A STUDY OF MOISTURE IN SOILS UNDER CROP ROTATIONS

IN

SOUTH-WESTERN MANITOBA

A THESIS

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ABSTRACT

Information is presented showing that the problem of assessing the relative moisture efficiency of crop rotations under study on District Experiment Substations located on soils varying in texture, can be successfully studied by the application of statistical methods. The results of this study show that the mixed-farming crop rotations of four and eight years duration in which grass and legume crops are included in the cropping system, are significantly more efficient in the utilization of soil moisture; tend to produce higher average crop yields; more efficiently conserve plant nutrients, and are more adaptable to a permanent agricultural economy in south-western Manitoba than are the two and three-year grain rotations.

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A STUDY OF MOISTURE IN SOILS UNDER CROP ROTATIONS IN SOUTH-WESTERN MANITOBA

I. INTRODUCTION:

Soil moisture is the prime factor in determining crop production in the semi-arid regions of the Great Central Plains of North America. Agricultural practices and operations are influenced by the regional and seasonal supply of moisture. Grain crop yields are directly related to the amount of water that is available in the soil over and above the minimum required for any crop at all.

The soils of south-western Manitoba have developed under limited precipitation, and are relatively rich in plant nutrients. The need for taking into account the moisture supply when adjusting a cropping system that will conserve the fertility of these soils must be recognized. In the design of a cropping system, careful thought must be given to the efficient use of the moisture supply by crops for maximum yields.

For a permanent agricultural economy in a region of limited precipitation, the need for a study of the soil moisture regime in relation to cropping practices must be recognized. In experimental cropping rotations on District Experiment Substations due consideration has not been given to soil moisture and to its most efficient use.

In this thesis a study is made of soil moisture investigations carried out on cropping rotations of two, three, four and eight years duration as conducted on District Experiment Substations at Boissevain, Goodlands and Hargrave in south-western Manitoba.

II. REVIEW OF LITERATURE:

Water is an essential plant nutrient and is required in much larger quantities than any other absorbed by the plant. The outstanding characteristic of water as a plant nutrient is its continuous one way flow from the soil through the roots, up the stems into the leaf surface where it is transpired. It is highly desirable that a soil should possess the capacity not only to supply plants with readily available water, but also to hold sufficient water in reserve to maintain continuous growth during periods of atmospheric drouth.

A. Physical Properties and Moisture Relationship:

Soils vary greatly in their water retaining capacity which depends largely upon the texture or size of mineral particles, the structure or manner in which these particles are arranged, and the amount of organic matter incorporated in the soil. On the basis of texture Ellis (13) in his study of Manitoba soils outlined a simplified field classification of soils on the basis of the respective separates (sand, silt, and clay) contained.

Sandy soils have numerous large pores or air spaces which insures free movement of gravitational water. Sands are relatively inert in chemical and physical properties; loose, non-cohesive, and have a very low water-holding capacity. Ellis (13) states that under free drainage, sands will retain .25 to .50 inches of water per foot. Doughty et al (11) rate the normal storage capacity to 4 feet of a sandy loam at 4 inches.

Clay soils are at the other extreme in regard to size of particles, consisting of 45 per cent or more of clay particles ranging in size less than .002 millimeters. These small particles are aggregated into granules which swell and become sticky when wetted. Because of the large proportion of particles of colloidal size in clay, water and cations as well are held in much greater quantities than in sand. The clay fraction in soils impart to it certain physical and chemical properties. Clay particles possess tremendous surface area and have very strong cohesive forces. They are negatively charged and carry cations and water molecules on their surface.

A cubical sand grain one millimeter on the edge has a total surface area of six square millimeters, but if it is divided into cubes of colloidal size 0.1 micron on the edge, the total surface would be 60,000 square millimeters (2). Clay particles are plate-like and have an even greater surface than cubes and spheres of similar volume. The extensive surface area of clays enable clay soils to hold much more water than sandy soils, but since the pores are much smaller gravitational water drains off more slowly. Clay textured soils under free drainage (13) may retain 3.5 inches of water per foot. Doughty et al (11) rate the normal storage capacity of certain clay soil in Saskatchewan at 8.6 inches of water per 4 feet of depth.

Loam soils have properties which are intermediate between those of clay and sand. They hold more water than sands, are better aerated, and easier to work than clays. Loams are rated as the most favourable from the standpoint of plant growth. In general, the water retention capacity of sandy loams is given (13) as 1.0 inch, that of loams as 2.0 inches, and that of clay loams as 3.0 inches per foot depth. The average water storage capacity of Saskatchewan loams to silt loams, and of clay loams to silty clay loams, to a depth of four feet, is given (11) as 6.2 inches and 7.2 inches respectively.

