A STUDY OF THE CLIMATE, SOILS AND GROUNDWATER IN THE MORDEN-WINKLER AREA AS THEY RELATE TO FEASIBILITY OF IRRIGATION

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FLOYD H. WILSON

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A STUDY OF THE CLIMATE, SOILS AND GROUNDWATER IN THE MORDEN-WINKLER AREA AS THEY RELATE TO FEASIBILITY OF IRRIGATION

I. INTRODUCTION:

There are many areas of the world where insufficient moisture makes crop production impossible. There are other areas where moisture may be deficient only during certain periods of the year or only in certain years. In either instance irrigation may be used to increase the amount of water available to the crop and to reduce the variation in water supply in order to increase production or to allow a greater latitude of crops to be grown. Before irrigation is practiced the need for irrigation and the suitability of the soil should be carefully evaluated. Many areas have been damaged or destroyed because of unwise irrigation practices and failure to recognize and accommodate for limitations imposed by soil characteristics. The most common hazard is salinization caused by use of water high in soluble salts, by inadequate drainage, or by a combination of these two factors. Other hazards such as high sodium content, high boron content, inadequate permeability, inadequate or excess water-holding capacity and shallow depth of permeable material may be locally important.

Since irrigation is under consideration in the Morden-Winkler area of Manitoba, a study was undertaken to determine the suitability of the soils for irrigation. This study included a detailed soil survey by the Manitoba Soil Survey and deep-drilling by the Canada Department of Agriculture, Research Branch, Lethbridge, to determine the properties of surface and subsurface soils as they relate to irrigation. Some of the results obtained in these studies are presented although this thesis deals in particular with the fluctuations in groundwater, the distribution of salts in three areas where it was considered they might be a problem under irrigation, and the effect of a frozen layer on moisture status and the movement of soluble salts in three locations during one season.

II. REVIEW OF LITERATURE:

A. Climate

Climate is a major factor in determining the benefits to be derived from irrigation of an area. Whether greater or more desirable growth will result from the application of additional water is usually correlated with the moisture deficit of the area, which is a function of precipitation and evaporation. Temperature and length of growing are also important in assessing the need for irrigation (11).

Moisture deficiency, which is the difference between precipitation and the need, can be estimated by different means. The need is determined by potential evapotranspiration. Thornthwaite (40) has used mean temperatures for estimating potential evapotranspiration. Pelton et al. (27) state that errors in this method arise from thermal lag, the effect of moisture availability on air temperature, and the effect of advection; and is not suitable for short-period estimates of potential evapotranspiration. They suggest, however, that the method can be used advantageously for monthly, growing-season, and annual potential evapotranspiration estimates.

B. Factors Affecting The Suitability Of Soils For Irrigation

In assessing the suitability of a soil for irrigation, the water-holding capacity, the permeability and hydraulic conductivity, the salinity, and the exchangeable sodium percent, are usually considered as well as the depth of permeable material, the water table if present, and the topography.

The lower limit of water availability to a plant in nonsaline soil is the wilting percent. The fifteen-atmosphere percentage is usually accepted as closely approximating the wilting percentage. This lower limit appears to be an intrinsic property that is largely determined by soil texture, nature of minerals, and organic matter content. The upper limit of available water depends not only on soil texture but on variations throughout the soil profile of such factors as pore size distribution and water conductivity (32). However, for most medium to fine textured soils, the upper limit of available water is approximately twice the moisture percentage of the lower limit (32). Over a considerable textural range the saturation percentage is approximately four times the fifteen-atmosphere percentage. Thus the saturation percentage can be used to supply information on soil texture and moisture retention. It is also the lowest feasible moisture content directly related to the field moisture range from which the moisture is easily extracted for salinity measurements.

It is well known that excess soluble salts produce harmful effects to plants by increasing the osmotic pressure of the soil solution. It is the total concentration of solute particles in solution rather than their chemical nature which is mainly responsible for the inhibitory effects of salts on plant growth. Plant growth is a function of total soil moisture stress, which is the sum of the soil moisture tension and the osmotic pressure of the soil solution so that, at a given soil moisture tension soluble salts decrease the amount of water available to plants. The salt content above which plant growth is affected depends on the texture of the soil, the distribution of salts in the profile, the species of plants, and to some extent, the composition of the salt. A soil is usually considered saline if the electrical conductivity (Ec) of a saturation soil extract is equal to or greater than 4 millimhos per centimeter and the exchangeable sodium percent (E.S.P.) is less than fifteen percent. A nonsaline soil has an Ec less than four millimhos per centimeter and an E.S.P. less than 15 percent.

Sodium ions may replace calcium and magnesium on the exchange complex if the sodium concentration in the soil solution becomes great enough. As water is lost through evaporation and evapotranspiration calcium and magnesium may be precipitated thus leading to increased adsorption of sodium on the exchange complex. This may result in adverse physical conditions such as low aggregate stability, slaking, low permeability, and crust formation. If the ratio of exchangeable sodium to the cation exchange capacity expressed as a percent is in excess of 15, the soil is considered to be an alkali soil. However, in soils containing alkaline earth carbonates and gypsum it is not possible to determine the amount of exchangeable sodium at moisture contents similar to those which occur in the field. This is because under these conditions dilution decreases the amount of exchangeable sodium and results in a corresponding increase in exchangeable calcium and magnesium. Some success has been attained in relating the total concentration of soluble cations in the saturation extract of soils to the exchangeable cation composition (32). Where Na^{+}, Ca^{++}, and Mg^{++} concentrations are expressed in milliequivalents per liter the sodium adsorption ratio (S.A.R.) may be calculated as follows:

$$S.A.R.= \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

The relation between S.A.R. and E.S.P. is sufficiently good that S.A.R. is useful in estimating probable harmful effects of sodium.

The effect of exchangeable sodium on soils is influenced by texture, surface area and type of clay mineral, potassium and soluble silicate status, and organic matter (32).

Hydraulic conductivity is the effective flow velocity or discharge velocity of water in a soil at unit hydraulic gradient, i.e.; when the driving force is equal to one gravity. It is expected that if the hydraulic conductivity is as low as 0.1 centimeters per hour (0.04 inches per hour) the soil is not suitable for irrigation (32). There should be no restrictions in permeability for a depth of 10 to 12 feet in a good irrigation soil as accumulation of water above slowly permeable material could result in eventual salinization by upward movement of salts.

C. Water And Salt Movement

(1) Water Movement

Translocation of salts is dependent primarily on water movement in the liquid phase. Movement of water in the vapor phase can result in condensation and further movement in the liquid phase. Trenel and Lundner (42) found that condensation and diffusion resulted in movement of 0.18 to 0.35 mm in spring, 0.28 to 0.7 mm in summer and 0.07 to 0.13 mm in autumn from the 5-10 centimeter layer of soil to deeper layers. Of these amounts, an average of 0.023, 0.013 and 0.055 mm condensed per night from the atmosphere in the spring, summer, and autumn respectively; and up to 0.13, 0.2 and 0.15 mm per night in spring, summer and autumn respectively moved to the surface in the vapor form due to temperature and vapor pressure gradients.

Bouyoucos (6) indicated that there was no rising of vapor during the night from warm soil below to a cool soil above, with which Lewis (38) was in agreement. The relative importance of vapor movement is indicated by Shaw (34) who suggests that the amount of water moved through the soil as vapor is negligible compared to liquid movement.

Downward movement of liquid water varies directly with the content of large pores and inversely with the tension required to drain these pores (3). Under field conditions soils are usually not uniform with depth and any porosity change will affect the rate of water flow. If fine materials are encountered the rate of advance may be slowed by resistance to flow of the extremely fine pores. If coarse materials are encountered, water movement stops until the soil becomes nearly saturated (15). Resistance to flow is also afforded by entrapped air (10).

Capillary movement is dependent upon a large number of air-water interfaces. Maximum movement takes place at or near saturation and decreases rapidly with moisture content to about the moisture equivalent where movement is very slow (5, 24, 46). This is the moisture content at which moisture films become discontinuous.

Theoretical concepts of capillarity suggest that water can rise for a considerable distance but in practice this does not seem to occur. Gardiner and Fireman (16) suggest that upward movement from 25 to 30 feet is possible provided sufficient time is allowed. King (17) found that moisture losses at the surface caused capillarity to act through a distance of 10 feet in 10 days. Shaw and Smith (35) indicated that little water will be lost if the water table is below 10 feet from the surface. Jackson, Blackburn, and Clark (20) found capillary movement quite marked through three feet of sand but almost insignificant through four feet. Romistroff (4) indicates that once water has penetrated beyond 16 to 20 inches it does not return to the surface except by way of plant roots. This has been substantiated at Rothamsted Experimental Station (7). Bouyoucos (7), using plaster of Paris blocks, detected no rise of water from a water table to the surface. Doering (13) by direct measurement, found an upward movement of 0.036 inches per day under fallow and 0.146 inches per day under a thin stand of morning glory from a depth of five feet with climatological conditions that produced an average evaporation of 0.34 inches per day.

(2) Salt Movement

(i) Downward Movement

Leaching of salts has been demonstrated by many workers. Thomas (39), in the Imperial Valley of California, found that when drainage was improved salts could be leached out of the root zone. Reeve (31) in Utah showed salt reductions with application of 1, 2, and 4 feet of irrigation water. Wheat yields increased 10.2, 8.8 and 4.7 bushels per acre for each foot of irrigation water applied to clay loam, silty clay loam and clay soils. Larson (21) in Washington found that after applying 4 to 6.73 feet of water in 1937 and 3.6 to 6.0 feet in 1938, salinity was reduced sufficiently to allow good crops of sugar beets, barley, and alfalfa to be grown. Heald (18) increased yields of sugar beets from 4 to 25, 30, and 32 tons per acre by applying 12, 17, and 24 inches of irrigation water respectively. Sandoval (33) found that by impounding runoff water salinity was reduced. He also found that the more soluble the salt the deeper it occurred in the soil.

(ii) Upward Movement

Upward movement of salts has also been demonstrated by many researchers. Sandoval (33) has attributed salinization of ridges to upward movement of capillary water containing salts. Matzek (22) attributed formation of Solonchak soils in North Dakota to upward movement of salts from a formerly high water table. Redman and McLelland (30) also report that Solonchaks occupy the ridges, and that lime content of the "A" plus "Ca" horizons is greater than the lime content of the "C" horizon. This is probably due to upward movement of lime. They also report that saline areas and high-lime areas became larger under cultivation due to increased evaporation. Similar results were reported by Ballantyne (2) who found that where slopes decreased there was a salt accumulation due to downslope water movement. Areas adjacent to sloughs were usually less saline than areas where slopes decreased. The highest salinity occurred near the surface of the soil profile suggesting upward movement of water containing salts. Wadleigh and Fireman (44) in irrigating saline plots with nonsaline water, and nonsaline plots with water of known salinity, found accumulations of salt (up to five to six percent) in the ridges and nonsaline soil in a pocket beneath the furrow. Accumulation of salt was greater in the ridges when irrigations were more frequent.

D. Frost

Storey (37) has described four types of frost; concrete, honeycomb, stalactite, and granular frost.

Concrete frost has been observed most frequently in cultivated fields. As little as one inch of soil concretely frozen is relatively impermeable to water but other frost structures seem to have little effect on water movement into or throughout a soil (37). Post and Dreibelbis (28) found that concrete frost formed when freezing was greater than three inches and that percolation was materially reduced or ceased entirely. This has been substantiated by Augustine (1), Trimble et al. (43), and Stoecketer and Weitzman (36). However, concrete frost becomes quite friable and permeable to water before it melts completely (43).

Mosiyenko (25) found that soils in which all pores were filled with ice due to presence of excess moisture during freezing were impermeable to water until thawing began. Permeability of a medium clay loam soil is restored when its moisture content falls below 60 to 65 percent of field moisture content.

Frost penetration is more rapid and its disappearance slower under bare conditions than under grass and surface mulches (4). This is because bare soils freeze to a greater depth. Frost penetration is seldom uniform even in places a few feet apart due to variability in microphysical environment. Willis (45) at Mandan, N.D., found that dry soils freeze deeper and faster than wet soils due primarily to a lower heat capacity. Penetration of frost can also be influenced by the depth of snow cover. Crawford and Legget (12) found that undisturbed snow reduced frost penetration an average of one foot for each foot of snow. Storey (37) states that 24 inches of snow can prevent frost penetration. If the snow cover is deeper than 24 inches, frozen soils may thaw from the bottom upward.

E. Geology Of The Morden-Winkler Area

During the Pleistocene era a till was deposited unconformably by the ice mass on the bedrock formation of the area. This till is associated with glacio fluvial deposits of sand and gravel derived from the melt waters of the retreating glacier. Upon this was laid lacustrine deposits of Glacial Lake Agassiz. The clay is of variable thickness although an average depth is about 125 feet, gradually thinning to the west where it approaches the abrupt rise of the bedrock at the Manitoba Escarpment (9). Over the major part of the map area lies sandy and silty deltaic deposits. A few low sandy beaches from which the clay has been removed by wave action of Lake Agassiz, may be observed running north - northwestward to south - southeastward. In some places, these deposits have been covered with clay and weathered shale outwash deposits by streams that flowed from ravines in the Manitoba Escarpment (14).

A noteable surface feature of the area is the Winkler Escarpment corresponding to the 900-foot contour. The surface deposits above this contour tend to be coarser in texture than those below. The depth of permeable material and the surface slope are also greater above the escarpment.

F. Origin Of Saline Soils

The origin, and to some extent the direct source of all the salt constituents are the primary minerals found in soils and exposed rock of the earth's crust, although there are probably few instances where sufficient salts have accumulated in place from this source alone to form a saline soil (32). DeSigmond (29) considers three factors necessary in the formation of a saline soil: (1) an arid climate, (2) an impermeable subsoil, (3) meteorological conditions which bring the soil periodically under the influence of excessive moisture. Richards (32) mentions a fourth factor, namely; irrigation. Saline soils are practically nonexistant in humid areas; in arid and semi-arid areas there is less water available for leaching, and because of high evaporation, salts may tend to concentrate in soils and surface waters.

Salinity of the underlying till in the Morden-Winkler area is attributed by Charron (9) to water from the saline bedrock being forced by artesian pressure into the sands and gravels associated with the till above. Numerous saline artesian and flowing wells occur in the area but due to the thickness and impermeability of the overlying clay surface salinity is not attributed to this source. Pratt (29) attributes salinity of the area to seepage and runoff from cretaceous shales of the Manitoba Escarpment, the salts accumulating where internal drainage is impeded by heavy textured subsoils.

III. INVESTIGATIONAL PROCEDURE:

A. Climatic Investigations

(1) Precipitation, Temperature, And Moisture Deficiency

Precipitation and temperature figures were obtained from the 1961 monthly meteorological reports (8) by adjusting the given monthly averages by the amount they deviated from the long-term average. Moisture deficiencies were calculated using Thornthwaite's tables (41).

Probable moisture deficiencies are estimated by multiplying the average daily evaporation by the days in each month in which the moisture is inadequate. Moisture deficiency days are estimated by allowing five days of adequate moisture supply following a rain of 0.25 to 0.49 inches; 10 days after a rain of 0.50 to 0.99 inches; 15 days after a rain of 1.00 to 1.99 inches; and 20 days after a rain of 2.00 inches or more. Days after rains are accumulative to a maximum of 20 days for any one period after a rain of 0.25 inches or more. This method has been used in North Dakota* and should apply similarly to Southern Manitoba. The average growing season temperatures at Morden and Jamestown, N.D., differ by less than one degree Fahrenheit. The average yearly precipitation between the two locations differ by less than one inch and the average growing season precipitation differs only by 0.22 of an inch.

(2) Length of Growing Season

The length of growing season data was obtained from the Dominion Experimental Farm, Morden, Manitoba.

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* Definite plan report on Garrison Diversion Unit Missouri River Basin Report, Missouri-Souris Projects Office, Bismarck, North Dakota, 1961.

B. B. Field Investigations And Collection Of Samples

(1) Soil Survey

Soils were mapped in detail on a series level. Five foot-traverses were made through each section; ten or more profile observations were made on each traverse depending upon photographic pattern, elevation changes, and differences in vegetative growth. When crystalline gypsum, pseudomycelium, salt crusts and/or poor vegetative growth were observed, the location was marked on the photograph. Surface and subsurface samples were taken at approximately one-third of these marked locations for electrical conductivity measurements to determine the magnitude of salinity.

(2) Deep Drilling

Concurrent with the soil survey, borings were made to a depth of 10 to 12 feet on a two-mile grid system. Samples were taken at one-foot intervals (two-foot intervals where subsoils appeared uniform) to a depth of 10 to 12 feet or until clay was encountered. These samples were hand textured, placed in quart sealers and taken to the laboratory for analysis. Based on these results, additional borings were made in areas that appeared saline, areas with restricted permeability and in areas in which the lighter sediments were underlain by clay at shallow depths.

(3) Surface Sampling

Additional surface samples were taken in three areas where additional information was required as to the extent and degree of salinity. One composite sample of the 0- to 3-foot depth was taken at each sampling site. Each site represented 25 to 30 acres.

