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. The Effect of Organic Matter on Soil Moisture:

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. Effect of Temperature on Soil Moisture:

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. Effect of Humidity on Soil Moisture:

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.

If, for example, the first 6-inch layer of soil becomes cooled below the temperature of the second 6-inch layer immediately below, the vapour pressure of the water molecules in the top 6-inch layer will be lowered, and diffusion of water molecules will take place in an upward direction, and thereby increasing the soil moisture content of the first 6-inch layer. Lebedeff has attached considerable importance to the movement of water vapour in soils of southern Russia and other semi-arid regions, when there is no direct connection between the water table and the capillary water in the upper layer. According to Lebedeff water moves from the deeper warmer levels to the higher, cooler levels where it condenses, amounting to 66 millimeters in a winter period. During a cool period in summer or autumn water moves from the deeper layer to the surface layers where it is evaporated during warm periods thereby drying out the deeper layers. Lebedeff calculated that about 72 millimeters of water per year condenses in the surface layer of soil.

I. The Effect of Evaporation on Soil Moisture:

The quantity of water lost from soil by evaporation depends on the moisture and temperature of the soil; the relative humidity of the air, and the air movement above the soil surface. Differences in evaporation are also due to dark and light-colored soils and from north and south-facing slopes, but these result mainly from differences in temperature. Baver (2) reports work conducted by Eser in 1884 indicating that evaporation from soils in contact with ground water was 2 to 4 times greater than from drained soils. According to Baver, King measured the evaporation from black marsh, sandy loam, and virgin clay loam soils in relation to depth of tillage. Evaporation was reduced 63 per cent by mulching over a period of 100 days when soil columns were placed in contact with a water surface. Baver reporting on more recent work by Veihmeyer, indicates that evaporation losses are confined to relatively shallow depths and that most of the water lost by evaporation takes place before a "mulch" is produced on the surface. Evaporation is greater during the summer months when temperatures are higher. Black soils absorb more of the sun's energy and also lose more water through evaporation than light-colored soils. The darker soils gain more by condensation at night. In the northern hemisphere, evaporation is greater on south slopes than on north, and on the south exposures it increases with slope. Baver reports data by Masure showing that evaporation at 17.0 to 17.5 degrees Centigrade, increased from 0.25 millimeter to 0.93 millimeter as the air humidity decreased from 91 to 75 per cent. Wind velocity speeds up evaporation by displacing saturated air with drier currents. Woolny's work as cited by Baver shows that a 12 mile per hour wind caused 7.8 grams of water to evaporate from 100 square centimeters of a granular loam as compared with 0.3 grams in still air, or an increase of 96.2 per cent.

It is of interest to study the relative amounts of water removed from the soil by evaporation and transpiration. There appears to be general agreement that transpiration losses greatly exceed evaporation losses. Kramer (25) cites work by Veihmeyer who indicates that under California conditions, most of the water lost by evaporation comes from the upper four inches, much less from the second four inches, and very little below eight inches. If evaporation removed water from the first eight to twelve inches of soil, then the remainder would be unchanged if it were not for the roots of plants. Further investigations by Veihmeyer indicate that a tank of soil with bare surface lost 18.9 pounds of water per square foot of surface in four years, equivalent to a depth of 3 3/8 inches of water, or less than one inch per year. A four year old prune tree growing in a similar tank lost 1250 pounds of water in one growing season.

Staple and Lehane (35) working under Saskatchewan conditions report that the approximate average daily evaporation measured by the intervals in days between rainfalls for the months of May, June and August was 0.2 inch; for July, 0.24 inch for September, 0.14 inch, and for October, 0.075 inch.

Dawley (10) reports that evaporation from an evaporation tank water surface at the Melita Reclamation Station in Manitoba, amount to 23.03 inches for the period from May 1st to August 31st, 1953. Comparing this with the work of Staple and Lehane, the average evaporation at Melita from a tank surface was .16 inch per day for May; 0.18 inch for June, 0.21 inch for July, and 0.19 inch for August.

J. Water Requirements of Plants:

Briggs and Shantz (5) define the term "water requirement as the ratio of the weight of water absorbed by a plant during its growth to the weight of dry matter produced. This is also known as the transpiration ratio. It is not constant and is dependent upon variations in environmental factors such as the temperature and humidity of the air, the velocity of the wind, the intensity of the solar radiation and the fertility of the soil. These workers report the water requirement of alfalfa as 1068, sweet clover 709, oats 614, barley 539, wheat 507, corn 369, sorghum 306, and millet 275.

The standard field crops differ as their efficiency in the use of water. Alfalfa uses four times as much water as millet and the more efficient sorghums in the production of a pound of dry matter. Corn ranks next to sorghum and millet in efficiency in the use of water. The water requirement of oats, barley and wheat is about twice that of millet, but only one-half that of alfalfa. On the basis of grain production, the water requirement of millet and the grain sorghums is approximately one-half that of oats and two-thirds that of wheat and barley.

Hendrickson and Veihmeyer (18) reported that the growth of peaches was not affected until the soil moisture was reduced to a point near the wilting point. Peaches picked from plots where the soil moisture was deficient, were slightly higher in percentage of sugar and lower in percentage of water. In the case of peaches, a deficiency of readily available soil moisture during the pit-hardening period seriously affects the subsequent size of the fruit. No differences in the keeping quality of peaches from wet and dry plots were observed during the period between picking and canning.

Hunter and Kelly (19) studied the extension of plant roots into dry soil and reported on corn roots penetrating a "dry" soil having an initial moisture content of 0.4 per cent. At the end of twelve days after germination, two plots were examined and the moisture content in the vicinity of the roots that had penetrated the "dry" soil was 1.04 per cent in one pot and 0.80 per cent in the second. After 24 days, numerous roots had grown into the "dry" soil for one to two inches. The average moisture content of the dry soil about the roots was 1.12 per cent. After 30 days it was found that, regardless of relative humidity, many roots had extended into the "dry" soil. The surfaces of the roots were moist with exudate and in most cases had a thin sheath of adhering soil grains. In this experiment, radio phosphorus was used in the "dry" soil. At the end of the experiment a Geiger counter did not reveal the presence of radiophosphorus in the aerial portion of the corn plant. This indicates that phosphorus is not taken in by the plant when the soil moisture is in short supply.

Hunter and Kelley (20) report that a guayule plant, Parthenium argentatum could absorb nutrients from moist soil, 48 inches below the surface that was at or below the permanent wilting point.

There is some evidence to indicate that water is not equally available over the entire range from field capacity down to the wilting point. Kramer (25) reports work, by Adrich and Work, who indicate that in the very heavy soils in Oregon, the growth rate of pears is closely related to the moisture content of the first three feet of soil. The fruits were reduced in size when the soil moisture dropped below 70 per cent of the readily available moisture.

Adams, Veihmeyer and Brown (1) report that where the soil moisture remained at the wilting point for extended periods in the upper 2 or 3 feet soil, plant heights and yields of cotton were reduced. Significant differences in quality of cotton were found between "wet" and "dry" treatments, but these differences were not of sufficient magnitude to be of economic importance. Cotton plants in the San Joaquin Valley in California will use the equivalent of about 24 inches of water, including surface evaporation and transpiration in producing normal yields of cotton.

Seeds of plants vary considerably in their requirement of water for germination. Hunter and Erickson (22) studied the germination of sugar beet seed, corn, soybeans and rice in relation to soil moisture. The specific moisture content required to germinate these seeds, was approximately 30.5 per cent. The minimum amounts of soil moisture required for sugar beet to attain this moisture content for germination was between 4.41 per cent and 5.45 per cent in the silt loam soil, 8.84 per cent and 9.47 per cent in the clay loam, 10.2 per cent and 12.0 per cent in the sandy clay loam and 16.8 per cent and 17.7 per cent in a clay soil.

K. <u>Effect of Fertility Level on Soil Moisture:</u>

Briggs and Shantz (5) report experiments showing a reduction in the water requirement when fertilizers are used. In soils that are highly productive this reduction amounts to only a small percentage. In low-fertility soils the water requirement may be reduced one-half or even two-thirds by the addition of fertilizers. High water requirement is often due to the deficiency of a single plant element. As the supply of such an element nears exhaustion the rate of growth, as measured by the assimilation of carbon dioxide, is greatly reduced, but there is no corresponding change in the transpiration. This results in a high water requirement. Plants grown in water culture were found to have an increased water requirement if the solution lacked a sufficient amount of plant food. Singh and Mehta (36) studied the water requirement of wheat as influenced by the fertility of the soil. These workers induced a variability in soil fertility by the application of different manures in the organic and inorganic forms. The results of this work point out that increasing the fertility of the soil, by addition of manures, reduces the quantity of water needed per unit of dry matter produced, but enhances the total quantity of water transpired by the crop.

Smith (37) reports that sweet clover, *Melilotus alba* and *M. officinalis*, produce a greater proportion of their total weight in roots under dry conditions than under moist conditions, but the total weight of the roots plus tops under the two conditions are about the same.

L. The Effect of Cultural Practices and Crop on Soil Moisture:

Glendening (16) reports work conducted in 1938 on the Santa Rita Experimental Range, to determine the effect of various kinds of litter cover upon soil moisture and germination and emergence of seedlings of 10 native grasses. The moisture content of the surface soil was 5.9 per cent under the barley straw mulch, and 2.7 per cent for bare soil. Average soil moisture at the 6-inch level was 7.6 per cent under barley straw and 6.1 per cent under bare soil. Germination and emergence of the grass seedlings was increased from 4 to more than 20 times by the use of mulches.

Browning (8) studied the seasonal distribution of soil moisture under different crops at the 24 to 36-inch level. Continuous bluegrass caused marked seasonal reduction in available water at the 24 to 36-inch depth. Alfalfa reduced practically all of the soil moisture in the 24 to 36 inch depth of soil. Browning (8) reported that no moisture was available at the 3 to 8-foot depth on Ida soils where alfalfa had been seeded down for 3 years or more. Moisture content varies with depth in the soil and is influenced by the water requirement of the plant and the type and distribution of the root systems. Oats have a relatively high moisture requirement early in the season and corn has the highest requirement for soil moisture in July and August. Browning's work reveals that the available moisture under each crop of a corn-oats-meadow rotation and under continuous bluegrass are about the same. Corn, oats, clover and bluegrass have different water requirements, and the moisture content under these crops would be different except that the high infiltration under clover and bluegrass offsets the higher losses that occur by transpiration under these crops.

McKibben, et al (28) report four seasons (1942-45 inclusive) study on the availability of soil moisture for forage production with and without irrigation, indicate that the soil moisture is approaching a critical low when 80 per cent of the available moisture has been removed. Irrigation should be started when the available soil moisture in the upper 12 inches of soil is reduced to about 35 per cent of the amount that the soil is capable of retaining at field capacity. Forage plants differ greatly in the depth from which they will extract water from the soil. Hagan and Peterson (17) reported on the moisture extraction of ladino clover, broadleaf trefoil, and alfalfa. They concluded that ladino clover extracted water the most rapidly in the top 2 feet of soil, and that the soil under ladino was first to reach the permanent wilting point for each depth. Broadleaf trefoil was intermediate and alfalfa mixtures the slowest in extracting water from the respective soils. Plantings containing the deeper-rooted legumes, (i.e. broadleaf trefoil and alfalfa), did not reduce the moisture to the wilting percentage for the surface two feet of soil within the sampling period of July, August and the first half of September. Within the third foot differences in extraction rate became small. In the fourth foot, extraction by trefoil plantings was faster and more complete than under ladino. In the fifth foot, extraction of water by trefoil continued but had nearly ceased under ladino. In the sixth foot, extraction by trefoil and alfalfa continued at about the same rate. In the seventh foot, alfalfa showed active extraction, but in the eighth foot extraction was slow. No water extraction by trefoil was recorded below six feet.

Kiesselbach, et al (24) reported on the planting of alfalfa, sweet clover, and red clover, seeded in soil that had not been cropped to alfalfa before, and that had a relatively abundant subsoil moisture. They stated that under sweet clover and red clover there was no significant moisture change below the sixth foot throughout a five-year period. In the sixth foot there was some depletion by sweet clover and slight restoration of moisture under red clover. Alfalfa, by contrast, had drawn heavily on the subsoil water to a depth of 15 feet by the end of the fourth year. Karraker and Bortner (23) reported that crops in Kentucky, grown on Maury silt loam, obtained water from the top 2 to 3 feet, because root penetration was negligible below this depth. In pot experiments with corn, 12 per cent of the water in the surface soil, and 23 to 24 per cent in the subsoil, was unavailable for the corn plants.

Painter and Leamer (30) conducted an experiment on Springer fine sandy loam in New Mexico to investigate the moisture requirements of Plainsmen grain sorghum. The roots of sorghum removed moisture to a depth of 57 inches on plots where there was a deficit of soil moisture with the greatest removal above 45 inches. On plots where there was a sufficient supply of available moisture, the sorghum plants removed moisture to a depth of 45 inches; the greatest removal was at about 21 inches.

Franzke and Hume (14) reported that soil moisture plays an important role in determining the level of hydrocyanic acid in sorghum plants. The level of hydrocyanic acid content in sorghum decreased as the moisture level of the soil increased. The greatest decrease in the hydrocyanic acid content of sorghum plants occurred where the increase in soil moisture and the application of manure were combined.

Hunter et al (21) report that the highest yields of turnips were produced in the greenhouse under conditions of low moisture tension and the lowest yields under high moisture tension. The effects of moisture tension on the ascorbic acid content of the fresh leaves, were opposite to the effects on yield. The higher percentage dry weight, higher ascorbic acid and higher carotene content, on the fresh weight basis, was found in plants grown under higher moisture tensions.

III. LOCATION AND DESCRIPTION OF AREAS STUDIED:

The soil moisture regime of cropping practices in an area is closely correlated with the physical features and climate of the region. During the course of his duties as Agricultural Research Officer in charge of District Experiment Substations in South-Western Manitoba, the author made a study of the physical features and climate of the Substations.

The three Substations selected for this study are located in the brown-black and black earth soil zones of South-Western Manitoba, and are shown on Map No. 4. They are situated on medium textured soil, thus making it possible to compare the soil moisture regime of the cropping practices under study on each station.

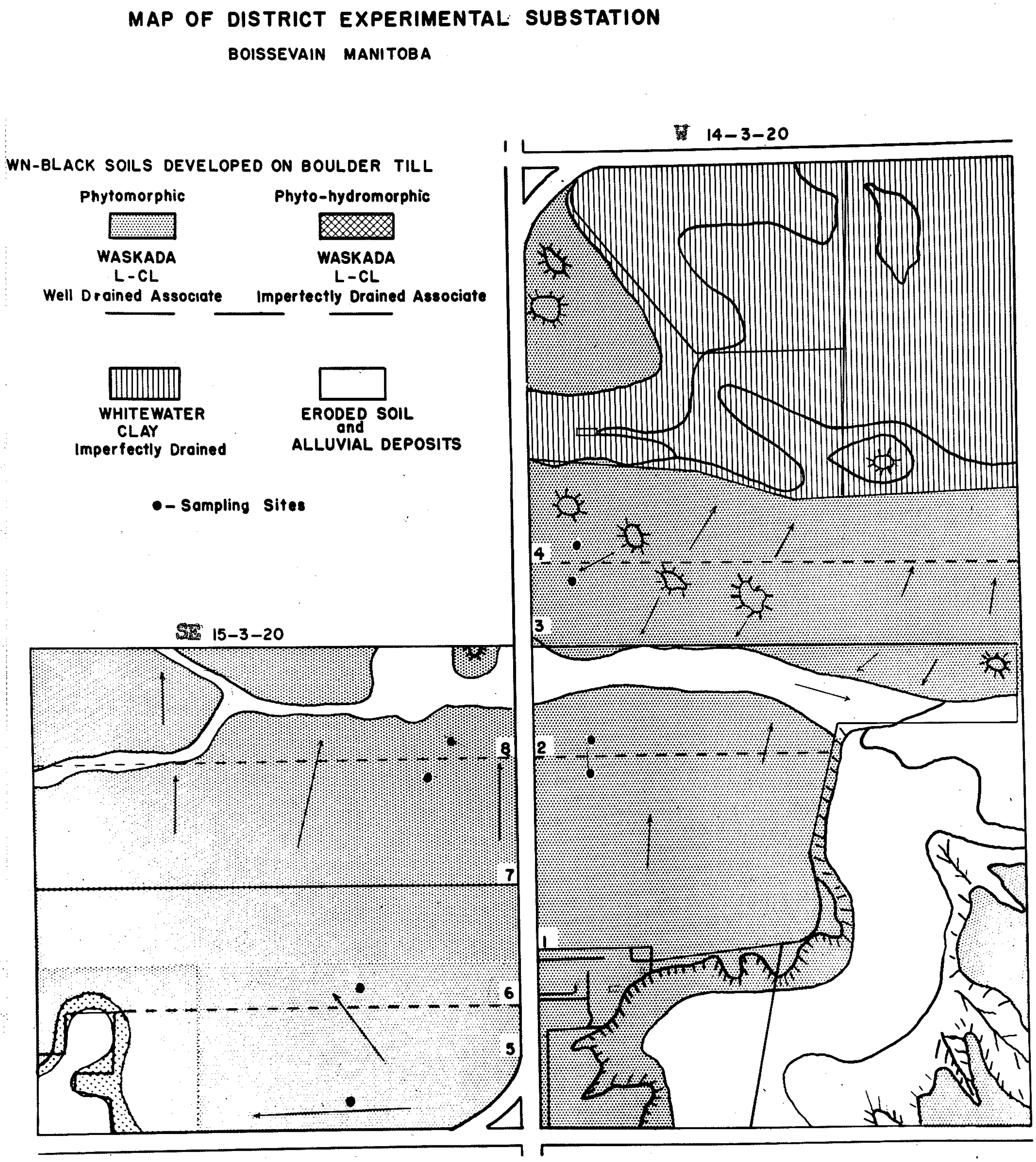
1. Description of Physical Features:

The Boissevain District Experiment Substation is located on the W$\frac{1}{2}$ of Section 14 and S.E. $\frac{1}{4}$ of Section 15 in Township 3, Range 20, West of the principal meridian as outlined on Map No. 1. It is irregular in its topographical features (32). The altitude of the land on the farm ranges from approximately 1750 feet above sea level at the building site to approximately 1700 feet in the ravine or depressed area at the foot of the slope on the north-west quarter of 14-3-20.

The land on the south half of the farm has a two to four degree slope to the north. On the southern portion of the north-west quarter of section 14, slopes are sharper and range up to nine per cent. In the north-eastern portion of this quarter section the area is comparatively level and is marked only by slight micro-relief. In the north-west corner of the same section there is a prominent knoll of boulder till capped with a mantle of sand and gravel.

The outstanding feature of the south-west quarter of Section 14 is a deep ravine and several tributary inlets. The ravine on the south side of the quarter has slopes of forty per cent or greater, and is approximately fifty feet deep. A small intermittent stream flows through this ravine in the spring season and during periods of high rainfall. In the northern portion of this section there is a depressional area which serves as a runway. Some sheet erosion has taken place from the surrounding slopes so

Map No. 1


MAP OF DISTRICT EXPERIMENTAL SUBSTATION
BOISSEVAIN MANITOBA
WN-BLACK SOILS DEVELOPED ON BOULDER TILL
Phytomorphic
Phyto-hydromorphic
WASKADA
L-CL
Well Drained Associate
WASKADA
L-CL
Imperfectly Drained Associate
WHITEWATER
CLAY
Imperfectly Drained
ERODED SOIL
and
ALLUVIAL DEPOSITS
● - Sampling Sites
W 14-3-20
SE 15-3-20
1
2
3
4
5
6
7
8

that the knolls are light in color, and the low-lying field is now covered by a fairly even distribution of surface materials deposited to a depth of 8 to 30 inches.