Ellis (13) reports the range of water retention within a four-foot column of soil as being from 1.0 inch to 14 inches for sands and clay respectively. Doughty et al (11) report the normal storage capacity of 4.0 inches to 8.6 inches per 4 foot depth for soils ranging in texture from sandy loam to clay respectively.

B. <u>The Effect of Structure on Soil Moisture:</u>

Soil structure, or arrangement of soil particles is important in the water relationship of a soil because it is directly related to pore size. Soil porosity (2) may be defined as that percentage of the soil which is not occupied by solid particles. Clays have higher total porosities than sands, and have a large number of small capillary pores which contribute to a high water-holding capacity. Sands have a small number of large or non-capillary pores which are responsible for rapid drainage and a low moisture-holding capacity. Baver (2) defines an ideal soil as one that has pore space about equally divided between large, small or non-capillary and capillary pores. A soil of this type would have enough small pores to give adequate water-holding capacity. In clay soils, treatments that tend to promote granulation produce larger pores so that the soil becomes more favorable for root development. Recent laboratory studies by Hedrick and Moury (23) on the effect of synthetic polyelectrolytes on aggregation, aeration and water relationships of clay, clay loam, silt loam and sands indicate these new soil conditioners increased the water held by 20 to 70 times the weight of the polyelectrolyte added.

Soil structure is important in soil productivity. Plants require both water and air for growth, and these in turn depend upon soil structure. Lack of moisture renders the plant incapable of utilizing the chemical nutrients to carry on its normal physiological functions. Lack of sufficient oxygen due to an excessive amount of water in the soil produces a condition where the plant cannot make efficient use of the nutrients in the soil.

C. <u>The Effect of Organic Matter on Soil Moisture</u>:

Soil organic matter or humus (34) represents a whole series of products ranging from undecayed plant and animal tissues to the black or brown amorphous material not resembling the original anatomical structure from which it was derived. It resembles clay in respect of its great surface area and high water-holding capacity. It also has a high wilting point. The addition of organic matter to sandy soils increases the ability of the soil to hold water for plant growth. Baver (2) reporting on work conducted by Feustel and Byers states that the amount of available water held was increased from 0.83 per cent to 7.5 per cent by the addition of peat moss to a 50-50 mixture of quartz sand and peat. In respect of clay, a 50-50 mixture of clay and peat did not appreciably increase the amount of available water, although the water-holding capacity was increased. Under field conditions it has been found difficult to make any appreciable change in the available water content of soils. Kramer (25) reporting on work in California stated that additions of manure up to 200 tons per acre did not greatly increase the content of water available to plants in sand, loam or clay soils. In New York, manure added at the rate of 8 and 16 tons per acre did not significantly increase the available water-holding capacity of Chenango loam, but did significantly increase the available water-holding capacity of Chenango fine sandy loam.

Martin and Craggs (27) report that when a loam soil was maintained at moisture contents of 25, 50, or 75 per cent of its water-holding capacity there were no major differences in the influence of organic residues upon the soil structure. In a completely saturated soil the beneficial action of organic residues was greatly reduced. In normal soil, decomposition of organic residues is brought about by the action of aerobic bacteria, actinomyces and filamentous fungi. In water-logged soil decomposition is carried on by anaerobic bacteria that do not produce the quantity and quality of soil aggregating substances as do the aerobic bacteria.

D. Classification of Soil Moisture:

Baver (2) follows the classification of soil moisture as proposed by Briggs in 1897, with the addition of water vapour as suggested by Lebedeff.

1. Gravitational Water:

Gravitational water occupies the larger soil pores and drains away under the influence of gravity. Shortly following a heavy rain or irrigation the soil may be completely saturated with water, and the air may be displaced from the non-capillary pore spaces between the particles. Two or three days after a rain all gravitational water usually drains out of the upper horizons of the soil and the pore spaces become filled with air. The movement of gravitational water in the soil is affected chiefly by the number, size and continuity of non-capillary pores through which it percolates. Sandy soils offer a minimum of resistance to the passage of soil water and such soils soon reach their field capacity. Percolation through clays is less rapid because of the pore spaces being smaller, and entrapped air often blocks the passages. Impermeable layers of soil frequently hinder the movement of gravitational water. Passages left in the soil by worms, burrowing animals, and by decaying roots, facilitate the movement of gravitational water.