(4) Groundwater Wells

To check groundwater depths and fluctuations, wells consisting of 3-inch galvanized downspouts with diagonal slits to allow entrance and exit of water, were installed throughout the area on different soil types. The depth to the water table was recorded approximately once every two weeks during the spring and once a month thereafter. Water samples were taken periodically for Ec measurements.

(5) Movement Studies

Three plots were located in October, 1961, on the Neuenberg soil series. Two of these plots were located on cultivated land at the north-center of Sec. 2, Twp. 2, Rge. 4 W, on the east and west side of an accumulation of blown soil. These plots were designated as "east" and "west". The third plot was located approximately ½ mile north, near the center ofSec. 11, Twp. 2, Rge. 4W, on permanent grass. A well was installed in each plot. Samples were taken by horizons until the "C" horizon was reached; then by 6-inch intervals to a depth of about 150 inches. These samples were analysed for Ec and nitrates, and percent moisture and field capacity were determined. In the spring of 1962 sampling to the groundwater level, as determined by depth to the water in the wells, commenced on April 26, and was repeated on May 2, 8, 16, 21; June 1, 5, 11, 18, 27; July 5, 16, 20; August 13, 27; September 10, 25; October 11, and November 12.

These samples were packed in moisture tins, a thermometer was inserted and the temperature recorded. Moisture percentages were determined on the samples prior to grinding to pass a 2 mm sieve. The following analyses were conducted: Ec of the saturation extract, and, on the samples from the cultivated plots, nitrates, and Ec of 1:5 extract.

Excess soil not used for samples was returned to the hole and the remainder of the hole filled with soil from outside the plot area.

On April 30, 1962, the east plot was seeded to wheat and fertilized with 27-14-0 at a rate of 100 pounds per acre. The west plot was planted to potatoes May 9, 1962, and fertilized with 14-4-7 at a rate of 325 pounds per acre. The potatoes were harvested September 15, 1962; the wheat was swathed in the first week of August 1962.

C. Laboratory Investigations

(1) Samples Taken During Deep Drilling

The samples were first dried (105 - 110° C) then mechanically ground and mixed. A saturated soil paste was made by adding distilled water and stirring mechanically until the soil flowed slightly when the container was tipped and the surface glistened as it reflected light.

(i) Saturation Percent - a portion of the saturated soil paste was dried at 110°C and the moisture content determined as in method 2b (32).

A saturation extract was obtained from the remainder of the saturated soil paste by filtration under suction. Electrical conductivity, sodium, and calcium plus magnesium was determined by the following procedures.

(ii) Electrical Conductivity of the Saturation Extract - Electrical resistance of the saturation extract was measured using a Model RC 16B2 conductivity bridge and a pipette type conductivity cell with platinum electrodes. Ec was calculated by dividing the cell constant by the measured resistance.

(iii) Sodium - Sodium was determined using a flame photometer as in method 10, (32).

(iv) Calcium plus Magnesium - These elements were determined by titration with Versenate as in method 7, (32).

(v) Disturbed Hydraulic Conductivity - Disturbed hydraulic conductivity was determined on dried samples ground to pass a 2 mm sieve as described in method 34b, (32).

(2) Samples Taken For Movement Studies

Samples taken during the first sampling (October 1961) were air dried and ground with a wooden roller to pass a 2 mm sieve. Field capacity was estimated on these samples using a pressure plate apparatus at 1/5 atmosphere tension.* The rest of the samples were oven dried and mechanically ground and the following analyses conducted:

(i) Conductivity of the 1:5 extract - Ec was measured on water extracts obtained after shaking 20 grams of soil with 100 millileters of distilled water in pint bottles for 30 minutes on a mechanical shaker. Following shaking the soil was allowed to settle for five minutes and then filtered. The first filtrate was discarded and Ec determined on the second portion by the method cited in III C (1) (ii).

(ii) Nitrates - Nitrates were determined by Harper's modification of the colorimetric phenoldisulphonic acid method.

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* Results obtained by Dr. M.A. Zwarich, Dept. of Soil Science, University of Manitoba, indicated that field capacity of very fine sandy loam soils in the Morden-Winkler area was more closely approximated by 1/5 atmosphere tension than by 1/3 atmosphere tension.

IV. FIELD AND LABORATORY ANALYSIS AND DISCUSSION OF RESULTS:

A. Climate

(1) Temperature, Precipitation, And Moisture Deficiency

Average annual percipitation in the Morden area is 20.58 inches of which 12.35 inches falls during the growing season (May to September). The growing season precipitation falls chiefly as local thunderstorms so the amount of rain received may be quite variable. The highest annual precipitation was the 27.20 inches which fell in 1944; the lowest was 10.85 inches (1920). Temperature, precipitation, and moisture deficiency data for Morden are shown together with similar data for three other Western Canadian stations(Table 1).

Table 1

Average Monthly Temperature, Precipitation, And Moisture Deficiency Of Four Western Canadian Locations

	Temperature (F°)				Precipitation (Inches)				Moisture Deficiency (Inches)			
Month	Leth-bridge	Medicine Hat	Indian Head	Morden	Leth-bridge	Medicine Hat	Indian Head	Morden	Leth-bridge	Medicine Hat	Indian Head	Morden
Jan.	18.2	13.7	1.8	3.2	.67	.72	.75	.97	.67	.72	.75	.97
Feb.	19.4	16.0	5.5	7.3	.78	.68	.71	.92	.78	.68	.71	.92
Mar.	29.0	28.0	18.6	21.3	1.19	.82	1.00	1.37	1.19	.82	1.00	1.37
Apr.	42.0	44.3	37.6	38.7	1.34	.99	.86	1.39	.04	-.39	.17	.70
May	51.9	55.2	51.0	53.0	2.07	1.53	1.70	2.26	-1.12	-1.66	-1.09	- .93
June	57.5	62.4	59.6	62.6	2.92	2.28	3.21	2.98	-1.16	-2.21	-1.28	-1.51
July	65.4	70.2	66.1	69.2	1.67	1.38	2.05	2.81	-2.84	-4.37	-3.29	-2.94
Aug.	62.9	66.6	63.2	66.4	1.30	1.39	1.89	2.19	-3.20	-3.49	-3.04	-2.69
Sept.	53.8	55.9	52.6	56.4	1.17	1.51	1.42	2.11	-1.09	-1.67	-1.12	- .75
Oct.	44.9	45.8	40.6	43.8	1.12	.72	.94	1.40	- .54	- .66	- .16	.30
Nov.	30.7	29.2	21.6	24.6	1.09	.71	1.08	1.19	1.09	.71	1.08	1.19
Dec.	22.0	18.6	8.0	10.0	.82	.82	.73	.99	.82	.82	.73	.99
Growing Season Total (May - Sept.)					9.74	8.09	10.27	12.35	-9.41	-13.40	-9.82	-8.82

Growing season temperatures at Morden are about equal to those of Medicine Hat and greater than those of Lethbridge and Indian Head. The growing season precipitation at Morden is more than at the other stations. This results in a growing season moisture deficit of 8.82 inches which is only six-tenths of an inch less than the deficit at Lethbridge, and 4.58 inches less than that at Medicine Hat. These deficit figures do not take into account soil-stored moisture from snow melt or time distribution of rainfall within the month.

Probable moisture deficiency of the Morden area is shown in Table 2.

Table 2

Probable Moisture Deficiency Of The Growing Season At Morden
(1930 to 1961 Inclusive)

	Month					
Deficit	May	June	July	August	September	Total
Highest...	5.46	8.06	5.88	9.57	4.20	26.45(1961)
Mean	1.18	1.22	1.51	2.03	1.73	7.64
Lowest ...	0.00	0.00	0.00	0.00	0.00	2.33(1956)

The deficit is lower than estimated from precipitation less potential evapotranspiration estimates but is in line with deficiencies of 7.9 and 11.5 inches calculated at the University of Alberta for Lethbridge and Medicine Hat (11).

Soils in Southeastern Manitoba are often at, or near, field capacity at the time of seeding (19, 23). This results in an available moisture content of from 8 to 12 inches of water in the 0- to 4-foot profile. The stored available moisture is approximately equal to the average moisture deficit but this does not mean that irrigation would be unnecessary. Available moisture cannot be completely extracted from soils without crop suffering, especially if the soil contains soluble salts. Many crops such as potatoes, onions, celery, and brome grass do not root to the four-foot depth. Other crops, such as peas, cannot tolerate high moisture stresses. Plants like alfalfa, although they grow well at less than optimum soil moisture content, are able to respond to additional moisture. Data from Vauxhall, Alberta, indicates that for that area alfalfa requires 24 inches of water, pasture grasses 22 inches, and grains and potatoes 18 inches of water for maximum growth (11). These amounts are from one-and-one-half to two times the total summer precipitation of the Morden area.

(2) Length Of Growing Season

The average dates of the last frost of spring and the first frost of autumn are May 23 and September 21, respectively. The average frost-free period is 121.8 days. The shortest frost-free period on record is 93 days in 1929; and the longest is 146 days in 1944. The average killing frost-free period (above 28°F) is 142.6 days from May 12 to October 1.

B. Characteristics Influencing Irrigation Suitability

The soils have been grouped into moderately coarse, medium, moderately fine, and fine textures. The medium-textured soils have been further divided as very fine sandy loam soils occurring in areas which were large enough to map separately from other medium-textured soils. The guide used in assessing the suitability of the soils for irrigation is shown in Table 3. This is slightly modified from the guide used in Western Canada (26), as it is understood that these standards are used only as guides and therefore judgement in their application and interpretation must be exercised.

Table 3

Classification Standards For Irrigation Suitability

Irrigation class	Saturation percent	Disturbed hydraulic conductivity (ins./hr.)	SAR	Conductivity and depth (mmhos/cm)	
				<2 ft.	>2 ft.
1	40 - 60	0.8 - 4.0	< 6	<4	< 8
2	35 - 65	0.3 - 0.8 or 4.0 - 5.0	< 8	<4	<12
3	30 - 65	0.1 - 0.3 or 5.0 - 7.0	<12	<8	<15
4	< 30 or > 65	< 0.1 or > 7.0	> 12	>8	>15

The properties that relate to irrigation classification of each textural grouping is shown in Table 4. These results are expressed as averages of the number of samples taken in each textural grouping during the deep-drilling procedures.

Table 4

Saturation Percent, Disturbed Hydraulic Conductivity, Sodium Adsorption Ratio, And Electrical Conductivity Of Soil Textural Groupings*

(Data are averages for the number of samples indicated)

Soil texture	Number of samples	Saturation percent	Disturbed hydraulic conductivity (in./hr.)	Sodium adsorption ratio Depth 0 - 3 ft.	Sodium adsorption ratio Depth >3 ft.	Electrical conductivity (mmhos/cm) Depth 0 - 3 ft.	Electrical conductivity (mmhos/cm) Depth >3 ft.
Very fine sand - fine sandy loam	32	42.0	3.0	1.4	1.9	1.4	1.8
Very fine sandy loam	63	45.2	2.3	2.0	2.7	2.8	3.2
Loam, silt loam, very fine sandy clay loam	61	49.4	1.1	2.6	3.5	3.3	4.4
Silty clay loam - clay loam	15	61.0	1.0	3.7	3.5	4.5	4.7
Silty clay - clay	28	70.8	0.5	3.1	5.0	3.4	5.7

* Averages calculated from analysis conducted at Vauxhall, Alberta.

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(1) Saturation Percentage

From Table 4 it appears that the first three textural groups would fall into class 1; the fourth group into class 2; and the fifth group into class 4. It is perhaps more meaningful to show the distribution according to irrigation class, as is shown in Table 5.

Table 5

Distribution Of Textural Groupings In Irrigation Classes On The Basis Of Their Saturation Percentage*

	Percent Distribution In Irrigation Classes			
Soil texture	Class 1	Class 2	Class 3	Class 4
Very fine sand - fine sandy loam	75	25	0	0
Very fine sandy loam	93	7	0	0
Loam, silt loam, very fine sandy clay loam	90	10	0	0
Clay loam, silty clay loam	53	20	0	27
Silty clay, clay	32	14	0	54

* Averages calculated from analysis conducted at Vauxhall, Alberta.

The saturation percentage of the first textural grouping indicates that it is slightly deficient in water-holding capacity. However, all the soils in this textural grouping that are in class 2 have saturation percentages within three percent of the minimum value required for class 1 soils. Over ninety percent of the soils of the second and third textural groupings have been rated as class 1 soils. Therefore, all soils in textural groups one, two, and three have a high rating for irrigation on the basis of saturation percentage. About 50 percent of clay loam - silty clay loam soils are in class 1 on the basis of saturation percentage but this percentage decreases with heavier textures until only about 30 percent are class 1 and over 50 percent class 4 in the clay textured soils.

(2) Disturbed Hydraulic Conductivity

Disturbed hydraulic conductivities are generally suitable particularly in the first three textural groupings although the lighter textures tend to be slightly excessive. The distribution of the samples in the irrigation classes is shown in Table 6.

Table 6

Distribution Of Textural Groupings In Irrigation Classes On The Basis Of Hydraulic Conductivity *

	Percent Distribution In Irrigation Classes			
Soil texture	Class 1	Class 2	Class 3	Class 4
Very fine sand - fine sandy loam	84	16	0	0
Very fine sandy loam	97	3	0	0
Loam, silt loam, very fine sandy clay loam	79	21	0	0
Clay loam - silty clay loam	47	40	13	0
Silty clay - clay	32	39	11	18

* Averages calculated from analysis conducted at Vauxhall, Alberta.

The disturbed hydraulic conductivity results of the first three textural groupings are what would be expected from saturation percentage results as both disturbed hydraulic conductivity and saturation percentage are dependent primarily on soil texture. The percentage of clay to clay loam samples occurring in classes 1 and 2 are higher than what would be expected from saturation percentage results. This is probably due to the good structure and high organic matter content of some of these soils.

(3) Sodium Adsorption Ratio

Although some alkali locations can be found in most textures and sodium adsorption ratio is higher in the heavier textures, exchangeable sodium does not appear to present a problem -- especially in those soils of suitable texture for irrigation. This is illustrated in Table 7.

The effect of exchangeable sodium on light-textured soils are likely to be small due to the porous nature of these soils. High organic matter content of the heavier textured soils would tend to reduce the harmful effects of exchangeable sodium by its favorable effects on physical properties. This has been indicated by the disturbed hydraulic conductivity results which are higher than what would be expected from the saturation percentage results.

Table 7

Distribution Of Textural Groupings In Irrigation Classes On The Basis Of Sodium Absorption Ratios*

(Shown in Percent)

Irrigation class	Allowable sodium adsorption ratio	Soil Textures And Depth									
		Very fine sand-fine sandy loam		Very fine sandy loam		Loam, silt loam, very fine sandy clay loam		Clay loam - silty clay loam		Silty clay - clay	
		0-3ft.	>3ft.	0-3ft.	>3ft.	0-3ft.	>3ft.	0-3ft.	>3ft.	0-3ft.	>3ft.
1	< 6	97	97	94	91	86.5	80.0	91	100	71	59.5
2	< 8	0	0	3	3	9.5	15.0	9	0	26.5	29.5
3	<12	0	0	1.5	4.5	4.0	5.0	0	0	2.5	8.0
4	>12	3	3	1.5	1.5	0	0	0	0	0	3.0

* Averages calculated from analysis conducted at Vauxhall, Alberta.

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(4) Salinity

The results in Table 8 indicate that subsoil salinity increases as the clay content increases, not only in magnitude but also in extent. The same general trend is apparent in surface salinities, with one exception which will be referred to later. Ninety-seven percent of the surface soils with very fine sand - fine sandy loam texture are nonsaline. This percentage decreases with heavier textures to fifty-five percent in clay textured soils. Eighty-six percent of the subsoils with very fine sand - fine sandy loam textures are nonsaline, this percentage decreases with heavier textures until only one-third of the subsoils of clay texture are nonsaline.