The south-east quarter of section 15 is more smooth in its topographical features than the other quarters. In the south-west corner of this quarter there is a poorly drained area which is part of the runway that turns and runs eastward across the northern portion of south-east 15-3-20. The prevailing geological surface material on this station is glacial till with thin alluvial and lacustrine sediments occurring over the till in low-lying areas.

The Goodlands District Experiment Substation is located on Section 15, Township 2, Range 24, West of the principal meridian. (See Map No. 2) It has a gently rolling topography with numerous small depressions that have slopes up to 6 per cent (12). It has an overall elevation of approximately 1625 feet above sea level. The southern part of the section contains a number of deep isolated basins, one of which is estimated to be 30 feet below the surrounding area. The northern part has depressional areas that are more shallow, and in many cases these are connected. In the centre of the section there is a shallow intermittent runway running from west to east that partly drains some areas during periods of excessive moisture.

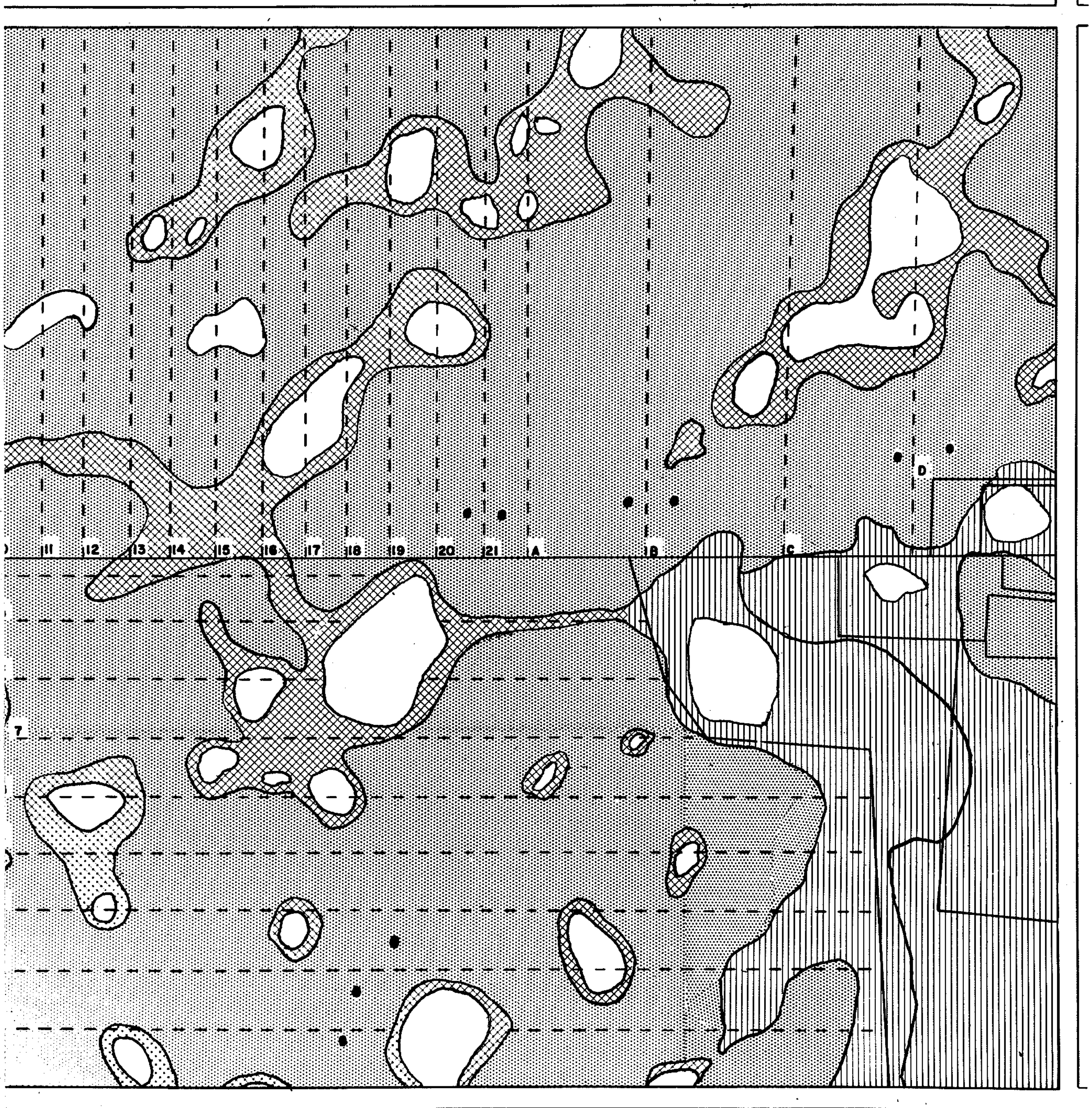
The prevailing geological surface deposit on this station is glacial drift. Approximately 100 acres in the eastern part of the south-east quarter is covered with a thin mantle of variable textured lacustrine material which is imperfectly to poorly drained, ranging from clay loam to clay, 15 to 40 inches thick.

The Hargrave District Experiment Substation is located on

Map No. 2

MAP OF DISTRICT EXPERIMENTAL SUBSTATION — GOODLANDS MANITOBA

15-2-24



SOILS DEVELOPED ON BOULDER TILL

WASKADA CLAY
Well Drained

WASKADA CLAY
Imperfectly Drained

WASKADA CLAY
Poorly Drained

• — Sampling Sites

— Imperfectly Drained Saline

Section 16, Township 11, Range 27, West of the principal meridian. (See Map No. 3) The topography is moderately undulating or irregular gently sloping in the western portion of the farm on Section 16, but becomes smoother in the eastern portion of Section 15 which has a slightly lower elevation (33). The station is situated approximately 1600 feet above sea level in the till plain area of the Western Upland region. The terrain is characterized by well drained ridges and knolls, gentle slopes and numerous small depressional areas which may be either aspen rimmed ponds or saline sloughs and swamps. Drainage on this station is localized and the runoff water from the ridges and knolls is caught in the sloughs, some of which are connected and partially drain in an easterly direction. Water collecting in the depressed areas percolates into the soil very slowly and much of the ponded water eventually evaporates leaving salt concentrations.

2. Climate:

Recorded weather data from 1911 to 1950 in the town of Boissevain located about two miles north-east of the station indicate a wide monthly range in rainfall. The seasonal precipitation from April to October has varied from 6.32 inches to 19.12 inches, indicating that periods of drought occur in this area of Manitoba.

Precipitation records have been kept on the Boissevain Substation since 1938 and are tabulated in Table No. 1. For the period of 1938 to 1953 inclusive the peak average rainfall was in June with an average of 3.78 inches. The mean monthly precipitation for the period of April to September inclusive for the years 1938 to 1953 inclusive was 2.27 inches.

Temperatures have been recorded on the Boissevain Substation since 1949. The annual mean temperature for the years 1949 to 1953 inclusive was 36.2 degrees Fahrenheit and the mean temperature for the summer

Map No. 3

MAP OF DISTRICT EXPERIMENTAL SUBSTATION
HARGRAVE MANITOBA
16-11-27

N

ACKEARTH SOILS DEVELOPED
ON BOULDER TILL

Phytomorphic

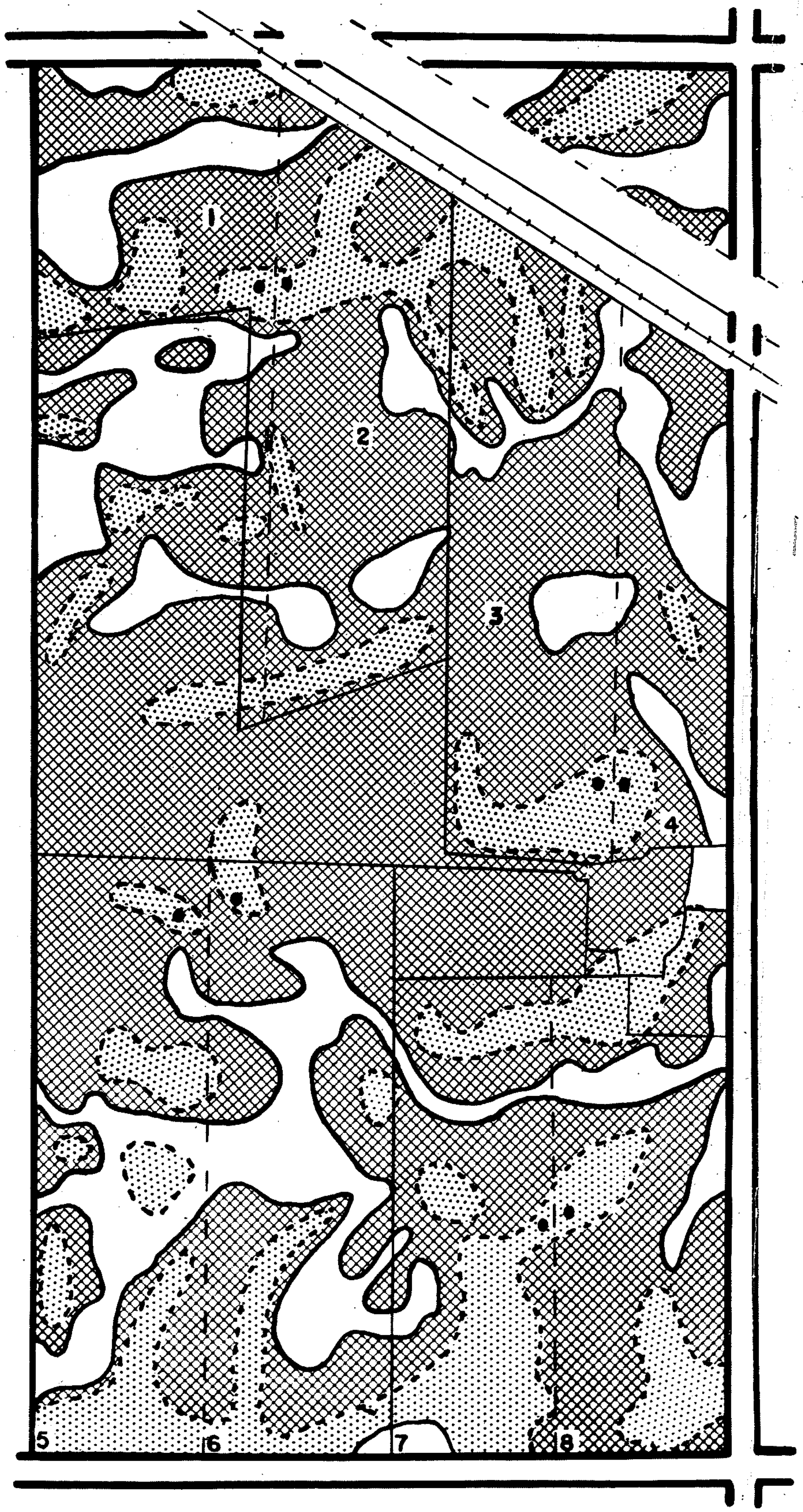
OXBOW
CL-HCL
Well Drained Associate

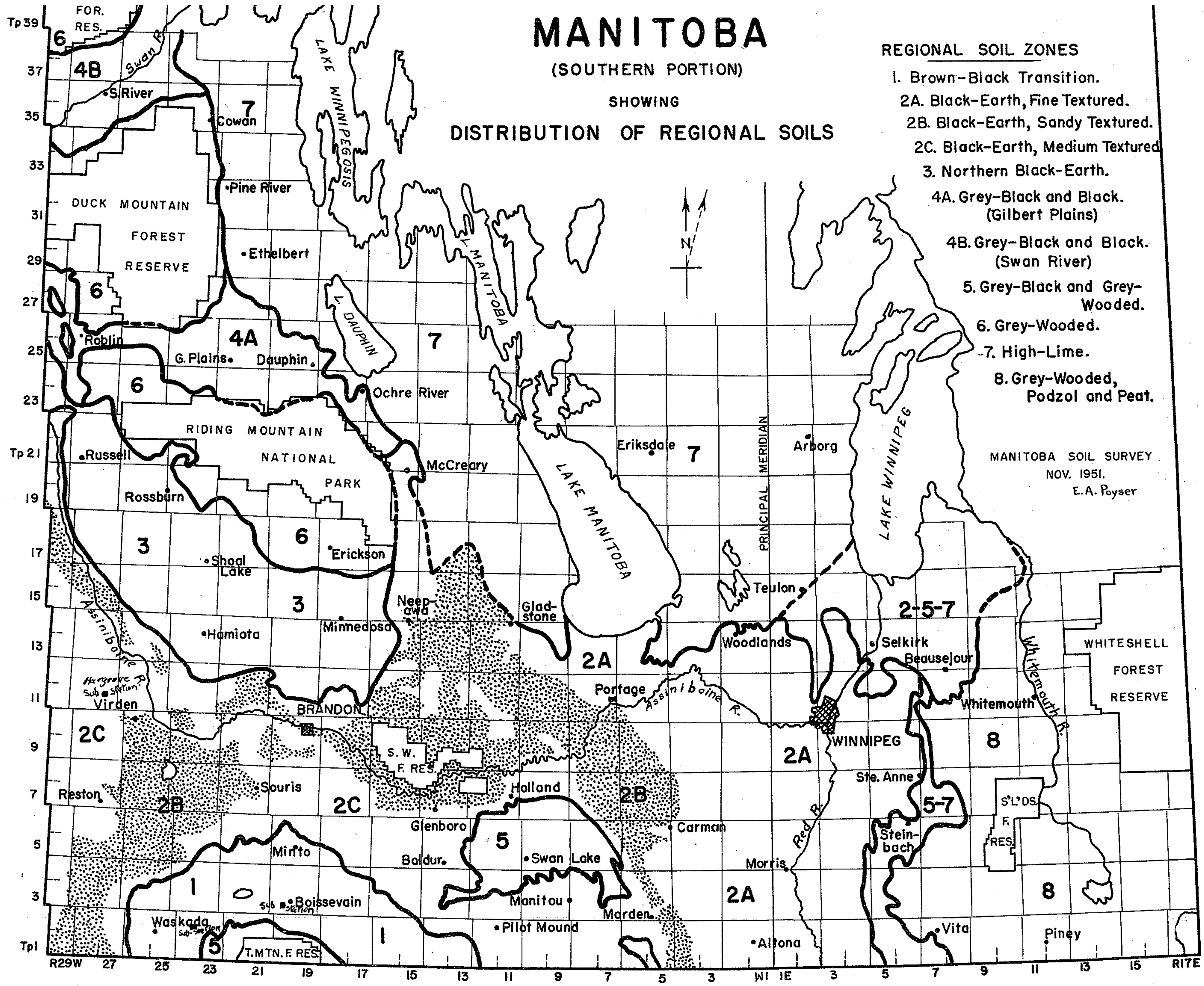
Phyto-hydromorphic

OXBOW
CL-HCL
mperfectly Drained Associate

Poorly Drained

•– Sampling Sites




MANITOBA
(SOUTHERN PORTION)
SHOWING
DISTRIBUTION OF REGIONAL SOILS
REGIONAL SOIL ZONES
1. Brown-Black Transition.
2A. Black-Earth, Fine Textured.
2B. Black-Earth, Sandy Textured.
2C. Black-Earth, Medium Textured
3. Northern Black-Earth.
4A. Grey-Black and Black. (Gilbert Plains)
4B. Grey-Black and Black. (Swan River)
5. Grey-Black and Grey-Wooded.
6. Grey-Wooded.
7. High-Lime.
8. Grey-Wooded, Podzol and Peat.
MANITOBA SOIL SURVEY
NOV. 1951.
E.A. Poyser
N
FOR. RES.
Swan R.
S. River
Cowan
LAKE WINNIPEGOSIS
Pine River
DUCK MOUNTAIN FOREST RESERVE
Ethelbert
L. DAUPHIN
L. MANITOBA
Roblin
G. Plains
Dauphin
Ochre River
RIDING MOUNTAIN NATIONAL PARK
Russell
Rossburn
McCreary
Eriksdale
LAKE MANITOBA
PRINCIPAL MERIDIAN
Arborg
LAKE WINNIPEG
Erickson
Shoal Lake
Neepawa
Gladstone
Teulon
Minnedosa
Hamiota
Assiniboine R.
Woodlands
Selkirk
Beausejour
WHITESHELL FOREST RESERVE
Whitemouth R.
Hargrave Sub-station
Virden
BRANDON
Portage
Assiniboine R.
WINNIPEG
Whitemouth
S.W. F. RES.
Holland
Ste. Anne
Reston
Souris
Glenboro
Carman
Red R.
S'L'DS. F. RES.
Steinbach
Minto
Baldur
Swan Lake
Morris
Boissevain
Sub-station
Manitou
Morden
Waskada
Sub-station
T. MTN. F. RES.
Pilot Mound
Altona
Vita
Piney
Tp 39
37
35
33
31
29
27
25
23
Tp 21
19
17
15
13
11
9
7
5
3
Tp1
R29W
27
25
23
21
19
17
15
13
11
9
7
5
3
W1 1E
3
5
7
9
11
13
15
R17E
6
4B
7
6
4A
7
6
3
6
3
7
2-5-7
2A
2C
2A
8
2B
2C
5
5-7
1
2A
8
1
5

- 28 -

Map No. 4

months of April to October was 53.9 degrees Fahrenheit for the same period. Temperature records have not been kept on the Goodlands and Hargrave Substations.

The record of precipitation for the Goodlands Substation is recorded in Table No. 2. Examination of the data for the years 1936 to 1953 indicates that the rainfall reaches its peak in June with an average of 3.55 inches for the period. This is slightly less than the average for the Boissevain Substation. The extreme high rainfall was recorded in 1937 when 6.31 inches fell in the month of July.

Precipitation records for the Hargrave Substation are tabulated in Table No. 3. The peak precipitation occurs in the month of June and the average for the period of 1940 to 1953 inclusive was 4.34 inches. An examination of the data indicates slightly more moist conditions in this part of the province. It is interesting to note the extremely high rainfall of 9.75 inches in June 1944 and 7.92 inches in July 1949. The rainfall picture for the south-western region of Manitoba is typical of a continental climate with the peak occurring in the month of June when the amount of solar radiation is at a maximum.