2. Capillary Water:

Capillary water is held by surface forces in the form of films around the soil particles, in the spaces between them, and in small capillary pores. After the gravitational water has drained away, the soil is at field capacity. This water is the main source of moisture for most plants. Capillary water moves very slowly and is not used by plants unless the roots actually come into contact with it. The downward movement of capillary water takes place under the combined influences of the gravitational - potential gradient and the capillary - potential gradient. If evaporation is prevented, downward movement will continue until the soil is drained or until equilibrium is reached with an impermeable layer or saturated water table.

3. Hygroscopic Water:

Hygroscopic water is held on the surface of soil particles by forces of adhesion in a very thin film, and is not available to plants. The maximum amount of water, based on a weight of dry soil, adsorbed on the surface of soil particles from an atmosphere slightly below 100 per cent relative humidity is known as the hygroscopic coefficient.

E. Terms Used in Soil Moisture Study:

1. Field Capacity:

The field capacity of a well drained soil is the moisture content that is reached two or three days after rain or irrigation has ceased, provided evaporation is prevented. Kramer (25) states that field capacity is not a true equilibrium value, but only a condition of slow water movement where the moisture content does not change appreciably between applications of water. Most well drained soils reach a state of field capacity very quickly, but the presence of a water table near the surface will greatly prolong the time required for drainage. Browning (7) reports that impermeable soils require a much longer time to reach field capacity than well-drained soils.

2. Moisture Equivalent:

The moisture equivalent was introduced by Briggs and McLane (4) in 1907, to denote the percentage of water retained by a soil when the moisture content is reduced by means of a constant centrifugal force until it is brought into a state of capillary equilibrium with the applied force. The moisture equivalent has been found to be closely related to the field capacity for fine-textured soils, but not for sands where the field capacity is higher than the moisture equivalent. Experiments by Veihmeyer and Hendrickson (41) show that the moisture equivalent values can be used to indicate the field capacity of deep-drained soils with no decided change in texture or structure, in cases where the moisture equivalent ranges from about 30 per cent down to about 12 or 14 per cent. Below 12 or 14 per cent, the moisture equivalent values appear to be less than the field capacity. Browning reports (7) that the ratio of field capacity to moisture equivalent is unity in the vicinity of a moisture equivalent of about 21 per cent; more than unity for moisture equivalents below 21 per cent and less than unity for moisture equivalents above 21 per cent. This ratio decreases slightly with depth. The moisture equivalent is recognized as one of the important physical measurements of soil. Several modifications for the determination of moisture equivalent have been reported. Buoyoucos (3) proposed a suction method in place of using a centrifuge machine. Pinckney and Alway (31) in comparing the reliability of the suction method with that of the Briggs-McLane centrifuge method, and reporting on 113 Minnesota soils, found a relationship between the two methods, but did not fully support the Buoyoucos method. The suction value of loams and soils of still finer texture averaged about one-tenth higher than the moisture equivalent, whereas with the individual soils it varied from practically equal to one-third higher. Suction values for the sands of coarsest texture were twice as high, or higher, and for the intermediate soils, namely the loams, it was generally intermediate but widely variable. Duplicate determinations by the suction method were found to be much less consistent than those with the centrifuge. Browning and Milan (6) compared the Briggs-McLane and the Goldbeck-Jackson centrifuge methods for determining the moisture equivalent of soils. A significant difference existed between the two methods unless all values obtained in Gooch crucibles were corrected by use of the regression equation between the two methods. When a Briggs-McLane moisture equivalent centrifuge is not available, satisfactory results can be obtained for most purposes by using the equipment recommended by Goldbeck and Jackson.

3. <u>Wilting Point</u>:

The wilting point, permanent wilting percentage, wilting coefficient, or wilting percentage (2), refers to the soil moisture content at which soil cannot supply water at a sufficient rate to maintain turgor, and plants wilt permanently. Kramer (25) outlines the Briggs and Shantz procedure of growing seedlings in glass tumblers of soil sealed with a mixture of paraffin and vaseline. When the leaves permanently wilted and did not recover over night when placed in a moist chamber, the moisture content of the soil was determined by oven-drying a sample at 105 degrees Centigrade and calculating the moisture content as a percentage of the dry soil weight. According to Briggs and Shantz the wilting point marks the moisture content at which absorption becomes too slow to replace the water lost by transpiration, and this results in wilting. Briggs and Shantz (5) report that soil texture is the only factor materially affecting the moisture content at permanent wilting. The age of plants did not affect the values, because the same results were obtained with seedlings as with well grown grass plants. Plants grown with different amounts of soil moisture wilted at the same moisture content, indicating that drought resistance had not been increased by growing the plants in dry soil. No important difference between different species of plants was noted in their ability to reduce the moisture content of the soil before wilting. Differences that occurred between various species of crop plants resulted from differences in root distribution rather than from differences in forces bringing about water absorption.