Table 8

Average Electrical Conductivity And Distribution Of Samples According To Salinity*

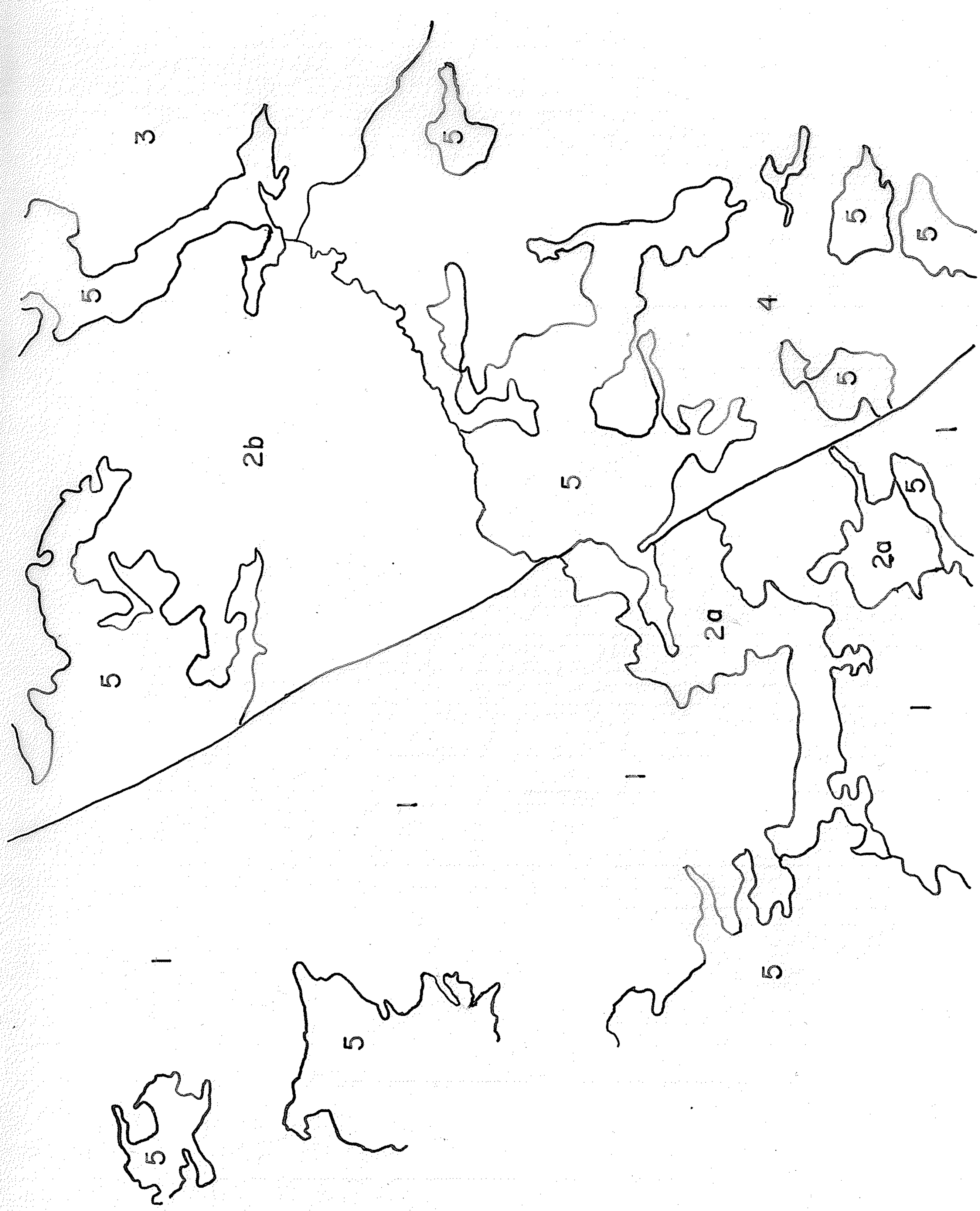
	Electrical conductivity (mmhos/cm)		Percent of nonsaline sampling locations	
	Depth		Depth	
Soil texture	0 - 3 ft.	> 3 ft.	0 - 3 ft.	> 3 ft.
Very fine sand-fine sandy loam	1.4**	1.8	97	86
Very fine sandy loam	2.8	3.2	73	74
Loam, silt loam, very fine sandy clay loam......	3.3	4.4	69	59
Clay loam - silty clay loam	4.5	4.7	67	53
Silty clay - clay	3.4	5.7	55	33

* Averages calculated from analysis conducted at Vauxhall, Alberta.

** By unpaired "t" test, this value was significantly different at 1% from the next higher value. None of the rest were different from the next higher value.

From Table 8, it appears that the first two textural groupings are relatively nonsaline. The third group, with approximately 40 percent of subsoils and 30 percent of surface soils saline, is considered marginal for irrigation. The last two groups are considered generally unsuitable due to the magnitude and the extent of the salinity.

As exchangeable sodium is not a problem, and saturation percent and disturbed hydraulic conductivity are dependent on texture, the salinity is the deciding factor in establishing the suitability of soils or areas not previously excluded from the suitable for irrigation class by texture. Thus the map area was divided into five general areas (Figure 1 and accompanying "Key to Soils" Table 9) based on soil texture, natural boundaries such as streams and escarpments, the nearness to the source of water, the desirability of having soils suitable for irrigation in a block, and the possibility of using natural drains to carry drainage water. The salinity of each area is shown in Table 10, Page 32.


3
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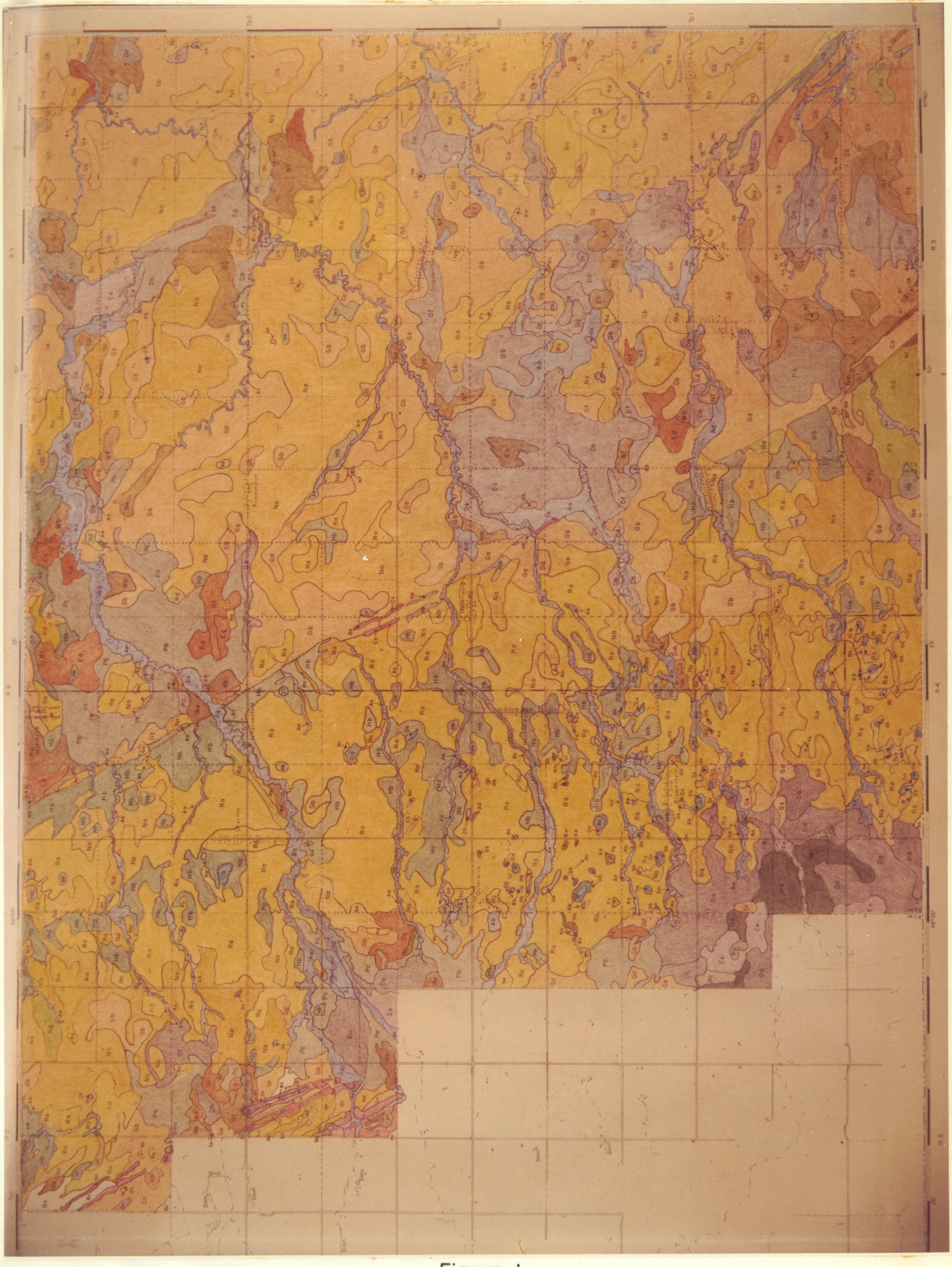

Figure I

Soils Map of the Morden-Winkler Area

Table 9

Key To Soils In Morden-Winkler Area

	Map symbol
1. Soils Developed on a Thin Mantle of Coarse Textured Outwash Deposits over Moderately Calcareous Till	
(a) Well-drained	
(1) Blumenstein complex	Bx
2. Soils Developed on Coarse Textured Outwash and Beach Deposits	
(a) Well-drained	
(1) Birkenhead series (Orthic Black)	Ba
(b) Moderately well drained	
(1) Schantzenfeld series (Rego Black)	Sa
3. Soils Developed on Moderately Coarse Textured Deltaic Deposits	
(a) Well-drained	
(1) Chortitz series (Orthic Black)	Ca
(b) Moderately well drained	
(1) Hochfeld series (Orthic Black)	Hb
(i) Hochfeld eroded phase	Hc
(ii) Hochfeld overblown phase	Hd
(2) Reinland series (Rego Black)	Ra
(i) Reinland eroded phase	Rb
(ii) Reinland overblown phase	Rc
(c) Moderately drained	
(1) Kronstal series (Gleyed Black)	Ka
4. Soils Developed on Medium Textured Deltaic Deposits	
(a) Moderately well drained	
(1) Rosengart series (Orthic Black)	Rd
(2) Reinfeld series (Orthic Black)	Re
(i) Reinfeld sand substrate phase	Rf
(3) Neuenberg series (Rego Black)	Na
(i) Neuenberg clay loam substrate phase	Nb
(ii) Neuenberg clay substrate phase	Nc
(b) Moderately drained	
(1) Friedensruh series (Gleyed Black)	Fa
(2) Gnadenthal series (Gleyed Rego Black)	Ga
(i) Gnadenthal sand substrate phase	Gb
(ii) Gnadenthal saline phase	Ge
(iii) Gnadenthal sand substrate, saline phase	Gd
(iv) Gnadenthal clay substrate phase	Ge
(v) Gnadenthal clay loam	Gf
(vi) Gnadenthal clay loam, sand substrate phase	Gg
(vii) Gnadenthal clay	Gh
(viii) Gnadenthal clay, saline phase	Gk
(ix) Gnadenthal clay, sand substrate phase	Gm
(c) Poorly drained	
(1) Osterwick series (carbonated Rego Humic Gleysol)	Oa
(i) Osterwick saline phase	OL
(2) Blumenfeld series (carbonated Rego Humic Gleysol)	Bb
(i) Blumenfeld saline phase	Bc
5. Soils Developed on Moderately Fine Textured Deltaic Deposits	
(a) Moderately well drained	
(1) Eigenhof series (Orthic Black)	Ec
(i) Eigenhof sand substrate phase	Ed
(ii) Eigenhof clay substrate phase	Ec
(iii) Eigenhof loam, sand substrate phase	Eg
(b) Moderately drained	
(1) Neuhorst series (Gleyed Rego Black)	Ne
(i) Neuhorst sand substrate phase	Nf
(ii) Neuhorst saline phase	Ng
(iii) Neuhorst sand substrate, saline phase	Nh
(iv) Neuhorst loam	Nk
(v) Neuhorst clay	Nm
(vi) Neuhorst clay, sand substrate phase	Nn
(vii) Neuhorst clay substrate phase	No
(viii) Neuhorst clay, sand substrate saline phase	Np
(2) Alluvial land (Orthic Regosol VFS-CL)	Ha
(c) Poorly drained	
(1) Schoenwiese series (carbonated Rego Humic Gleysol)	Sb
(i) Schoenwiese saline phase	Sc

(2) Alluvial land (Orthic Regosol VFS-CL)	Ab
6. Soils Developed on Fine Textured Lacustrine Deposits	
(a) Moderately well drained	
(1) Winkler series (Orthic Black)	Wa
(i) Winkler sand substrate phase	Wb
(ii) Winkler fine sandy loam	Wc
(iii) Winkler clay loam, sand substrate phase	Wd
(iv) Winkler clay loam	We
(b) Moderately drained	
(1) Plum Coulee series (Gleyed Black)	Pa
(i) Plum Coulee sand substrate phase	Pb
(ii) Plum Coulee clay loam, sand substrate phase	Pc
(iii) Plum Coulee sand substrate, saline phase	Pd
(2) Dead Horse series (Gleyed Rego Black)	Da
(i) Dead Horse sand substrate phase	Db
(ii) Dead Horse saline phase	Dc
(iii) Dead Horse sand substrate, saline phase	Dd
(iv) Dead Horse clay loam	De
(v) Dead Horse clay loam, sand substrate phase	Df
(vi) Dead Horse clay loam, saline phase	Dg
(vii) Dead Horse loam, sand substrate phase	Dh
(viii) Dead Horse loam, saline phase	Dk
(ix) Dead Horse fine sandy loam, sand substrate phase	Dm
(3) Hasket series (Gleyed Rego Black)	Ha
(4) Edenburg series (Gleyed Black Solonetz)	Ea
(i) Edenburg sand substrate phase	Eb
(5) Elias series (Mull Regosol) (SiC-C)	Ee
(6) Alluvial land (Orthic Regosol) (C)	Ac
(c) Poorly drained	
(1) Osborne series (Rego Humic Gleysol)	Oc

Table 10

Average Salinity Of Potential Irrigation Areas*

Area	Electrical conductivity (mmhos/cm) Depth 0 - 3 ft.	>3 ft.	Number of samples
1	1.0	1.8	25
2a	2.1	2.5	19
2b	3.4	4.1	68
3	1.3	2.3	23
4	3.7	4.8	54
5	3.6	4.9	24

* Averages calculated from analysis conducted at Vauxhall, Alberta.

Differences in salinity arise due to differences in drainage positions. The soils of area 2a are above the 900-foot contour where the soils are deeper and the surface slope greater than areas below this contour. This results in better drainage and consequently less salts. Areas adjacent to, and below, the 900-foot contour are usually salinized, probably due to drainage water from soils above the contour.

However, it was felt that additional samples were necessary to get a more accurate evaluation of salinity in areas 2b and 4 since these areas, although otherwise suitable for irrigation, contained appreciable soluble salts. Area 2a was included in this survey as the soil types are similar to those in area 2b.

As the Gnadenthal soil series is the only soil series occurring to any appreciable extent in each of the three areas, results for this soil series have been separated from the salinity results of the other soil series. This was to determine the effects of location as distinct from soil series on salt content of the soil. These results are shown in Table 11.

Table 11

Salinity Of The 0- To 3-Foot Depth In Areas 2a, 2b, And 4

Area	Soil type	Electrical conductivity (mmhos/cm)	Number of samples	Standard deviation
2a	Gnadenthal	1.8	33	1.48
	Others	1.8	46	
2b	Gnadenthal	2.4	127	2.12
	Neuenberg	1.5	165	
4	Gnadenthal	4.2	100	3.11
	Others	3.9	59	

These results indicate that the surface salinity is slightly less than indicated by the results obtained from deep-drilling samples shown in Table 10. This is probably due to the time of sampling. Deep drilling was done in June of 1960, July of 1961, and October of 1962. The surface sampling was done throughout the summer of 1962. This summer had abnormally high precipitation (17.7 inches from May to August inclusive) which may have leached some salts below the three-foot level. Samples taken during deep drilling were taken mainly from road allowances where ditches may have affected water and salt content. Surface samples were taken throughout the fields so they would not be affected by ditches.

By the modified "t" test there is a significant difference at five percent between the salinity of areas 2a and 2b and at one percent between areas 2b and 4. This would lead one to believe that although salinity increases with heavier textures, the location of the soil is more important than texture in determining whether or not a soil is saline. Area 4 appears to have been a lagoon area at one time where salts were deposited behind beaches of Lake Agassiz. One such beach is located in the southeast part of Twp. 1, Rge. 3W. Further evidence of this is the extent of clay and clay loam soils found in this area. This may also be why the surface salinity of the clay loam - silty clay loam textural grouping is higher than that of the silty clay-clay textural grouping as shown in Table 8. That is to say that most of the clay loam textured soils occur in area 4 and are therefore more saline.

C. Irrigation Suitability

(1) Land Suitable For Irrigation - Areas 1 and 2a

These areas include soils above the 900-foot contour extending northwestward from the American border in Twp. 1, Rge. 4W. The soils of area 1 were developed on deep moderately coarse textured deposits, dominantly fine sand and loamy very fine sand underlain by fine sediments at 12 to 15 or more feet. The soils mapped are chiefly calcareous Rego Blacks on loamy very fine sand (Ra)* with Orthic Blacks on very fine sand (Hb) occupying the slightly higher elevations; and Calcareous Rego Blacks on very fine sandy loam (Na) occupying the lower positions. There are many creeks issuing from the Manitoba Escarpment which dissect the

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* Letters in brackets refer to map symbols used on the soil map (Figure 1).

area; and the western portion of Twp. 1, Rge. 4W, is dotted with small depressions. There are little or no salts in the surface, subsurface, or groundwater. Water retention is low but within suitable range for irrigation. Permeability is good and exchangeable sodium is low. Area 2a has soils and associated characteristics similar to those described below for area 2b except that the salinity is low. This may, in part, be due to a greater depth to the clay substrata.

