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