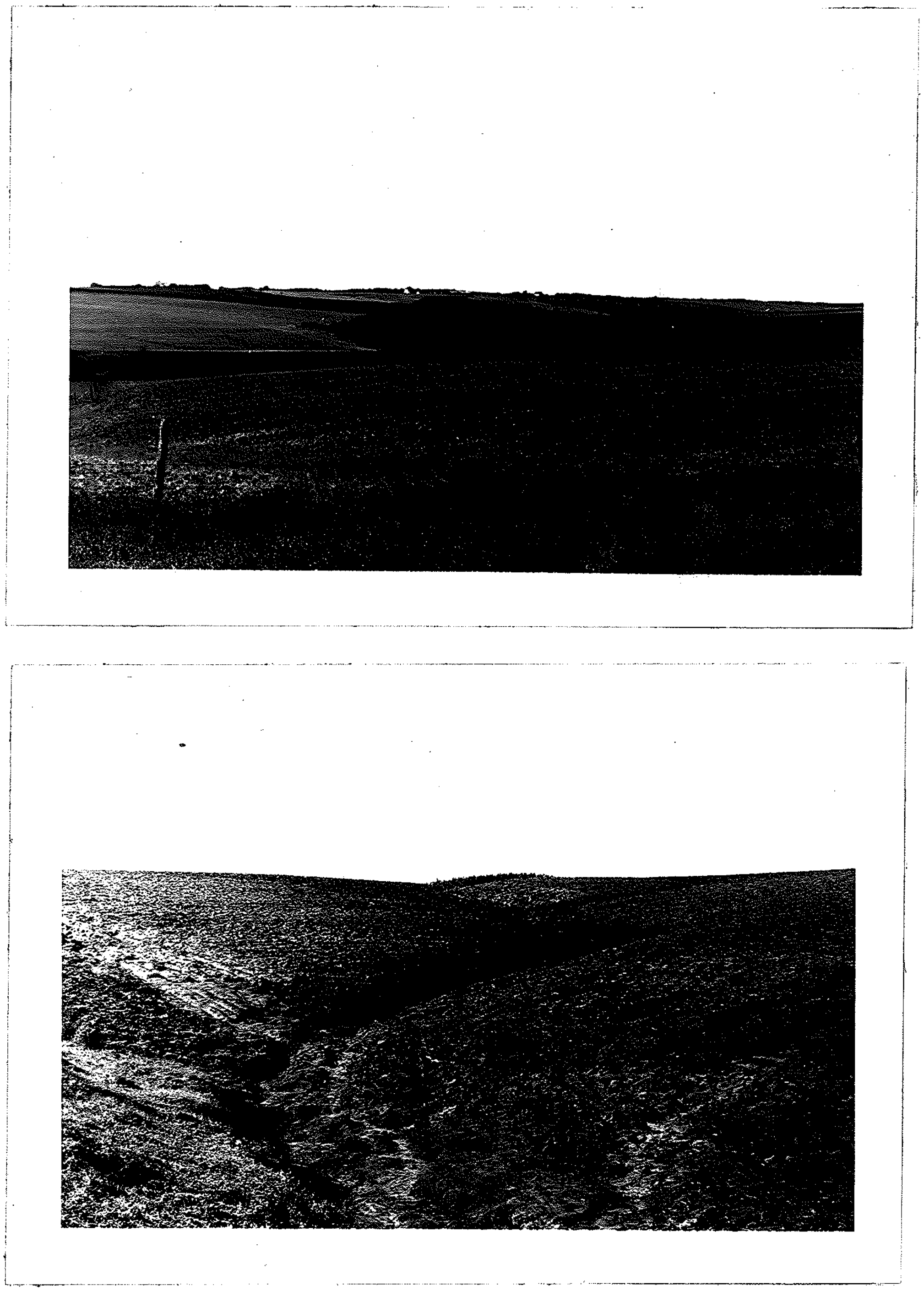


Figure 2.

Landscape and water erosion of the Harding Soil Association - Harding, Manitoba

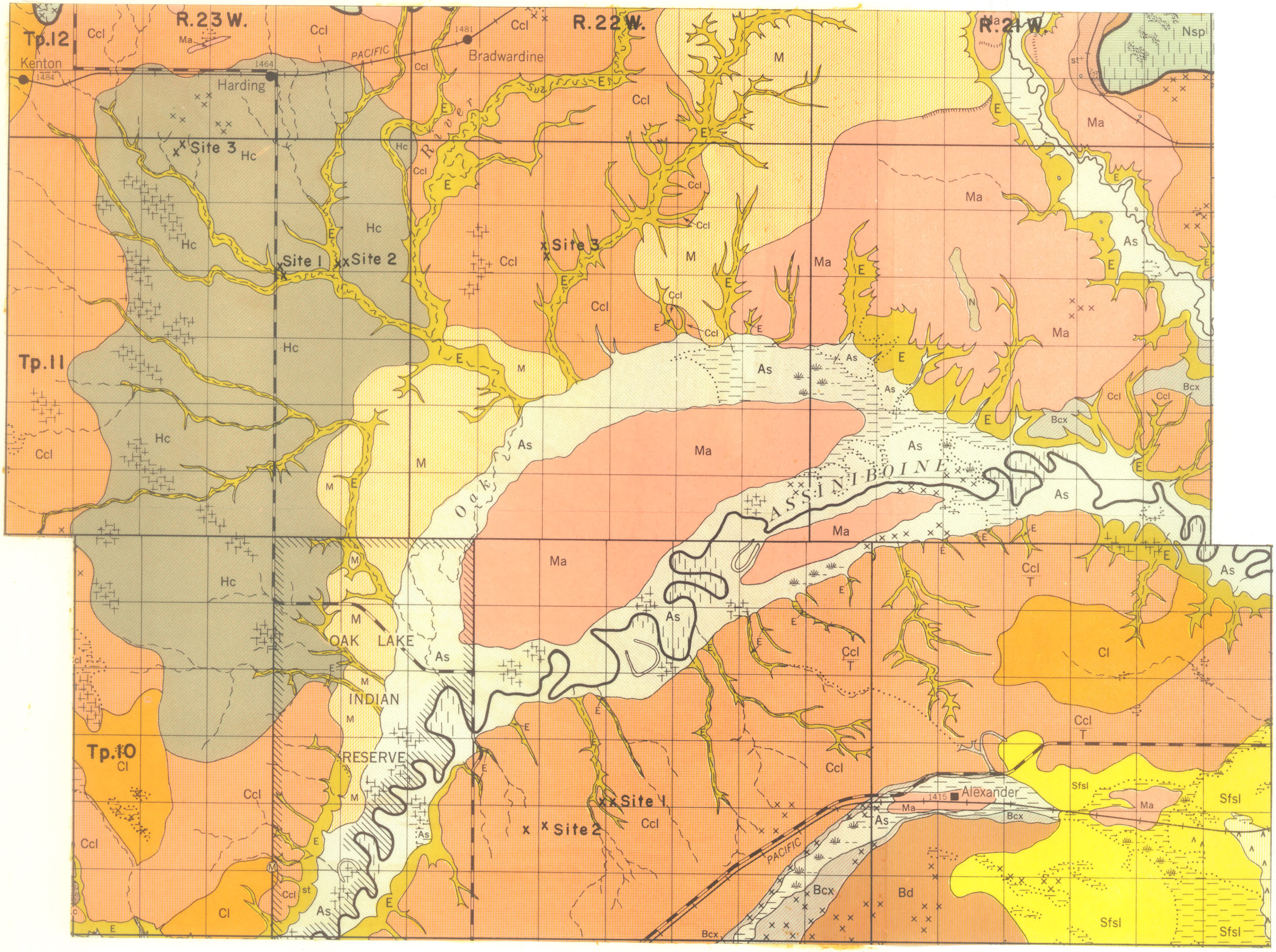


Figure 3. Location of Soil Profile Sampling Sites

Note: Map is a portion of the Virden mapsheet, Soils Report Number 6, Published by the Manitoba Department of Agriculture, 1956.

Hc - Harding Soil Association
Ccl - Carroll Soil Association

cultivated Carroll and Harding soil profiles are shown in Figures 4 to 7.