(2) Land Marginal For Irrigation Due To Salinity - Area 2b

This is an area adjacent to and below the 900-foot contour in the lower part of Twp. 2, Rge. 3 and 4W. These soils consist of moderately well-drained to moderately drained soils on moderately coarse to medium textured deposits with variable textured substrata underlain by clay at 6 to 10 feet. Dominant soil types mapped are Calcareous Rego Blacks on very fine sandy loam (Na) and Gleyed Calcareous Rego Blacks on loam, silty loam, very fine sandy clay loam with a sand substrate phase (Gb).

Water retention and permeability are in the optimum range for irrigation. Exchangeable sodium is low. Salinity is higher than above the 900-foot contour probably due to less leaching and more capillary rise brought about by finer textures. High concentrations of salt tend to be local in nature. Subsoil salinity is higher and more widespread than surface salinity. Iron staining is more prominent below the 900-foot contour indicating poorer drainage conditions. With improved surface drainage and installed subsurface drains to ensure leaching of salts, this area could be classed as very good for irrigation.

(3) Land Marginal Or Not Suitable For Irrigation Due To Shallow Depth To Clay Substrate - Area 3

These soils occur in an area north of Blumengart extending across the northern portion of Twp. 2, Rge. 3W. Deep drilling indicates that the material overlying the clay gets shallower to the north and east. The soils, which are moderately to moderately well drained, were developed on moderately coarse to moderately fine textured deposits underlain by clay at four to six feet. The surface textures range from very fine sandy loam to clay loam. Permeability and waterholding capacity are good and exchangeable sodium percentage is low. Salinity does not appear to be a problem under dryland farming conditions.

(4) Land Not Suitable For Irrigation Due To Excessive Salinity - Area 4

This is an area below the 900-foot contour in the Schonweise-Rosenort district in Twp. 1, Rge. 3W. The soils were developed on medium to moderately fine textured material underlain by clay at six to eight feet from the surface. Most soils in the area are moderately drained and quite saline. Heavy salt concentrations at the surface are of local occurrence whereas in the subsurface and groundwater they are continuous. The dominant soils mapped are Gleyed Calcareous Rego Blacks on loam, silty loam, very fine sandy clay loam, sand substrate phase (Gb), and saline phase (Gd); and Gleyed Rego Blacks on clay loam, silty clay loam, and sandy clay, sand substrate phase (Nf) and sand substrate saline phase (Nh). Salinity is high but water-holding capacity, permeability, and exchangeable sodium percent are all suitable for irrigation.

(5) Land Not Suitable For Irrigation Due To Heavy Textures - Area 5

These soils occur mainly along the Manitoba Escarpment as clay outwash material and along the east side of the Winkler Escarpment where clay materials, carried by intermittent streams from the Manitoba escarpment, were deposited where the streams flowed out onto level ground. These soils are developed on a mantle of clay underlain by sandy material at three to seven feet. The most common soils mapped are Gleyed Rego Blacks on silty clay to clay sand substrate phase (Db); Orthic Blacks on silty clay to clay sand substrate phase (Wb); Gleyed Rego Blacks on alluvial clay (Ha); and Mull Regosols on silty clay to clay (Ee).

Water-holding capacity is generally excessive and, although the permeability is low, it is, in most cases, still adequate. Salinity is high, particularly in subsoils. Exchangeable sodium is slightly higher than in other soils but it is still not considered to be a problem.

D. Groundwater Studies

Nineteen wells were installed throughout the area in July 1960. An additional 10 wells were installed in July 1961 in areas potentially more suitable for irrigation. Some of these wells have since been destroyed. The locations of the wells are shown in Figure 2. The purpose of this part of the study was threefold:

(a) to see what effect heavy rains would have on the groundwater levels;

(b) to check groundwater levels;

(c) to check groundwater salinity.

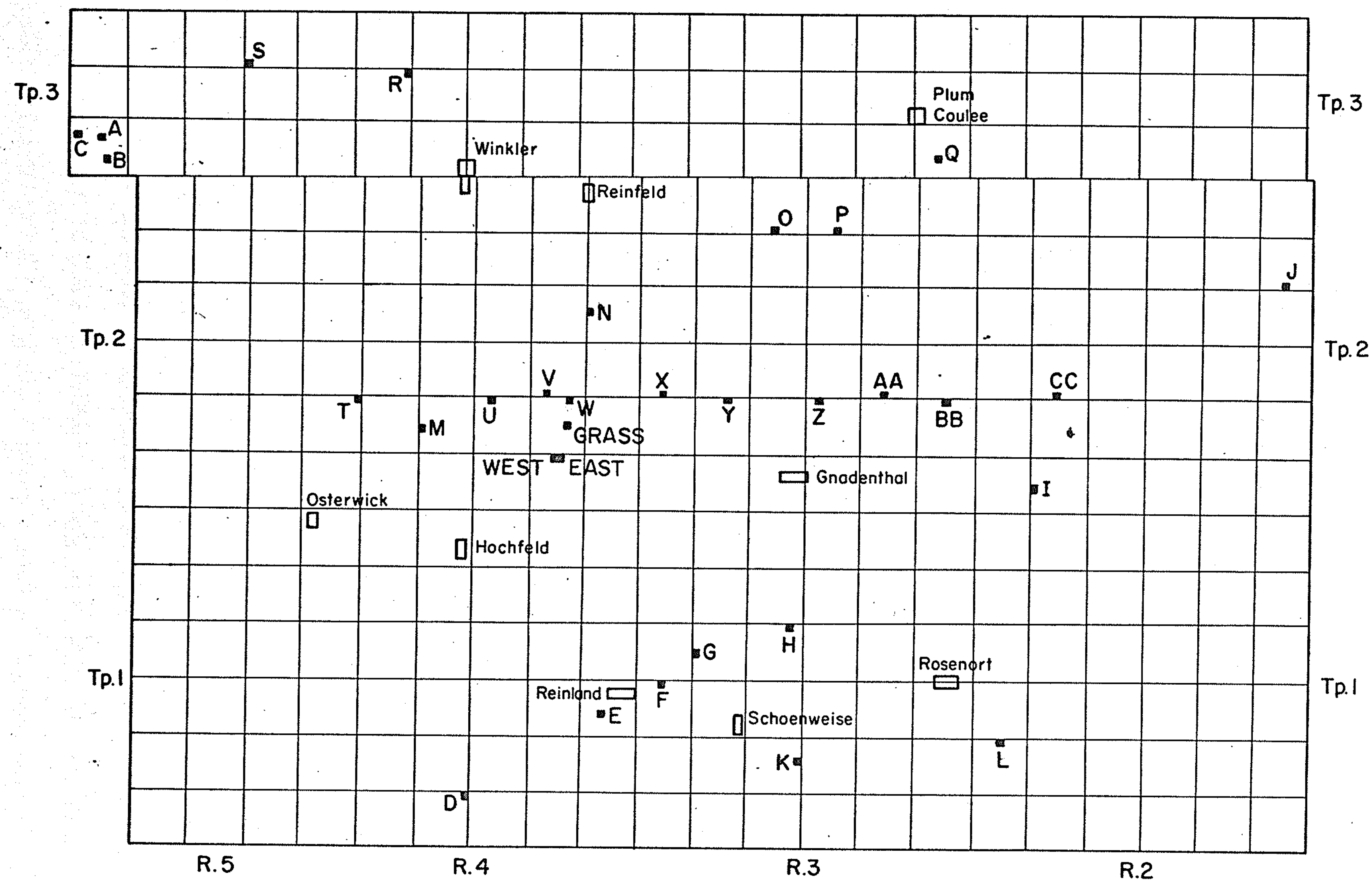

Figure 2

Location of Wells for the Study of Groundwater in the Morden-Winkler Area

The results obtained are considered to be general indications only due to the short period of time since installation and to poor location of some of the wells, i.e.; near ditches, hedges, or sloughs.

The effect of intense rains has not been clearly established as no intense rains, say three to four inches, have fallen while the ground was unfrozen since the installation of the wells. The summer of 1961 was exceptionally dry. Less than four inches of rain fell before the beginning of September. There was, however, 3.62 inches of rain during September which raised the water table in eleven wells by as much as $1\frac{1}{2}$ feet and decreased the rate of decline in one other well. The water table at the rest of the locations was below the bottom of the well so that any rise, if such did occur, could not be measured. A rain of 2.02 inches in July, 1962, raised the water table in four wells and appears to have caused a reduction in the rate of recession in the rest. The only other relatively intense rain fell on May 13, 1962. This was one of twenty rainy days of that month in which there was a total of 8.40 inches of rain. Although the water table rose sharply in May it is not possible to attribute the rise directly to this particular rain.

Groundwater levels rise in the spring as a result of snow melt and rainfall to about four feet from the surface. There is a tendency for water tables above the 900-foot contour to be slightly higher than those below, e.g.; an average of 3'10" vs. 4'7" in the spring of 1962 and 4'10" vs. 6'8" in the spring of 1963. This is likely due to the coarser, drier, more permeable nature of the surface deposits above the 900-foot contour. In 1962 the wells all reached a peak in the first half of June. Thereafter water dropped about 0.03

feet per day for six to eight weeks, later decreasing to about .01 feet per day. Late in the year the water table reaches a near static level of eight to 10 feet from the surface, rising again in the spring of the following year. The groundwater levels of representative wells, one from above and one from below the Winkler Escarpment, are shown in Figure 3 and Figure 4 respectively. (See Page 42 and 43.)

The salinity of the groundwater is considerably higher below the 900-foot contour than above. The salinity of the water from the wells above the 900-foot contour, excluding those on clay textured soils, range from 0.6 to 1.4 mmhos per centimeter with an average of 1.1 mmhos. The salinity of the water from the wells in area 2b range from 0.9 to 12.1 mmhos, with an average of 4.3 mmhos. The salinity of the water from the wells on clay range from 5.3 to 16.9 mmhos, with an average of 10.1 mmhos. The wells on clay above the escarpment are less than half as saline as those below the escarpment. This may be due to a sand substrate four to eight feet below the surface at the location of the two wells on clay textured surface deposits above the escarpment. Pratt (29) makes this comment about the salinity of the clay soils: "As they occur in an area which is continually subject to seepage water from adjacent higher land, the accumulation of salts in depressional areas is easily understandable." The salinity of the water in the 32 wells is shown in Table 12.

The salinity of the groundwater tends to remain constant or increase slightly during the growing season. This is probably due to dilution effects caused by excess moisture in the spring. This effect has been reported by Sandoval *et al.* (33). The salinities of representative wells "S" and "V" are shown on the graph in Figure 3 and Figure 4.

Table 12

Average Salinity Of The Groundwater Of Several Samplings From Each Of Thirty-Two Wells

(Ec expressed as mmhos/cm)

Above 900-foot contour			Below 900-foot contour								
Well	Area	Ec	Well	Area	Ec	Well	Area	Ec	Well	Area	Ec
A	5	5.5	K	5	16.9	V	2b	2.4	S	*	2.7
C	5	5.3	O	5	Dry	W	2b	0.9	R	*	2.9
B	1	0.6	Q*	5	12.8	N	2b	7.6	J	*	11.0
T	1	1.0	H	4	19.4	X	2b	Dry	CC	*	5.4
M	1	1.4	G	4	7.2	Y	2b	1.8	I	*	1.4
U	1	0.7	F	4	3.8	Z	2b	1.3	L	*	0.7
D	1	1.2	P	3	4.3	East	2b	12.1	-	-	-
E	1	1.1	AA	3	0.7	West	2b	6.7	-	-	-
-	-	-	BB	3	0.7	Grass	2b	1.7	-	-	-

* Wells located outside of areas classed for irrigation suitability.

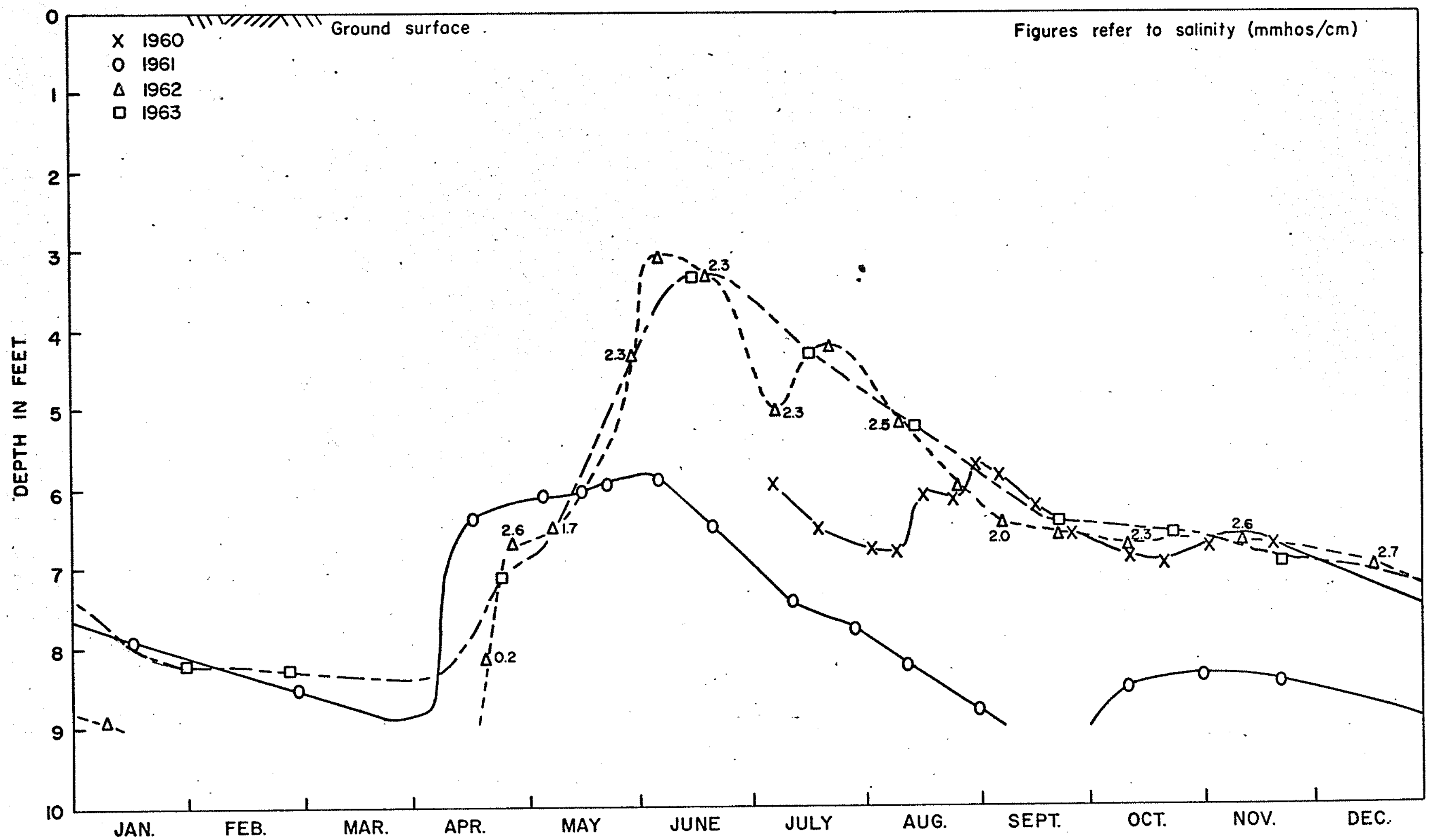

Figure 3

Waterlevel and Salinity of a Typical Well Located Above the 900-Foot Contour (Well "S")