IV. INVESTIGATIONAL PROCEDURE:

1. Field Investigations:

The rotations outlined for the study of soil moisture in this thesis include two eight-year rotations on the Substations at Boissevain and Hargrave, and a two, three, and four-year rotation on the Substation at Goodlands. When designing a rotation for study on a farm or plot area, the land is divided into as many fields or plots, as there are years in the rotation. The following outline will indicate the cropping sequence of the rotations on District Experiment Substations where the soil moisture

Table No. 1

Precipitation Record (inches) for Boissevain District Experiment Substation.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	★ Total Annual Snow-fall.	Total Annual Rain-fall.	Total Annual Precip-itation.
1938	.01	.01	.67	.76	1.60	.98	2.26	2.19	-	1.04	1.19	1.14	20.3	9.82	11.85
1939	.80	1.55	.25	1.45	2.28	3.24	2.52	2.31	.77	.31	.11	.39	32.9	12.71	15.98
1940	.35	1.30	1.00	2.30	2.36	3.71	3.54	5.16	.95	1.13	.66	.60	59.0	17.16	23.06
1941	1.00	.45	1.50	2.67	5.23	3.00	1.01	2.95	5.47	1.59	1.46	.33	61.9	20.47	26.66
1942	.50	.55	2.85	1.02	1.98	1.08	3.26	3.17	1.67	.10	.81	1.40	60.5	12.34	18.39
1943	1.50	1.50	1.80	.68	2.65	3.99	2.73	4.63	.54	.81	.55	-	63.0	15.08	21.38
1944	.40	.60	1.80	.29	2.53	8.95	1.99	3.75	1.24	-	1.09	.60	40.00	19.24	23.24
1945	.73	1.00	3.42	1.91	1.97	3.53	1.68	2.94	1.25	.97	1.70	.75	52.8	16.57	21.85
1946	.95	.13	1.03	.50	.55	2.18	2.15	2.60	1.20	2.85	1.15	.40	57.0	9.99	15.69
1947	1.00	2.87	.90	.43	.65	7.72	.76	3.87	.84	.43	.82	2.50	84.0	14.39	22.79
1948	1.35	.95	.85	2.78	2.81	2.57	4.99	2.56	.04	1.20	2.32	3.48	86.0	17.30	25.90
1949	2.55	.55	1.25	2.29	1.28	3.46	2.78	.69	1.22	2.84	.79	1.30	67.5	14.25	21.00
1950	2.03	.35	.65	1.85	4.04	4.64	2.14	1.06	1.97	.49	.84	1.53	104.5	11.14	21.59
1951	1.05	1.12	1.40	.86	.44	3.14	1.30	3.77	1.81	1.33	.90	.35	65.4	10.93	17.47
1952	1.32	-	.28	-	.34	4.25	2.50	2.25	.23	.05	.57	.05	19.0	9.94	11.84
1953	.65	.71	2.52	1.13	3.87	3.99	1.12	1.16	1.01	.47	.02	.74	56.5	11.74	17.39
Average	1.01	.85	1.38	1.31	2.16	3.78	2.30	2.82	1.26	0.98	0.94	0.97	58.13	13.94	19.76
EXTREMES.															
Low	.01	.00	.25	.00	.34	.98	.76	.69	.00	.00	.02	.00	20.3		
Year	1938	1952	1939	1952	1952	1938	1947	1949	1938	1944	1953	1943	1938		
High	2.55	2.87	3.42	2.78	5.23	8.95	4.99	5.16	5.47	2.85	2.32	3.48	104.5		
Year	1949	1947	1945	1948	1941	1944	1948	1940	1941	1946	1948	1948	1950		

★ Ten inches snow is equal to one inch of precipitation.

Table No. 2

Precipitation Record (inches) for Goodlands District Experiment Substation.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	* Total Annual Snow-fall.	Total Annual Rain-fall.	Total Annual Precip-itation.
1936	1.70	.20	2.60	.08	.87	2.03	.27	1.27	1.65	.49	.25	1.40	61.0	6.72	12.82
1937	1.10	.50	.40	1.73	2.74	5.75	6.31	.25	1.56	1.70	.90	.30	32.0	20.04	23.24
1938	.60	1.25	.78	.59	1.17	1.20	3.26	1.55	-	1.09	1.40	1.00	37.5	10.14	13.89
1939	.70	.75	.56	1.01	2.59	3.51	3.36	2.46	.72	.45	.07	.40	25.2	14.07	16.59
1940	.30	1.75	.50	1.87	2.68	3.13	5.67	4.51	.56	.61	.95	.52	58.4	17.21	23.05
1941	.52	.55	1.65	2.13	2.69	3.45	1.30	4.17	4.20	1.46	1.07	.64	55.7	18.26	23.83
1942	.35	.30	3.74	1.06	1.46	2.42	3.36	2.82	.66	.17	.81	1.37	63.3	12.19	18.52
1943	1.50	1.60	1.85	.49	1.45	4.28	3.08	2.33	.63	.03	.65	.15	60.3	12.02	18.05
1944	.50	.65	2.40	.76	2.53	8.19	2.38	4.91	1.74	-	.97	.35	46.0	20.78	25.38
1945	.93	.60	2.89	1.24	1.03	3.72	2.69	2.29	1.00	.98	1.70	.30	48.8	14.49	19.37
1946	.80	.90	.25	.07	1.32	1.65	1.95	1.58	.82	1.25	.90	.36	43.0	7.55	11.85
1947	.80	1.40	.50	.74	1.03	4.25	3.41	2.91	.92	.40	.40	1.10	43.8	13.48	17.86
1948	.75	.85	.60	3.09	2.39	1.66	4.88	1.00	-	1.25	1.00	2.50	65.0	13.47	19.97
1949	1.95	1.40	1.00	.75	1.15	4.77	3.74	.45	.84	1.60	.85	1.15	66.0	13.05	19.65
1950	1.15	.60	.25	1.50	2.10	5.00	2.19	2.46	2.56	.47	.45	.85	58.0	13.78	19.58
1951	.70	.88	1.10	.43	.68	2.09	2.60	4.70	1.88	1.01	.55	.80	45.4	12.88	17.42
1952	1.10	-	.20	-	.40	2.60	1.74	1.05	.04	-	.18	-	13.1	6.00	7.31
1953	.70	.40	1.15	.76	3.85	4.23	1.83	.70	.30	1.56	.55	.16	30.6	13.13	16.19
Average	.90	.81	1.24	1.01	1.78	3.55	3.00	2.30	1.12	.81	.76	.74	47.4	13.29	18.03
EXTREMES.															
Low	.30	-	.20	-	.40	1.20	.27	.25	-	-	.07	-			
Year	1940	1952	1952	1952	1952	1938	1936	1937	'38'48	'44'52	1939	1952			
High	1.95	1.75	3.74	3.09	3.85	5.75	6.31	4.91	4.20	1.70	1.70	2.50			
Year	1949	1940	1942	1938	1953	1937	1937	1944	1941	1937	1945	1948			

* Ten inches snow is equal to one inch of precipitation.

Table No. 3

Precipitation Record (inches) for Hargrave District Experiment Substation.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	✱ Total Annual Snow-fall.	Total Annual Rain-fall.	Total Annual Precip-itation.
1940	.20	.90	.85	1.00	1.99	2.58	1.65	3.15	.54	1.25	.90	1.10	52.0	10.91	16.11
1941	.90	.50	1.00	3.06	1.74	2.65	4.49	1.37	3.74	.61	1.30	-	48.5	16.51	21.36
1942	.40	.60	3.00	1.00	3.12	2.73	1.72	4.86	.77	-	.50	1.50	60.0	14.20	20.20
1943	1.00	.20	.10	.13	3.65	3.51	1.24	.81	.37	.54	.40	-	26.0	9.35	11.95
1944	.22	.60	1.10	1.28	1.86	9.75	1.32	3.29	.89	-	.20	.33	24.0	18.44	20.84
1945	1.20	.45	2.18	1.89	.70	2.77	.54	1.20	2.36	.77	.80	.90	46.0	11.16	15.76
1946	.90	2.10	.90	.38	1.52	2.61	4.36	2.61	1.73	2.00	.70	.80	79.0	12.71	20.61
1947	.32	2.00	.80	.56	.90	8.29	.36	3.80	1.54	.24	.80	1.30	56.2	15.29	20.91
1948	1.00	1.60	1.00	2.09	3.16	3.10	4.57	2.57	-	.94	1.70	3.60	97.0	15.63	25.33
1949	.10	.60	1.40	-	3.80	4.95	7.92	1.31	.76	.67	.40	1.50	45.0	18.91	23.41
1950	.10	.20	.50	.40	3.40	5.73	5.11	3.65	1.70	.66	.10	.40	58.0	16.15	21.95
1951	.70	1.20	1.70	.57	1.60	1.97	.97	2.21	1.87	1.29	.70	.30	57.0	9.38	15.08
1952	1.30	-	.20	.20	.25	5.19	1.28	5.55	.35	-	.20	.30	22.0	12.62	14.82
1953	1.30	.80	3.30	.76	2.36	4.97	1.42	.36	1.30	1.16	.30	.60	69.0	11.73	18.63
Average	.69	.84	1.29	.95	2.15	4.34	2.64	2.62	1.28	.72	.64	.90	52.8	13.78	19.06
EXTREMES.															
Low	.10	0.00	.10	.00	.70	1.97	.54	.36	.00	0.00	.10	.00			
Year	'49'50	1952	1943	1949	1945	1951	1945	1953	1948	1942,'44,'52	1950	1941'43			
High	1.30	2.10	3.30	3.06	3.80	9.75	7.92	5.55	3.74	2.00	1.70	3.60			
Year	'52'53	1946	1953	1941	1949	1944	1949	1952	1941	1946	1948	1948			

✱ Ten inches snow is equal to one inch of precipitation.

investigations were conducted.

Boissevain - Eight Year Mixed-Farming Rotation.

Rotation Year 1	Fallow	Field 3
Rotation Year 2	Wheat on Fallow	Field 7
Rotation Year 3	Oats, Seed Alfalfa and Brome	Field 1
Rotation Year 4	Hay, First Year	Field 5
Rotation Year 5	Pasture	Field 4
Rotation Year 6	Sod-breaking	Field 8
Rotation Year 7	Wheat on Breaking	Field 2
Rotation Year 8	Wheat, second crop after break	Field 6

The field plan for the Boissevain District Experiment Substation is outlined on Map 1.

Goodlands - Two Year Grain Rotation.

Rotation Year 1	Fallow	Field 20
Rotation Year 2	Wheat on Fallow	Field 21

- Three Year Grain Rotation.

Rotation Year 1	Fallow	Field 2
Rotation Year 2	Wheat on Fallow	Field 3
Rotation Year 3	Wheat on Second Crop	Field 1

- Four Year Mixed-Farming Rotation.

Rotation Year 1	Fallow	Field D
Rotation Year 2	Wheat on Fallow, seed clover and brome	Field B
Rotation Year 3	Clover Hay and Break	Field C
Rotation Year 4	Barley after Hay and Breaking	Field A

The field plan for the Goodlands District Experiment Substation is outlined on Map 2.

Hargrave - Eight Year Mixed-Farming Rotation.

Rotation Year 1	Fallow	Field 1
Rotation Year 2	Wheat on Fallow	Field 7
Rotation Year 3	Barley seed, alfalfa and brome	Field 6
Rotation Year 4	Hay, First Year	Field 3
Rotation Year 5	Pasture	Field 2
Rotation Year 6	Sod-breaking	Field 8
Rotation Year 7	Wheat on Sod-breaking	Field 5
Rotation Year 8	Oats	Field 4

The field plan for the Hargrave District Experiment Substation is outlined on Map 3.

The sampling sites for soil moisture samples are shown on the soil map of each Substation (see maps 1, 2, 3). These sites were chosen on the well-drained soil associate, characteristic of the Substation area.

A composite of five soil moisture samples were taken at 0-12, 13-24, 25-36, and 37-48 inches in depth at each sampling site by means of a four-inch post hole auger. Two sets of samples were taken; one in the spring before any appreciable growth had started, and the second set early in the fall after harvest. Each sample of 300 to 400 grams of moist soil was placed in a rubber-sealed "Gem" pint-size fruit jar to prevent loss of moisture. After all samples were taken in the field, percentage moisture determinations on a dry-weight basis were made at the Experimental Farm at Brandon.

In order to calculate the amount of water in inches to a depth of four feet, the volume weight of the soil for each station was calculated. Samples were taken using a square sampling tube 4 inches by 4 inches by 6 inches deep. The percentage moisture on a dry weight basis was calculated and the volume weights determined.

2. <u>Laboratory Investigations</u>:

A. <u>Total Moisture Percentage</u>:

The "sealed" soil samples were brought into the laboratory at Brandon where all weights were recorded in grams using a "Toledo" counter-type scale. The samples were dried at a temperature of 105 degrees Centigrade to 110 degrees Centigrade for a 48-hour period. Checks were made and at no instance was there found to be any change in weight after drying for this period. All samples were allowed to cool before recording the final weight from which the percentage moisture was calculated on a dry weight basis.

B. Moisture Equivalent:

Moisture equivalent determinations were made on each sample using the method by Briggs and McLane (4). The calculations were made at the Soils Department of the University of Manitoba as no soil centrifuge was available at Brandon.

C. Relative Moisture:

Relative moisture calculations were determined to express the soil moisture present in a sample as a percentage of the moisture equivalent. This method was used by Conrad (9) to minimize error that would occur in results due to variations in soil texture. This method was particularly valuable in this study where there were differences in soil texture as indicated by variations in the moisture equivalent. The Tukey method (39) was used to determine significance among the relative moisture groups, and found to be a very convenient way of separating several values into groups where there was no significance within any one, but significance among the groups.

V. RESULTS AND DISCUSSION OF RESULTS:

There was considerable variation in the percentage of total moisture from field to field and from depth to depth. In grain fields the total moisture percentage was greater in the first foot in the spring than in depths deeper in the profile. In the fall there was a reduction in moisture throughout the four foot depth in the grain fields but an increase in the case of fallow fields. The term "total moisture percentage" has little significance unless it is expressed in relation to the moisture equivalent which is an expression of field capacity for medium-textured soils. The total moisture, moisture equivalent, relative moisture, and calculated hygroscopic coefficient results are recorded in Table Number 4 for fields sampled on the Boissevain District Experiment Substation. The moisture equivalent values obtained for the Boissevain Substation indicate that there is some variation in texture in the respective fields and depths. Examination of the data shows that the values are near the value 21 which is a close estimation of the field capacity. Before the eight-year cropping system was established on the Boissevain Substation moderate soil erosion by wind and water had occurred. This would explain some of the variation in the moisture equivalent results obtained.

The relative soil moisture data for fields studied on the Boissevain Substation are recorded in Table No. 5, and the relative moisture groups as determined by the Tukey (39) method are also recorded in this table. The data in Table No. 5 was analyzed statistically and the resulting analysis of variance is recorded in Table No. 6. The results of grouping the mean relative moisture percentages by using the Tukey method are recorded in Table No. 7.

The analysis of variance of the Boissevain relative soil moisture results as outlined in Table Number 6, indicates significance at the one per cent level for the main effects of fields, depths and samples. All second order interactions are significant at the one per cent level. The minimum significant difference of 8.48 per cent is required to separate the mean relative moisture percentages into groups. The results of grouping the means as tabulated in Table Number 7, indicate that group 4 contains the greater number of values ranging from 56.14 per cent to 43.60 per cent. Fields having moisture values in this range were deficient in moisture to the point where plants were unable to maintain turgidity. Relative moisture groups 1, 2 and 3 had sufficient moisture to keep the crop from wilting, and each group was significant from the one above in the order 1 (wet), 2 (moist),

Table No. 4

PERCENT SOIL MOISTURE, MOISTURE EQUIVALENT, RELATIVE MOISTURE AND CALCULATED HYGROSCOPIC COEFFICIENT FOR FIELDS SAMPLED ON BOISSEVAIN DISTRICT EXPERIMENT SUBSTATION.

Field and Depth in Inches	Total Moisture Percent		Moisture Equivalent Percent		Relative Moisture Percent		Calculated Hygroscopic Coefficient	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
No. 1								
0-12 Inches	17.68	12.44	19.18	19.93	92.18	62.42	7.09	7.37
13-24 "	8.44	9.38	17.65	18.90	47.82	49.63	6.53	6.99
25-36 "	7.86	8.58	17.83	16.61	44.08	51.66	6.60	6.14
37-48 "	7.08	11.63	17.50	22.65	40.46	51.35	6.48	8.38
No. 2								
0-12 Inches	24.93	9.43	23.55	21.22	105.86	44.44	8.71	7.85
13-24 "	19.20	6.55	26.58	14.80	72.23	44.26	9.83	5.48
25-36 "	15.30	8.82	22.68	21.49	67.46	41.04	8.39	7.95
37-48 "	16.38	11.72	23.02	22.76	71.16	51.49	8.52	8.42
No. 3								
0-12 Inches	23.40	16.34	20.39	19.08	114.76	85.64	7.54	7.06
13-24 "	16.44	20.05	19.09	21.73	86.12	92.27	7.06	8.04
25-36 "	10.39	12.90	17.38	15.44	59.78	83.55	6.43	5.71
37-48 "	8.26	10.42	15.81	9.89	52.24	105.36	5.85	3.65
No. 4								
0-12 Inches	21.05	10.48	21.36	20.48	98.55	51.17	7.90	7.58
13-24 "	13.43	8.57	23.67	20.16	56.74	42.51	8.76	7.46
25-36 "	12.46	8.18	24.37	20.34	51.13	40.22	9.02	7.53
37-48 "	13.21	7.52	28.24	18.57	46.78	40.50	10.45	6.87

Continued.

Table No. 4 - Cont'd.

..........Boissevain

Field and Depth in	Total Moisture Percent		Moisture Equivalent Percent		Relative Moisture Percent		Calculated Hygroscopic Coefficient	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
No. 5								
0-12 Inches	19.21	10.32	24.82	22.09	77.40	46.72	9.18	8.17
13-24 "	12.24	10.03	21.90	21.28	55.89	47.13	8.10	7.87
25-36 "	9.04	8.54	23.96	17.95	37.73	47.58	8.86	6.64
37-48 "	9.02	9.49	22.92	19.18	39.35	49.48	8.48	7.10
No. 6								
0-12 Inches	19.28	11.49	22.62	23.20	85.23	49.53	8.37	8.58
13-24 "	9.09	8.78	20.92	22.39	43.45	39.21	7.74	8.28
25-36 "	8.19	8.27	18.10	20.32	45.25	40.70	6.70	7.52
37-48 "	6.91	7.15	14.70	16.92	47.01	52.26	5.44	6.26
No. 7								
0-12 Inches	28.06	14.18	25.39	21.99	110.52	64.48	9.39	8.14
13-24 "	20.22	13.48	25.05	26.18	80.72	51.49	9.27	9.69
25-36 "	18.48	12.35	23.19	20.61	79.69	59.92	8.58	7.63
37-48 "	17.40	13.78	23.05	17.30	75.49	79.65	8.53	6.40
No. 8								
0-12 Inches	18.07	16.86	17.03	20.13	106.11	83.76	6.30	7.45
13-24 "	15.88	13.14	24.62	14.28	64.50	92.01	9.11	5.28
25-36 "	12.25	10.88	22.05	13.09	55.56	83.12	8.16	4.84
37-48 "	11.91	10.65	22.32	13.19	53.36	80.74	8.26	4.88

Table No. 5

RELATIVE SOIL MOISTURE:
BOISSEVAIN DISTRICT EXPERIMENT SUBSTATION

Rotation Year	Crop and Field No.	Time of Sampling	Relative Moisture in Per Cent Depth 0-12 ins.	Depth 13-24 ins.	Depth 25-36 ins.	Depth 37-48 ins.	Total	Mean Relative Moisture Per Cent	Relative Moisture Group
1	Fallow (3)	Spring	114.76	86.12	59.78	52.24	312.90	78.22	2
		Fall	85.64	92.77	83.55	105.36	367.32	91.83	1
2	Wheat on Fallow (7)	Spring	110.52	80.72	79.69	75.49	346.42	86.60	2
		Fall	64.48	51.49	59.92	79.65	255.54	63.88	3
3	Oats on Second Crop (1)	Spring	92.18	47.82	44.08	40.46	224.54	56.14	4
		Fall	62.42	49.63	51.66	51.35	215.06	53.76	4
4	Hay First Year (5)	Spring	77.40	55.89	37.73	39.35	210.37	52.59	4
		Fall	46.72	47.13	47.58	49.48	190.91	47.73	4
5	Pasture (4)	Spring	98.55	56.74	51.13	46.78	253.20	63.30	3
		Fall	51.17	42.51	40.22	40.50	174.40	43.60	4
6	Sod-breaking (8)	Spring	106.11	64.50	55.56	53.36	279.53	69.88	3
		Fall	83.76	92.01	83.12	80.74	339.63	84.91	2
7	Wheat on Breaking (2)	Spring	105.86	72.33	67.46	71.16	316.81	79.20	2
		Fall	44.44	44.26	41.04	51.49	181.23	45.31	4
8	Wheat on Second Crop (6)	Spring	85.23	43.45	45.25	47.01	220.94	55.24	4
		Fall	49.52	39.21	40.70	52.26	181.69	45.42	4

Table No. 6

ANALYSIS OF VARIANCE OF DATA IN TABLE NO. 5.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F-Value
Fields (F)	7	10571.68	1510.24	45.31 xx
Depths (D)	3	5876.89	1958.96	58.77 xx
Samplings (S)	1	1047.58	1047.58	31.43 xx
F X D	21	966.66	46.03	1.38
F X S	7	4131.58	590.22	17.71 xx
D X S	3	5271.94	1757.31	52.72 xx
F X D X S	21	699.84	33.33	
TOTAL	63	28566.17		

xx - Significant at one per cent level.