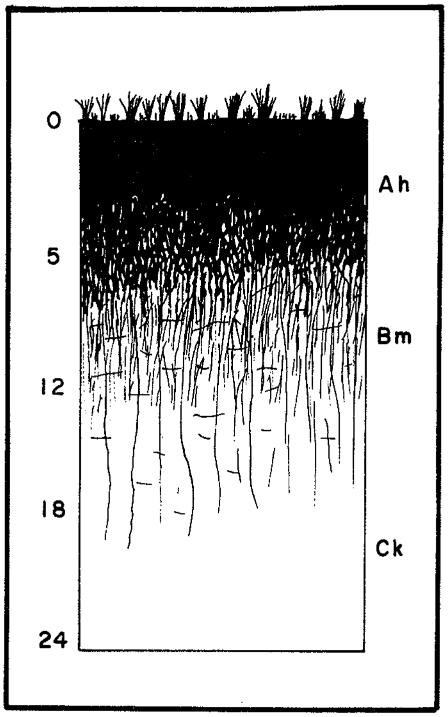
Soil Sampling Procedure

Three soil horizons were identified at the virgin Carroll sites, namely the Ah, Bm and the Ck, the core sampling depths in each were 1-4 inches, 5-8 inches and 18-21 inches, respectively. At the virgin Harding sites three horizons, namely the Ah, Bm and Ck, were identified, the sampling depths were 1-4 inches, 5-8 inches and 16-19 inches, respectively. At the cultivated sites in both soil associations, three horizons, the Ap, Bm and Ck, were identified. It appeared that the Ck horizons of the cultivated profiles were similar to the Ck horizons of the virgin sites for both soil associations and therefore soil cores were not obtained from this horizon at the cultivated sites. The sampling depths of the cultivated Carroll Ap and Bm horizons were 1-4 inches and 8-11 inches, respectively. The sampling depths of the cultivated Harding Ap and Bm horizons were 1-4 inches and 6-9 inches, respectively.

Nine soil cores were obtained from each horizon at each site according to the procedure outlined by Uhland and O'Neal (62). Composite soil samples were also obtained from each horizon.

Laboratory Investigations

In the laboratory, permeability measurements were carried out on soil cores in order to characterize the permeability of each soil horizon of the two soil associations under virgin and cultivated conditions.



Virgin Carroll Soil Profile

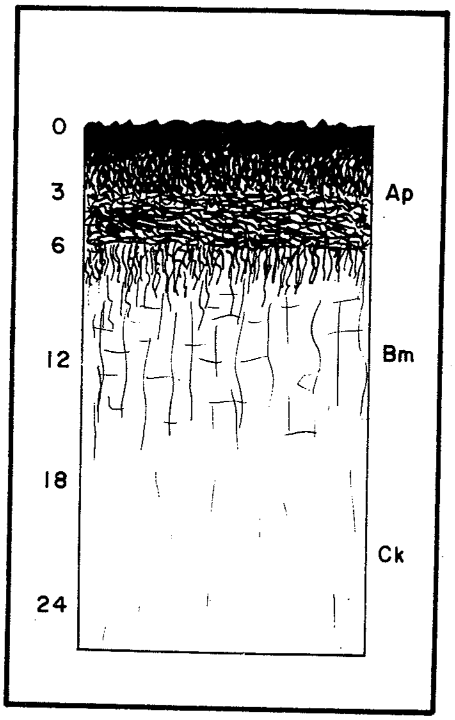
Figure 4. Schematic Diagram and Generalized Description of the Virgin Carroll Soil Profile.

Profile Description

Ah Horizon - 0-6 inches in depth, very dark grey silty clay loam, fine granular structure, friable, neutral to slightly alkaline in reaction, high in organic matter, grades into -

Bm Horizon - 6-14 inches in depth, dark brown silty clay to clay, medium columnar structure, breaks into finer granular aggregates, firm, neutral to slightly alkaline in reaction, grades into -

Ck Horizon - very pale brown-buff silty clay to clay, may be stratified with finer or coarser layers, fine pseudo-crumb structure, friable, alkaline in reaction and calcareous. Layers of lime carbonate often occur in the upper portions of this horizon.



Cultivated Carroll Soil Profile

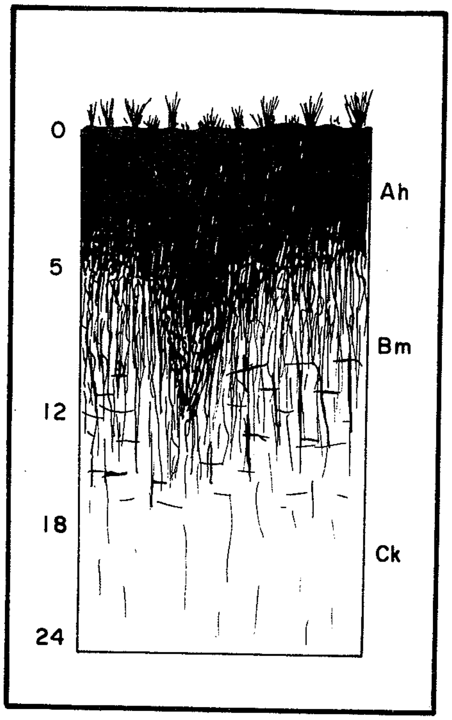
Figure 5. Schematic Diagram and Generalized Description of the Cultivated Carroll Soil Profile.

Profile Description

Ap Horizon - 0-5 inches in depth, light grey to dark brown in color, silty clay to clay loam, fine granular aggregates with some evidence of platy structure, friable, slightly alkaline in reaction, grades into -

Bm Horizon - 5-10 inches, brown silty clay loam to clay, evidence of platy structure in the upper portion with remnants of a medium columnar structure in the lower portion of the horizon, slightly alkaline in reaction, friable, grades into -

Ck Horizon - very pale brown-buff silty clay to clay, may be stratified with finer or coarser layers, fine pseudo-crumb structure, friable, alkaline in reaction and calcareous. Layers of lime carbonate often occur in the upper portions of this horizon.



Virgin Harding Soil Profile

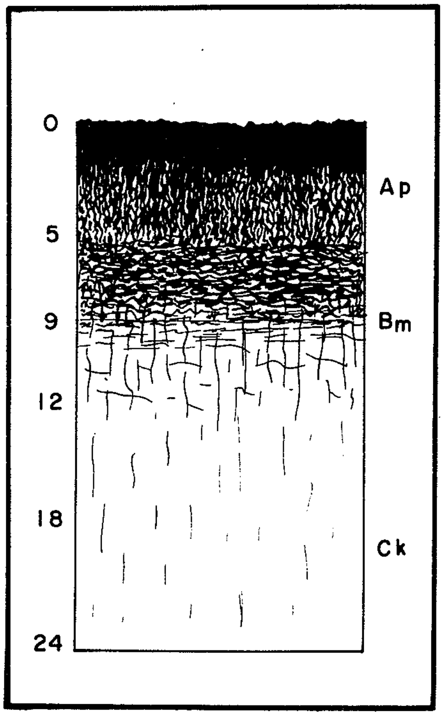
Figure 6. Schematic Diagram and Generalized Description of the Virgin Harding Soil Profile.

Profile Description

Ah Horizon - 0-6 inches in depth, dark grey to very dark grey silty clay to clay, granular aggregates which are firm and hard when dry, neutral to slightly alkaline in reaction, high in organic matter, tongues into -

Bm Horizon - greyish brown silty clay to clay, 6-12 inches in depth, firm well developed blocky columnar structure, slightly alkaline in reaction, grades into -

Ck Horizon - light brown silty clay to clay, plastic and sticky when wet, alkaline in reaction, fine granular structure, calcareous and iron stained.



Cultivated Harding Soil Profile

Figure 7. Schematic Diagram and Generalized Description of the Cultivated Harding Soil Profile.

Profile Description

Ap Horizon -	0-5 inches in depth, dark grey to dark brown in color, silty clay to clay, very fine granular structure in the upper portion and some evidence of platy structure in the lower portion, slightly alkaline in reaction, grades into -
Bm Horizon -	5-10 inches in depth, brownish silty clay to clay, strongly developed platy structure with some remnants of a blocky columnar structure in the lower portion, slightly alkaline in reaction, grades into -
Ck Horizon -	light brown silty clay to clay, plastic and sticky when wet, alkaline in reaction, fine granular structure, calcareous and iron stained.