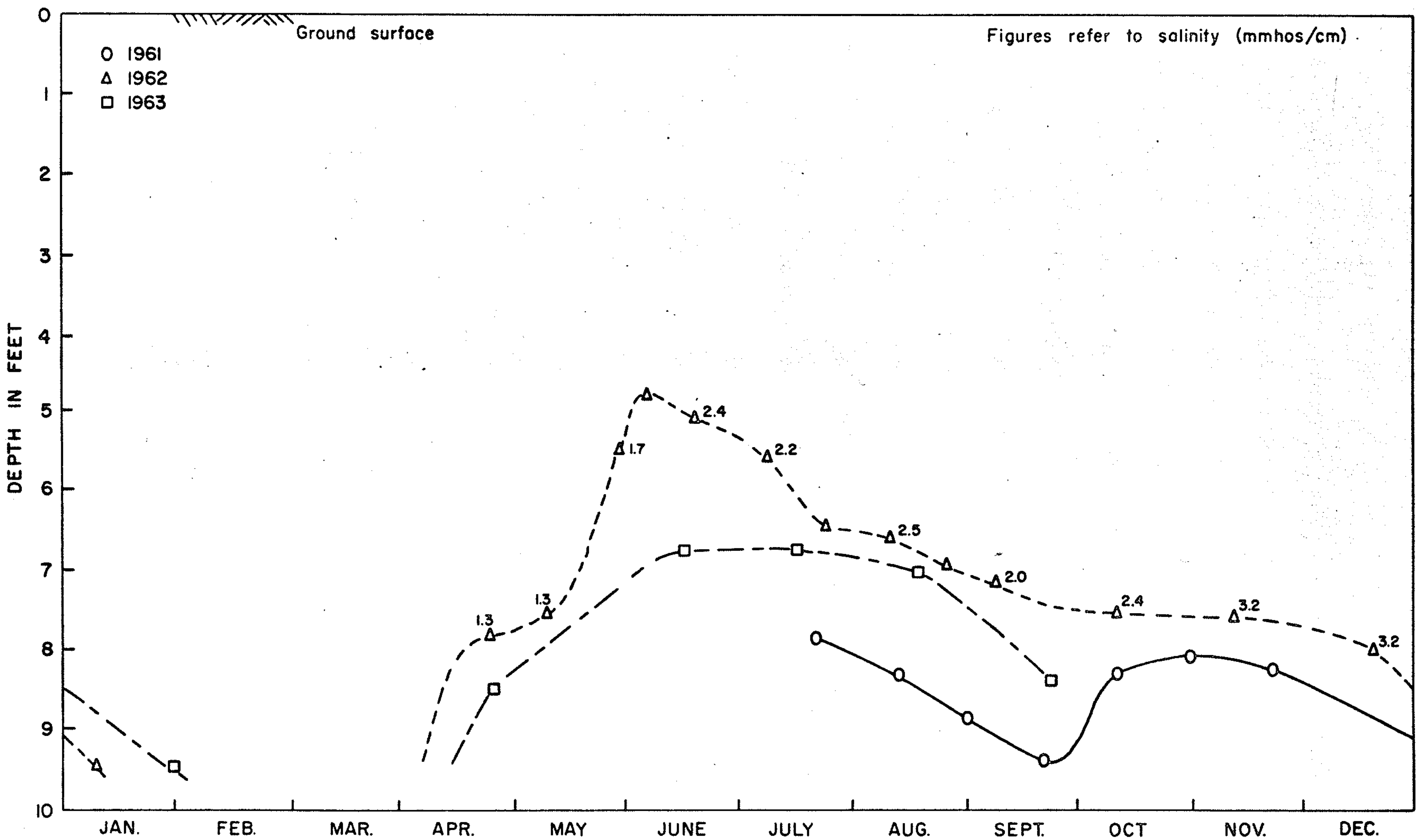

Figure 4

Waterlevel and Salinity of a Typical Well Located Below the 900-Foot Contour (Well "V")

E. Movement Studies

The soil selected for this study was a Neuenberg very fine sandy loam, typical of a large acreage of soil potentially suitable for irrigation. A description and chemical analysis appears as follows:

The Neuenberg series consists of moderately to moderately well drained Rego Black Soils developed on moderately to strongly calcareous, moderately coarse to medium textured deltaic deposits. These deposits are usually stratified and are underlain by lacustrine clay, commonly within 10 to 12 feet from the surface. The profile consists of a moderately thick, dark grey "Ah" horizon over a light brownish grey "C" horizon. The latter has brownish-yellow mottles caused by iron staining. The cultivated soils are usually calcareous to the surface and have a lime-carbonate accumulation in the upper part of the "C" horizon. The thickness of the "Ah" horizon varies considerably, and there is a slightly mottled appearance in the field due to the variable lime content of the "Ap" horizon. A typical soil profile has been described as follows:

Ap	0 - 6"	Very dark grey (10YR 3/1 dry), VFSL; weak, fine crumb, very friable when moist, soft when dry; mildly alkaline and calcareous. Grades through an abrupt, smooth boundary into:
Ah	6 - 12"	Very dark grey (10YR 3/1 dry) VFSL; weak, fine crumb, very friable when moist, soft when dry; mildly alkaline and calcareous. Grades through a clear, smooth boundary into:
AC	12 - 24"	Grey (10YR 5/1 dry) LVFS; weak, fine crumb; very friable when moist, slightly hard when dry; moderately alkaline and strongly calcareous; weakly iron stained. Grades through a gradual smooth boundary into:
C1	24 - 30"	Pale brown (10YR 6/3 dry) VFS; structureless; loose when moist, soft when dry; moderately alkaline and strongly calcareous; iron stained. Grades through a gradual, wavy boundary into:

C2 30"+ Light yellowish brown (2.5Y 6/4 dry) VFS; structureless; loose when moist, soft when dry; moderately alkaline and strongly calcareous; iron stained.

Range in Characteristics:

Neuenberg very fine sandy loam is the most common type encountered although light loams also occur. The normal Neuenberg soils have a variable thickness of the "Ah" horizon, within the range of five to 12 inches, probably due partly to wind erosion and partly to minor variations in the soil-forming processes resulting from slight differences in topography. These soils generally become coarser with depth, the "C" horizon being either very fine sand or very fine sandy loam to loam stratified with bands of very fine sand. The underlying clay is commonly within 10 to 12 feet of the surface. Cultivated soils usually have a lime-carbonate accumulation in the lower part of the "A" horizon. This is probably due to upward movement of lime during periods of high water. Moderate accumulations of gypsum are sometimes found in the "C" horizon. However, this condition is sporadic. The degree of iron staining is slight and variable in the upper "C" horizon. Below four feet it is heavy.

The mechanical and chemical analysis of a Neuenberg soil is shown in Table 13.

Table 13

Mechanical And Chemical Analysis Of The Neuenberg Soil Series

	Horizon And Depth					
	Ap	Ah	AC1	AC2	C1	C2
	0 - 5"	5 - 11"	11 - 15"	15 - 22"	22 - 36"	36 - 48"
Percent coarse sand	0.0	0.0	0.0	0.0	0.0	0.0
" medium sand	0.98	1.39	1.63	1.76	0.41	0.52
" fine sand	7.57	10.00	8.16	9.86	8.16	1.94
" very fine sand	62.04	52.93	59.03	62.71	70.26	31.97
" total sand	70.59	64.32	68.82	74.34	78.83	34.43
" silt	13.59	13.49	12.54	12.57	12.21	47.19
" clay	15.62	22.19	18.64	13.09	8.96	18.38
Textural class	VFSL	VFSCL	VFSL	VFSL	VFSL	L
1/3 atmosphere	22.11	23.55	19.93	14.91	10.77	27.20
pH	7.1	8.0	8.2	8.2	8.1	7.8
Conductivity	1.49	0.38	0.29	0.48	0.38	0.84
Percent $CaCO_3$	0.30	10.08	11.53	10.14	15.40	27.13
" organic carbon	3.76	1.87	0.84	0.36	0.0	0.41
" total nitrogen	.350	.180	.08	.044	-	-
Available P (ppm)	14.1	2.38	1.06	0.42	-	-
Exchangeable cations						
Ca Meq./100 gm........	22.9	21.5	17.3	-	15.3	-
Mg " " "	2.35	5.5	6.8	-	3.1	-
K " " "	0.18	0.61	0.20	-	0.10	-
Na " " "	0.37	1.08	.84	-	0.37	-
C.E.C. Calc.	30.73	28.61	25.13	-	18.87	-
C.E.C. (NH_4 Distill)	25.80	17.26	9.76	-	3.63	-

Since the sampling area was small a systematic sampling system was followed to avoid sampling at or very close to a previous sampling hole. Sampling locations were two feet apart, as shown in Figure 5, extending out from the well in such a way as to minimize possible effects of the accumulation of blown soil between the east and west plots, and the aspen bluff near the grass plot. As the wells were located about 35 feet on either side of the blown soil, the only effect of its presence would be to divert some runoff water away from the east plot and increase the amount passing over the west plot. Most of the runoff occurred prior to sampling when the soils were frozen so the effects of the blown soil would be slight. The aspen bluff near the grass plot had accumulated snow and undoubtedly contributed to the flooding which occurred on the grass plot.

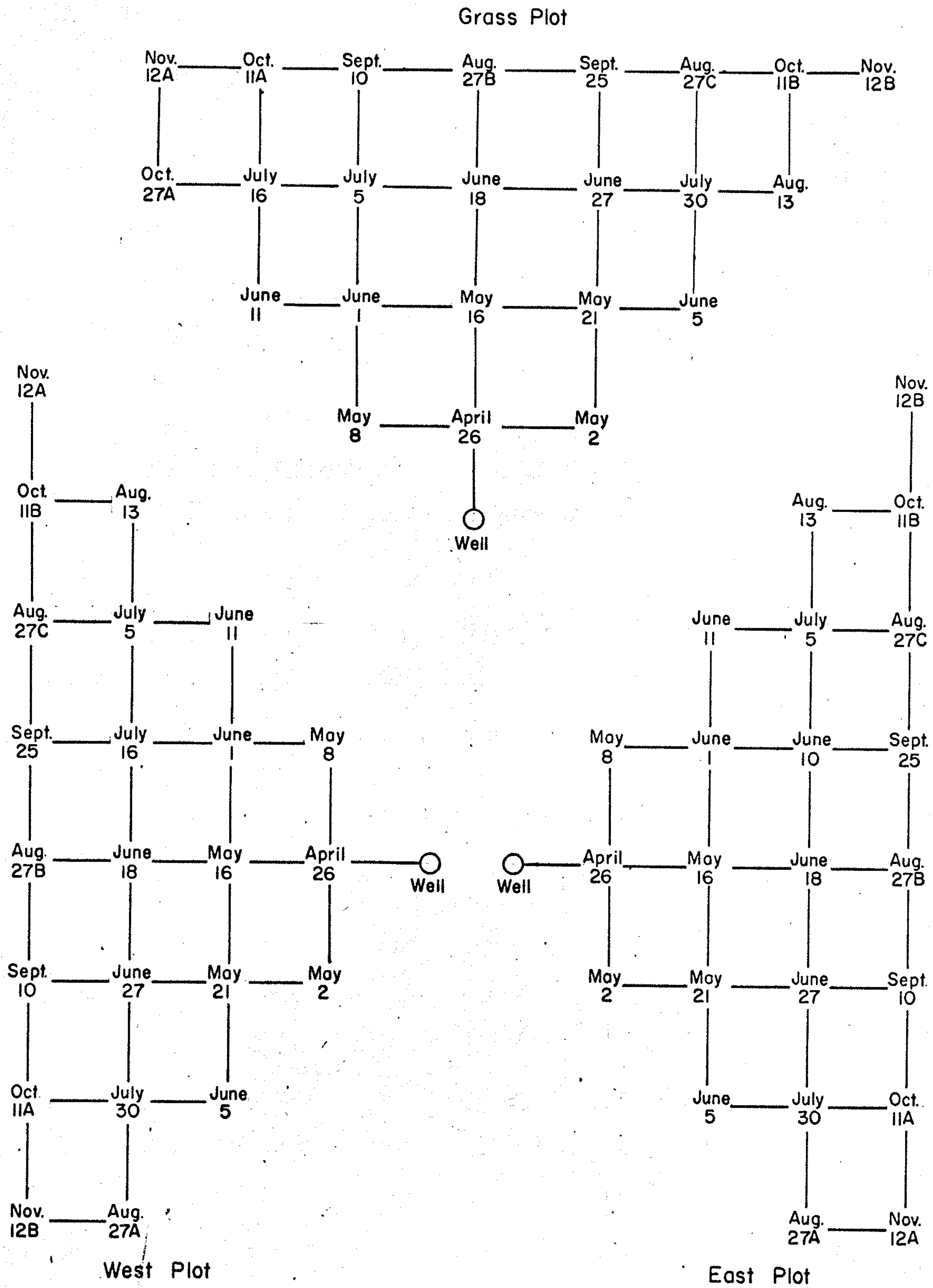

Figure 5
Sampling Diagrams for East, West, and Grass Plots

(1) Frost Penetration And Duration

The soil was considered frozen when its temperature was 0°C or lower. No inspection was made to determine the type of frost present. The recorded temperatures for the three plots appear in Tables 14, 15 and 16. Since the depth of frost and the length of time it remains in the soil is of main interest, only the temperatures to mid July will be given here. The complete temperature results appear in Appendixes 1, 2 and 3.

Table 14

Soil Temperatures (Degrees Centigrade) Of East Plot

(Line indicates depths and dates at which frost occurred)

Depth in inches	Sampling Dates							
	April 26	May 2	May 8	May 16	May 21	June 1	June 5	June 11
0 - 6	11.0	20.0	14.5	9.5	15.5	13.0	16.0	24.0
6 - 10	7.0	11.5	9.5	8.5	12.5	11.0	14.0	20.0
10 - 14	6.5	10.5	8.0	7.5	11.0	9.5	14.0	17.0
14 - 18	6.0	10.5	7.0	7.0	9.5	9.0	12.0	16.0
18 - 22	4.0	10.5	6.0	6.5	10.5	9.0	11.0	14.5
22 - 26	1.0	10.0	5.0	5.0	7.5	8.0	9.0	13.0
26 - 32	0.0	5.5	3.5	4.5	6.0	10.0	8.0	11.5
32 - 38	-0.5	-0.5	0.0	2.5	5.5	7.0	7.0	12.0
38 - 44	-0.5	0.0	0.0	0.0	2.5	5.5	6.0	9.5
44 - 52	-0.5	-0.5	-0.5	-0.5	-0.5	3.0	3.5	9.0
52 - 58	-0.5	-0.5	0.0	0.0	-0.5	0.0	2.5	6.5
58 - 64	-0.5	-0.5	-0.5	-0.5	3.0	1.5	2.0	6.0
64 - 70	1.5	4.5	1.5	2.5	4.5	4.5	3.5	-
70 - 76	2.0	7.0	2.0	2.5	4.5	3.5	4.0	-
76 - 82	3.0	3.5	3.0	2.5	4.5	5.0	4.0	-

Table 15

Soil Temperatures (Degrees Centigrade) Of West Plot

(Line indicates depths and dates at which frost occurred)

Depth in inches	Sampling Dates							
	April 26	May 2	May 8	May 16	May 21	June 1	June 5	June 11
0 - 5	12.0	18.5	14.5	12.0	13.5	16.5	15.5	26.0
5 - 10	8.5	12.0	8.5	8.5	11.5	9.0	14.0	19.5
10 - 14	6.5	8.5	6.0	7.5	10.5	9.5	12.5	18.5
14 - 18	5.5	7.5	5.0	6.5	8.5	9.0	11.0	12.0
18 - 22	4.5	7.0	4.5	5.5	9.0	8.5	10.0	16.5
22 - 26	1.5	4.5	4.0	4.5	7.0	7.0	8.5	14.0
26 - 30	1.0	1.0	2.5	4.5	7.5	9.0	8.0	15.0
30 - 36	-0.5	-0.5	0.5	2.0	5.5	9.0	7.5	14.0
36 - 42	-0.5	0.0	-0.5	0.0	1.0	6.0	5.5	8.0
42 - 48	-0.5	-0.5	0.0	0.0	1.0	4.5	6.0	7.0
48 - 54	-0.5	0.0	-0.5	-0.5	0.0	1.5	3.0	8.0
54 - 60	-0.5	-0.5	0.0	-0.5	0.0	0.0	0.5	7.0
60 - 66	-0.5	0.0	0.0	0.0	3.0	0.0	0.0	-
66 - 72	1.0	4.0	1.0	2.5	1.5	-	3.0	-
72 - 78	1.5	4.5	3.0	3.0	4.0	-	2.5	-

Table 16

Soil Temperatures (Degrees Centigrade) Of Grass Plot

(Line indicates depths and dates at which frost occurred)

Depth in inches	Sampling Dates							
	April 26	May 2	May 8	May 16	May 21	June 1	June 5	June 11
0 - 4	12.0	15.5	13.0	12.5	16.0	13.5	16.0	24.5
4 - 8	8.0	11.5	9.0	10.5	13.5	11.0	14.0	19.5
8 - 12	6.0	9.5	7.0	10.5	11.5	11.0	13.0	17.5
12 - 16	5.5	7.5	5.5	-	-	-	-	17.0
16 - 20	4.0	8.0	5.5	-	-	-	-	15.0
20 - 22	3.5	7.5	5.5					
22 - 26	4.5	6.5	5.0					
26 - 29	4.0	4.5	4.5					
29 - 35	2.5	4.5	4.5					
35 - 41	0.0	4.5	3.5					
41 - 48	0.0	4.5	3.5					
48 - 54	0.0	1.5	-					
54 - 60	1.0	1.5	-					
60 - 66	2.5	2.0	-					
66 - 72	1.0	3.5	-					

Frost penetration was a little more than 60 inches in the cultivated (east and west) plots and remained in the soil until the first week of June. The grass plot had frost between 30 and 50 inches on the April 26 sampling but this had disappeared by the May 2 sampling. This may have been due to shallower frost penetration, although a more probable explanation is as follows. When the soil was frozen the grass plot was well below field capacity. The water table was greater than 15 feet below the surface so could not have contributed moisture to the freezing layer by capillary action. Thus considerable pore space would be left free of ice and the soil would be quite permeable to water. Percolating water could then melt the ice. The surface of the grass plot was flooded in the spring with snow melt waters. This may have contributed to thawing of the frozen layer although flooding itself should not cause thawing as water is often found above a frozen layer in wet depressions until early summer.

(2) Moisture Studies

Moisture contents are expressed as relative wetness. This is a ratio of the soil moisture percent to its field capacity. When relative wetness is equal to, or greater than unity the moisture content is at or above field capacity. Reference will be made to relative wetness data for the east, west, and grass plots in Table 17, Table 18 and Table 19.