Furr and Reeve (15) have made an extensive study of the range of soil moisture percentages through which plants undergo permanent wilting. Samples of about 80 soils, representing 50 soil types in California were collected for the study. Furr and Reeve introduced the terms "wilting range" and "ultimate wilting point" as proposed by Taylor et al who defined the wilting coefficient and the ultimate wilting point as the moisture content at which all the leaves remain completely wilted in a humid atmosphere. The ultimate wilting point represents approximately the lower limit of the range of soil moisture percentages in which plants are able to maintain life, though at this stage many of the leaves and probably some of the roots are dead. Furr and Reeve concluded that Russian Giant sunflowers, *Helianthus annuus L.* seedling root and stem elongation is negligible at soil moisture percentages below the first permanent wilting point and that the extraction of moisture in the wilting range is dependent almost entirely on water movement to the roots by diffusion of water vapour. The soil moisture within the wilting range provides the plant with an emergency reservoir that enables many species of plants to survive periods of drought or to mature seed after vegetative growth has ceased.

4. Available Moisture:

Moisture that is "readily available" (25) may be defined as that which can be used by plants above the permanent wilting percentage. Gravitational water comes into this category but it usually drains away so quickly that it is of little value for plant growth. Readily available water is considered to be that included in the range from field capacity, or moisture equivalent down to the permanent wilting point. In sandy soils this range is quite narrow, whereas in clay soils it is quite wide.

5. Relative Moisture:

Relative moisture is the term applied to the ratio of per cent moisture content to moisture equivalent. The use of such a ratio enables comparisons to be made between soils or soil horizons which differ in texture. Relative moisture data were particularly useful in the investigation reported in this thesis, for the purpose of comparing the moisture changes in various fields where the soils were not completely uniform in texture. Conrad and Veihmeyer (9) report that the ratio of the residual moisture at permanent wilting to the moisture equivalent averaged about 50 percent.

F. Movement of Soil Moisture:

The movement of soil moisture is relatively complex mainly because of the various forces acting upon it, and because it may move in different states. Wadleigh and Richards (38) state that the movement of water into and through soil can be expressed in terms of the force which tends to produce the motion of the water. Gravity and the gradient of the moisture tension in the soil are the two components that must be considered. Downward movement takes place in response to the force of gravity when the soil is wetted by rain or irrigation. Upward movement occurs when the surface is being dried by evaporation. In a soil moisture system the moisture always streams through the soil in the direction of the decrease in hydraulic tension, or head. The component of force arising from the tension gradient in the soil water may act in any direction. When water is at rest under gravity, that is in a static condition, the pressure gradient force is equal to and opposite to gravity.

The Darcy Law for the movement of water in saturated soils states that the velocity of water movement (V) is proportional to the hydraulic gradient (i) as expressed by the equation $V=Pi$, where P is the permeability constant. In the case of unsaturated soils its application is not reliable due to the fact that some of the pores are filled with gas and are not available for transmitting water. Moore (37) found very little flow of moisture in unsaturated soils at or below the moisture equivalent. Veihmeyer and Hendrickson (40) placed a mass of soil, wetted to field capacity , in a large cylinder with dry soil on each side of it. At the end of 139 days water had moved into the dry soil a distance of 8 inches. From a practical point of view this would indicate that during periods of rapid transpiration, the available water on the particles of soil in contact with the roots is removed much faster than it can be replaced by capillary movement.

G. <u>Effect of Temperature on Soil Moisture:</u>

Soil temperature (25) influences the amount of available water to plants. Water has great viscosity at lower temperature than at higher, resulting in a decreased movement of water from the soil to an absorbing surface at low temperatures. Russell (34) suggests that the surface tension of water decreases with increasing temperature. Briggs and Shantz (5) reporting on work of other investigators, state that all data indicate that shade produces an increase in the water requirement, probably due to a reduction in photosynthesis, which in turn decreases the rate of growth and so increases the water requirement. Moore (29) reports that under field conditions, rapid changes in soil temperature above a water table would be accompanied by rising water tables with rising temperature, and falling water tables with falling temperature.

H. <u>Effect of Humidity on Soil Moisture:</u>

Lebedeff (26) considers the relative humidity of the soil air to be always 100 percent if the moisture content of the soil exceeds the hygroscopic coefficient. Under normal field conditions, the soil atmosphere is in a saturated condition with the exception of the top layer which often becomes air-dry. Movement of water vapour in the soil is affected by the relative temperatures and vapour pressures of the various soil horizons.