Table No. 7

GROUPING OF MEAN RELATIVE MOISTURE
PERCENTAGES BY TUKEY METHOD.

Group 1	Group 2	Group 3	Group 4
91.83	86.60	69.88	56.14
	84.91	63.88	55.24
	79.20	63.30	53.76
	78.22		52.59
			47.73
			45.42
			45.31
			43.60

and 3 (dry).

The mean relative soil moisture in the fallow field (No. 3) was significantly greater in the fall than in the spring and was significantly greater in moisture content than all other fields. The storage of moisture in the sod-breaking field (No. 8) was significantly less than the amount stored in the fallow field. It was of interest to note that the relative soil moisture group for wheat on breaking (No. 2) was the same in the spring as the relative soil moisture group of sod-breaking field (No. 8) in the fall. In other words, sufficient moisture was stored in the sod-breaking to provide for an average yield of wheat the following year. The results indicated that grain grown on second crop after sod-breaking (No. 6) may be deficit in moisture if a season has below average rainfall. Wheat on fallow (No. 7) reduced the stored moisture from the top of relative moisture group 2 to group 3. Mean relative moisture percentages falling in group 3 were approaching the wilting point and must rely upon rainfall the following year to produce a crop. The soil moisture in the pasture field (No. 4) was significantly greater in the spring than in the fall. Alfalfa and brome grass depleted the moisture to a depth of more than four feet in this field. Fields under alfalfa and brome should be broken early in the season to ensure a good storage of moisture to depth of more than four feet. The relative soil moisture is represented graphically in Figures Number 1 to Number 3, inclusive.

It is significant to note that the per cent relative moisture in the soil at the time of the fall sampling (September 11) was below the wilting point in field 1 which was second crop oats after fallow; in field 2, wheat on breaking; in field 4, pasture; in field 5, hay, and in field 6, wheat on second crop after breaking. This would indicate that the crops in

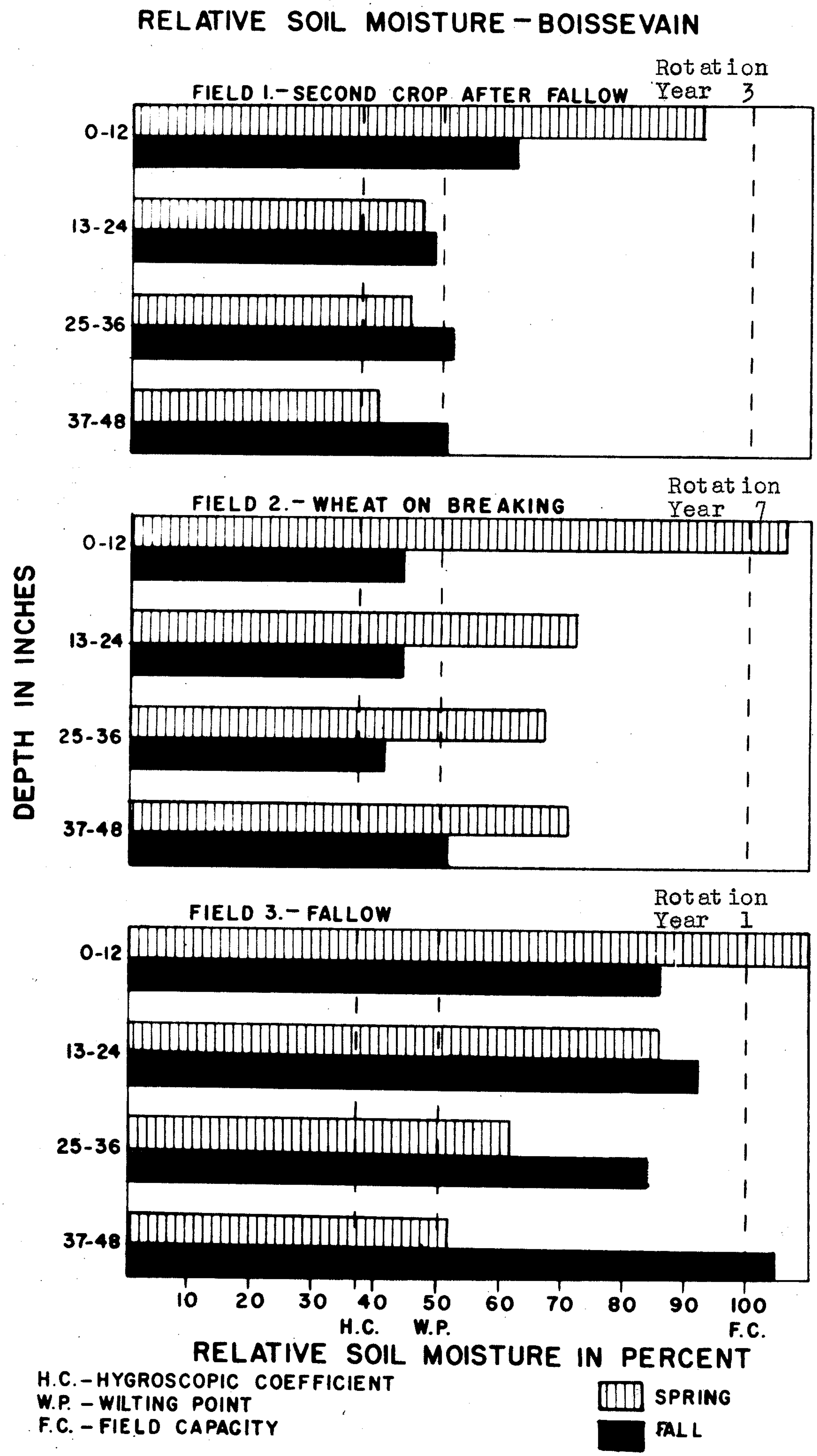

RELATIVE SOIL MOISTURE - BOISSEVAIN
FIELD 1.- SECOND CROP AFTER FALLOW
Rotation Year 3
FIELD 2.- WHEAT ON BREAKING
Rotation Year 7
FIELD 3.- FALLOW
Rotation Year 1
DEPTH IN INCHES
0-12
13-24
25-36
37-48
10
20
30
40
50
60
70
80
90
100
H.C.
W.P.
F.C.
RELATIVE SOIL MOISTURE IN PERCENT
H.C. - HYGROSCOPIC COEFFICIENT
W.P. - WILTING POINT
F.C. - FIELD CAPACITY
SPRING
FALL

Figure No.1

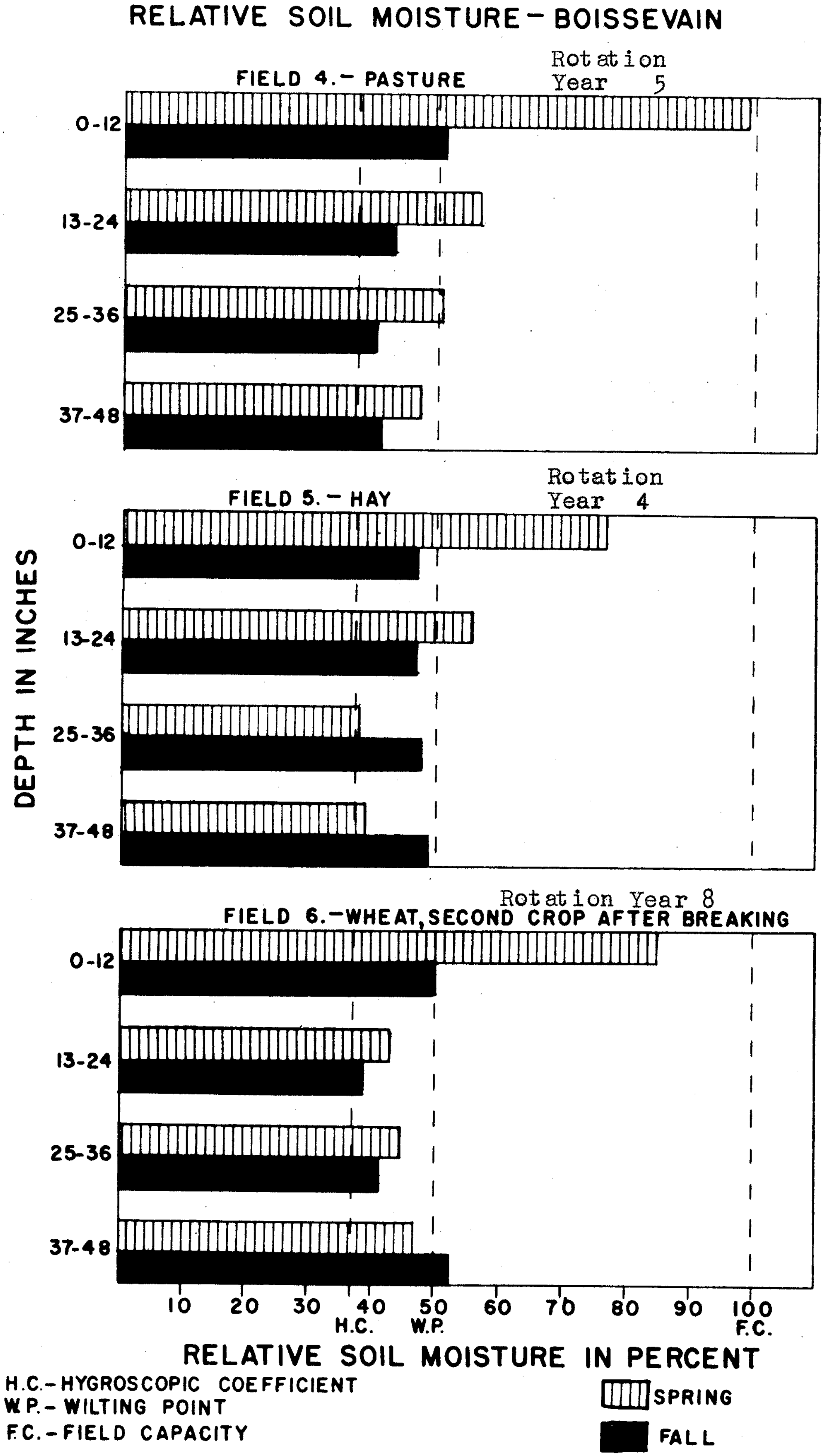
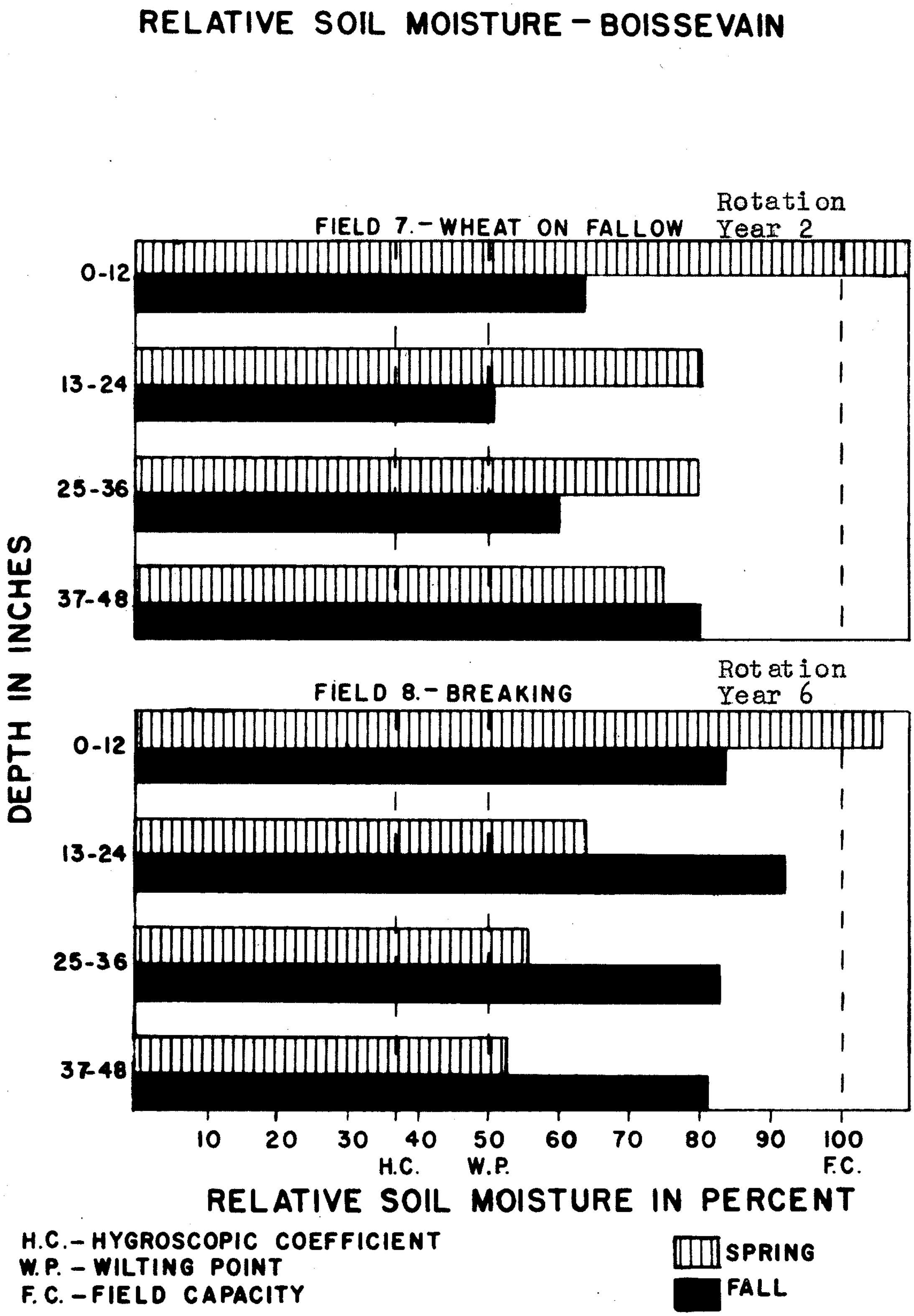

RELATIVE SOIL MOISTURE - BOISSEVAIN
FIELD 4. - PASTURE
Rotation Year 5
FIELD 5. - HAY
Rotation Year 4
FIELD 6. - WHEAT, SECOND CROP AFTER BREAKING
Rotation Year 8
DEPTH IN INCHES
0-12
13-24
25-36
37-48
10
20
30
40
50
60
70
80
90
100
H.C.
W.P.
F.C.
RELATIVE SOIL MOISTURE IN PERCENT
H.C. - HYGROSCOPIC COEFFICIENT
W.P. - WILTING POINT
F.C. - FIELD CAPACITY
SPRING
FALL

Figure No.2



RELATIVE SOIL MOISTURE - BOISSEVAIN
FIELD 7.- WHEAT ON FALLOW
Rotation Year 2
FIELD 8.- BREAKING
Rotation Year 6
DEPTH IN INCHES
0-12
13-24
25-36
37-48
10
20
30
40
50
60
70
80
90
100
H.C.
W.P.
F.C.
RELATIVE SOIL MOISTURE IN PERCENT
H.C.- HYGROSCOPIC COEFFICIENT
W.P. - WILTING POINT
F.C. - FIELD CAPACITY
SPRING
FALL

Figure No. 3

the above fields were able to utilize the soil moisture below the wilting point.

The total moisture percentage, moisture equivalent percentage, relative moisture percentage, and the calculated hygroscopic coefficient data are recorded in Table No. 8 for fields sampled on the Goodlands District Experiment Substation. The total moisture percentage values are variable, but the moisture equivalent figures are more uniform indicating a soil with greater uniformity and texture. The relative soil moisture percentage figures are recorded in Table No. 9. The relative moisture groups are also recorded in this table. The data in Table No. 9 was analyzed statistically and the resulting analysis of variance is recorded in Table No. 10. The grouped mean relative moisture percentages are recorded in Table No. 11.

The analysis of variance of the relative soil moisture results at Goodlands is found in Table No. 10. The main field effect is significant at the five per cent level and the main effects due to depths and samples are significant at the one per cent level. Second order interactions of fields x samples, and depths x samples, are significant at the one per cent level. The field x depth interaction is not significant. The minimum significant difference required to separate the mean relative soil moisture values in groups is 14.20 per cent. Table No. 12 gives the results of grouping the mean relative moisture percentages. The greatest number of means fall in group 2 having a range of relative moisture from 90.58 per cent to 66.26 per cent. Group 3 contains relative moisture values ranging from 60.90 per cent to 50.02 per cent. One value is found in each of groups 1 and 4.

In the two-year fallow, wheat rotation at Goodlands all mean relative moisture values occur in groups 2 and 3. In case of the fallow

Table No. 8

PERCENT SOIL MOISTURE, MOISTURE EQUIVALENT, RELATIVE MOISTURE AND CALCULATED HYGROSCOPIC COEFFICIENT FOR FIELDS SAMPLED ON GOODLANDS DISTRICT EXPERIMENT SUBSTATION.

Field and Depth in Inches	Total Moisture Percent		Moisture Equivalent Percent		Relative Moisture Percent		Calculated Hygroscopic Coefficient	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
No. 20								
0-12 Inches	18.05	18.64	21.83	21.59	82.68	86.34	8.08	7.99
13-24 "	11.71	12.97	22.95	21.05	51.02	61.62	8.49	7.79
25-36 "	12.46	19.45	23.22	20.89	53.56	93.11	8.59	7.73
37-48 "	13.06	16.27	23.23	21.74	56.22	74.84	8.60	8.04
No. 21								
0-12 Inches	22.81	9.54	20.95	22.32	108.88	42.74	7.75	8.26
13-24 "	19.62	11.24	23.37	28.80	83.95	39.03	8.65	10.66
25-36 "	19.34	15.57	22.64	27.40	85.42	56.82	8.38	10.14
37-48 "	18.34	14.54	21.82	23.65	84.05	61.48	8.07	8.75
No. 1								
0-12 Inches	30.56	11.41	24.57	23.38	124.38	48.80	9.09	8.65
13-24 "	16.57	14.46	24.25	23.39	68.33	61.82	8.97	8.65
25-36 "	16.50	19.21	21.96	24.28	75.14	79.12	8.12	8.98
37-48 "	16.19	19.29	22.43	23.57	72.18	81.84	8.30	8.72
No. 2								
0-12 Inches	19.24	19.83	21.86	21.02	88.01	94.34	8.09	7.78
13-24 "	12.50	20.45	22.95	22.02	50.47	92.87	8.49	8.15
25-36 "	13.90	17.14	22.90	19.98	60.70	85.78	8.47	7.39
37-48 "	15.42	15.93	22.78	18.35	67.69	86.81	8.43	6.79

Continued.

Table No. 8 - Cont'd.