Movement of water to the frost layer is apparent in the cultivated plots as most of the samples taken from the frost layer are at or near field capacity. At the time of freezing the soil was below field capacity. The grass plot had been flooded by snow melt prior to the April 26 sampling date so all samples taken were above field capacity.

The frost layer in the cultivated plots appears to be impermeable to water as the soil above the frost layer is above field capacity. The soils are above field capacity to the surface in the west plot, i.e.; a perched water table. In the east plot the soils are above field capacity immediately above the frozen layer, but not to the surface. This may be due, in part, to the ridge of blown material diverting all the runoff water from the east plot, or due to textural differences resulting in an estimated field capacity larger than actual field capacity.

The relation of the groundwater levels to the frost layer is shown along with the relative wetness data in Tables 17, 18 and 19. The main rise of the water table occurred at or slightly before complete thawing of the frost layer in the cultivated plots. This may have been due to differences in the penetration of the frost thus differences in the time of thawing, thawing of the frost layer from lower depths, or lateral movement of water from other areas.

In this textural class (very fine sandy loam) there is a capillary fringe above the water table in which the soil is at or near field capacity. This fringe is about $4\frac{1}{2}$ feet in thickness and existed at all times throughout the sampling period. This fringe could be a contributing factor in the supply of water to plants and in the redistribution of salts.

The major concentration of salts in the profile is between the 6- and 24-inch depths. The upper edge of the capillary fringe is between these depths between the first week of June and the middle of July. As plants use moisture, this would be the zone of deposition of salts. Thus, it appears possible, that the capillary fringe may be of importance in the redistribution of salts in the soil profile. This should occur to the greatest extent when water consumption by plants is at its greatest. For cereals this would normally occur during June and early July.

Table 17

Moisture Content Of East Plot Expressed As A Ratio Of Soil Moisture To Field Capacity
(October 1961 And April to November 1962)

Depth in inches	Field capacity	1961 Oct. 17	1962 Apr. 26	May 8	May 16	May 21	June 1	June 5	June 11	June 18	June 27	July 5	July 16	July 30	Aug. 13	Aug. 27	Sept. 10	Sept. 25	Oct. 11	Nov. 12
0 - 6	21.41	.97	1.26	1.12	1.20	1.17	1.36	1.16	1.20	1.19	.96	.66	.70	.8	.93	.92	1.11	.82	.95	1.05
6 - 10	26.89	.90	.92	.90	.96	1.03	1.01	1.03	.97	.94	.85	.58	.62	.5	.75	.77	-	.77	.76	.79
10 - 14	22.20	1.00	.85	.91	.93	1.05	1.04	1.08	1.05	.97	.88	.84	.72	.5	.61	.78	.86	.81	.79	.77
14 - 18	18.41	.91	.91	.88	.84	1.06	1.16	1.05	1.13	1.02	.86	.91	.70	.6	.66	.74	.82	.79	.75	.75
18 - 22	14.31	.94	.93	.87	.90	1.23	1.57	1.28	1.49	1.38	1.11	1.14	.75	.6	.86	.98	.81	.75	.77	.83
22 - 26	10.82	.89	1.14	.92	1.31	1.86	2.33	1.98	2.13	2.13	1.60	1.47	1.09	.9	1.12	1.27	1.25	.91	.99	1.32
26 - 32	11.10	.82	.91	1.01	1.59	2.11	2.34	2.22	2.31	2.19	1.87	1.44	1.33	1.0	1.18	1.26	1.03	1.09	1.03	1.17
32 - 38	21.81	.84	1.04	.82	.97	1.22	1.16	1.10	1.14	1.08	1.01	.91	.88	.9	.91	.91	.90	.94	.90	.92
38 - 44	25.24	.85	1.11	1.04	1.11	1.16	1.11	1.11	1.09	1.07	1.05	.98	1.01	.9	.95	1.00	1.04	1.04	1.03	1.02
44 - 52	28.90	.89	1.08	.99	1.02	1.08	1.13	1.08	1.06	1.05	1.08	1.05	1.06	1.0	.98	1.01	.99	.97	.99	1.00
52 - 58	29.04	.94	1.06	1.07	1.08	-	1.14	1.10	1.17	1.11	1.07	1.11	1.03	1.0	1.05	1.07	1.03	1.05	1.03	1.05
58 - 64	30.13	1.02	1.01	1.02	.94	-	1.07	1.06	1.11	1.09	1.07	1.07	1.02	1.0	1.03	1.04	1.04	1.06	1.06	1.03
64 - 70	30.87	1.03	.90	.92	.83	-	1.03	1.11	-	-	1.06	1.07	.99	.9	1.09	1.05	1.06	1.08	1.08	1.02
70 - 76	30.55	1.04	.98	.88	.98	-	1.02	1.16	-	-	1.11	1.06	1.02	1.0	1.09	1.04	1.01	1.05	1.02	1.01
76 - 82	30.64	1.00	.99	1.03	.96	-	1.04	1.12	-	-	-	1.08	1.01	.9	1.02	1.04	1.02	1.00	1.02	1.01
82 - 88	30.93	1.01	.91	.91	.97	-	1.06	-	-	-	-	1.06	1.07	1.0	1.08	1.07	1.07	1.03	1.03	1.01
88 - 94	30.20	1.02	1.09	1.03	1.05	-	1.13	-	-	-	-	1.13	-	1.0	1.13	1.08	1.07	1.08	1.07	1.05
94 - 100	32.40	.99	.95	1.00	.99	-	1.04	-	-	-	-	-	-	-	-	-	.99	.97	1.02	1.05
100 - 106	31.30	1.06	1.10	1.01	1.07	-	-													
106 - 112	32.28	1.09	1.05	1.14	1.00	-	-													
112 - 118	31.35	1.02	1.06	1.03	1.05	-	-													
118 - 124	31.27	1.07	1.03	1.06	1.09	-	-													
124 - 130	32.61	1.03	1.05	1.09	1.10															
130 - 136	32.71	1.13	.97	1.06	1.03															
136 - 142	30.50	1.17	-	1.03	1.08															
142 - 148	13.61	2.32	-	2.45	-															
148 - 154	26.00	1.41	-	1.20	-															
154 - 160	27.70	1.19	-	1.11	-															

- - - Frost layer

Upper edge of water table

Table 19

Moisture Content Of Grass Plot Expressed As A Ratio Of Soil Moisture To Field Capacity
(October 1961 And April to November 1962)

Depth in inches	Field Capacity	1961 Oct. 19	1962 Apr. 26	May 8	May 16	May 21	June 1	June 5	June 11	June 18	June 27	July 5	July 16	July 30	Aug. 13	Aug. 27	Sept. 10	Sept. 25	Oct. 11	Nov. 12
0 - 4	37.61	.85	1.36	1.22	1.19	1.53	1.56	1.57	1.56	1.44	1.37	1.18	1.34	1.10	1.03	.91	1.01	.59	.63	.99
4 - 8	26.77	.86	1.67	1.48	1.58	1.79	1.65	1.80	1.74	1.61	1.55	1.29	1.13	.95	.94	.84	.74	.58	.51	.92
8 - 12	22.66	.74	1.60	1.65	1.90	2.06	1.82	1.95	1.77	1.67	1.55	1.38	1.17	1.09	1.05	.93	.86	.79	.75	.89
12 - 16	20.94	.69	1.71	1.76	-	-	-	-	1.88	1.73	1.58	1.47	1.30	1.17	1.15	1.04	1.00	.91	.84	.94
16 - 20	19.77	.59	1.62	1.62	-	-	-	-	1.91	1.48	1.53	1.43	1.27	1.15	1.09	.96	.99	.85	.77	.89
20 - 22	18.53	.49	1.57	1.65	-	-	-	-	-	1.75	1.57	1.52	1.37	1.14	1.08	.92	.97	.78	.75	.81
22 - 26	15.84	.35	1.82	1.88	-	-	-	-	-	1.87	1.74	1.74	1.53	1.25	1.25	1.07	1.12	.81	.86	.88
26 - 29	13.59	.35	1.91	2.17	-	-	-	-	-	1.99	2.02	1.97	1.91	1.64	1.48	1.23	1.17	1.10	1.03	1.00
29 - 35	12.31	.35	1.85	2.16	-	-	-	-	-	2.55	2.01	2.25	2.23	1.95	1.70	1.47	1.27	1.09	1.03	1.04
35 - 41	12.38	.45	1.92	2.24	-	-	-	-	-	-	1.93	2.20	2.18	2.14	2.08	1.88	1.53	1.39	1.20	1.16
41 - 48	12.46	.55	1.90	2.15	-	-	-	-	-	-	-	-	1.99	2.13	2.01	2.08	1.89	1.80	1.63	1.46
48 - 54	14.91	.58	1.72	-	-	-	-	-	-	-	-	-	-	1.80	1.87	1.76	1.75	1.72	1.78	1.67
54 - 60	29.22	.62																		
60 - 66	6.77	.73																		
66 - 72	5.43	.69																		
72 - 78	4.81	1.22																		
78 - 84	30.00	.82																		
84 - 90	35.87	.97																		
90 - 96	37.19	.91																		
96 - 102	37.28	.89																		
102 - 108	35.50	.84																		
108 - 114	34.75	.90																		
114 - 120	36.54	1.00																		
120 - 126	40.07	.92																		
126 - 132	39.40	1.04																		
132 - 138	40.61	.75																		

--- Frost layer

Upper edge of water table

(3) Salt Movement

Ideally, on each sampling date more than one site should have been sampled to permit calculation of analysis of variance. This, however, would have resulted in almost an impossible number of samples. As an alternative each plot was sampled at more than one location on three sampling dates and a composite standard deviation calculated. This, taken at 95 percent confidence interval indicates that in the east plot at any one depth there are no samples that are significantly different. In other words, the variability in samples can be accounted for by sampling location alone and any changes in Ec due to salt movement, if such did occur, cannot be detected. The Ec to the five-foot depth is shown in Table 20. Only those samples taken to this depth were included in statistical calculations. The complete Ec results appear in Appendix 4.

In the west plot there are two depths that have significantly different salt content at different sampling dates. The 0- to 5-inch depth has one sample (one sampling date at one depth) which is significantly different from other samples taken at this depth. The 42- to 48-inch depth has significantly different samples on five sampling dates. It is believed that these differences are due to chance alone as the coefficient of variability is high. The samples on which the statistics were calculated appear in Table 21 and the complete results appear in Appendix 5.

Table 20

Conductivity (mmhos/cm) Of 1:5 Extract For April To November 1962 - East Plot

Depth in inches	Apr. 26	May 2	May 8	May 16	May 21	June 1	June 5	June 11	June 18	June 27	July 5	July 16	July 30
0 - 6	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.3	0.4	0.5
6 - 10	1.5	0.5	1.0	2.2	0.4	1.3	0.4	1.1	1.3	0.5	0.6	2.9	1.9
10 - 14	1.4	1.7	4.5	5.5	1.2	1.8	1.2	5.6	5.5	0.6	6.0	5.9	2.4
14 - 18	0.9	1.3	5.1	2.7	1.7	1.5	1.1	0.6	3.5	0.6	4.4	5.5	1.1
18 - 22	0.8	1.0	1.5	1.0	0.9	0.7	0.7	0.9	0.7	0.7	1.5	1.0	0.8
22 - 26	0.7	0.8	0.8	0.8	1.0	0.7	0.8	0.8	0.6	0.7	1.3	0.9	0.8
26 - 32	0.7	0.7	0.8	1.2	1.5	1.1	1.1	0.9	0.9	1.0	1.0	1.0	0.8
32 - 38	1.1	1.1	1.1	1.4	1.5	1.5	1.3	1.3	1.4	1.3	1.3	1.4	1.3
38 - 44	1.2	1.3	1.6	2.0	2.2	1.8	2.2	1.7	1.5	1.4	1.4	1.4	2.1
44 - 52	3.0	2.2	1.9	2.0	2.3	3.5	1.8	1.9	1.5	1.6	4.7	3.9	2.0
52 - 58	2.7	2.8	2.3	2.7	1.8	3.9	1.7	4.1	3.9	3.5	3.6	2.8	5.0
58 - 64	2.1	2.1	2.0	1.7	2.0	2.7	2.9	4.1	2.1	2.1	4.7	2.3	2.6

Replicate samples taken on the same date are designated by A,B,C.

	A	B	C			A	B	A	B
Aug. 13	Aug. 27	Aug. 27	Aug. 27	Sept. 10	Sept. 25	Oct. 11	Oct. 11	Nov. 12	Nov. 12
0.7	0.4	0.5	0.7	0.4	0.4	0.5	0.5	0.5	0.5
6.1	0.9	6.0	6.7	2.9	2.5	1.7	0.7	4.4	1.3
5.0	2.6	6.3	7.0	3.5	5.8	2.1	6.3	2.8	6.9
3.2	1.6	1.8	4.0	2.2	5.9	1.1	6.0	1.2	6.2
1.1	1.1	1.1	1.3	1.1	1.3	0.8	1.0	0.8	1.8
0.9	1.0	1.1	1.1	1.1	0.8	0.6	0.8	0.7	2.0
0.8	0.8	1.2	0.9	0.9	0.8	0.8	1.1	0.7	0.9
1.2	1.2	1.5	1.2	1.5	1.2	1.0	1.4	1.1	1.2
1.3	1.9	1.5	1.7	1.6	1.4	1.5	2.0	1.3	1.5
3.4	2.0	3.7	6.6	1.7	2.2	2.4	6.0	1.5	4.9
4.4	4.4	5.9	4.9	3.5	1.9	4.6	4.7	1.7	3.2
3.1	3.5	3.4	2.4	4.2	2.9	3.8	5.6	1.9	4.7

(4) Nitrate Movement

Significant differences in nitrate content in the east plot appear after seeding and fertilization. These differences appear in the 0- to 10-inch layer and are deeper in the profile at later sampling dates indicating that leaching is taking place. No significant differences appear below the three-foot depth or after July first.

In the west plot there are only two depths that are significantly different. This is hard to explain as, according to the owner, the plot was fertilized on May 9 with 325 pounds per acre of 14-14-7 fertilizer. As in the salt movement study there is a very large variation due to sampling location so that only very large differences are statistically different. The nitrate contents of the east and west plots to a depth of five feet are shown in Tables 22 and 23.

Table 22

Nitrates (ppm) For Depths And Dates Shown - East Plot

Depth in inches	Apr. 26	May 2	May 8	May 16	May 21	June 1	June 5	June 11	June 18	June 27	July 5	July 16	July
0 - 6	7.6	18.6*	47.8*	3.9	6.1	1.8	2.1	2.2	1.5	2.5	2.6	1.0	1.
6 - 10	10.3	22.0*	20.4*	17.5*	23.2*	2.4	2.4	1.5	0.5	1.2	2.0	0.4	3.
10 - 14	7.4	10.7	25.7	22.0	7.6	2.5	2.6	3.4	2.2	1.6	2.0	4.7	6.
14 - 18	5.4	10.6	11.2	29.4*	3.7	3.2	5.3	10.0	6.1	7.0	9.0	17.2	6.
18 - 22	2.2	5.3	3.5	7.8	10.2	10.0	13.4	15.4	10.6	16.8	15.2	12.8	3.
22 - 26	1.3	2.0	1.3	2.4	26.9*	10.5	20.3*	14.1*	8.1	20.2*	11.4	6.8	2.
26 - 32	0.4	0.9	1.0	1.2	3.8	28.5*	11.7*	14.1*	5.7	11.2*	6.9	3.3	2.
32 - 38	0.5	1.4	0.5	0.9	1.1	6.8	2.7	4.4	2.8	1.7	3.3	1.3	1.
38 - 44	0.7	0.7	0.7	1.0	1.1	1.2	0.5	1.3	0.9	0.8	2.2	0.5	0.
44 - 52	0.9	1.1	0.8	0.9	1.1	0.7	0.4	1.2	0.4	0.6	1.4	0.5	0.
52 - 58	1.0	1.2	0.8	1.2	1.5	0.9	0.8	1.2	0.6	0.8	1.0	0.4	0.
58 - 64	1.4	1.2	1.1	1.0	1.6	1.3	1.7	1.3	0.8	1.2	1.2	0.7	1.

* Significantly different at 5 percent by modified "t" test from other values in the same depth.