Mechanical analysis and organic matter determinations were conducted on the composite soil samples obtained from each soil horizon at each site as this data is of value in assessing differences in permeability.

Permeability, Bulk Density and Pore Space Distribution

Permeability (field and saturated), bulk density and pore space distribution data was obtained for each soil core by the method outlined by Uhland and O'Neal (62).

Mechanical Analysis

Mechanical analysis data was obtained by the method outlined by Kilmer and Alexander (32).

Organic Matter

Organic matter data was obtained by the method outlined by Ehrlich (25).

Statistical Analysis of Data

Statistical analysis of the permeability data was carried out in order to determine if the differences in permeability measurements for the various horizons within and between the two soil associations were of significance.

In total, twenty-seven soil cores were obtained of each soil horizon (nine from each of the three sites). Data from some of the cores had to be discarded due to obvious root channels, cracks, or because they were damaged or broken. In order to carry out the statistical analysis, fifteen permeability values for each horizon were selected at random and the analysis of variance conducted. Since some of the permeability values obtained were zero, a square root transformation of the data was conducted and these values used for the analysis of variance.

TABLE

PERMEABILITY OF SOIL CORES OBTAINED AT THREE SITE RROLL AND HARDING SOIL ASSOCIATIONS

(Permeability-

		Carroll									Harding									
		Virgin						Cultivated			Virgin						Cultivated			
		Ah (1-4 in.)		Bm (5-8 in.)		Ck (18-21 in.)		Ap (1-4 in.)		B (8-11	Ah (1-4 in.)		Bm (5-8 in.)		Ck (16-19 in.)		Ap (1-4 in.)		Bm (6-9 in.)	
Site	Core No.	Field	Sat.[1]	Field	Sat.	Field	Sat.	Field	Sat.	Field	Field	Sat.	Field	Sat.	Field	Sat.	Field	Sat.	Field	Sat.
1	1	3.85	1.13*	5.53	2.94**	1.68	1.43**	0.26	0.11	1.08	2.59	2.59	4.10	2.03	2.59	2.12	0.19	0.09	0.00	0.00
	2	1.30	1.04	5.02	2.33	2.38	1.43	0.30	0.13**	0.13	0.17	0.10*	1.99	1.34**	1.81	1.77	0.95	0.43	0.00	0.07**
	3	1.51	0.69	4.15	2.25	1.90	1.56	0.22	0.13**	2.24	0.10	0.09*	3.03	5.79**	1.08	1.12	0.61	0.26	0.00	0.00**
	4	1.43	0.69	2.85	1.30	8.12	2.25*	1.86	0.69	1.82	0.13	0.14	3.03	6.05**	4.66	3.63*	0.35	0.13**	0.00	0.00
	5	1.34	0.61	4.28	2.25	3.85	1.82	0.22	0.17	3.01	0.43	0.35	7.34	4.32	1.94	1.86**	0.30	0.15	0.00	0.00
	6	1.37	0.78	4.02	2.16	2.89	1.30	1.25	0.69	4.11	0.26	0.22	5.71	6.13	2.42	1.38**	0.22	0.11**	0.00	0.00
	7	5.62	3.03*	4.97	2.77**	2.46	0.86	0.93	0.43	2.72	1.96	1.12	6.26	6.39	1.77	0.95	0.69	0.30	0.00	0.00
	8	6.40	2.33*	2.29	1.12**	4.15	1.90*	0.24	0.11	3.59	0.65	0.31	2.24	3.71	3.11	1.82**	0.61	0.26**	0.00	0.09**
	9	2.25	2.59*	3.33	1.47**	2.29	1.47**	--	-- *	--	0.85	0.39	1.64	2.25	--	-- *	0.22	0.12	0.00	0.00
2	10	20.31	4.36*	--	-- *	0.95	0.48	0.22	0.08	1.21	4.32	0.86	9.50	3.24	7.95	1.08	0.09	0.04	0.00	0.00
	11	27.65	17.80	17.45	3.93*	1.64	0.51	0.28	0.10	2.16	3.63	1.08**	12.96	5.70*	0.22	0.22**	2.33	0.74	0.00	0.00
	12	8.99	2.33*	0.91	1.02**	14.17	3.04*	0.28	0.10**	2.24	6.05	2.07*	2.33	1.29**	1.29	0.52	0.11	0.04	--	-- *
	13	5.36	1.47	0.43	0.09	0.95	0.88	0.73	0.61	2.42	5.62	0.86	2.07	0.99**	2.33	0.69	2.85	2.72*	0.00	0.00
	14	2.50	0.78**	--	-- *	1.12	0.67**	0.56	0.73	2.07	1.08	0.52	7.99	4.10	1.81	0.61	0.39	0.04	0.00	0.00
	15	6.65	1.12**	--	-- *	1.73	0.78	1.08	0.35**	2.59	2.42	0.69	3.11	1.21	1.73	0.61**	0.69	0.22	0.00	0.00
	16	10.28	2.07*	6.92	2.98**	0.35	0.29**	1.12	0.65**	2.94	2.59	1.08**	--	-- *	2.59	0.56**	0.04	0.16	0.00	0.00**
	17	30.56	3.67*	0.26	0.22**	0.82	0.51**	0.26	0.26	2.42	4.32	0.86	9.50	5.18	12.96	7.77*	0.22	0.28	0.00	0.00
	18	10.20	1.82**	13.48	3.83**	0.69	0.32	0.26	0.35**	2.51	3.02	0.95**	13.61	7.77*	1.51	0.56	1.25	0.73	--	-- *
3	19	0.93	0.43	1.64	1.04	2.68	1.04**	0.00	0.00*	0.60	5.62	2.03	1.90	0.95	0.22	0.22	0.00	0.00**	0.00	0.00
	20	1.43	0.73	1.38	0.69	1.73	0.86	1.10	0.56	0.87	25.92	12.96*	0.95	0.65**	1.38	0.26	0.24	0.04	0.00	0.00
	21	0.64	0.43	1.38	0.78	2.07	1.12	2.62	2.07*	1.20	--	-- *	--	-- *	1.04	0.17	0.30	0.04**	--	-- *
	22	2.02	1.21	1.64	1.55	2.16	1.04	0.64	0.30**	1.00	3.24	1.34	0.86	0.04	1.38	0.52	0.20	0.00**	0.00	0.00**
	23	1.37	0.78	1.73	1.34	1.43	0.61**	0.30	0.17**	0.40	2.59	1.55	1.73	0.26	0.09	0.04*	0.64	0.35**	0.00	0.00
	24	0.97	0.61	1.73	0.95	1.38	0.69	0.80	0.56	0.46	2.16	0.69	1.56	1.82	0.09	0.04*	0.24	0.04	0.00	0.00*
	25	1.38	0.82	1.86	0.86	0.95	0.52**	0.40	0.26	0.32	26.79	6.05*	13.82	4.75*	0.43	0.13	0.21	0.04**	--	-- *
	26	1.66	0.86	2.33	1.30	0.99	0.69	0.30	0.17**	0.67	21.60	13.82*	2.07	1.81**	0.09	0.04*	0.11	0.00**	0.00	0.00**
	27	0.67	0.52	2.59	1.73	1.60	0.86	1.82	1.00	0.42	4.96	3.45	1.12	0.95	2.07	0.61	0.14	0.00**	--	-- *

*discarded - root channels, damaged, etc.

**discarded at random to permit statistical analysis based on 15 cores rizon

1Sat. - saturated soil cores

RESULTS AND DISCUSSION

Permeability Data--Carroll and Harding Soil Associations

The field and saturated permeability values for each soil core obtained from the virgin and cultivated sites of the Carroll and Harding soil associations are shown in Table 1.

The field permeability values obtained were of assistance in identifying those soil cores in which the permeability values deviated widely from the permeability values exhibited by the majority of the soil cores. Several factors can influence the permeability of a soil core as determined in the laboratory. The soil in the core may have been compacted or cracked during the taking of the core and as such would exhibit a permeability value different than that of the undisturbed soil. A root may have been removed or pulled out of the soil core upon its extraction from the soil thus leaving a channel through which water would flow more rapidly under laboratory conditions as compared to the undisturbed soil. Those soil cores, which under saturated permeability measurements, continued to show wide deviations in respect to permeability values were removed from the cylinder and observed closely. Compaction, cracking and root channels were all identified as reasons for the abnormal behaviour of certain soil cores and as such the permeability values for these cores were discarded as shown in Table 1.