..........Goodlands

Field and Depth in Inches	Total Moisture Percent		Moisture Equivalent Percent		Relative Moisture Percent		Calculated Hygroscopic Coefficient	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
No. 3								
0-12 Inches	21.95	8.43	25.84	22.72	84.94	37.10	9.56	8.41
13-24 "	19.67	8.20	23.11	20.64	85.11	39.73	8.55	7.64
25-36 "	17.83	11.06	24.45	18.08	83.12	61.17	7.94	6.69
37-48 "	18.00	14.46	22.32	20.99	80.64	68.89	8.26	7.77
Field A								
0-12 Inches	12.45	11.04	23.51	21.78	104.00	50.69	8.70	8.06
13-24 "	17.40	6.15	22.72	15.89	76.58	38.70	8.41	5.88
25-36 "	16.56	9.31	21.32	21.25	77.67	43.81	7.89	7.86
37-48 "	15.59	11.09	22.33	18.25	69.82	60.77	8.26	6.75
Field B								
0-12 Inches	22.71	10.26	21.25	20.41	106.87	50.27	7.86	7.55
13-24 "	24.04	9.39	23.79	27.16	101.05	34.57	8.80	9.05
25-36 "	27.48	11.11	25.45	17.74	107.98	62.63	9.42	6.56
37-48 "	26.12	12.44	23.60	16.84	110.68	73.87	8.73	6.23
Field C								
0-12 Inches	16.58	11.96	20.86	22.22	79.48	53.82	7.72	8.22
13-24 "	12.77	14.85	20.31	23.05	62.88	64.42	7.51	8.53
25-36 "	8.75	15.00	20.02	20.39	43.71	73.56	7.41	7.54
37-48 "	8.84	16.46	20.38	20.11	43.38	81.85	7.54	7.44
Field D								
0-12 Inches	19.86	19.17	21.48	22.03	92.46	87.02	7.95	8.15
13-24 "	13.65	17.12	20.96	19.81	65.12	86.42	7.76	7.33
25-36 "	10.63	16.29	20.79	19.98	51.13	81.53	7.69	7.39
37-48 "	10.05	17.32	17.84	21.48	56.33	80.63	6.60	7.95

Table No. 9

RELATIVE SOIL MOISTURE:
GOODLANDS DISTRICT EXPERIMENT SUBSTATION

Rotation Year	Crop and Field No.	Time of Sampling	Relative Moisture in Per Cent: Depth 0-12 ins.	Depth 13-24 ins.	Depth 25-36 ins.	Depth 37-48 ins.	Total	Mean Relative Moisture Per Cent	Relative Moisture Group
1	Fallow (20)	Spring	82.68	51.02	53.66	56.22	243.58	60.90	3
		Fall	86.34	61.62	93.11	74.84	315.91	78.98	2
2	Wheat on Fallow (21)	Spring	108.88	83.95	85.42	84.05	362.30	90.58	2
		Fall	42.74	39.03	56.82	61.48	200.07	50.02	3
1	Fallow (2)	Spring	88.01	50.47	60.70	67.69	266.87	66.72	2
		Fall	94.34	92.87	85.78	86.81	359.80	89.95	2
2	Wheat on Fallow (3)	Spring	84.94	85.11	83.12	80.64	333.81	83.45	2
		Fall	37.10	39.73	61.17	68.89	206.89	51.72	3
3	Wheat on Second Crop (1)	Spring	124.38	68.33	75.14	72.18	340.03	85.01	2
		Fall	48.80	61.82	79.12	81.84	271.58	67.90	2
1	Fallow (D)	Spring	92.46	65.12	51.13	56.33	265.04	66.26	2
		Fall	87.02	86.42	81.53	80.63	335.60	83.90	2
2	Wheat on Fallow (B)	Spring	106.87	101.05	107.98	110.68	426.58	106.64	1
		Fall	50.27	34.57	62.63	73.87	221.34	55.34	3
3	Clover Hay and Break (C)	Spring	79.48	62.88	43.71	43.38	229.45	57.36	3
		Fall	53.82	64.42	73.56	81.85	273.65	68.41	2
4	Barley (A)	Spring	104.00	76.58	77.67	69.82	328.07	82.02	2
		Fall	50.69	38.70	43.81	60.77	193.97	48.49	4

Table No. 10

ANALYSIS OF VARIANCE OF DATA IN TABLE 9.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F-Value	
Fields (F)	8	2440.72	305.09	3.18	x
Depths (D)	3	1901.09	633.70	6.62	xx
Samplings (S)	1	2414.20	2414.20	25.21	xx
F X D	24	2218.59	92.44	.96	
F X S	8	13589.41	1698.68	17.74	xx
D X S	3	4217.99	1406.00	14.68	xx
F X D X S	24	2298.83	95.78		
TOTAL	71	29080.83			

x - Significant at five per cent level.
xx - Significant at one per cent level.

Table No. 11

GROUPING OF MEAN RELATIVE MOISTURE PERCENTAGES BY TUKEY METHOD.

Group 1	Group 2	Group 3	Group 4
106.64	90.58	60.90	48.49
	89.95	57.36	
	85.01	55.34	
	83.90	51.72	
	83.45	50.02	
	82.02		
	78.98		
	68.41		
	67.90		
	66.72		
	66.26		

field (No. 20) the mean relative moisture was significantly greater in the fall than in the spring, and in the wheat on fallow field (No. 21), the moisture was significantly less in the fall than in the spring.

In the fallow, wheat, wheat rotation located on fields 1, 2 and 3, the moisture was not used efficiently as the relative moisture percentage fell in group 2 for wheat on second crop and for the fallow field. In the wheat on fallow field (No. 3) the moisture regime is the same as for wheat on fallow (No. 21) in the two-year rotation.

In the four-year mixed farming rotation having a cropping sequence of fallow, wheat seed to clover and brome, clover hay and break, and barley, the relative moisture groups are fairly well distributed. For instance, the moisture in the fallow field (D) increased during the summer and had the same relative moisture group rating as the other fallow fields discussed in the two and three-year rotations. Relative soil moisture in the wheat on fallow field (B) passed from above field capacity in the spring down to a relative moisture percentage near the wilting point in the fall. This means that there was a greater range of moisture available for crop growth than in the two and three-year rotation. The clover hay and brome crop (C) used the soil moisture, plus any rainfall in producing a crop of hay, and in this way the moisture was used as it was received. After breaking the clover and brome field, moisture was stored, bringing the moisture up to relative moisture group 2 or higher. The barley crop which follows utilizes the moisture stored after breaking the clover and brome. Breaking after harvesting a crop of sweet clover and brome, leaves the soil in a receptive condition to allow the rain to percolate deeper into the soil profile. The decaying roots of the legume also facilitate this downward movement of water. The relative soil moisture is represented graphically in

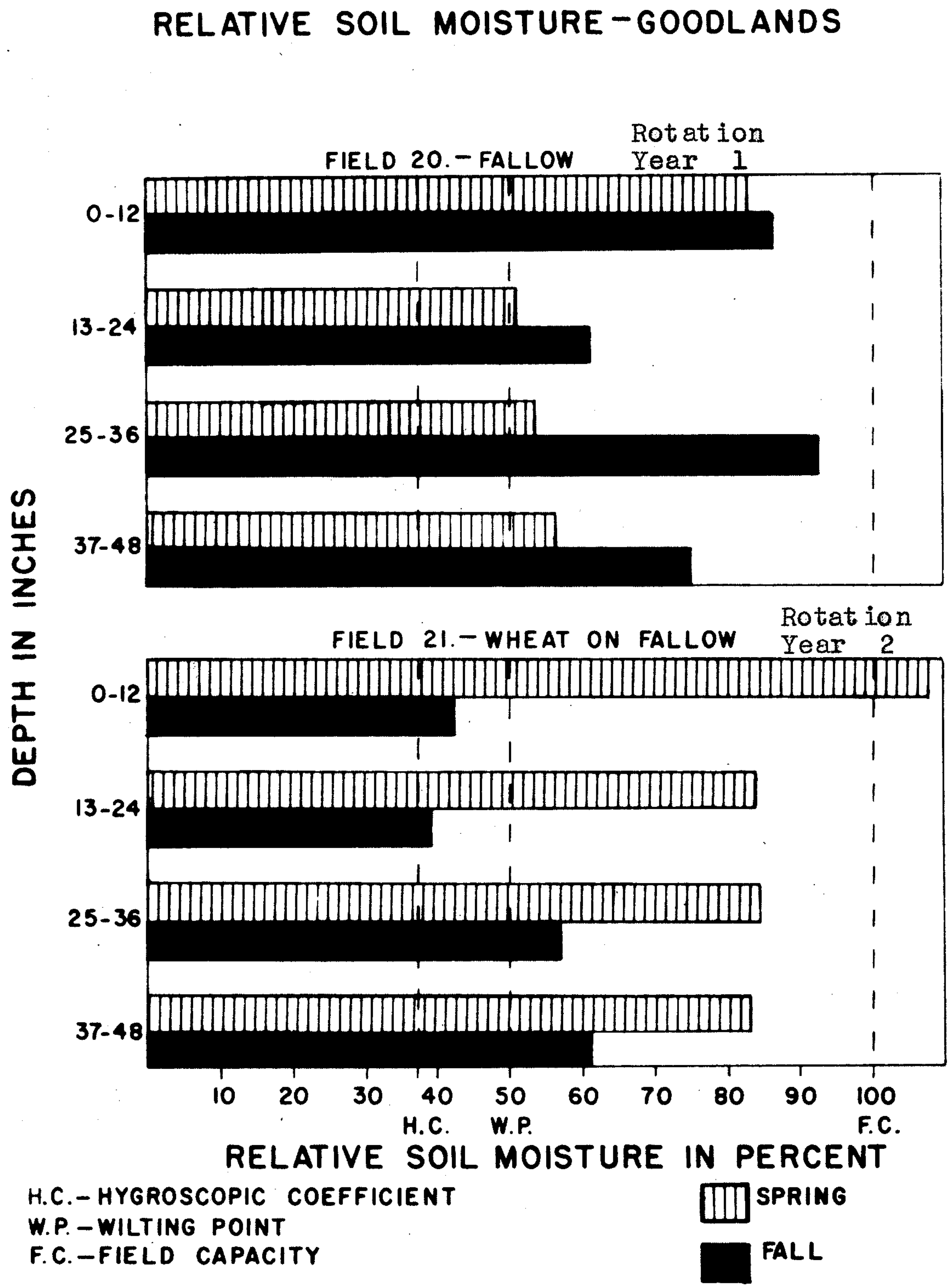

RELATIVE SOIL MOISTURE-GOODLANDS
FIELD 20.-FALLOW
Rotation Year 1
FIELD 21.-WHEAT ON FALLOW
Rotation Year 2
DEPTH IN INCHES
0-12
13-24
25-36
37-48
10 20 30 40 50 60 70 80 90 100
H.C.
W.P.
F.C.
RELATIVE SOIL MOISTURE IN PERCENT
H.C.-HYGROSCOPIC COEFFICIENT
W.P.-WILTING POINT
F.C.-FIELD CAPACITY
SPRING
FALL

Figure No. 4

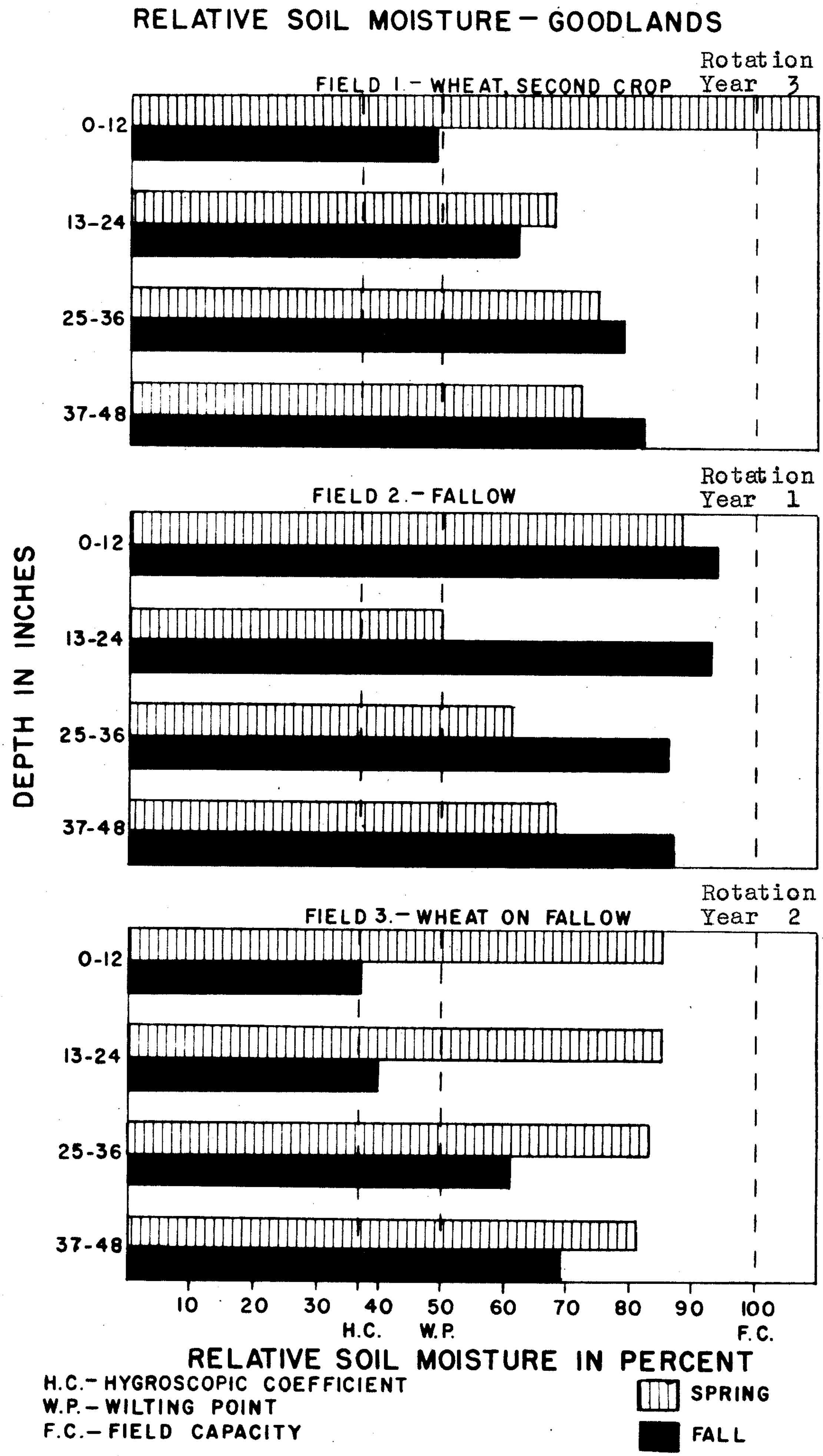
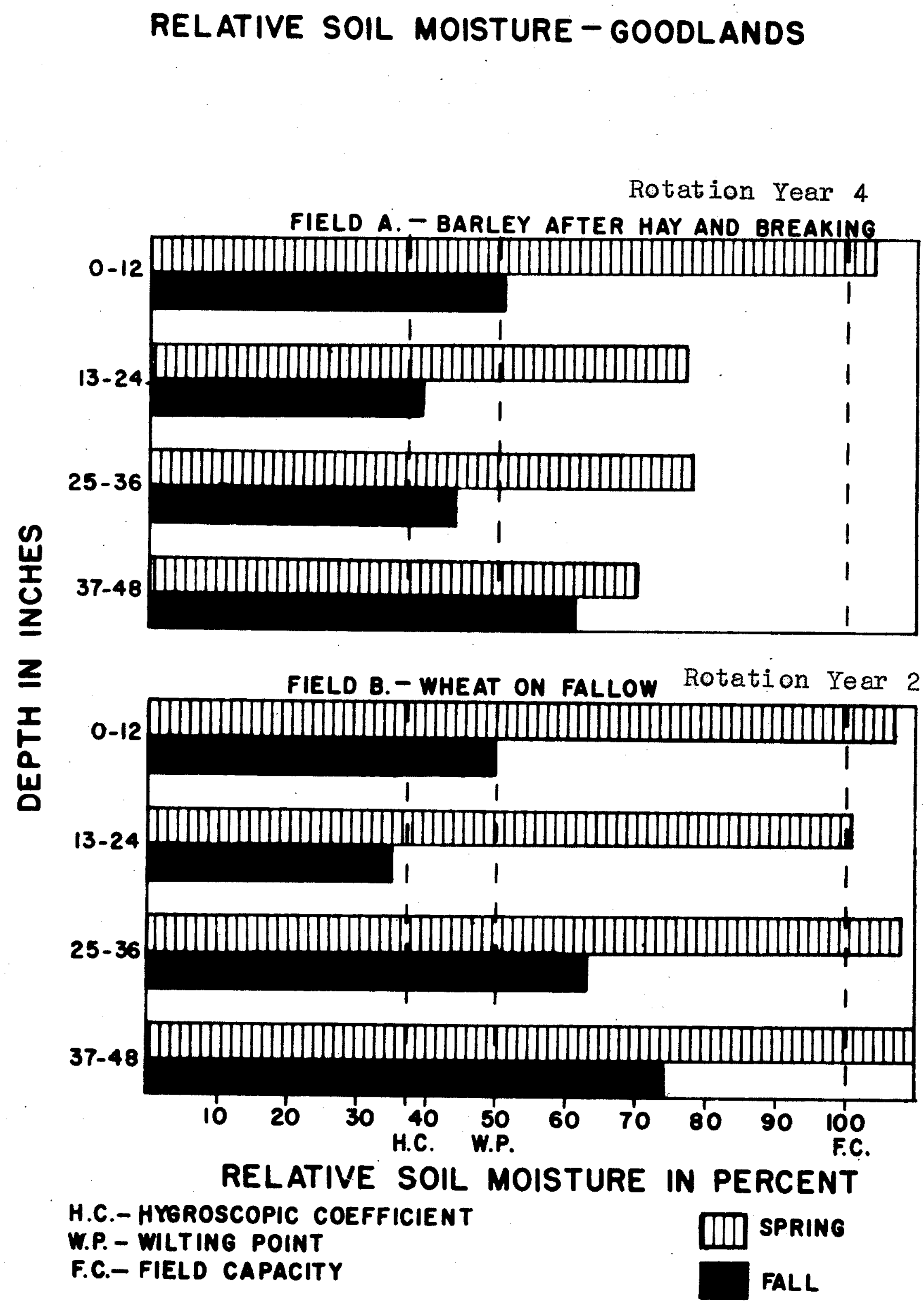

RELATIVE SOIL MOISTURE — GOODLANDS
FIELD 1.— WHEAT, SECOND CROP
Rotation Year 3
FIELD 2.— FALLOW
Rotation Year 1
FIELD 3.— WHEAT ON FALLOW
Rotation Year 2
DEPTH IN INCHES
0-12
13-24
25-36
37-48
10 20 30 40 50 60 70 80 90 100
H.C.
W.P.
F.C.
RELATIVE SOIL MOISTURE IN PERCENT
H.C.— HYGROSCOPIC COEFFICIENT
W.P.— WILTING POINT
F.C.— FIELD CAPACITY
SPRING
FALL