30	Aug. 13	A Aug. 27	B Aug. 27	C Aug. 27	Sept. 10	Sept. 25	A Oct. 11	B Oct. 11	A Nov. 12	B Nov. 12
	3.0	6.5	7.6	6.3	8.1	6.5	6.7	7.6	3.4	7.4
	2.8	3.8	9.0	5.8	5.1	7.6	12.7	6.6	5.5	5.4
	7.0	10.7	13.0	13.7	4.1	7.1	34.8	4.7	17.2	3.8
	4.9	12.4	9.5	11.4	9.1	9.6	17.5	7.8	11.4	4.4
	3.4	7.3	6.5	10.2	7.5	5.9	8.5	7.3	5.7	4.7
	2.2	4.3	2.9	8.1	5.9	3.7	4.2	5.2	3.3	6.7
	2.1	1.7	1.6	4.7	2.9	2.3	1.9	4.5	2.5	4.5
	1.5	1.0	1.3	2.1	1.2	0.9	0.5	3.0	1.6	3.8
	0.8	0.4	1.0	1.3	0.5	0.5	0.4	1.1	2.1	1.8
	0.5	0.4	1.1	1.3	0.4	0.7	1.1	0.9	0.4	0.5
	0.9	0.5	1.3	1.3	0.6	0.9	1.0	1.0	0.7	0.6
	1.1	0.9	1.5	1.4	0.9	0.8	1.3	0.5	1.0	1.0

Table 23

Nitrates (ppm) For Depths And Dates Shown - West Plot

Depth in inches	Apr. 26	May 2	May 8	May 16	May 21	June 1	June 5	June 11	June 18	June 27	July 5	July 16	July
0 - 5	0.0	0.5	2.4	1.3	0.6	0.3	2.4	1.6	38.4	90.9*	35.8	47.0	19.
5 - 10	0.2	0.5	0.2	0.8	1.8	1.2	1.3	1.7	6.5	25.7*	3.2	5.0	3.8
10 - 14	0.1	0.4	0.1	0.3	2.5	1.7	0.5	1.2	1.9	9.9	3.6	11.1	1.
14 - 18	0.2	0.4	0.3	0.2	4.5	0.7	0.3	1.2	1.0	1.9	3.1	4.5	1.6
18 - 22	1.2	0.2	1.8	0.0	4.7	0.7	0.1	0.9	0.4	5.0	1.2	5.1	0.9
22 - 26	7.3	0.0	4.6	3.6	5.0	1.4	0.2	1.3	2.9	1.3	1.1	6.1	0.5
26 - 30	13.7	0.1	4.9	8.6	10.6	3.9	0.1	3.7	3.5	0.2	2.9	5.9	1.0
30 - 36	8.7	2.5	1.3	2.3	9.9	5.3	0.0	3.2	2.9	0.6	2.0	4.0	1.5
36 - 42	3.1	2.9	1.0	1.3	2.9	3.0	1.6	3.0	2.9	2.7	1.2	0.8	2.5
42 - 48	1.5	1.3	1.0	1.0	3.9	1.0	0.5	3.3	1.3	1.9	0.6	0.8	1.9
48 - 54	1.1	1.0	0.8	0.9	2.1	0.9	0.4	1.8	0.5	1.7	0.9	0.5	1.2
54 - 60	1.1	1.2	0.9	1.1	2.3	1.0	0.6	1.2	0.8	1.9	1.2	0.9	1.2

* Significantly differ at 5 percent by modified "t" test from other values in the same depth.

July 5	July 16	July [illegible]0	Aug. 13	A Aug. 27	B Aug. 27	C Aug. 27	Sept. 10	Sept. 25	A Oct. 11	B Oct. 11	A Nov. 12	B Nov. 12
35.8	47.0	19.3	2.4	19.3	3.3	1.5	2.9	16.6	22.5	43.6	25.2	10.2
3.2	5.0	3.8	1.2	4.4	1.4	0.8	1.5	7.1	9.7	4.7	4.9	3.7
3.6	11.1	1.7	1.1	4.2	1.7	0.6	3.4	6.0	9.3	2.1	4.1	3.7
3.1	4.5	1.6	1.5	0.5	3.0	0.8	3.0	5.7	8.1	1.8	3.2	4.0
1.2	5.1	0.9	1.5	0.6	4.0	0.7	4.0	3.9	9.9	0.8	1.7	4.7
1.1	6.1	0.5	3.0	0.5	4.0	0.8	5.0	3.8	8.6	0.9	1.5	3.7
2.9	5.9	1.0	3.7	1.6	3.4	1.0	5.5	2.9	7.5	0.8	1.3	6.4
2.0	4.0	1.5	2.2	2.9	1.6	0.5	5.0	1.5	6.3	1.1	0.7	6.4
1.2	0.8	2.5	1.2	2.6	0.7	0.2	3.6	1.3	4.4	0.5	0.4	5.4
0.6	0.8	1.9	1.0	2.1	0.8	0.6	2.4	1.2	2.4	0.5	0.4	3.5
0.9	0.5	1.2	0.5	1.0	1.0	0.7	-	1.0	1.7	0.5	0.7	1.6
1.2	0.9	1.2	0.8	1.0	1.1	0.7	2.5	1.4	1.6	1.3	1.0	1.5

V. SUMMARY AND CONCLUSIONS:

In order to determine the feasibility of irrigation in the Morden-Winkler area, a study was conducted to ascertain the suitability of the soils for irrigation. A study of the related factors -- climate, groundwater, and salt and water movement -- was indicated.

Climatic comparisons are made between four Western Canadian locations, and moisture deficits are estimated by two methods.

A soil survey was conducted by the Manitoba Soil Survey. Deep drilling was employed to obtain surface and subsurface samples for analysis. The analyses conducted on these samples were: saturation percentage, disturbed hydraulic conductivity, sodium adsorption ratio and electrical conductivity. These results enabled division of the map area into five general areas indicating irrigation suitability. The surface salinity in three of these areas is compared.

Groundwater levels were recorded at regular intervals at thirty-two locations, and salinity measurements were made periodically.

In an attempt to evaluate the effects of a frozen layer and a water table, soil temperatures and moisture contents were recorded on one grass plot and two cultivated plots between April 26 and November 12 of 1962. Electrical conductivity and nitrate content were determined in an attempt to relate their movement to moisture conditions.

1. Climate

(a) Although the average growing-season rainfall is 12.35 inches there is an average growing-season moisture deficiency of 8.82 inches. Probable moisture deficiency, calculated by a different procedure, indicates a moisture deficiency of 7.64 inches.

(b) Soil-stored moisture is usually considerable and would reduce the moisture deficit.

Therefore, it is concluded that irrigation would be needed only as a supplement to natural rainfall.

2. Irrigation Suitability

(a) Most of the very fine sand to very fine sandy clay loam textured soils have saturation percentages between 40 and 60 percent. Clay loam soils tend to have a saturation percentage slightly in excess of 60 percent, and clay soils have a very high saturation percentage.

(b) Most textures have a disturbed hydraulic conductivity between 0.8 and 4.0 inches per hour. Very fine sand textured soils tend to have a disturbed hydraulic conductivity near 4.0 inches per hour. Clay textured soils usually have a disturbed hydraulic conductivity less than 0.8 inches per hour but due to their well-structured nature the deficiency is not large.

(c) Exchangeable sodium, as indicated by S.A.R. tends to be low.

(d) Salinity tends to increase with heavier textures, particularly in subsoils. Soils above the 900-foot contour tend to have low salt concentrations in the surface, subsurface and groundwater. Below the 900-foot contour salinity tends to be higher. High salinities are local in nature except in area 4 where high surface salinity is common and high subsurface and groundwater salinity is prevalent.

From the above four factors it is concluded that very fine sand to very fine sandy clay loam textured soils are suitable for irrigation provided soluble salt concentration is not high.

3. Groundwater Studies

(a) Groundwater salinity is high below the 900-foot contour, the salinity tends to remain constant or increase slightly throughout the growing season.

(b) Groundwater levels tend to be higher above the 900-foot contour in the spring due to the coarser, more permeable nature of the soil.

(c) Heavy rains tend to decrease the rate of decline or increase the groundwater level.

(d) Groundwater levels decrease from about four feet from the surface in the spring to eight to ten feet from the surface in late winter.

Therefore, it is concluded that the water table is sufficiently close to the surface to affect irrigation practices. This is particularly so below the 900-foot contour where heavy applications of water and additional drainage would be required to leach soluble salts from the soil.

4. Movement Studies

(a) Frost and moisture studies

(i) Moisture is drawn to a freezing layer provided moisture is available below the frost line.

(ii) A frozen layer, which is impermeable to water, remained in the soil about one month longer in the cultivated plots than in the grass plot, where the frost layer appeared to be permeable.

(iii) The soil above the frozen layer was above field capacity but immediately below the frozen layer the soil was below field capacity.

(iv) The main rise of the water table coincided with or was slightly before complete thawing of the frozen layer.

It is concluded from the above results that a frozen layer can cause a perched water table if sufficient moisture is available at the time of freezing to form an impermeable layer

(b) Moisture and soluble salt studies

(i) There is a capillary fringe about four-and-one-half feet thick above the water table.

(ii) The upper edge of the capillary fringe is in the surface 30 inches until about mid July, which is the most active period of plant growth.

(iii) The main concentration of salts in the profile is in the surface 30 inches.

It is concluded that the capillary fringe could be important in supplying water to plants and in redistribution of salts in the profile . Raising of the water table by irrigation may cause the soil to be moist to the surface and cause salts to accumulate there by evaporation.

(c) Soluble salt and nitrate movement studies

(i) Most differences in salinity could be attributed to variability in sampling location.

(ii) Variations in nitrate content are also large but there appears to be downward nitrate movement in the east plot.

It is concluded that variability due to sampling location is too large to detect any vertical salt or nitrate movement.

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VII. APPENDIXES:

Appendix 1

Soil Temperatures Of East Plot (Degrees Centigrade)

Depth in inches	Apr. 26	May 2	May 8	May 16	May 21	June 1	June 5	June 11	June 18	June 27	July 5	July 16	July 3
0 - 6	11.0	20.0	14.5	9.5	15.5	13.0	16.0	24.0	24.0	24.0	25.0	25.0	21.0
6 - 10	7.0	11.5	9.5	8.5	12.5	11.0	14.0	20.0	19.0	22.0	21.0	23.0	19.0
10 - 14	6.5	10.5	8.0	7.5	11.0	9.5	14.0	17.0	17.0	21.0	21.0	22.0	17.5
14 - 18	6.0	10.5	7.0	7.0	9.5	9.0	12.0	16.0	16.0	20.0	19.5	19.0	17.5
18 - 22	4.0	10.5	6.0	6.5	10.5	9.0	11.0	14.5	16.0	19.5	21.0	18.0	17.0
22 - 26	1.0	10.0	5.0	5.0	7.5	8.0	9.0	13.0	15.0	17.5	22.0	18.0	17.0
26 - 32	0.0	5.5	3.5	4.5	6.0	10.0	8.0	11.5	13.5	15.0	19.0	16.0	16 0
32 - 38	-0.5	-0.5	0.0	2.5	5.5	7.0	7.0	12.0	12.5	14.5	16.0	15.5	14.5
38 - 44	-0.5	0.0	0.0	0.0	2.5	5.5	6.0	9.5	11.5	13.0	14.5	14.5	14.0
44 - 52	-0.5	-0.5	-0.5	-0.5	-0.5	3.0	3.5	9.0	10.5	12.5	13.5	14.5	14.0
52 - 58	-0.5	-0.5	0.0	0.0	-0.5	0.0	2.5	6.5	8.0	11.5	13.0	13.5	13.0
58 - 64	-0.5	-0.5	-0.5	-0.5	3.0	1.5	2.0	6.0	6.0	12.0	13.0	12.0	12.0
64 - 70	1.5	4.5	1.5	2.5	4.5	4.5	3.5	-	-	10.0	12.5	10.5	12.0
70 - 76	2.0	7.0	2.0	2.5	4.5	3.5	4.0	-	-	11.0	12.0	10.0	12.0
76 - 82	3.0	3.5	3.0	2.5	4.5	5.0	4.0	-	-	-	12.0	9.5	12.0
82 - 88	1.5	5.5	3.0	3.5	5.5	4.0	-	-	-	-	12.0	9.0	11.0
88 - 94	3.0	5.5	4.0	3.5	5.5	5.0	-	-	-	-	7.5	-	9,5
94 - 100	3.0	7.0	3.5	4.5	5.5	4.0	-	-	-	-	-	-	9.0
100 - 106	4.0	6.5	4.5	4.5	6.0								
106 - 112	5.0	6.0	4.5	5.0	6.0								
112 - 118	5.0	6.0	4.5	5.0	6.0								
118 - 124	4.0	7.0	4.5	5.0	5.0								
124 - 130	5.0	7.5	4.5	4.5	6.5								
130 - 136	4.0	6.5	5.0	5.0	6.5								
136 - 142	-	8.0	5.5	6.5	-								
142 - 148	-	7.5	5.5	6.5	9.0								
148 - 154	-	7.5	5.0	6.0	5.0								
154 - 160	-	6.5	4.5	4.5	-								

	A	B	C			A	B	A	B
Aug. 13	Aug. 27	Aug. 27	Aug. 27	Sept. 10	Sept. 25	Oct. 11	Oct. 11	Nov. 12	Nov. 12
21.5	25.0	22.5	23.5	11.5	13.5	13.0	12.0	3.0	3.0
21.5	22.0	20.0	20.5	12.0	13.0	12.5	12.5	4.0	4.0
20.0	20.0	21.0	21.0	12.0	13.0	12.0	12.0	4.5	4.5
19.5	20.0	20.0	20.0	12.0	13.0	12.0	12.5	5.0	5.0
19.5	21.0	20.5	20.5	13.0	13.0	12.0	12.0	5.5	6.5
19.0	20.0	19.0	18.5	13.0	14.0	12.0	12.0	6.5	6.0
18.0	18.5	19.5	18.0	13.5	13.5	12.0	12.0	6.5	6.0
17.0	17.5	17.0	17.0	13.5	12.0	12.0	12.0	6.5	6.5
15.5	17.0	16.0	16.0	13.5	12.0	11.5	12.0	7.0	6.5
15.5	17.0	15.5	15.5	13.0	12.0	11.5	11.5	8.0	7.0
14.0	16.5	15.0	15.0	12.5	12.0	11.5	11.5	8.0	8.0
14.0	16.0	14.0	14.5	12.5	12.0	11.0	11.0	8.5	8.0
13.0	15.0	15.0	14.0	12.0	12.5	11.0	10.5	8.5	8.0
12.0	13.5	15.0	14.0	11.5	11.5	10.5	10.0	9.0	8.5
11.5	13.5	14.5	13.5	11.0	11.5	10.0	10.0	9.0	9.0
11.5	15.0	13.5	13.0	11.0	11.0	10.0	10.0	9.0	9.0
10.5	12.0	11.5	12.0	10.5	11.0	10.0	10.0	9.0	9.0
-	-	-	-	10.0	10.5	10.0	10.0	9.0	9.0

Appendix 2

Soil Temperatures Of West Plot (Degrees Centigrade)

Depth in inches	Apr. 26	May 2	May 8	May 16	May 21	June 1	June 5	June 11	June 18	June 27	July 5	July 16	July 30	Aug.
0 - 5	12.0	18.5	14.5	12.0	13.5	16.5	15.5	26.0	21.5	24.0	23.0	26.0	19.0	22.5
5 - 10	8.5	12.0	8.5	8.5	11.5	9.0	14.0	19.5	19.0	21.0	20.0	21.5	18.5	20.0
10 - 14	6.5	8.5	6.0	7.5	10.5	9.5	12.5	18.5	15.5	19.5	19.5	19.5	18.0	19.0
14 - 18	5.5	7.5	5.0	6.5	8.5	9.0	11.0	12.0	15.0	18.5	18.0	19.0	18.0	19.0
18 - 22	4.5	7.0	4.5	5.5	9.0	8.5	10.0	16.5	14.0	18.0	18.5	21.0	17.5	18.0
22 - 26	1.5	4.5	4.0	4.5	7.0	7.0	8.5	14.0	13.0	16.0	17.5	18.0	17.5	18.0
26 - 30	1.0	1.0	2.5	4.5	7.5	9.0	8.0	15.0	12.5	16.0	16.5	18.0	16.5	17.0
30 - 36	-0.5	-0.5	0.5	2.0	5.5	9.0	7.5	14.0	11.5	14.0	13.0	15.0	16.0	16.0
36 - 42	-0.5	0.0	-0.5	0.0	1.0	6.0	5.5	8.0	10.0	11.5	13.0	14.0	15.0	15.0
42 - 48	-0.5	-0.5	0.0	0.0	1.0	4.5	6.0	7.0	9.5	11.5	12.5	15.0	14.0	15.0
48 - 54	-0.5	0.0	-0.5	-0.5	0.0	1.5	3.0	8.0	8.5	9.5	11.0	12.0	13.0	14.0
54 - 60	-0.5	-0.5	0.0	-0.5	0.0	0.0	0.5	7.0	8.0	9.5	10.5	14.0	12.0	13.5
60 - 66	-0.5	0.0	0.0	0.0	3.0	0.0	0.0	-	6.0	-	-	12.0	11.0	13.5
66 - 72	1.0	4.0	1.0	2.5	1.5	-	3.0	-	-	-	-	-	11.0	12.5
72 - 78	1.5	4.5	3.0	3.0	4.0	-	2.5	-	-	-	-	-	-	-
78 - 84	2.0	5.0	2.5	3.5	6.5	-	-	-	-	-	-	-	-	-
84 - 90	2.0	5.0	3.0	4.0	6.0	-	-	-	-	-	-	-	-	-
90 - 96	2.5	3.5	3.5	4.0	8.0	-	-	-	-	-	-	-	-	-
96 - 102	2.5	4.5	4.0	3.5	6.5									
102 - 108	3.0	5.0	3.0	3.5	5.5									
108 - 114	3.0	4.5	4.0	5.5	4.0									
114 - 120	3.0	5.0	4.5	5.5	7.0									
120 - 126	3.0	6.5	4.0	5.0	6.0									
126 - 132	3.5	5.0	4.5	4.5	6.5									
132 - 138	3.5	5.0	4.5	5.0	5.0									
138 - 144	-	5.0	4.5	5.5	6.0									
144 - 150	-	6.0	4.5	5.5	6.0									
150 - 156	-	6.0	4.5	5.5	6.0									