Average Permeability of the Virgin and Cultivated Carroll Soil

The permeabilities of the Ah, Bm and Ck horizons of the virgin Carroll soil were 0.78, 1.40 and 0.95 inches per hour, respectively (Table 2). The higher permeability of the Bm horizon can be attributed

TABLE 2

PERMEABILITY OF EACH HORIZON OF THE CARROLL AND HARDING SOIL ASSOCIATIONS

(Permeability in./hr.)

Carroll										Harding									
Virgin						Cultivated				Virgin						Cultivated			
Ah (1-4 in.)		Bm (5-8 in.)		Ck (18-21 in.)		Ap (1-4 in.)		Bm (8-11 in.)		Ah (1-4 in.)		Bm (5-8 in.)		Ck (16-19 in.)		Ap (1-4 in.)		Bm (6-9 in.)	
Core No.	Perm.[1]	Core No.	Perm.	Core No.	Perm.	Core No.	Perm.	Core No.	Perm.	Core No.	Perm	Core No.	Perm	Core No.	Perm.	Core No.	Perm	Core No.	Perm.
2	1.04	2	2.33	2	1.43	1	0.11	1	0.54	1	2.59	1	2.03	1	2.12	1	0.09	2	0.07
3	0.69	3	2.55	3	1.56	4	0.68	4	0.59	5	0.35	5	4.32	2	1.77	2	0.43	4	0.00
4	0.69	4	1.30	5	1.82	5	0.17	5	0.99	6	0.22	6	6.13	3	1.12	3	0.26	5	0.00
5	0.61	5	2.25	6	1.30	6	0.69	6	1.12	7	1.12	7	6.39	7	0.95	5	0.15	6	0.00
6	0.78	6	2.16	7	0.86	7	0.43	7	1.08	8	0.31	8	3.71	10	1.08	7	0.30	7	0.00
13	1.47	13	0.09	10	0.48	8	0.11	8	1.51	9	0.39	9	2.25	12	0.52	9	0.12	9	0.00
19	0.43	19	1.04	11	0.51	10	0.08	10	1.21	10	0.86	10	3.24	13	0.69	10	0.04	10	0.00
20	0.73	20	0.69	13	0.88	11	0.10	11	1.12	14	0.52	14	4.10	14	0.61	11	0.74	11	0.00
21	0.43	21	0.78	15	0.78	13	0.61	12	1.12	15	0.69	15	1.21	18	0.56	12	0.04	13	0.00
22	1.21	22	1.55	18	0.32	14	0.73	13	1.21	17	0.86	17	5.18	19	0.22	14	0.04	14	0.00
23	0.78	23	1.34	21	1.12	17	0.26	14	1.04	19	2.03	19	0.95	20	0.26	15	0.22	15	0.00
24	0.61	24	0.95	22	1.04	20	0.56	17	1.17	22	1.34	22	0.04	21	0.17	16	0.16	17	0.00
25	0.82	25	0.86	24	0.69	24	0.56	20	0.17	23	1.55	23	0.26	22	0.52	17	0.28	19	0.00
26	0.86	26	1.30	26	0.69	25	0.26	24	0.09	24	0.69	24	1.82	25	0.13	20	0.04	20	0.00
27	0.52	27	1.73	27	0.86	27	1.00	27	0.04	27	3.45	27	0.95	27	0.61	24	0.04	23	0.00
Ave.	0.78		1.40		0.95		0.42		0.87		1.13		2.94		0.75		0.20		0.01

[1] Perm. = Saturated permeability

to the prismatic to columnar structure of this horizon relative to the granular structure of the Ah horizon and the fine crumb-like structure of the Ck horizon (Figure 4, page 19).

The permeabilities of the cultivated Carroll Ap and Bm horizons were 0.42 and 0.87 inches per hour, respectively. The Ck horizon at the cultivated sites was not sampled as it was assumed to be identical to the Ck horizon at the virgin sites.

Field observations of the cultivated Carroll soil profiles indicated that cultivation had modified the soil structure in the Ap and Bm horizons. The Ap horizons exhibited a finer granular structure and some degree of platy structure whereas the Bm horizon of the cultivated sites showed evidence of a platy structure in the upper portion of this horizon and remnants of the prismatic to columnar structure in the lower portion of the horizon (Figure 5, page 20). The platy type of structure in the Ap and Bm horizons in the cultivated soils appears to have restricted water movement through the soil thus resulting in lowering the permeability rate by some forty to fifty per cent.

Average Permeability of the Virgin and Cultivated Harding Soil

The permeabilities of the Ah, Bm and Ck horizons of the virgin Harding soil were 1.13, 2.94 and 0.75 inches per hour, respectively (Table 2). The Bm horizon exhibited a well developed blocky columnar structure as compared to the granular structure of the Ah horizon and the fine crumb-like structure of the Ck horizon and as such exhibited a much higher permeability (Figure 6, page 21).

The permeabilities of the Ap and Bm horizons of the cultivated

Harding soil were 0.20 and 0.01 inches per hour, respectively. The Ck horizon of the cultivated sites appeared to be identical to the Ck horizon of the virgin sites and it was assumed that the average permeability would be the same, namely 0.75 inches per hour.

Field observations of the virgin and cultivated Harding soil profiles indicated that cultivation had modified the structure of the Ap and Bm horizons of the soil. The Ap horizon of the cultivated soil showed a very fine granular structure in the upper portion and fairly strong evidence of a platy structure in the lower portion. The Bm horizon of the cultivated soil showed almost complete destruction of the blocky columnar structure exhibited under virgin conditions and the formation of a strongly developed platy structure particularly in the upper portion of this horizon (Figure 7, page 22).

Uhland and O'Neal (62) indicate that a platy structure results in a lower permeability rate as compared to those horizons exhibiting granular, blocky, columnar or prismatic structure. A reduction of eighty to almost one hundred per cent in the average permeability of the Ap and Bm horizons of the cultivated Harding soil as compared to the Ah and Bm horizons of the virgin soil can probably be attributed to a large degree to the platy structure which was formed as a result of cultivation.

Statistical Analysis of Permeability Data

The analysis of the permeability data (Tables 4 and 5) indicates that as an average of both managements, there is no significant difference between the Carroll and Harding soil associations in respect to permeability.

TABLE 3

SQUARE ROOT TRANSFORMATION OF PERMEABILITY DATA--STATISTICAL ANALYSIS

Site	Core No.	Carroll				Harding			
		Virgin		Cultivated		Virgin		Cultivated	
		Ah	Bm	Ap	Bm	Ah	Bm	Ap	Bm
1	1	--	--	0.78	1.02	1.76	1.59	0.77	--
	2	1.24	1.68	--	--	--	--	0.96	0.75
	3	1.09	1.66	--	--	--	--	0.87	--
	4	1.09	1.34	1.09	1.04	--	--	--	0.71
	5	1.05	1.66	0.82	1.22	0.92	2.20	0.81	0.71
	6	1.03	1.60	1.09	1.27	0.85	2.57	--	0.71
	7	--	--	0.96	1.26	1.27	2.62	0.89	0.71
	8	--	--	0.78	1.42	0.90	2.05	--	--
	9	--	--	--	--	0.94	1.66	0.78	0.71
2	10	--	--	0.76	1.31	1.16	1.93	0.73	0.71
	11	--	--	0.77	1.27	--	--	1.11	0.71
	12	--	--	--	1.27	--	--	0.73	--
	13	1.40	0.77	1.05	1.31	--	--	--	0.71
	14	--	--	1.11	1.24	1.01	2.14	0.73	0.71
	15	--	--	--	--	1.09	1.31	0.84	0.71
	16	--	--	--	--	--	--	0.81	--
	17	--	--	0.87	1.29	1.17	2.38	0.88	0.71
	18	--	--	--	--	--	--	--	--
3	19	0.96	1.24	--	--	1.59	1.20	--	0.71
	20	1.11	1.09	1.03	0.82	--	--	0.73	0.71
	21	0.96	1.13	--	--	--	--	--	--
	22	1.31	1.43	--	--	1.36	0.73	--	--
	23	1.13	1.36	--	--	1.43	0.87	--	0.71
	24	1.05	1.20	1.03	0.77	1.09	1.52	0.73	--
	25	1.15	1.17	0.87	--	--	--	--	--
	26	1.17	1.34	--	--	--	--	--	--
	27	1.01	1.49	1.22	0.73	1.99	1.20	--	--
Sample No.		15	15	15	15	15	15	15	15