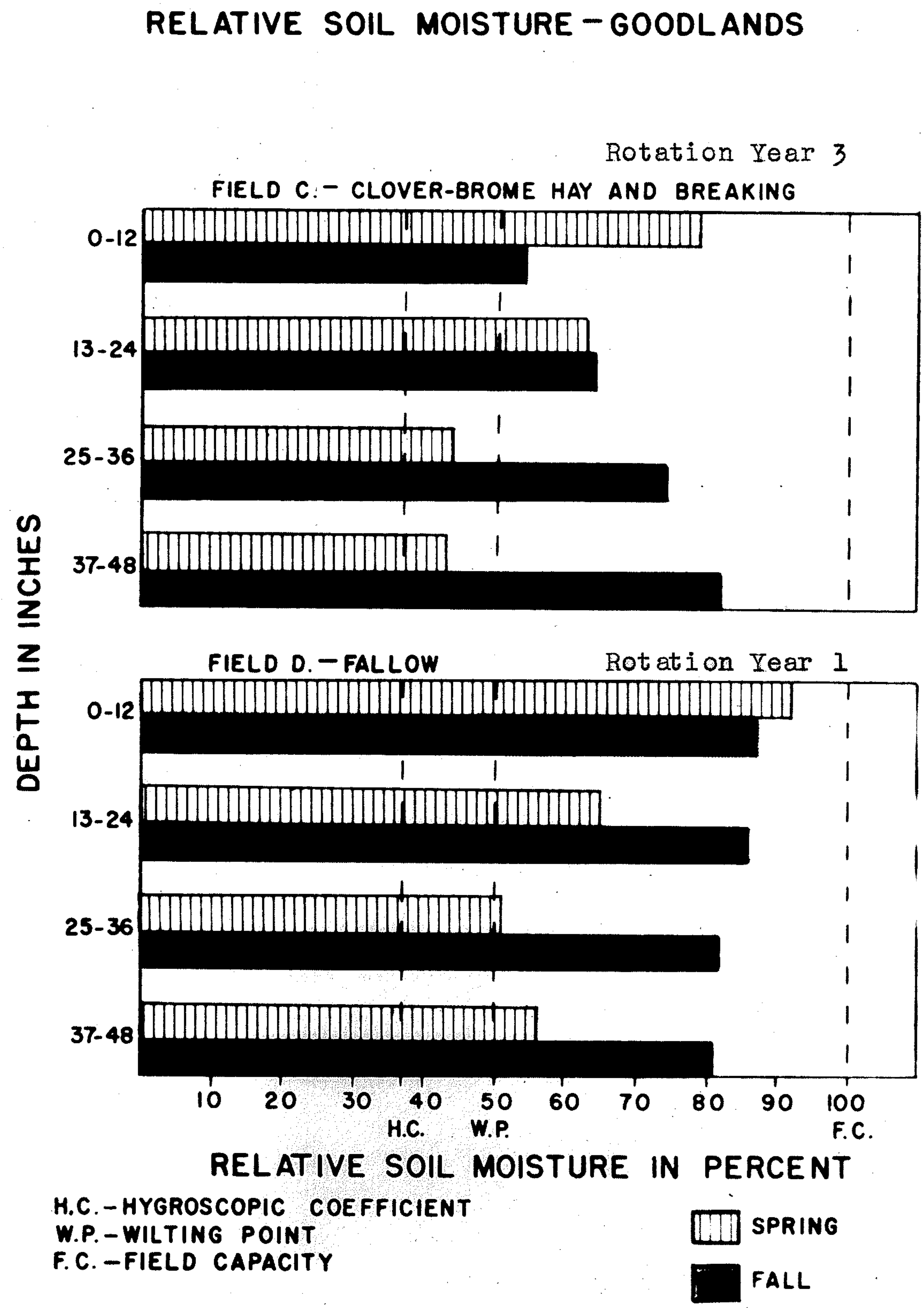
Figure No. 5



RELATIVE SOIL MOISTURE - GOODLANDS
Rotation Year 4
FIELD A. - BARLEY AFTER HAY AND BREAKING
0-12
13-24
25-36
37-48
DEPTH IN INCHES
FIELD B. - WHEAT ON FALLOW
Rotation Year 2
0-12
13-24
25-36
37-48
10
20
30
40
H.C.
50
W.P.
60
70
80
90
100
F.C.
RELATIVE SOIL MOISTURE IN PERCENT
H.C. - HYGROSCOPIC COEFFICIENT
W.P. - WILTING POINT
F.C. - FIELD CAPACITY
SPRING
FALL

Figure No. 6

Figure No. 7


RELATIVE SOIL MOISTURE — GOODLANDS
Rotation Year 3
FIELD C. — CLOVER-BROME HAY AND BREAKING
0-12
13-24
25-36
37-48
DEPTH IN INCHES
FIELD D. — FALLOW
Rotation Year 1
0-12
13-24
25-36
37-48
10
20
30
40
50
60
70
80
90
100
H.C.
W.P.
F.C.
RELATIVE SOIL MOISTURE IN PERCENT
H.C. - HYGROSCOPIC COEFFICIENT
W.P. - WILTING POINT
F.C. - FIELD CAPACITY
SPRING
FALL

Figures Number 4 to Number 7, inclusive.

There is further evidence to indicate that field crops utilize the soil moisture from below the "calculated" wilting point on the Goodlands station. This point is clearly defined in the case of wheat on fallow, field 21 in the two-year fallow, wheat rotation; for wheat on fallow on field 3 in the three-year fallow, wheat, wheat rotation, and for wheat on fallow in field 3 in the four-year rotation of fallow, wheat seed to clover and brome, hay and break, and barley.

The total moisture percentage, moisture equivalent percentage, relative moisture percentage, and calculated hygroscopic coefficient data are recorded in Table No. 12 for fields sampled on the Hargrave District Experiment Substation. There is some variation in the percentage of total moisture and also in the moisture equivalent data. The rolling topography of the Hargrave station helps to explain some of the variations in the moisture equivalent data, but on the whole the soil can be classed as having a medium texture. It will be noted that the relative moisture figures for spring sampling indicate a condition above field capacity on fields 1, 3, 5, 6, 7 and 8. This is indicative of a greater supply of soil moisture on the Hargrave Substation than on either the Boissevain or the Goodlands Sub-stations. The relative soil moisture figures are set up in Table No. 13 in a manner convenient for statistical analysis. The analysis of variance of this data is recorded in Table No. 14, and the relative moisture groups in Table No. 15 as determined by the Tukey method.

The analysis of variance Table Number 14, for relative soil moisture results at Hargrave, indicates significance at the one per cent level for main effects and second order interactions, excepting the fields x depths interaction. The minimum significant difference required to separate

Table No.12

PERCENT SOIL MOISTURE, MOISTURE EQUIVALENT, RELATIVE MOISTURE AND CALCULATED HYGROSCOPIC COEFFICIENT FOR FIELDS SAMPLED ON HARGRAVE DISTRICT EXPERIMENT SUBSTATION.

Field and Depth in Inches	Total Moisture Percent		Moisture Equivalent Percent		Relative Moisture Percent		Calculated Hygroscopic Coefficient	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
<u>No. 1</u>								
0-12 Inches	27.49	21.35	27.31	21.81	100.65	97.89	10.10	8.07
13-24 "	18.23	18.99	21.60	19.46	84.40	97.58	7.99	7.20
25-36 "	16.48	13.45	19.81	14.08	83.19	95.52	7.33	5.21
37-48 "	17.30	12.96	21.06	14.15	82.15	91.59	7.79	5.24
<u>No. 2</u>								
0-12 Inches	17.92	15.33	21.25	21.25	84.33	72.14	7.86	7.86
13-24 "	14.05	7.82	18.20	17.64	77.20	44.33	6.73	6.53
25-36 "	12.76	9.82	17.13	20.73	74.49	47.37	6.34	7.67
37-48 "	13.44	10.96	17.62	21.17	76.28	51.77	6.52	7.83
<u>No. 3</u>								
0-12 Inches	28.73	10.42	25.98	20.17	110.58	51.66	9.61	7.46
13-24 "	18.40	10.98	21.67	21.53	84.91	51.00	8.02	7.97
25-36 "	11.42	11.95	18.08	21.34	63.16	56.00	6.69	7.90
37-48 "	11.98	12.32	19.82	21.35	60.44	57.70	7.33	7.90
<u>No. 4</u>								
0-12 Inches	22.02	14.68	22.82	18.49	96.49	79.39	8.44	6.84
13-24 "	17.19	9.83	19.83	19.53	86.69	50.33	7.34	7.23
25-36 "	16.94	13.53	20.51	20.05	82.59	67.48	7.59	7.42
37-48 "	17.20	15.66	21.48	21.24	80.07	73.73	7.95	7.86

Continued.

Table No.12 - Cont'd.

..........Hargrave

Field and Depth in Inches	Total Moisture Percent		Moisture Equivalent Percent		Relative Moisture Percent		Calculated Hygroscopic Coefficient	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
No. 5								
0-12 Inches	25.68	13.47	24.81	22.09	103.50	60.98	9.18	8.17
13-24 "	20.67	11.70	21.52	19.38	96.05	60.37	7.96	7.17
25-36 "	11.57	13.60	14.17	18.24	81.65	74.56	5.24	6.75
37-48 "	14.94	14.74	16.46	18.92	90.76	77.91	6.09	7.00
No. 6								
0-12 Inches	26.63	15.97	23.84	18.92	111.70	84.41	8.82	7.00
13-24 "	20.89	11.60	22.25	19.91	93.89	58.26	8.23	7.37
25-36 "	16.50	11.46	17.87	20.51	92.33	55.88	6.61	7.59
37-48 "	16.75	14.32	19.68	19.43	85.11	73.70	7.28	7.19
No. 7								
0-12 Inches	25.59	13.64	23.18	19.48	110.40	70.02	8.58	7.21
13-24 "	25.35	7.88	20.12	18.90	125.99	41.69	7.44	6.99
25-36 "	26.71	10.58	21.75	21.75	122.80	48.64	8.05	8.05
37-48 "	27.59	14.19	20.16	20.16	136.85	70.39	7.46	7.46
No. 8								
0-12 Inches	21.87	18.92	20.43	19.77	107.05	95.70	7.56	7.31
13-24 "	14.40	16.22	18.67	21.63	77.13	74.99	6.91	8.00
25-36 "	10.98	16.86	17.65	21.46	62.21	78.56	6.53	7.94
37-48 "	9.60	15.75	16.79	20.25	57.18	77.78	6.21	7.49

Table No. 13

RELATIVE SOIL MOISTURE:
HARGRAVE DISTRICT EXPERIMENT SUBSTATION

Rotation Year	Crop and Field No.	Time of Sampling	Relative Moisture in Per Cent Depth 0-12	Depth 13-24	Depth 25-36	Depth 37-48	Total	Mean Relative Moisture	Relative Moisture Group
			ins.	ins.	ins.	ins.		Per Cent	
1	Fallow (1)	Spring	100.65	84.40	83.19	82.15	350.39	87.60	2
		Fall	97.89	97.58	95.52	81.59	382.58	95.64	2
2	Wheat on Fallow (7)	Spring	110.40	125.99	122.80	136.85	496.04	124.01	1
		Fall	70.02	41.69	48.64	70.39	230.74	57.68	3
3	Barley Seed to Hay (6)	Spring	111.70	93.89	92.33	85.11	383.03	95.76	2
		Fall	84.41	58.26	55.88	73.70	272.25	68.06	2
4	Hay (3)	Spring	110.58	84.91	63.16	60.44	319.09	79.77	2
		Fall	51.66	51.00	56.00	57.70	216.36	54.09	3
5	Pasture (2)	Spring	84.33	77.20	74.49	76.28	312.30	78.08	2
		Fall	72.14	44.33	47.37	51.77	215.61	53.90	3
6	Sod-breaking (8)	Spring	107.05	77.13	62.21	57.18	303.57	75.89	2
		Fall	95.70	74.99	78.56	77.78	327.03	81.76	2
7	Wheat on Breaking (5)	Spring	103.50	96.05	81.65	90.76	371.96	92.99	2
		Fall	60.98	60.37	74.56	77.91	273.82	68.46	2
8	Oats on Second Crop (4)	Spring	96.49	86.69	82.59	80.07	345.84	86.46	2
		Fall	79.39	50.33	67.48	73.73	270.93	67.73	2

Table No. 14

Analysis of Variance of Data in Table 13.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F-Value
Fields (F)	7	5033.18	719.11	7.30 xx
Depths (D)	3	2485.95	828.65	8.42 xx
Samples (S)	1	7501.73	7501.73	76.20 xx
F X D	21	1819.20	86.63	.88
F X S	7	7421.80	1060.26	11.08 xx
D X S	3	908.57	302.86	3.38 xx
F X D X S	21	2067.46	98.45	
TOTAL	63	27238.51		

xx - Significant at one per cent level.

Table No. 15

Grouping of Mean Relative Moisture Percentages by Tukey Method.

Group 1	Group 2	Group 3
124.01	95.76	57.68
	95.64	54.09
	92.99	53.90
	87.60	
	86.46	
	81.76	
	79.77	
	78.08	
	75.89	
	68.46	
	68.06	
	67.73	

the means into groups using the Tukey method, is 14.55 per cent. Table Number 15 gives the results of grouping the means. Group 2 contains all values ranging from 95.76 per cent to 67.73 per cent. Group 3 contains values ranging from 57.68 per cent to 53.90 per cent. Only one value is found in group 1.

The results of grouping the relative moisture percentages indicate that the moisture was more abundant at this station than at either Boissevain or Goodlands. A greater number of values were found in the higher moisture groups 1 and 2. It is significant to note that there were five fields on this station that showed the same relative moisture grouping in the spring and fall. These are the fallow (No. 1); Wheat on breaking (No. 5), Oats on second crop after breaking (No. 4), Barley on second crop after fallow (No. 6), and sod-breaking (No. 8). Wheat on fallow (No. 7) used a wide range of moisture during the season. The range was from a condition above field capacity down to near the wilting point. The soil moisture for both the pasture field (No. 2) and the hay field (No. 3) was the same at both spring and fall samplings. The moisture in these two latter fields was down to the wilting point. The relative soil moisture is represented graphically in Figures Number 8 to Number 10, inclusive.

A careful examination of the relative soil moisture data and the graphical representation of this data reveals that the soil moisture was utilized from below the wilting point in field 2. (See Figure No. 8) This field was used for pasture in 1953. It will be noted that the deeply rooted alfalfa plants were able to extract soil moisture as far as three feet below the surface. A similar condition exists in field 7, wheat on fallow (See Figure No. 10), where moisture has been depleted to below the wilting point at the one to three foot level.