July 5	July 16	July 30	Aug. 13	A Aug. 27	B Aug. 27	C Aug. 27	Sept. 10	Sept. 25	A Oct. 11	B Oct. 11	A Nov. 12	B Nov. 12
23.0	26.0	19.0	22.5	26.0	25.0	25.0	12.0	15.0	12.0	12.5	5.5	5.0
20.0	21.5	18.5	20.0	22.0	22.5	22.0	12.0	13.5	12.5	13.0	5.0	4.5
19.5	19.5	18.0	19.0	21.5	21.0	20.0	12.0	14.0	12.0	13.0	4.5	5.0
18.0	19.0	18.0	19.0	20.5	20.0	21.5	13.0	14.0	13.0	13.0	5.0	5.0
18.5	21.0	17.5	18.0	20.0	19.5	20.0	13.0	14.0	12.5	13.0	5.5	5.5
17.5	18.0	17.5	18.0	20.0	19.0	19.0	13.0	14.0	13.0	13.0	5.5	5.5
16.5	18.0	16.5	17.0	20.0	19.0	18.5	13.0	13.0	12.0	12.5	6.0	7.0
13.0	15.0	16.0	16.0	18.0	19.0	18.0	13.5	13.0	12.0	12.5	6.0	6.0
13.0	14.0	15.0	15.0	18.0	17.0	17.0	13.0	13.5	12.0	12.0	6.5	6.5
12.5	15.0	14.0	15.0	18.0	17.5	16.0	13.0	12.5	12.0	12.0	7.0	7.0
11.0	12.0	13.0	14.0	15.5	17.5	16.0	12.5	13.0	12.0	12.0	7.5	7.5
10.5	14.0	12.0	13.5	15.0	16.5	16.0	12.5	12.0	11.5	12.0	7.5	8.0
-	12.0	11.0	13.5	15.5	15.0	15.5	12.0	12.0	11.0	11.5	8.0	8.0
-	-	11.0	12.5	14.5	14.0	15.0	11.5	12.0	11.0	11.0	8.5	8.0
-	-	-	-	15.0	14.0	14.0	11.0	12.0	10.5	11.0	8.5	8.5
-	-	-	-	14.0	13.0	13.0	10.5	11.5	10.5	10.0	8.5	9.0
-	-	-	-	-	-	-	-	11.0	10.5	10.0	9.0	9.0
-	-	--	-	-	-	-	-	-	-	-	9.0	9.0

Appendix 3

Soil Temperatures Of Grass Plot (Degrees Centigrade)

Depth in inches	Apr. 26	May 2	May 8	May 16	May 21	June 1	June 5	June 11	June 18	June 27	July 5	July 16	July 3
0 - 4	12.0	15.5	13.0	12.5	16.0	13.5	16.0	24.5	22.0	26.0	24.5	21.0	21.5
4 - 8	8.0	11.5	9.0	10.5	13.5	11.0	14.0	19.5	18.0	22.5	21.5	20.5	18.0
8 - 12	6.0	9.5	7.0	10.5	11.5	11.0	13.0	17.5	17.0	20.5	20.0	19.5	18.0
12 - 16	5.5	7.5	5.5	-	-	-	-	17.0	16.0	19.0	19.0	18.0	18.0
16 - 20	4.0	8.0	5.5	-	-	-	-	15.0	15.0	18.5	19.0	18.0	18.0
20 - 22	3.5	7.5	5.5	-	-	-	-	-	15.0	18.0	17.5	19.0	18.0
22 - 26	4.5	6.5	5.0	-	-	-	-	-	15.0	18.0	17.0	16.5	17.0
26 - 29	4.0	4.5	4.5	-	-	-	-	-	14.0	16.0	16.0	15.5	16.5
29 - 35	2.5	4.5	4.5	-	-	-	-	-	13.0	15.5	15.0	15.0	16.0
35 - 41	0.0	4.5	3.5	-	-	-	-	-	-	15.0	16.5	14.0	15.0
41 - 48	0.0	4.5	3.5	-	-	-	-	-	-	-	-	14.0	14.5
48 - 54	0.0	1.5	-	-	-	-	-	-	-	-	-	-	14.0
54 - 60	1.0	1.5	-	-	-	-	-	-	-	-	-	-	14.0
60 - 66	2.5	2.0	-	-	-	-	-	-	-	-	-	-	13.0
66 - 72	1.0	3.5	-	-	-	-	-	-	-	-	-	-	-
72 - 78	-	3.0	-	-	-	-	-	-	-	-	-	-	-
78 - 84	-	-	-	-	-	-	-	-	-	-	-	-	-
84 - 90	-	-	-	-	-	-	-	-	-	-	-	-	-

		A	B	C			A	B	A	B
0	Aug. 13	Aug. 27	Aug. 27	Aug. 27	Sept. 10	Sept. 25	Oct. 11	Oct. 11	Nov. 12	Nov. 12
	22.5	24.0	22.0	23.5	12.5	17.0	12.0	12.5	5.5	6.0
	20.0	20.0	19.5	22.0	12.0	14.5	12.0	12.0	4.0	4.5
	20.0	19.0	19.5	19.5	12.5	14.0	11.5	11.5	5.0	5.0
	19.0	19.0	19.0	19.0	12.5	14.0	11.5	12.0	5.0	5.5
	19.5	19.0	19.5	18.5	13.0	13.5	11.0	11.5	5.5	5.5
	20.0	18.5	20.0	20.0	13.0	14.0	11.5	11.5	5.5	6.0
	20.0	18.0	19.0	19.5	13.0	13.5	11.5	11.5	7.0	5.5
	19.5	17.5	19.0	19.5	13.0	13.0	11.5	11.5	7.0	6.5
	19.5	17.0	18.0	17.0	13.0	12.5	11.5	11.5	7.0	7.0
	18.0	17.0	17.0	17.5	13.0	14.0	11.0	11.0	7.0	7.0
	18.0	-	14.5	17.0	13.0	12.5	11.5	11.5	8.0	8.0
	14.5	16.0	15.5	16.0	13.0	12.5	11.0	11.0	8.0	8.0
	14.5	14.5	14.5	15.5	12.5	12.5	11.0	11.5	8.0	8.5
	14.0	14.0	15.0	16.0	12.5	12.5	11.0	11.0	8.0	9.0
	-	14.0	16.0	14.5	12.0	12.0	11.0	11.0	9.0	9.0
	-	-	-	-	12.0	12.0	10.5	11.0	9.0	9.0
	-	-	-	-	-	12.0	11.0	11.0	9.0	9.0
	-	-	-	-	-	-	10.0	10.0	9.0	9.0

Appendix 4

Conductivity (Mmhos/cm) Of 1:5 Extract For April To November 1962 - East Plot

Depth in inches	Apr. 26	May 2	May 8	May 16	May 21	June 1	June 5	June 11	June 18	June 27	July 5	July 16	July 3
0 - 6	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.3	0.4	0.5
6 - 10	1.5	0.5	1.0	2.2	0.4	1.3	0.4	1.1	1.3	0.5	0.6	2.9	1.9
10 - 14	1.4	1.7	4.5	5.5	1.2	1.8	1.2	5.6	5.5	0.6	6.0	5.9	2.4
14 - 18	0.9	1.3	5.1	2.7	1.7	1.5	1.1	0.6	3.5	0.6	4.4	5.5	1.1
18 - 22	0.8	1.0	1.5	1.0	0.9	0.7	0.7	0.9	0.7	0.7	1.5	1.0	0.8
22 - 26	0.7	0.8	0.8	0.8	1.0	0.7	0.8	0.8	0.6	0.7	1.3	0.9	0.8
26 - 32	0.7	0.7	0.8	1.2	1.5	1.1	1.1	0.9	0.9	1.0	1.0	1.0	0.8
32 - 38	1.1	1.1	1.1	1.4	1.5	1.5	1.3	1.3	1.4	1.3	1.3	1.4	1.3
38 - 44	1.2	1.3	1.6	2.0	2.2	1.8	2.2	1.7	1.5	1.4	1.4	1.4	2.1
44 - 52	3.0	2.2	1.9	2.0	2.3	3.5	1.8	1.9	1.5	1.6	4.7	3.9	2.0
52 - 58	2.7	2.8	2.3	2.7	1.8	3.9	1.7	4.1	3.9	3.5	3.6	2.8	5.0
58 - 64	2.1	2.1	2.0	1.7	2.0	2.7	2.9	4.1	2.1	2.1	4.7	2.3	2.6
64 - 70	1.3	1.5	1.5	1.9	1.8	-	2.2	-	-	2.1	2.3	3.3	4.7
70 - 76	3.3	2.9	1.4	1.8	1.7	-	2.0	-	-	2.7	2.0	2.0	2.6
76 - 82	1.9	2.9	1.8	1.7	2.5	-	1.9	-	-	-	1.9	4.3	2.3
82 - 88	3.1	1.4	1.4	4.3	4.1	-	-	-	-	-	1.8	2.0	4.7
88 - 94	3.8	3.1	2.2	4.5	4.1	-	-	-	-	-	4.2	-	4.9
94 - 100	3.8	2.9	4.0	4.2	4.2	-	-	-	-	-	-	-	4.3
100 - 106	3.7	3.0	3.6	4.4	4.1								
106 - 112	3.7	3.0	3.9	4.5	4.1								
112 - 118	3.7	3.0	3.7	4.7	4.0								
118 - 124	2.8	3.0	3.8	4.4	4.4								
124 - 130	2.8	3.0	3.9	4.4	2.7								
130 - 136	1.4	1.8	1.8	1.8	2.7								
136 - 142	-	2.4	1.5	1.7	-								
142 - 148	-	1.5	1.6	1.6	3.4								
148 - 154	-	1.5	3.7	4.7	1.6								
154 - 160	-	1.4	3.7	1.3	1.4								

	A	B	C			A	B	A	B
Aug. 13	Aug. 27	Aug. 27	Aug. 27	Sept. 10	Sept. 25	Oct. 11	Oct. 11	Nov. 12	Nov. 12
0.7	0.4	0.5	0.7	0.4	0.4	0.5	0.5	0.5	0.5
6.1	0.9	6.0	6.7	2.9	2.5	1.7	0.7	4.4	1.3
5.0	2.6	6.3	7.0	3.5	5.8	2.1	6.3	2.8	6.9
3.2	1.6	1.8	4.0	2.2	5.9	1.1	6.0	1.2	6.2
1.1	1.1	1.1	1.3	1.1	1.3	0.8	1.0	0.8	1.8
0.9	1.0	1.1	1.1	1.1	0.8	0.6	0.8	0.7	2.0
0.8	0.8	1.2	0.9	0.9	0.8	0.8	1.1	0.7	0.9
1.2	1.2	1.5	1.2	1.5	1.2	1.0	1.4	1.1	1.2
1.3	1.9	1.5	1.7	1.6	1.4	1.5	2.0	1.3	1.5
3.4	2.0	3.7	6.6	1.7	2.2	2.4	6.0	1.5	4.9
4.4	4.4	5.9	4.9	3.5	1.9	4.6	4.7	1.7	3.2
3.1	3.5	3.4	2.4	4.2	2.9	3.8	5.6	1.9	4.7
2.0	4.2	2.9	2.4	2.0	2.2	2.5	2.2	1.8	4.6
1.9	2.1	2.2	2.3	1.9	1.8	1.9	4.7	1.9	4.1
4.9	1.9	5.0	6.1	1.9	3.6	1.9	5.1	5.5	4.1
3.7	5.4	5.0	5.3	5.0	4.2	2.6	5.0	4.1	4.8
1.8	2.5	2.0	4.1	2.9	3.3	1.9	2.9	2.3	2.5
-	-	-	-	5.3	1.6	5.1	1.8	4.5	2.1

Appendix 5

Conductivity (Mmhos/cm) of 1:5 Extract For April To November 1962 - West Plot

Depth in inches	Apr. 26	May 2	May 8	May 16	May 21	June 1	June 5	June 11	June 18	June 27	July 5	July 16	July
0 - 5	0.4	0.3	0.6	0.5	0.4	0.5	0.4	0.4	0.6	1.2	0.7	1.0	1.1
5 - 10	2.7	2.1	1.6	1.3	2.2	1.0	3.2	1.0	3.5	4.4	5.5	1.8	4.9
10 - 14	4.9	2.3	3.6	5.4	6.1	3.6	6.0	5.4	5.3	2.4	5.9	6.2	6.1
14 - 18	4.9	2.3	5.8	6.0	6.2	3.1	5.8	5.4	5.3	4.8	5.5	2.6	3.6
18 - 22	1.7	2.3	1.1	5.2	6.0	1.5	5.5	1.4	1.2	5.6	1.9	0.7	5.5
22 - 26	1.1	1.5	1.2	1.5	5.4	0.8	4.8	1.0	0.8	5.5	0.9	0.6	4.1
26 - 30	1.4	1.4	1.3	2.2	3.2	0.8	2.7	0.8	0.8	3.0	1.4	0.8	1.5
30 - 36	1.3	1.5	1.4	1.3	3.4	1.1	2.1	0.9	1.1	1.0	1.4	1.4	0.9
36 - 42	1.3	1.5	1.5	1.6	3.0	1.9	1.5	1.3	3.1	1.1	1.5	2.7	1.0
42 - 48	1.4	1.2	1.4	3.2	2.8	4.4	1.1	2.7	2.1	1.0	4.2	1.5	0.9
48 - 54	1.4	1.5	3.7	1.5	3.8	3.0	3.7	2.7	1.2	0.9	3.8	1.5	1.1
54 - 60	3.0	2.9	3.8	3.4	4.5	4.4	3.7	3.0	3.5	1.6	3.9	2.2	4.8
60 - 66	3.3	2.9	3.8	3.0	4.2	4.5	3.7	-	3.6	-	-	4.5	4.8
66 - 72	3.2	3.0	1.8	2.3	3.3	-	2.5	-	-	-	-	-	-
72 - 78	2.7	2.4	-	1.7	4.0	-	3.8	-	-	-	-	-	-
78 - 84	2.2	3.0	1.7	1.7	4.1	-	-	-	-	-	-	-	-
84 - 90	3.3	2.9	3.3	3.7	4.1	-	-	-	-	-	-	-	-
90 - 96	3.3	2.9	3.3	3.8	4.2	-	-	-	-	-	-	-	-
96 - 102	2.8	2.9	3.5	3.9	3.7								
102 - 108	2.5	2.8	3.5	3.6	4.0								
108 - 114	2.4	2.9	3.2	3.8	4.0								
114 - 120	1.4	2.7	3.2	3.7	2.0								
120 - 126	1.3	1.6	1.3	1.7	2.3								
126 - 132	1.3	1.4	1.2	1.6	1.5								
132 - 138	1.1	2.3	2.9	1.8	1.5								
138 - 144	-	1.9	1.4	3.4	4.2								
144 - 150	-	1.6	1.2	2.8	1.9								
150 - 156	-	1.5	1.6	2.4	3.7								

	A	B	C			A	B	A	B
Aug. 13	Aug. 27	Aug. 27	Aug. 27	Sept. 10	Sept. 25	Oct. 11	Oct. 11	Nov. 12	Nov. 12
0.9	0.9	2.4	1.3	1.3	0.8	0.6	0.9	0.9	0.8
4.9	4.5	6.8	2.9	6.0	4.9	5.0	1.1	1.1	2.1
5.4	6.4	5.7	2.3	6.1	5.6	5.6	0.6	0.9	5.4
2.5	6.8	1.4	0.9	5.9	0.9	5.8	0.6	0.8	2.1
1.3	6.7	1.1	0.7	1.9	0.7	5.7	0.6	0.7	0.8
0.8	4.4	1.1	0.9	1.2	0.7	5.3	0.6	0.7	0.8
1.0	1.0	4.3	1.2	1.4	0.9	1.3	0.9	1.0	1.0
1.1	6.4	4.2	1.4	1.2	1.1	1.1	1.1	1.3	1.1
1.3	5.8	3.6	6.6	3.3	4.6	1.4	1.6	1.8	1.2
1.3	3.4	3.8	3.2	5.0	3.1	0.9	1.7	1.2	1.2
5.1	4.8	5.7	3.7	3.3	2.4	2.6	1.4	2.0	1.5
4.3	4.5	4.4	6.5	4.0	2.2	5.0	4.8	2.2	4.7
4.1	6.1	4.6	2.5	4.4	2.3	1.7	3.7	1.5	2.3
2.0	5.8	5.0	4.5	3.9	1.6	3.1	3.8	1.5	4.2
–	3.8	2.3	1.8	5.1	3.5	4.6	2.1	1.4	5.3
–	4.2	3.4	5.8	4.7	3.8	3.3	5.0	4.2	4.7
–	–	–	–	–	3.8	3.7	4.2	3.8	4.8
–	–	–	–	–	–	–	–	3.7	4.2