TABLE 4

ANALYSIS OF VARIANCE OF PERMEABILITY DATA FOR THE CARROLL AND HARDING SOIL ASSOCIATIONS

	D.F.	S.S.	M.S.	F Value
Locations	1	0.01	0.01	0.27
Management	1	6.07	6.07	160**
Location x Management	1	2.10	2.10	55**
Depth	1	1.22	1.22	32**
Location x Depth	1	0.01	0.01	0.27
Management x Depth	1	0.72	0.72	19**
Location x Management x Depth	1	0.66	0.66	17**
Error	112	4.36	0.038	
Total	119	15.15		

NOTE F value should exceed 3.94 at the 5% level of significance and 6.90 at the 1% level of significance.

** = significant at 1% level.

Location x Management	L.S.D. = 0.20
Location x Depth	L.S.D. = 0.20
Location x Management x Depth	L.S.D. = 1.18

TABLE 5

TABLE OF MEANS--STATISTICAL ANALYSIS--PERMEABILITY DATA

Location	Management	Horizon	Mean	Mean	Mean
Carroll (1)	Virgin	Ah	1.12	1.23	1.14
		Bm	1.34		
	Cultivated	Ap	0.95	1.05	
		Bm	1.15		
Harding (2)	Virgin	Ah	1.25	1.49	1.13
		Bm	1.73		
	Cultivated	Ap	0.82	0.76	
		Bm	0.71		
	Depth (1) (Ah and Ap horizons)				1.04
	Depth (2) (Bm horizons)				1.23
Location (1) Depth (1)					1.04
Location (1) Depth (2)					1.25
Location (2) Depth (1)					1.04
Location (2) Depth (2)					1.22
Management (1) (Virgin)					1.36
Management (2) (Cultivated)					0.91
Management (1) Depth (1)					1.18
Management (1) Depth (2)					1.54
Management (2) Depth (1)					0.89
Management (2) Depth (2)					0.93

Management differences were significant, that is, the permeability values for virgin soils were significantly greater than those of the soils under cultivation.

The significant location x management interaction indicates that the affects of managements are not the same at both locations. Virgin soils were more permeable and cultivated soils less permeable for the Harding soil association than for the Carroll soil association. This would suggest that while virgin soils were more permeable than the cultivated soils at both locations, the magnitude of the difference between managements is not the same. In particular, the difference in permeability of the virgin and cultivated Harding soil is significantly greater than the difference between virgin and cultivated conditions of the Carroll soil. Depths or horizons were found to be significantly different.

The significant management x depth interaction suggests that although under virgin and cultivated conditions the more permeable soils were at the lower depth, the magnitude of this difference was not constant. Permeability was significantly higher in the virgin soils and the difference in permeability of the two horizons in the virgin soils was significantly greater than the small non-significant difference observed between the horizons of the cultivated soils.

The second order interaction, location x management x depth was significant. Relatively greater differences in permeability were detected between the horizons in the virgin soil of the Harding soil association than those of the virgin Carroll soil association. By contrast, relatively little difference in permeability is detected between horizons in the cultivated soil of the Harding soil association while at the Carroll soil association the difference in permeability for the horizons of the cultivated soil was essentially as large as that noted for the virgin soil. The permeability of the cultivated soils has decreased relatively more on the Harding soil association than the Carroll association. Consequently, the difference between management on the Carroll soil association, as an average of both horizons, is significantly smaller than the difference between managements on the Harding soil association in respect to permeability.

Bulk Density Measurements of the Carroll and Harding Soil Associations

The average bulk density values for the various horizons of the Carroll and Harding soil associations are shown in Table 6.

Virgin Carroll

The average bulk density values of the virgin Carroll Ah, Bm and Ck horizons were 0.90 g/cc., 1.00 g/cc. and 1.12 g/cc., respectively. The increase in bulk density can be attributed, in part, to the decrease in the organic matter content with depth and also structural differences that exist among the horizons.

Cultivated Carroll

The average bulk density of the Ah horizon was 1.04 g/cc. and 1.04 g/cc. for the Bm horizon. The Ck horizon was assumed to have the same average bulk density as the Ck horizon of the virgin soil, namely 1.12 g/cc.

TABLE 6

BULK DENSITY OF EACH HORIZON OF THE CARROLL AND HARDING SOIL ASSOCIATIONS

(Bulk Density g./cc.)

Carroll										Harding									
Virgin						Cultivated				Virgin						Cultivated			
Ah (1-4 in.)		Bm (5-8 in.)		Ck (18-21 in.)		Ap (1-4 in.)		Bm (8-11 in.)		Ah (1-4 in.)		Bm (5-8 in.)		Ck (16-19 in.)		Ap (1-4 in.)		Bm (6-9 in.)	
Core No.	BD[1]	Core No.	BD	Core No.	BD	Core No.	BD	Core No.	BD	Core No.	BD	Core No.	BD	Core No.	BD	Core No.	BD	Core No.	BD
2	0.81	2	0.93	2	1.05	1	0.99	1	0.93	1	0.98	1	0.94	1	1.10	1	1.30	2	1.24
3	0.80	3	0.96	3	1.05	4	0.95	4	1.00	5	1.00	5	1.05	2	1.00	2	1.28	4	1.27
4	0.76	4	1.07	5	1.00	5	1.05	5	1.00	6	1.16	6	0.80	3	1.07	3	1.29	5	1.24
5	0.93	5	1.12	6	0.93	6	0.96	6	1.05	7	1.03	7	0.95	7	1.11	5	1.32	6	1.25
6	0.89	6	0.96	7	1.08	7	1.02	7	1.15	8	1.16	8	0.99	10	1.19	7	1.35	7	1.22
13	0.77	13	0.90	10	1.20	8	1.07	8	1.10	9	1.14	9	0.64	12	1.14	9	1.27	9	1.27
19	0.98	19	1.05	11	1.21	10	1.04	10	0.94	10	1.01	10	1.11	13	1.15	10	1.40	10	1.18
20	0.97	20	1.01	13	1.05	11	1.03	11	0.96	14	0.98	14	1.13	14	1.13	11	1.24	11	1.27
21	0.99	21	1.04	15	1.08	13	1.06	12	0.95	15	1.02	15	1.12	18	1.22	12	1.20	13	1.40
22	0.82	22	0.99	18	1.19	14	1.01	13	0.90	17	1.03	17	1.09	19	1.28	14	1.18	14	1.38
23	0.94	23	1.04	21	1.21	17	1.04	14	0.96	19	0.88	19	0.91	20	1.17	15	1.28	15	1.24
24	0.98	24	1.10	22	1.28	20	1.11	17	0.95	22	0.77	22	1.03	21	1.16	16	1.17	17	1.13
25	0.99	25	1.01	24	1.20	24	1.11	20	1.13	23	0.98	23	1.09	22	1.22	17	1.39	19	1.17
26	0.90	26	0.97	26	1.08	25	1.13	24	1.28	24	0.89	24	0.97	25	1.24	20	1.02	20	1.24
27	0.97	27	0.91	27	1.18	27	1.07	27	1.35	27	0.67	27	0.84	27	1.31	24	1.11	23	1.18
Ave.	0.90		1.00		1.12		1.04		1.04		0.98		0.98		1.16		1.22		1.22

[1] BD = Bulk density

Cultivation of the Carroll soil has resulted in a loss of organic matter (Table 11, page 45) from the Ap soil horizon and this in turn has resulted in a change in structure (Figures 4 and 5, pages 19 and 20). The lower organic matter content of the Ap and Bm horizons coupled with a structure which is more dense can be cited as reasons for the bulk density values increasing for the Ap soil horizons in the Carroll soil association under cultivation.