RELATIVE SOIL MOISTURE - HARGRAVE

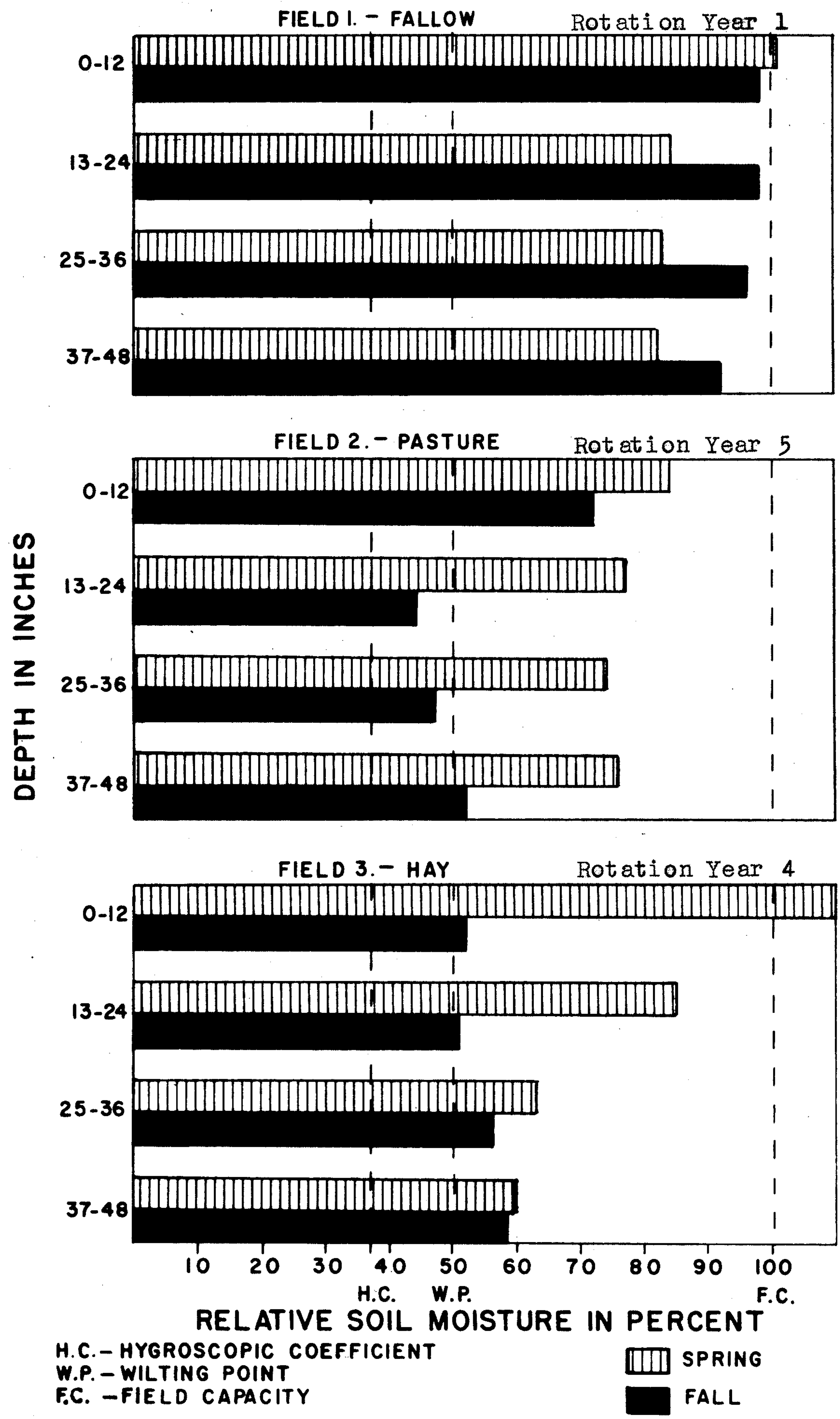


Figure No.8

RELATIVE SOIL MOISTURE — HARGRAVE

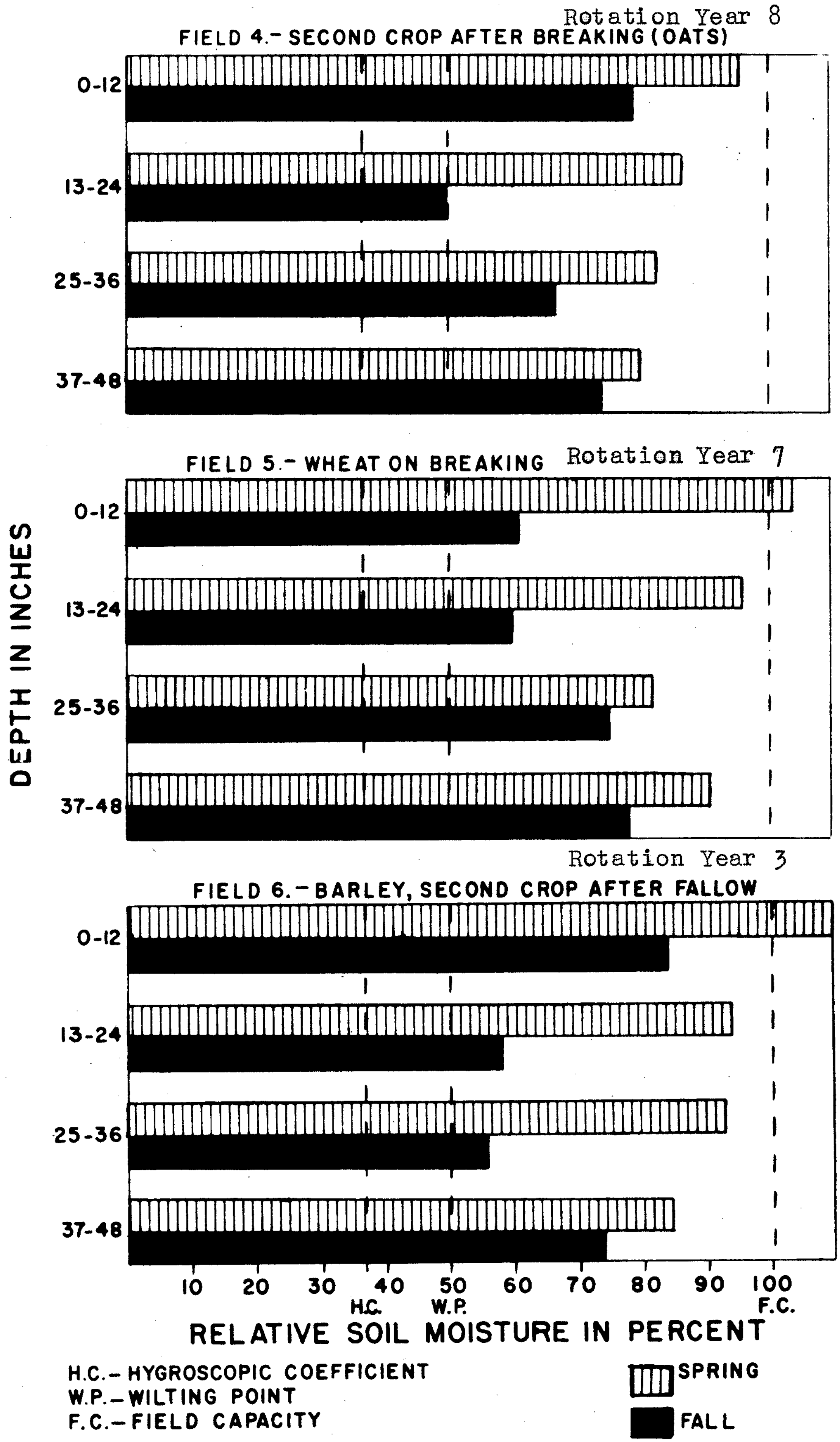
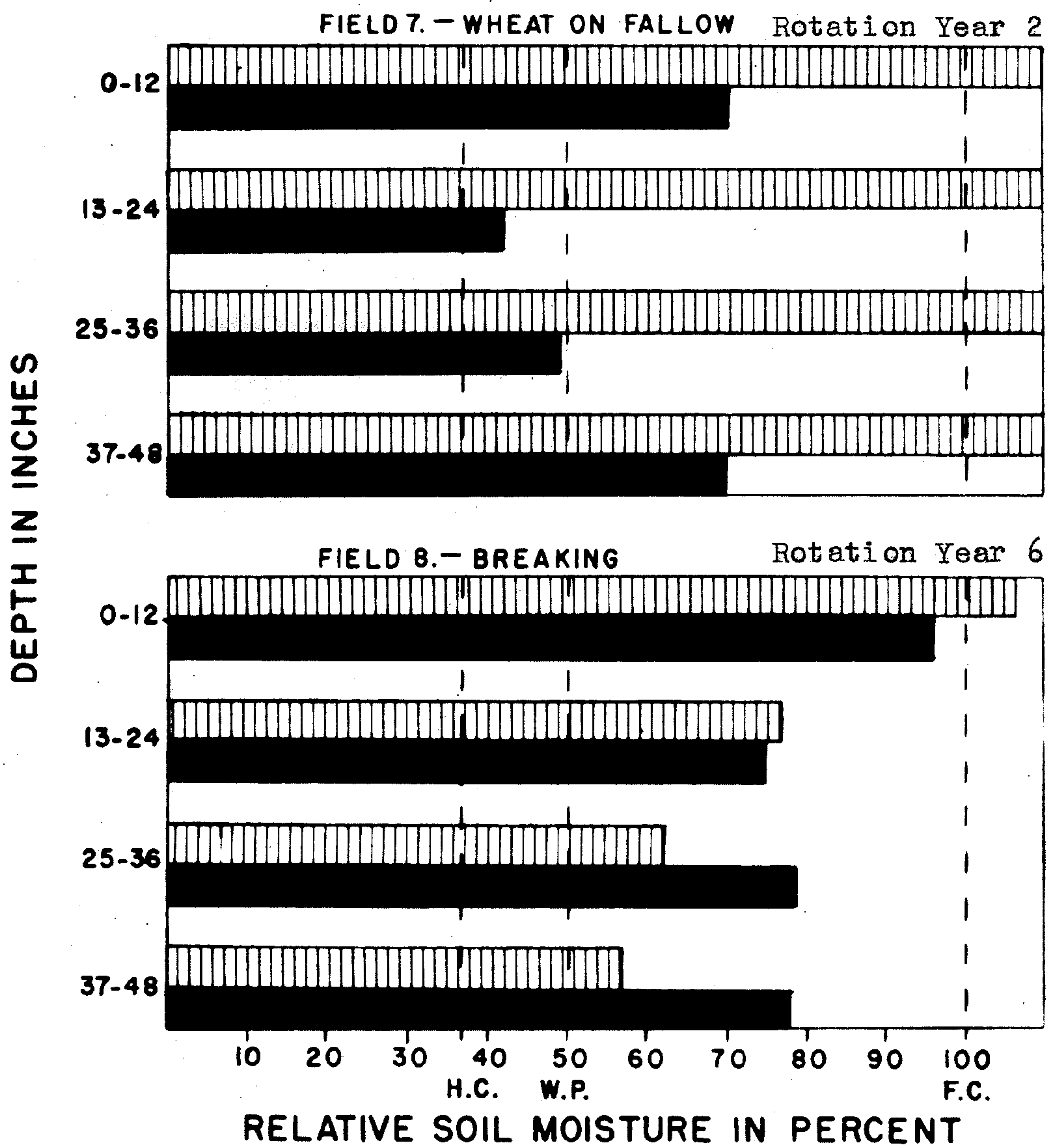


Figure No. 9

RELATIVE SOIL MOISTURE—HARGRAVE



H.C.—HYGROSCOPIC COEFFICIENT
W.P.—WILTING POINT
F.C.—FIELD CAPACITY

Figure No. 10

Russell (34) states that the amount of water that is available to plants depends on the amount held per unit volume of soil and on the depth from which plants extract water. Hygroscopic water is unavailable for plant use and is considered to be approximately .37 times the water content of field capacity or the moisture equivalent. The percentage of total moisture less the calculated hygroscopic water will give the water available in per cent. The weight of water in pounds is calculated by multiplying the percentage water in a given volume of soil by the volume weight per cubic foot. This figure can be converted to inches of water by dividing by 5.2 which is the weight in pounds of one inch of water spread over one square foot of surface. The volume weight of soil based on a dry weight basis is calculated to be 71.51 pounds per cubic foot for Boissevain; 78.86 pounds per cubic foot for Goodlands, and 73.18 pounds per cubic foot for Hargrave. The amount of water found in soil at any given time is rarely at field capacity and for this reason, a condition of moisture deficit exists. It can be calculated by subtracting the total moisture from the moisture equivalent. Using this method, the total amount of water in inches is calculated for the crops on the rotations studied.

The amount of available moisture present in a four foot profile was less in the fall than in the spring in fields that were in crop. The fallow fields and sod-breaking fields, showed a storage of soil moisture. There was a greater deficit in the fall than in the spring in fields under crops. In the case of fallow and sod-breaking fields, the opposite was true. The negative figures indicate a condition where the total moisture at the time of sampling was greater than the moisture equivalent or field capacity. The total available moisture, and moisture deficit are recorded for all fields in Tables Number 16 to Number 18, inclusive.

Table No. 16

AVAILABLE MOISTURE AND MOISTURE DEFICIT:
BOISSEVAIN DISTRICT EXPERIMENT SUBSTATION

Field and Depth in Inches	✱ Rtn. Yr.	Available Moisture				Moisture Deficit			
		Percent		Pounds per cu. ft.		Percent		Pounds per cu. ft.	
		Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
No. 3	1								
0-12 Inches		15.86	9.28	11.34	6.64	-3.01	2.74	-2.15	1.96
13-24 "		9.38	12.01	6.71	8.59	2.65	1.68	1.90	1.20
25-36 "		3.96	7.19	2.83	5.14	6.99	2.54	5.00	1.82
37-48 "		2.41	6.77	1.72	4.84	7.55	- .53	5.40	- .38
TOTAL				22.60	25.21			10.15	4.60
No. 7	2								
0-12 Inches		18.67	6.04	13.35	4.32	-2.67	7.81	-1.91	5.58
13-24 "		10.95	3.79	7.83	2.71	4.83	12.70	3.45	9.08
25-36 "		9.90	4.72	7.08	3.38	4.71	8.26	3.37	5.91
37-48 "		8.87	7.38	6.34	5.28	5.65	3.52	4.04	2.52
TOTAL				34.60	15.69			8.95	23.09
No. 1	3								
0-12 Inches		10.59	5.07	7.57	3.62	1.50	7.49	1.07	5.36
13-24 "		1.91	2.39	1.36	1.71	9.21	9.52	6.59	6.81
25-36 "		1.26	2.44	.90	1.74	9.97	8.03	7.13	5.74
37-48 "		.60	3.25	.43	2.32	10.42	11.02	7.45	7.88
TOTAL				10.26	9.39			22.24	25.79
No. 5	4								
0-12 Inches		10.03	2.15	7.17	1.54	5.61	11.77	4.01	8.42
13-24 "		4.14	2.16	2.96	1.54	9.66	11.25	6.91	8.04
25-36 "		.18	1.90	.13	1.36	14.92	9.41	10.67	6.73
37-48 "		.54	2.39	.39	1.71	13.90	9.69	9.94	6.93
TOTAL				10.65	6.15			31.53	30.12

✱ Rotation Year

Continued.

Table No. 16 - Cont'd.

AVAILABLE MOISTURE AND MOISTURE DEFICIT:
BOISSEVAIN DISTRICT EXPERIMENT SUBSTATION

Field and Depth in Inches	* Rtn. Yr.	Available Moisture				Moisture Deficit			
		Percent		Pounds per cu. ft.		Percent		Pounds per cu. ft.	
		Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
No. 4	5								
0-12 Inches		13.15	2.90	9.40	2.07	.31	10.00	.22	7.15
13-24 "		4.67	1.11	3.34	.79	10.24	11.59	7.32	8.29
25-36 "		3.44	.65	2.46	.46	11.91	12.16	8.52	8.70
37-48 "		2.76	.65	1.97	.46	15.03	11.05	10.75	7.90
TOTAL				17.17	3.78			26.81	32.04
No. 8	6								
0-12 Inches		11.77	9.41	8.42	6.73	-1.04	3.27	- .74	2.34
13-24 "		6.77	7.86	4.84	5.62	8.74	1.14	6.25	.81
25-36 "		4.09	6.04	2.92	4.32	9.80	2.21	7.01	1.58
37-48 "		3.65	5.77	2.61	4.13	10.41	2.54	7.44	1.82
TOTAL				18.79	20.80			19.96	6.55
No. 2	7								
0-12 Inches		16.22	1.58	11.60	1.13	-1.38	11.79	- .99	8.43
13-24 "		9.37	1.07	6.70	.76	7.38	8.25	5.27	5.90
25-36 "		6.91	.87	4.94	.62	7.38	12.67	5.27	9.06
37-48 "		7.86	3.30	5.62	2.36	6.64	11.04	4.75	7.89
TOTAL				28.86	4.87			14.30	31.28
No. 6	8								
0-12 Inches		10.91	2.91	7.80	2.08	3.34	11.71	2.39	8.37
13-24 "		1.35	.50	.96	.36	11.83	13.61	8.46	9.73
25-36 "		1.49	.75	1.06	.54	9.91	12.05	7.09	8.62
37-48 "		1.47	.89	1.05	.64	7.79	9.77	5.57	6.99
TOTAL				10.87	3.62			23.51	33.71

* Rotation Year

Table No. 17

AVAILABLE MOISTURE AND MOISTURE DEFICIT:
GOODLANDS DISTRICT EXPERIMENT SUBSTATION

Field and Depth in Inches	* Rtn. Yr.	Available Moisture				Moisture Deficit			
		Percent		Pounds per cu. ft.		Percent		Pounds per cu. ft.	
		Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
No. 20	1								
0-12 Inches		9.97	10.65	7.86	8.40	3.78	2.95	2.98	2.33
13-24 "		3.22	5.18	2.54	4.08	11.24	8.08	8.86	6.37
25-36 "		3.87	11.72	3.05	9.24	10.76	1.44	8.48	1.14
37-48 "		4.46	8.23	3.52	6.49	10.17	5.47	8.02	4.31
TOTALS				16.97	28.21			28.34	14.15
No. 21	2								
0-12 Inches		15.06	1.28	11.88	1.01	-1.86	12.78	-1.47	10.08
13-24 "		10.97	.58	8.65	.46	3.75	17.56	2.96	13.85
25-36 "		10.96	5.43	8.64	4.28	3.30	11.83	2.60	9.33
37-48 "		10.27	5.79	8.10	4.56	3.48	9.11	2.74	7.18
TOTALS				37.27	10.31			6.83	40.44

* Rotation Year

Continued.

Table No. 17 - Cont'd.

..........Goodlands

Field and Depth in Inches	* Rtn. Yr.	Available Moisture				Moisture Deficit			
		Percent		Pounds per cu. ft.		Percent		Pounds per cu. ft.	
		Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
No. 2	1								
0-12 Inches		11.15	12.05	8.79	9.50	2.62	1.19	2.07	.94
13-24 "		4.01	12.30	3.16	9.70	10.45	1.57	8.24	1.24
25-36 "		5.43	9.75	4.28	7.69	9.00	2.84	7.08	2.24
37-48 "		6.99	9.14	5.51	7.21	7.36	2.42	5.80	1.91
TOTALS				21.74	34.10			23.19	6.33
No. 3	2								
0-12 Inches		12.39	.02	9.77	.02	3.89	14.29	3.07	11.27
13-24 "		11.12	.56	8.77	.44	3.44	12.44	2.71	9.81
25-36 "		9.89	4.37	7.80	3.45	3.62	7.02	2.85	5.54
37-48 "		9.74	6.69	7.68	5.28	4.32	6.53	3.41	5.15
TOTALS				34.02	9.19			12.04	31.77
No. 1	3								
0-12 Inches		21.47	2.76	16.93	2.18	-5.99	11.97	-4.72	9.44
13-24 "		7.60	5.81	5.99	4.58	7.68	8.93	6.06	7.04
25-36 "		8.38	10.23	6.61	8.07	5.46	5.07	4.31	4.00
37-48 "		7.89	10.57	6.22	8.34	6.24	4.28	4.92	3.38
TOTALS				35.75	23.17			10.57	23.86

* Rotation Year

Continued.

Table No. 17 - Cont'd.

.........Goodlands

Field and Depth in Inches	★ Rtn. Yr.	Available Moisture				Moisture Deficit			
		Percent		Pounds per cu. ft.		Percent		Pounds per cu. ft.	
		Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
Field D	1								
0-12 Inches		11.91	11.02	9.39	8.69	1.62	2.86	1.28	2.26
13-24 "		5.89	9.79	4.64	7.72	7.31	2.69	5.76	2.12
25-36 "		2.94	8.90	2.32	7.02	10.16	3.69	8.01	2.91
37-48 "		3.45	9.37	2.72	7.39	7.79	4.16	6.14	3.28
TOTALS				19.07	30.82			21.19	10.57
Field B	2								
0-12 Inches		14.85	2.71	11.71	2.14	-1.46	10.15	-1.15	8.00
13-24 "		15.24	.34	12.02	.27	- .25	17.77	- .20	14.01
25-36 "		18.06	4.55	14.24	3.59	-2.03	6.63	-1.60	5.23
37-48 "		17.39	6.21	13.71	4.90	-2.52	4.40	-1.99	3.47
TOTALS				51.68	10.90			-4.94	30.71
Field C	3								
0-12 Inches		8.86	3.74	6.99	2.95	4.28	10.26	3.38	8.09
13-24 "		5.26	6.32	4.15	4.98	7.54	8.20	5.95	6.47
25-36 "		1.34	7.46	1.06	5.88	11.27	5.39	8.89	4.25
37-48 "		1.30	9.02	1.02	7.11	11.54	3.65	9.10	2.88
TOTALS				13.22	20.92			27.32	21.69
Field A	4								
0-12 Inches		15.75	2.98	12.42	2.35	- .94	10.74	- .74	8.47
13-24 "		8.99	.27	7.09	.21	5.32	9.74	4.20	7.68
25-36 "		8.67	1.45	6.84	1.14	4.76	11.94	3.75	9.42
37-48 "		7.33	4.34	5.78	3.42	6.74	7.16	5.32	5.65
TOTALS				32.13	7.12			12.53	31.22

★ Rotation Year

Table 18

AVAILABLE MOISTURE AND MOISTURE DEFICIT:
HARGRAVE DISTRICT EXPERIMENT SUBSTATION

Field and Depth in Inches	* Rtn. Yr.	Available Moisture				Moisture Deficit			
		Percent		Pounds per cu. ft.		Percent		Pounds per cu. ft.	
		Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
No. 1	1								
0-12 Inches		17.39	13.28	12.73	9.72	- .18	.46	- .13	.34
13-24 "		10.24	11.79	7.49	8.63	3.37	.47	2.47	.34
25-36 "		9.15	8.24	6.70	6.03	3.33	.63	2.44	.46
37-48 "		9.51	7.72	6.96	5.65	3.76	1.19	2.75	.87
TOTALS				33.88	30.03			7.53	2.01
No. 7	2								
0-12 Inches		17.01	6.43	12.45	4.70	-2.41	5.84	-1.76	4.27
13-24 "		17.91	.89	13.11	.65	-5.23	11.02	-3.83	8.06
25-36 "		18.66	2.53	13.66	1.85	-4.96	11.17	-3.63	8.17
37-48 "		20.13	6.73	14.73	4.92	-7.43	5.97	-5.44	4.37
TOTALS				53.95	12.12			-14.66	24.87
No. 6	3								
0-12 Inches		17.81	8.97	13.03	6.56	-2.79	2.95	-2.04	2.16
13-24 "		12.66	4.23	9.26	3.10	1.36	8.31	1.00	6.08
25-36 "		9.89	8.91	7.24	6.52	1.37	9.05	1.00	6.62
37-48 "		9.47	9.56	6.93	7.00	2.93	5.11	2.14	3.74
TOTALS				36.46	23.18			2.10	18.60
No. 3	4								
0-12 Inches		19.12	2.96	13.99	2.17	-2.75	9.75	-2.01	7.14
13-24 "		10.38	3.01	7.60	2.20	3.27	10.55	2.39	7.72
25-36 "		4.73	4.05	3.46	2.96	6.66	9.39	4.87	6.87
37-48 "		4.65	4.42	3.40	3.23	7.84	9.09	5.74	6.65
TOTALS				28.45	10.56			10.99	28.38

* Rotation Year

Continued.

Table No. 18 - Cont'd.

..........Hargrave

Field and Depth in Inches	* Rtn. Yr.	Available Moisture				Moisture Deficit			
		Percent		Pounds per cu. ft.		Percent		Pounds per cu. ft.	
		Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
No. 2	5								
0-12 Inches		10.06	7.47	7.36	5.47	3.33	5.92	2.44	4.33
13-24 "		7.32	.50	5.36	.37	4.15	9.82	3.04	7.19
25-36 "		6.42	2.15	4.70	1.57	4.37	10.91	3.20	7.98
37-48 "		6.92	3.13	5.06	2.29	4.18	10.21	3.06	7.47
TOTALS				22.48	9.70			11.74	26.97
No. 8	6								
0-12 Inches		14.31	11.61	10.47	8.50	-1.44	.85	-1.05	.62
13-24 "		7.49	8.22	5.48	6.02	4.27	5.41	3.12	3.96
25-36 "		4.45	8.92	3.26	6.53	6.67	4.60	4.88	3.37
37-48 "		3.39	8.26	2.48	6.04	7.19	4.50	5.26	3.29
TOTALS				21.69	27.09			12.21	11.24
No. 5	7								
0-12 Inches		16.50	5.30	12.07	3.88	- .87	8.62	- .64	6.31
13-24 "		12.71	4.53	9.30	3.32	.85	7.68	.62	5.62
25-36 "		6.33	6.85	4.63	5.01	2.60	4.64	1.90	3.40
37-48 "		8.85	7.74	6.48	5.66	1.52	4.18	1.11	3.06
TOTALS				32.48	17.87			2.99	18.39
No. 4	8								
0-12 Inches		13.58	7.84	9.94	5.74	.80	3.81	.58	2.79
13-24 "		9.85	2.60	7.21	1.90	2.64	9.70	1.93	7.10
25-36 "		9.35	6.11	6.84	4.47	3.57	6.52	2.61	4.77
37-48 "		9.25	7.80	6.77	5.71	4.28	5.58	3.13	4.08
TOTALS				30.76	17.82			8.25	18.74

* Rotation Year

In Tables 16 to 18 inclusive data are presented showing the weight of available water in pounds per cubic foot for each one foot depth down to four feet. The amount of water in inches can be determined by dividing each weight of water by 5.2. By following this procedure data is presented in Tables 19, 20, and 21 showing a comparison by foot depths of available moisture in the spring and fall. This data is very important when assessing the total moisture that was available for crop growth in 1953. The total available moisture used by the crop can be obtained by subtracting the available moisture in inches in the fall from the moisture that was available in the spring, and then by adding the total rainfall that fell during the period. It should be pointed out that only the "effective" rainfall should be considered. Sometimes rain falls so fast that much of it runs off and little is taken in by the soil to be of any use for plant growth. However, in this study the total rainfall for the period is considered as being utilized by the crop.