Virgin Harding

The average bulk densities of the virgin Harding Ah, Bm and Ck soil horizons were 0.98 g/cc., 0.98 g/cc. and 1.16 g/cc., respectively. The Ah and Bm horizons displayed similar average bulk density values. The well developed blocky columnar structure of the Bm horizon can be cited as a reason for the lowering of the bulk density of this horizon relative to the value which would be expected as being nearer that displayed by the Ck horizon.

Cultivated Harding

The average bulk density for the Ah horizon was 1.22 g/cc. and 1.22 g/cc. for the Bm horizon. The Ck horizon was assumed to have the same bulk density as the Ck horizon of the virgin soil, namely 1.16 g/cc.

Cultivation of the Harding soil has resulted in a loss of organic matter (Table 11, page 45) and also a modification of the structure (Figures 6 and 7, pages 21 and 22). The combined affect of lower organic matter content and a dense platy structure in the Ap and Bm horizons of the cultivated soil appears to have caused the marked increase in bulk density as compared to the Ah and Bm horizons of the virgin Harding soil.

Pore Space Measurements of the Carroll and Harding Soil Associations

The average macro, capillary and air pore space of the virgin and cultivated Carroll and Harding soils are shown in Tables 7, 8, and 9, respectively.

Virgin Carroll

The average macro, capillary and air pore space of the virgin Carroll soil Ah, Bm and Ck horizons, expressed as a percentage of the total soil volume, was 6.78, 49.97 and 9.10, respectively, for the Ah horizon; 8.57, 44.90, and 8.66, respectively, for the Bm horizon and 8.24, 43.02, and 6.63, respectively for the Ck horizon.

Cultivated Carroll

The average macro, capillary and air pore space of the cultivated Carroll soil Ap and Bm horizons, expressed as a percentage of the total soil volume, was 10.28, 41.59, and 9.54, respectively, for the Ap horizon and 10.37, 39.58, and 10.78, respectively, for the Bm horizon. The Ck horizon of the cultivated soil was assumed to be the same as the Ck horizon of the virgin soil in respect to pore space distribution measurements.

Virgin Harding

The average macro, capillary and air pore space of the virgin Harding soil Ah, Bm and Ck horizons, expressed as a percentage of the total soil volume, was 7.36, 47.42, and 8.18, respectively, for the Ah horizon, 8.82, 48.43, and 5.85, respectively, for the Bm horizon and

TABLE 7

MACRO PORE SPACE OF EACH HORIZON OF THE CARROLL AND HARDING SOIL ASSOCIATIONS

(Per cent of total soil core volume)

Carroll										Harding									
Virgin						Cultivated				Virgin						Cultivated			
Ah (1-4 in.)		Bm (5-8 in.)		Ck (18-21 in.)		Ap (1-4 in.)		Bm (8-11 in.)		Ah (1-4 in.)		Bm (5-8 in.)		Ck (16-19 in.)		Ap (1-4 in.)		Bm (6-9 in.)	
Core No.	MPS[1]	Core No.	MPS	Core No.	MPS	Core No.	MPS	Core No.	MPS	Core No.	MPS	Core No.	MPS	Core No.	MPS	Core No.	MPS	Core No.	MPS
2	8.66	2	12.39	2	10.09	1	9.22	1	12.97	1	8.36	1	9.80	1	11.24	1	2.31	2	2.88
3	8.07	3	11.53	3	10.37	4	11.82	4	10.09	5	7.49	5	8.64	2	12.68	2	5.76	4	2.31
4	8.07	4	10.95	5	11.82	5	7.20	5	9.80	6	5.76	6	11.24	3	11.82	3	3.46	5	0.58
5	7.20	5	13.26	6	10.09	6	11.53	6	9.51	7	8.36	7	12.10	7	9.51	5	2.59	6	0.86
6	8.36	6	12.10	7	8.93	7	10.95	7	9.22	8	5.19	8	8.65	10	5.48	7	4.03	7	2.02
13	6.34	13	4.90	10	5.19	8	6.63	8	10.66	9	6.92	9	5.76	12	4.90	9	4.90	9	0.29
19	6.63	19	5.71	11	5.19	10	7.20	10	12.10	10	6.34	10	6.92	13	6.63	10	1.73	10	0.29
20	5.48	20	6.63	13	6.34	11	7.78	11	12.39	14	6.92	14	7.20	14	5.48	11	5.76	11	1.73
21	5.19	21	8.93	15	6.92	13	9.80	12	10.95	15	6.63	15	6.63	18	5.76	12	1.15	13	0.86
22	10.37	22	7.20	18	4.90	14	13.26	13	10.37	17	6.05	17	7.49	19	6.63	14	2.02	14	0.29
23	6.92	23	5.76	21	7.49	17	12.68	14	10.95	19	10.66	19	10.95	20	6.34	15	4.32	15	0.86
24	4.32	24	6.05	22	7.20	20	12.10	17	12.39	22	6.05	22	2.59	21	9.22	16	1.44	17	0.86
25	6.92	25	7.20	24	7.20	24	12.10	20	11.82	23	9.51	23	9.22	22	9.51	17	5.19	19	0.86
26	4.32	26	6.92	26	11.82	25	9.51	24	7.78	24	7.20	24	16.41	25	6.92	20	3.17	20	0.58
27	4.90	27	8.65	27	10.08	27	12.39	27	4.61	27	8.93	27	8.65	27	8.93	24	5.19	23	0.29
Ave.	6.78		8.57		8.24		10.28		10.37		7.36		8.82		8.07		3.53		1.04

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[1] MPS = Macro Pore Space

TABLE 8

CAPILLARY PORE SPACE OF EACH HORIZON OF THE CARROLL AND HARDING SOIL ASSOCIATIONS

(Per cent of total soil core volume)

Carroll										Harding									
Virgin						Cultivated				Virgin						Cultivated			
Ah (1-4 in.)		Bm (5-8 in.)		Ck (18-21 in.)		Ap (1-4 in.)		Bm (8-11 in.)		Ah (1-4 in.)		Bm (5-8 in.)		Ck (16-19 in.)		Ap (1-4 in.)		Bm (6-9 in.)	
Core No.	CPS[1]	Core No.	CPS	Core No.	CPS	Core No.	CPS	Core No.	CPS	Core No.	CPS	Core No.	CPS	Core No.	CPS	Core No.	CPS	Core No.	CPS
2	48.99	2	38.62	2	40.35	1	42.62	1	42.07	1	46.40	1	46.40	1	46.40	1	41.50	2	49.57
3	48.41	3	39.77	3	37.18	4	40.92	4	41.21	5	52.74	5	44.67	2	44.09	2	40.35	4	49.57
4	52.45	4	36.31	5	41.21	5	42.36	5	40.05	6	41.79	6	50.14	3	46.40	3	42.65	5	51.87
5	40.63	5	32.56	6	40.35	6	41.21	6	39.76	7	45.82	7	46.69	7	45.82	5	39.77	6	51.87
6	45.24	6	40.92	7	37.46	7	40.05	7	36.59	8	44.67	8	50.14	10	48.70	7	43.80	7	51.87
13	56.20	13	54.76	10	48.70	8	41.49	8	38.04	9	45.82	9	59.08	12	48.41	9	37.75	9	51.87
19	50.72	19	47.84	11	47.84	10	42.07	10	40.92	10	48.41	10	45.53	13	46.11	10	42.65	10	55.04
20	49.86	20	47.55	13	50.72	11	42.65	11	40.92	14	46.69	14	44.38	14	47.55	11	46.11	11	48.99
21	52.16	21	47.26	15	46.97	13	40.92	12	38.48	15	42.07	15	46.11	18	46.69	12	53.31	13	45.24
22	49.28	22	51.87	18	47.55	14	43.80	13	41.50	17	50.14	17	46.40	19	44.38	14	52.16	14	46.40
23	51.00	23	51.00	21	39.77	17	40.06	14	38.32	19	48.13	19	45.24	20	44.67	15	46.97	15	51.87
24	51.30	24	40.35	22	40.92	20	41.79	17	38.62	22	47.55	22	55.04	21	45.82	16	53.31	17	55.33
25	48.13	25	47.55	24	42.07	24	38.62	20	40.63	23	48.13	23	47.84	22	42.94	17	37.17	19	54.18
26	52.45	26	49.28	26	43.52	25	41.21	24	35.45	24	50.43	24	46.11	25	46.10	20	54.47	20	51.87
27	52.74	27	47.84	27	40.63	27	44.09	27	41.21	27	52.45	27	52.74	27	36.02	24	60.52	23	55.04
Ave.	49.97		44.90		43.02		41.59		39.58		47.42		48.43		45.34		46.17		51.37