The total rainfall that fell at the Boissevain District Experiment Substation between the spring sampling date on May 21st and the fall sampling date on September 11th was 9.24 inches. It is interesting to note that only .51 inches out of the 9.24 inches of rainfall was actually stored in the fallow field (No. 1) to a depth of four feet. Due to cultivation there was a loss of soil moisture in the first foot in the fallow field but a slight gain in the remainder of the profile. A similar set of conditions exist in case of the sod-breaking field (No. 8) where only .38 inches of moisture was stored out of the 9.24 inches that fell. The field records indicate that a total of 5.34 inches of rain fell between the period that this field was broken and the fall sampling date. An examination of the relative moisture data as expressed graphically in Figures No. 1 and 2 for fields No. 1 and

Table No. 19

MOISTURE AVAILABLE FOR CROP GROWTH IN FOUR FOOT COLUMN OF SOIL
BOISSEVAIN DISTRICT EXPERIMENT SUBSTATION 1953.

Field No.	Crop	Rotation Year	Depth in inches	Available Moisture		Moisture Used By Crop		
				Spring ins.	Fall ins.	From soil ins.	Rainfall ins.	Total ins.
No. 3	Fallow	1	0-12	2.18	1.28			
			13-24	1.29	1.65			
			25-36	.54	.99			
			37-48	.33	.93			
			Total	4.34	4.85			
No. 7	Wheat on Fallow	2	0-12	2.57	.83	1.74		
			13-24	1.50	.52	.98		
			25-36	1.36	.65	.71		
			37-48	1.22	1.01	.21		
			Total	6.65	3.01	3.64	9.24	12.88
No. 1	Oats on 2nd crop	3	0-12	1.45	.70	.75		
			13-24	.26	.33	- .07		
			25-36	.17	.33	- .16		
			37-48	.08	.45	- .37		
			Total	1.96	1.81	.15	9.24	9.39
No. 5	Hay - 1st year	4	0-12	1.38	.30	1.08		
			13-24	.57	.30	.27		
			25-36	.02	.26	- .24		
			37-48	.07	.53	- .46		
			Total	2.04	1.39	.65	9.24	9.89

Continued.

Table No. 19 - Cont'd.

MOISTURE AVAILABLE FOR CROP GROWTH IN FOUR FOOT COLUMN OF SOIL
BOISSEVAIN DISTRICT EXPERIMENT SUBSTATION 1953.

Field No.	Crop	Rotation Year	Depth in inches	Available Moisture		Moisture Used By Crop		
				Spring ins.	Fall ins.	From soil ins.	Rainfall ins.	Total ins.
No. 4	Pasture	5	0-12	1.81	.40	1.41		
			13-24	.64	.15	.49		
			25-36	.47	.09	.38		
			37-48	.38	.09	.29		
			Total	3.30	.73	2.57	9.24	11.81
No. 8	Sod-Breaking	6	0-12	1.62	1.29			
			13-24	.93	1.05			
			25-36	.56	.83			
			37-48	.50	.79			
			Total	3.61	3.99			
No. 2	Wheat on Breaking	7	0-12	2.23	.21	2.02		
			13-24	1.29	.15	1.14		
			25-36	.95	.12	.83		
			37-48	1.08	.45	.63		
			Total	5.55	.93	4.62	9.24	13.86
No. 6	Wheat on 2nd crop	8	0-12	1.50	.40	1.10		
			13-24	.18	.07	.11		
			25-36	.20	.10	.10		
			37-48	.20	.12	.08		
			Total	2.08	.69	1.39	9.24	10.63

Table No. 20

MOISTURE AVAILABLE FOR CROP GROWTH IN FOUR FOOT COLUMN OF SOIL
GOODLANDS DISTRICT EXPERIMENTAL SUBSTATION 1953.

Field No.	Crop	Rotation Year	Depth in inches	Available Moisture		Moisture Used By Crop		
				Spring ins.	Fall ins.	From soil ins.	Rainfall ins.	Total ins.
20	Fallow	1	0-12	1.51	1.61			
			13-24	.49	.78			
			25-36	.59	1.78			
			37-48	.67	1.25			
			Total	3.26	5.42			
21	Wheat on fallow	2	0-12	2.28	.19	2.09		
			13-24	1.66	.09	1.57		
			25-36	1.66	.82	.84		
			37-48	1.56	.88	.68		
			Total	7.16	1.98	5.18	10.76	15.94

Continued.

Table No. 20 - Cont'd.

MOISTURE AVAILABLE FOR CROP GROWTH IN FOUR FOOT COLUMN OF SOIL
GOODLANDS DISTRICT EXPERIMENTAL SUBSTATION 1953.

Field No.	Crop	Rotation Year	Depth in inches	Available Moisture		Moisture Used By Crop		
				Spring ins.	Fall ins.	From soil ins.	Rainfall ins.	Total ins.
2	Fallow	1	0-12	1.69	1.83			
			13-24	.61	1.86			
			25-36	.82	1.48			
			37-48	1.06	1.39			
			Total	4.18	6.56			
3	Wheat on fallow	2	0-12	1.89	.00	1.89		
			13-24	1.69	.08	1.61		
			25-36	1.50	.66	.84		
			37-48	1.48	1.01	.47		
			Total	6.56	1.75	4.81	10.76	15.57
1	Wheat on 2nd crop	3	0-12	3.25	.42	2.83		
			13-24	1.15	.88	.27		
			25-36	1.27	1.55	- .28		
			37-48	1.20	1.60	- .40		
			Total	6.87	4.45	2.42	10.76	13.18

Continued.

Table No. 20 - Cont'd.

MOISTURE AVAILABLE FOR CROP GROWTH IN FOUR FOOT COLUMN OF SOIL
GOODLANDS DISTRICT EXPERIMENTAL SUBSTATION 1953.

Field No.	Crop	Rotation Year	Depth in inches	Available Moisture		Moisture Used By Crop		
				Spring ins.	Fall ins.	From soil ins.	Rainfall ins.	Total ins.
D	Fallow	1	0-12	1.80	1.67			
			13-24	.89	1.48			
			25-36	.45	1.35			
			37-48	.52	1.42			
			Total	3.66	5.92			
B	Wheat on fallow	2	0-12	2.25	.41	1.84		
			13-24	2.31	.05	2.26		
			25-36	2.74	.69	2.05		
			37-48	2.64	.94	1.70		
			Total	9.94	2.09	7.85	10.76	18.61
C	Hay-Break	3	0-12	1.34	.57			
			13-24	.80	.96			
			25-36	.20	1.13			
			37-48	.20	1.37			
			Total	2.54	4.03			
A	Barley	4	0-12	2.39	.45	1.94		
			13-24	1.36	.04	1.32		
			25-36	1.31	.22	1.09		
			37-48	1.11	.66	.45		
			Total	6.17	1.37	4.80	10.76	15.56

Table No. 21

MOISTURE AVAILABLE FOR CROP GROWTH IN FOUR FOOT COLUMN OF SOIL
HARGRAVE DISTRICT EXPERIMENT SUBSTATIONS

Field No.	Crop	Rotation Year	Depth in inches	Available Moisture		Moisture Used By Crop		
				Spring ins.	Fall ins.	From soil ins.	Rainfall ins.	Total ins.
1	Fallow	1	0-12	2.45	1.87			
			13-24	1.44	1.66			
			25-36	1.29	1.16			
			37-48	1.34	1.09			
			Total	6.52	5.78			
7	Wheat on fallow	2	0-12	2.39	.90	1.49		
			13-24	2.52	.13	2.39		
			25-36	2.63	.35	2.28		
			37-48	2.83	.95	1.88		
			Total	10.37	2.33	8.04	9.62	17.66
6	Barley Seed to hay	3	0-12	2.50	1.26	1.24		
			13-24	1.78	.60	1.18		
			25-36	1.39	1.25	.14		
			37-48	1.33	1.35	- .02		
			Total	7.00	4.46	2.54	9.62	12.16
3	Hay	4	0-12	2.69	.42	2.27		
			13-24	1.46	.42	1.04		
			25-36	.66	.57	.09		
			37-48	.65	.62	.03		
			Total	5.46	2.03	3.43	9.62	13.05

Continued.

Table No. 21 - Cont'd.

MOISTURE AVAILABLE FOR CROP GROWTH IN FOUR FOOT COLUMN OF SOIL
HARGRAVE DISTRICT EXPERIMENT SUBSTATIONS

Field No.	Crop	Rotation Year	Depth in inches	Available Moisture		Moisture Used By Crop		
				Spring ins.	Fall ins.	From soil ins.	Rainfall ins.	Total ins.
2	Pasture	5	0-12	1.42	1.05	.37		
			13-24	1.03	.07	.96		
			25-36	.90	.30	.60		
			37-48	.97	.44	.53		
			Total	4.32	1.86	2.46	9.62	12.08
8	Sod Breaking	6	0-12	2.01	1.63			
			13-24	1.05	1.16			
			25-36	.63	1.25			
			37-48	.48	1.16			
			Total	4.17	5.20			
5	Wheat on Breaking	7	0-12	2.32	.75	1.57		
			13-24	1.79	.64	1.15		
			25-36	.89	.96	- .07		
			37-48	1.25	1.09	.16		
			Total	6.25	3.44	2.81	9.62	12.43
4	Oats on 2nd Crop	8	0-12	1.91	1.10	.81		
			13-24	1.39	.36	1.03		
			25-36	1.31	.86	.45		
			37-48	1.30	1.10	.20		
			Total	5.91	3.42	2.49	9.62	12.11

No. 5 on the Boissevain Substation reveals that moisture conditions in the fall were close to the wilting point. A slight variation in the moisture of the soil taken from different holes would account for the difference in moisture showing slightly more favorable conditions in the fall. These variations are too small to be of any consequence. The important thing to note in regard to the crop grown on fields No. 1 and 5 is that it was maintained almost entirely from moisture that fell as rain, and not by soil moisture. The moisture derived from the soil for wheat on breaking on field No. 2 was greater than that derived from the soil for wheat on fallow on field No. 7. The decaying alfalfa roots in the first crop after breaking greatly facilitate the downward movement of water and at the same time provide organic matter which increases the water retention properties of the soil.

The total rainfall recorded on the Goodlands District Experiment Substation from the time of the spring sampling to the date of the fall sampling was 10.76 inches. In the fallow field (No. 20) in the two-year fallow, wheat rotation, the available moisture stored for the period was 2.16 inches; in the three-year fallow, wheat, wheat rotation 2.38 inches was stored in the fallow field (No. 2), and in the four-year mixed-farming rotation 2.26 inches of available moisture was stored in fallow field D. There was some loss of moisture in field D in the first foot but in the other two fallow fields there was a storage of moisture. In the two and three year rotations the trash is left on the surface but in the four year rotation the trash is turned under by ploughing. It is interesting to note that the greatest amount of available moisture used for crop growth was in field B for wheat on fallow in the four year mixed farming rotation and this amounted to 7.85 inches. This compares to 5.18 inches of available moisture used in the two-year rotation and 4.81 inches in the three-year rotation. In the hay and break field (C) in the four-year mixed farming rotation the beneficial effect of ploughing down sweet clover can be noted by the substantial increase in soil moisture amounting 1.49 inches to a depth of four feet. The loose, open structure of the first foot due to ploughing down sweet clover can be attributed to the decrease in available moisture in the first foot at the time of the fall sampling.

The total rainfall that fell at the Hargrave District Experiment Substation amounted to 9.62 inches for the period between the spring sampling date on May 14th to September 9th. In the fallow field (1) there was an apparent decrease in available moisture from spring to fall samplings. This field was adjacent to the pasture field and the animals were allowed to tramp it hard. The sod-breaking field 8 showed an increase of 1.03 inches of available moisture out of the 7.63 inches that fell between the time of breaking and fall sampling. The amount of moisture available for wheat on fallow field 7 amounted to 8.04 inches and for wheat on breaking on field 5 amounted to 2.81 inches. On the whole the supply of moisture available for crops on the Hargrave Substation was more plentiful than on the other two stations.

An examination of the available moisture data for the fall sampling indicates that both the cereal crops and the forage crops draw on the available moisture supply down to a depth of about two feet. Below the two foot level there appears to be a gradual increase in the amount of available moisture.

VI. CROP ROTATION YIELDS ON THE SUBSTATIONS STUDIED:

A crop rotation is the practice of growing a series of different crops upon the same land in a definite order, and in a succession that is recurring. Rotations vary in length depending upon the needs of the farm.

A well-designed crop rotation is one that will contribute to each individual farm enterprise, maintain soil fertility, and efficiently utilize the supply of available moisture.

Crop yields have been recorded for the rotations under study on the Boissevain, Goodlands and Hargrave Substations since they were established. The yield data and moisture required to produce a crop in 1953 are recorded in Table No. 22. It was impossible to obtain crop yields at the sites where the soil moisture samples were taken. This would have been a good procedure from a sound statistical standpoint, but not feasible in the operation of a District Experiment Substation where the operator wishes to cut his grain as soon as it is ready. For this reason the average yield of grain for the entire field is given.

On the average, crop yields have been higher in the mixed farming rotations where grass and legume crops are included in the cropping program. This point is well illustrated with reference to the Goodlands Substation where an adapt comparison is made and outlined in Table Number 22, between a two or three-year grain growing rotation and a four year mixed-farming rotation.

VII. General Summary:

The investigations conducted in this study and the statistical analysis of the results, confirm the observations that there is a significant difference in the efficient utilization of soil moisture in producing crops under the different cropping rotations. It is concluded that careful thought must be given to climatic factors when designing a cropping system for a region. Soil moisture and soil fertility are two important natural resources from the standpoint of crop production. Proper utilization and conservation of these two factors are of prime importance in maintaining a permanent

Table No. 22

YIELDS AND WATER REQUIREMENT OF CROPS:
DISTRICT EXPERIMENT SUBSTATIONS 1953.

Rotation Year	Crop and Field	Average Yield Per acre Bus.	Average Yield Per acre Tons.	Average Years	1953 Yield Bus.	1953 Yield Tons.	Inches of Moisture Used By Crop 1953. From Soil	Rainfall	Total
Boissevain Eight-Year Rotation:-									
2	Wheat on Fallow (7)	25.6		8	27.0		3.64	9.24	12.88
3	Oats 2nd Crop (1)	28.4		6	40.3		.15	9.24	9.39
4	Hay 1st Year (5)		.95	8		.63	.65	9.24	9.89
5	Pasture (4)		1.29	4		1.27	2.57	9.24	11.81
7	Wheat on Break (2)	24.0		8	28.6		4.62	9.24	13.86
8	Wheat 2nd Crop (6)	20.0		1	20.0		1.39	9.24	10.63
Goodlands - Two-Year Rotation:-									
2	Wheat on Fallow (21)	23.8		16	26.0		5.18	10.76	15.94
- Three-Year Rotation:-									
2	Wheat on Fallow (3)	23.8		16	25.0		4.81	10.76	15.57
3	Wheat 2nd Crop (1)	17.0		16	14.0		2.42	10.76	13.18
- Four-Year Rotation:-									
2	Wheat on Fallow (B)	27.0		16	26.4		7.85	10.76	18.61
4	Barley on Break (A)	36.4		16	30.8		4.80	10.76	15.56
Hargrave Eight-Year Rotation:-									
2	Wheat on Fallow (7)	30.5		13	30.6		8.04	9.62	17.66
3	Barley 2nd Crop (6)	33.4		13	28.0		2.54	9.62	12.16
4	Hay 1st Year (3)		1.3	13		1.6	3.43	9.62	13.05
5	Pasture (2)		1.0	1			2.46	9.62	12.08
7	Wheat on Break (5)	27.6		12	30.7		2.81	9.62	12.43
8	Oats 2nd Crop (4)	48.6		13	52.2		2.49	9.62	12.11

agricultural economy in a region of limited precipitation.

It is important to use good cultural practices during the fallow and sod-breaking years of the eight-year mixed-farming rotation in order to restore the moisture supply. This can be accomplished in a season where the precipitation is comparable to 1953. Reference to Table No. 22 indicates that yields were above the average on the Boissevain substation. It will be noted that the amount of moisture derived from the soil and used by the crop was low. Rainfall was not heavy on the Boissevain Substation in 1953, but it came at very timely intervals during June and produced good stands of grain.

From the standpoint of moisture use, the eight-year rotation utilized the available moisture in an efficient manner and for this reason it can be recommended as being adaptable to climatic conditions of south-western Manitoba. During periods of drought that occur in the region, this rotation would supply more feed for livestock than the wild pasture would.

A disadvantage of the two-year fallow, wheat rotation, and the three year fallow, wheat, wheat rotation, is the long period of non-productivity that elapses during moisture storage. It appears that some other factor, other than moisture, is involved as yields of grain are not as high on the shorter grain rotations as on the mixed-farming rotations. The results of comparing the relative soil moisture indicate that the moisture supply is not as nearly depleted on the grain rotations as on the mixed-farming rotations, and at the same time, grain yields are not as high on the former as on the latter.

On the Hargrave Substation moisture conditions are sufficient to maintain a high level of crop yields under the eight-year program. The eight-year rotation would be more practical than the shorter grain rotations in the area represented by this Substation. In depressions accumulations of salts are found. Alfalfa and brome hay crops will greatly assist in keeping the soil moisture at a lower level and will also assist in alleviating the alkaline condition.

VIII. CONCLUSIONS:

1. The method of studying soil moisture from the relative moisture standpoint and the application of statistical methods, has proven to be a successful approach to the problem of assessing the relative moisture efficiency of cropping practices under study on District Experiment Substations in south-western Manitoba.

2. Laboratory determinations of the moisture equivalent confirm that there is considerable variation in texture among fields and depths, particularly on the Boissevain Substation. These differences in texture produce differences in the amount of water available for crop growth.

3. There was a very significant difference in the relative soil moisture among fields and depths within rotations in all cases and between samples taken in the spring and fall.

4. The moisture content of soils falling into the relative moisture groups as outlined in this study may be classed as wet, moist, intermediate, dry, and powder dry.

5. The results of this study indicate that the eight-year mixed-farming rotations and the shorter term four-year rotation at Goodlands are properly designed to coincide with the moisture conditions of the region.

6. The average precipitation of south-western Manitoba is sufficient to warrant the inclusion of grass and legumes in the cropping rotations.

Proper management methods must be employed in breaking so that adequate moisture can be stored in the soil profile to compensate for what has been used by the grass and legume crops.

7. The results of this study indicate that wheat in the rotations studied draws moisture chiefly from the top two feet of soil. The amount of available moisture at the time of fall sampling showed a slight increase below two feet in fields that were under cereal crops.

8. The most outstanding conclusion as a result of this study is that under field conditions crops utilize the soil moisture from below the "calculated" wilting point. This is a very important result and helps to explain the reason for relatively good crops of wheat in south-western Manitoba when soil moisture appears to be in a short supply.

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