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[1] CPS = Capillary pore space

TABLE 9

AIR PORE SPACE OF EACH HORIZON OF THE CARROLL AND HARDING SOIL ASSOCIATIONS

(Per cent of total soil core volume)

Carroll										Harding									
Virgin						Cultivated				Virgin						Cultivated			
Ah (1-4 in.)		Bm (5-8 in.)		Ck (18-21 in.)		Ap (1-4 in.)		Bm (8-11 in.)		Ah (1-4 in.)		Bm (5-8 in.)		Ck (16-19 in.)		Ap (1-4 in.)		Bm (6-9 in.)	
Core No.	APS[1]	Core No.	APS	Core No.	APS	Core No.	APS	Core No.	APS	Core No.	APS	Core No.	APS	Core No.	APS	Core No.	APS	Core No.	APS
2	10.78	2	13.90	2	9.94	1	11.80	1	9.87	1	7.26	1	8.33	1	0.85	1	7.31	2	0.76
3	13.33	3	12.47	3	12.83	4	11.41	4	10.97	5	2.03	5	7.07	2	5.49	2	4.59	4	0.20
4	9.80	4	12.36	5	9.23	5	10.82	5	12.42	6	8.68	6	8.43	3	1.40	3	5.11	5	0.76
5	17.26	5	11.92	6	14.47	6	11.03	6	11.11	7	6.94	7	5.36	7	2.78	5	7.83	6	0.09
6	12.82	6	10.75	7	13.36	7	10.51	7	10.80	8	6.37	8	3.85	10	0.91	7	1.23	7	0.07
13	8.40	13	6.38	10	0.83	8	11.50	8	9.80	9	4.24	9	10.92	12	3.67	9	9.43	9	0.08
19	5.67	19	6.78	11	2.31	10	11.48	10	11.51	10	7.14	10	5.66	13	3.86	10	2.79	10	0.14
20	8.06	20	7.71	13	3.69	11	10.70	11	10.46	14	9.41	14	5.78	14	4.33	11	1.34	11	1.36
21	5.29	21	4.56	15	5.36	13	9.28	12	15.72	15	12.81	15	5.00	18	1.51	12	0.26	13	2.07
22	9.41	22	3.57	18	2.64	14	14.83	13	15.17	17	4.94	17	4.89	19	0.69	14	1.30	14	1.23
23	6.61	23	3.99	21	7.08	17	8.01	14	14.50	19	8.01	19	9.47	20	4.84	15	0.41	15	0.48
24	7.40	24	12.09	22	3.58	20	4.35	17	13.14	22	17.34	22	3.50	21	1.21	16	1.10	17	1.17
25	7.59	25	7.14	24	5.45	24	7.52	20	4.92	23	5.38	23	1.81	22	1.51	17	5.19	19	0.81
26	8.27	26	7.20	26	3.91	25	6.76	24	8.38	24	8.79	24	0.85	25	0.19	20	3.87	20	0.76
27	5.76	27	9.17	27	4.76	27	2.96	27	2.96	27	13.34	27	6.91	27	5.62	24	0.00	23	0.14
Ave.	9.10		8.66		6.63		9.54		10.78		8.18		5.85		2.59		3.45		0.67

[1] APS = Air pore space

8.07, 45.34, and 2.59, respectively for the Ck horizon.

Cultivated Harding

The average macro, capillary and air pore space of the cultivated Harding soil Ap and Bm horizons, expressed as a percentage of the total soil volume, was 3.53, 46.17, and 3.45, respectively, for the Ap horizon and 1.04, 51.37, and 0.67, respectively for the Bm horizon. The Ck horizon of the cultivated soil was assumed to be the same as the Ck horizon of the virgin soil in respect to pore space distribution measurements.

Discussion

Several workers, (4), (39), (46), have found relationships between the macro pore space displayed by a soil and the permeability of the soil. In general, similar conclusions can be made on the basis of this investigation even though the values for macro pore space did not always prove to be good indicators of the actual permeability of each soil horizon.

The virgin Carroll and Harding soils displayed similar values in regards to the average per cent macro pore space for each of the comparative horizons (Table 7, page 38). The average permeability values for each of the comparable soil horizons of the virgin Carroll and Harding soil (Table 2, page 27) were not similar and as such the macro pore space values, if used to predict the permeability of each soil horizon, would have given values different from those found by actual measurements of permeability. The same is true in respect to these soils under cultivation.

The relationship of the per cent macro pore space and the actual permeability values for the various horizons of the Carroll and Harding soils, under virgin and cultivated conditions, indicated that measurements of the macro pore space was not a good indicator of actual permeability but only a guide to possible permeability relationships.

In regards to the capillary pore space, as related to the Carroll and Harding soil associations under virgin and cultivated conditions, it is interesting to note that both soils had similar values for each horizon under both types of management (Table 8, page 39).

The air pore space measurements of the Carroll and Harding soils association indicated that under virgin conditions similar air pore space was found in each comparable horizon. Under cultivation, the air pore space remained similar to that of the virgin soil in the case of the Carroll association whereas there was a marked reduction in the air pore space of each horizon in the Harding association (Table 9, page 40). The reduction of the air pore space in the Harding soil association as a result of cultivation may be worthy of future investigations in relation to plant growth.

Mechanical Analysis of the Carroll and Harding Soil Associations

The results of the mechanical analysis of each soil profile at each site in the Carroll and Harding soil associations are shown in Table 10.

Generally, the mechanical analysis of each soil profile indicated that the field selection of these profiles by hand texturing resulted in the obtaining of soil profiles having a similar texture.

TABLE 10

MECHANICAL ANALYSIS OF EACH PROFILE OF THE CARROLL AND HARDING SOIL ASSOCIATIONS

	Virgin Profiles						Cultivated Profiles					
Soil Association	Site	Horizon	% Sand	% Silt	% Clay	Texture	Site	Horizon	% Sand	% Silt	% Clay	Texture
Carroll	1	Ah	5.8	56.8	37.4	silty clay	1	Ap	27.5	49.8	22.7	silty clay loam
	1	Bm	54.2	24.7	21.1	clay loam	1	Bm	9.2	43.8	47.0	clay
	1	Ck	35.9	35.4	28.7	clay loam	1	Ck	35.9	35.4	28.7	clay loam
	2	Ah	10.7	50.8	38.5	silty clay	2	Ap	15.4	59.6	25.0	silty clay loam
	2	Bm	14.0	50.7	35.3	silty clay	2	Bm	7.0	16.3	76.7	clay
	2	Ck	2.9	48.8	48.3	clay	2	Ck	2.9	48.8	48.3	clay
	3	Ah	27.3	55.1	17.6	silty clay loam	3	Ap	23.0	52.7	24.3	silty clay loam
	3	Bm	31.5	50.9	17.6	silty clay loam	3	Bm	8.1	60.0	31.9	silty clay
	3	Ck	27.6	55.9	16.5	clay loam	3	Ck	27.6	55.9	16.5	clay loam
Harding	1	Ah	7.2	57.2	35.6	silty clay	1	Ap	15.0	51.3	33.7	silty clay
	1	Bm	10.8	50.2	39.0	silty clay	1	Bm	10.6	44.0	45.4	clay loam
	1	Ck	7.4	40.5	52.1	clay	1	Ck	7.4	40.5	52.1	clay
	2	Ah	4.1	40.8	55.1	clay	2	Ap	5.4	48.6	46.0	clay
	2	Bm	2.0	37.9	60.1	clay	2	Bm	3.2	41.0	55.8	clay
	2	Ck	1.1	38.4	60.5	clay	2	Ck	1.1	38.4	60.5	clay
	3	Ah	3.6	53.2	43.2	silty clay	3	Ap	11.5	53.4	35.1	silty clay
	3	Bm	2.2	46.0	51.8	clay	3	Bm	8.2	43.3	48.5	clay
	3	Ck	0.1	49.3	49.6	silty clay	3	Ck	0.1	49.3	49.6	clay

Organic Matter Determinations of the Carroll and Harding Soil Associations

Organic matter determinations were carried out on the Ah horizons of the virgin soils and the Ap horizons of the cultivated soils of the Carroll and Harding soil associations. The results of these determinations are shown in Table 11.

The data shows that the Ah horizon of the virgin Carroll soil had an average organic matter content of 8.3 per cent and the Ah horizon of the virgin Harding soil had an average per cent organic matter content of 7.4. The Ap horizon of the cultivated Carroll soil displayed an average organic matter content of 4.8 while the Ap horizon of the cultivated Harding soil displayed an average per cent organic matter content of 3.6.

Cultivation and erosion have resulted in a loss of a 42.5 and 51.4 per cent, respectively, of the organic matter in the surface horizons of the Carroll and Harding soils. The lower organic matter content of the Ap horizons relative to the Ah horizons of both the Carroll and Harding soil associations no doubt has been a factor in reducing the permeability of these soils under cultivation.

TABLE 11

ORGANIC MATTER CONTENT OF THE SURFACE HORIZONS OF THE CARROLL AND HARDING SOIL ASSOCIATIONS

Site		% Organic Matter	Ave. % Organic Matter	Ave. % Loss of Organic Matter
1	Virgin Carroll - Ah	7.7		
2	Virgin Carroll - Ah	7.2	8.3	
3	Virgin Carroll - Ah	10.0		
1	Cultivated Carroll - Ap	4.4		
2	Cultivated Carroll - Ap	4.4	4.8	42.5
3	Cultivated Carroll - Ap	5.5		
1	Virgin Harding - Ah	7.3		
2	Virgin Harding - Ah	8.8	7.4	
3	Virgin Harding - Ah	6.1		
1	Cultivated Harding - Ap	4.1		
2	Cultivated Harding - Ap	3.5	3.6	51.4
3	Cultivated Harding - Ap	3.2		

GENERAL DISCUSSION

Permeability

Water permeability studies of the Carroll and Harding soil associations in Manitoba provided some interesting information in regards to the movement of water through the various horizons of these soils under virgin and cultivated conditions.

The Ah horizons of virgin soils, because they contain the maximum amount of organic matter and have the greatest concentration of plant roots relative to the lower horizons, have always been regarded as probably having a higher permeability rate as compared to the other soil horizons. The results of this study indicated that under virgin conditions the Bm horizons of both the Carroll and Harding soils had a higher average permeability rate than the respective Ah horizons of these soils (Table 2, page 27).

Baver (9) states that the amount of water percolating through a soil profile is determined by the permeability of the least pervious horizon. It becomes important to know the permeability rate of each soil horizon in that the horizon having the lowest permeability regulates the rate of movement of water through the soil profile. The results of this study indicate that in the case of the virgin Carroll soil, the permeability rate of the Ah horizon determines the rate of movement of water through the profile as the average permeability rates for the Ah, Bm and Ck horizons were 0.78, 1.40, and 0.95 inches per hour, respectively (Table 2, page 27). In the case of the virgin Harding soil, the permeability rate of the Ck horizon regulates the amount of water moving through the soil as the average permeability rates of the Ah, Bm and Ck horizons were 1.13, 2.94, and 0.75 inches per hour, respectively. The amount of water that could percolate through both the virgin Carroll and Harding soil would be about the same because the least pervious horizon of the Carroll soil had an average permeability rate of 0.78 inches per hour whereas the least permeable horizon of the Harding soil had a permeability rate of 0.75 inches per hour.

In the case of these soils under cultivation, the Ap horizon of the Carroll proved to be the least permeable horizon having an average permeability rate of 0.42 inches per hour as compared to 0.87 inches per hour for the Bm horizon and 0.95 inches per hour for the Ck horizon. The Bm horizon of the Harding soil was the least permeable having an average permeability rate of 0.01 inches per hour as compared to 0.20 for the Ap horizon and 0.75 inches per hour for the Ck horizon. These results would tend to lead to the conclusion that under cultivation, the Harding soil would be more susceptible to water erosion than the Carroll soil.

Cultivation of the soil does have an affect upon the soil permeability. It is important to know this effect in order to recommend management practices that will increase the rate of water movement in the soil in order to conserve moisture for plant use and to prevent serious soil erosion.

Studies of the virgin and cultivated Carroll and Harding soils showed that the permeability rates for the soil horizons affected by cultivation were lower than the corresponding horizons under virgin conditions.

Statistical analysis of the permeability data indicates:

(1) The permeability values for the virgin soils of both the Carroll and Harding soil associations were significantly greater than the permeability values for these soils under cultivation.

(2) The difference in permeability of the virgin and cultivated Harding soil is significantly greater than the difference between virgin and cultivated conditions of the Carroll soil.

(3) The Bm horizons of the virgin soils have a significantly greater permeability than the Ah horizons.

(4) The permeability of the cultivated soils has decreased relatively more on the Harding soil association as compared to the Carroll association. The difference between virgin and cultivated conditions on the Carroll soil association as an average of the upper two horizons is significantly smaller than the difference between virgin and cultivated conditions on the Harding soil association in respect to permeability.

The practical application of this information can be related to recommendations regarding soil management practices. The incorporation of trash, depth and type of tillage, crops grown in a rotation all have an affect upon the soil structure and consequently upon the permeability. Those practices which increase the permeability of a soil for water result in a greater amount of water being made available for plant use and also reduce the susceptibility of a soil to water erosion.

Bulk Density and Pore Space Distribution

Cultivation of the Carroll and Harding soils has resulted in an increase in the bulk density of those horizons affected by cultivation. A reduction in the size and arrangement of the soil aggregates and the loss of organic matter due to cultivation and erosion have contributed to this increase in bulk density.

The capillary pore space of the Carroll and Harding soils was not appreciable affected by cultivation.

The air pore space was found to have been reduced greatly in the Harding soil association due to cultivation although little or no change was observed in respect to the air pore space in the Carroll soil association due to cultivation. The severe reduction in respect to the air pore space of the Harding soil under cultivation may warrant further investigations relative to plant growth.

In general, a relationship was found between the macro pore space exhibited by the various soil horizons of both the Carroll and Harding soils and their permeability. The macro pore space was found useful only as a guide to the permeability that a horizon might exhibit but did not provide an accurate assessment of the actual permeability.

Soil Core Sampling Technique

Results of this study indicate that the taking of twenty-seven soil cores of each horizon, upon which permeability values were obtained, was not sufficient. This is particularly true in the case of sampling the Ah and Bm horizons of virgin soils where the affect of root channels and structure in the soil cause a wide range in permeability values obtained. Twenty-seven cores are probably sufficient in the case of sampling cultivated soils or the lower horizons of virgin soils.

Detailed soil horizon descriptions should be prepared in the field at the time the soil cores are obtained so that the permeability values obtained can be closely related to the structural arrangement of each horizon.

CONCLUSIONS

1. The Carroll and Harding soil associations have higher permeability rates under virgin conditions than when cultivated.
2. The Bm horizons of the virgin Carroll and Harding soil associations exhibit higher permeability values than the Ah and Ck horizons.
3. The permeability of the cultivated soils has decreased relatively more on the Harding soil association as compared to the Carroll soil association. The difference between virgin and cultivated conditions on the Carroll soil as an average of the upper two soil horizons is significantly smaller than the difference between virgin and cultivated conditions on the Harding soil association in respect to permeability.
4. Cultivation of the Carroll and Harding soil associations has resulted in an increase in the bulk density of those horizons affected by tillage.
5. No constant relationship between permeability values and pore space values was observed.
6. The air pore space of the Harding soil association was reduced by a greater degree due to cultivation than was that of the Carroll soil association.
7. Cultivation had little or no affect upon the capillary pore space of the Carroll and Harding soil associations.
8. Cultivation of the Carroll and Harding soil associations has resulted in a loss of forty to fifty per cent of the organic matter from the Ap soil horizon.

9. The Harding soil association is more susceptible to water erosion than the Carroll soil association under cultivated conditions.

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