ZERO TILLAGE IN MANITOBA: AN EVALUATION BY SOIL PHYSICAL PROPERTIES

by

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ABSTRACT

The use of zero tillage for crop production reduces the time and power requirements for soil preparation as well as the cost. Soil physical properties are altered by tillage operations. A comparative evaluation of zero and conventional tillage was made by studying the soil physical properties to determine their response to both tillage systems.

Soil moisture content, soil aeration, soil strength, soil temperature, crop emergence and crop yields were the factors used in evaluating the tillage operations. The comparisons were made in Manitoba on a loamy sand soil at Carman a sandy loam soil at Portage la Prairie and a clay soil at Sanford. Wheat, barley, flax and rape were planted in zero and conventional tillage plots. Conventional tillage operations were discing or cultivating followed by harrowing.

The soil moisture content was determined by the gravimetric method. Soil aeration was evaluated by measuring oxygen diffusion rate, air-filled porosity and total soil porosity. Soil strength was compared by measuring soil resistance to penetration and soil bulk density. Soil temperature was measured by copper-constantan thermocouples.

Soil moisture content, soil strength and soil temperature were generally higher under zero tillage. Soil aeration was significantly lower under zero tillage in the top soil layer (0 to 3 inch). Crop emergence and crop yield under zero tillage were generally higher than under conventional tillage. The changes in soil physical properties, affected by zero tillage, did not have an adverse effect on crop production for the conditions of this study.

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CHAPTER 1

INTRODUCTION

Tillage is one of the major operations in crop growing. Farmers have spent much time, effort and money in order to prepare a suitable seedbed.

The changes in the soil physical properties due to tillage can influence the chemical and biological processes involved in plant growth. The major soil physical properties used to evaluate tillage are soil moisture, aeration, strength and temperature. Many tillage systems such as plowing, discing, plow-plant have been used. However, no one is suited to all soils or to all environmental conditions for optimum plant growth.

Farmers, agronomists and engineers are interested in finding the optimum system to achieve higher crop production with reasonable economic investment. To realize this goal the relations between the soil and machines, and between the soil and plants must be well understood.

Soil physical properties can be altered by field machines. Farm machines, for instance tillage tools, farm tractors, moving agricultural machinery cause changes in soil aeration and in other physical properties of the soil. Excessive tillage operations will destroy the soil environment needed for good plant growth.

Evaluation of tillage systems for the best results has been done in many areas. The soil physical properties were compared between zero and conventional tillage.

Different soil types responded to tillage systems in different ways. In Europe and in the United States, some areas were suitable for zero tillage while others were not. Comparisons of zero and conventional tillage have been made in Canada. Alberta and Saskatchewan have reported success when growing cereal crops under zero tillage. The zero tillage system can not be recommended as optimum in every area until further investigations are conducted.

The objectives of this study were to determine the effect of zero and conventional tillage on (i) soil moisture, (ii) soil aeration, (iii) soil strength and (iv) soil temperature. The effect of soil physical properties on crop emergence and yields were evaluated.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Tillage System Definition

Soil tillage is a basic agricultural operation. It is characterized by complex objectives and a wide choice of methods to achieve these objectives. There are many differing personal opinions on tillage objectives and methods. The main purposes of the tillage operation are (44):

(1) To prepare the soil for fast and accurate mechanical planting at the proper depth.

(2) To obtain a soil condition that increases seed germination and emergence.

(3) To improve the soil for rapid water intake and to reduce compaction.

The tillage system may be divided into three main different systems:

(1) Conventional: A system of soil preparation including plowing, discing, harrowing and planting with a standard planter. It generally gives good yields on all soils in different climates (39).

(2) Minimum: A system defined as a group of soil preparation methods in which the number of operations is

less than in the conventional system. It is desirable from the standpoint of soil and water conservation because of larger aggregate size and reduced soil compaction.

(3) Zero tillage or no-tillage: It is defined as a system with no soil preparation. It is a new technique for cropping and can be adapted to a variety of soil conditions. Production costs can be reduced under favorable condtions.

2.2 Soil Parameters Approach

Tillage operations effect crop production by changing the physical properties of the soil. The soil parameters have to be well understood in order to interpret the functions of tillage. The four major soil parameters of moisture content, aeration, temperature and soil strength are adequate for the evaluation of tillage operations (14, 15). Because of the dynamic relationship between tillage and soil at least these four soil parameters must be evaluated in assessing tillage operations (14).

2.3 Progress on Research of Tillage Systems

Much tillage research has been done since 1925 to determine whether tillage will improve crop production and whether reduction in tillage will reduce soil compaction as well as production costs (64, 69).

In the past tillage was a traditional art rather than a logically developed sequence of operations. Farmers tended to plow deep and overwork the soil when preparing seedbeds (31). This overworking of the soil caused the desirable soil properties to be destroyed. Plowing and the other necessary tillage operations account for approximately 14 percent of the total cost of growing a cereal crop (77). No apparent advantage in plowing to a depth greater than 4 inches has been found (3).

2.3.1 Research on minimum tillage

Numerous investigators have studied tillage practices in order to find the optimum operations for improved crop production. Desirable soil conditions and yields have been shown to improve with minimum seedbed preparation as compared to conventional seedbed preparations (13, 40). Production costs and soil compaction have been reduced. Coarse and medium textured soils have responded to minimum tillage better than fine soil (69). Heavier clay soils were not likely to benefit from direct seeding techniques for corn growing (59).

2.3.2 Research on zero tillage

Research strongly supports the following characteristics of a zero tillage system. Zero tillage gives more stable soil structure, more available water, more rapid rate of plant growth and improves land utilization (49). Many researchers (8, 24, 25, 72) have reported that use of a zero tillage system resulted in successful crop production. Zero tillage has been shown to be a practical and useful concept for crop production. Corn production over a nine year period has been excellent using zero tillage (27). Several research reports (49, 54, 56, 61, 69) have indicated that zero tillage systems have produced higher crop yields. Less water run-off, less evaporation, negligible soil erosion and improved soil conditions including less soil compaction were also noticed. The development of a cropping system base on zero tillage provided a significant reduction in power and time requirement (73).

2.4 Effect of Tillage on Soil Physical Properties

2.4.1 Effect on soil moisture content Many studies indicate that minimum tillage systems resulted in higher rates of infiltration. Zero tillage was found to be the system under which optimum crop growth was obtained with maximum soil and water conservation (73). Available soil moisture was increased by zero tillage (27, 58). It was observed that crops under a zero tillage system better tolerated drought for one to two weeks (61). An experiment with corn showed that more moisture was maintained in the top 18 inches of soil with zero tillage as compared to conventional tillage (55). This result was supported by other workers (49, 42, 10) who found significantly more soil moisture under zero tillage compared to conventional tillage. There was approximately 0.3 inches more available water in the 0 to 6 inch depth and 0.7 inches more in the 0 to 24 inch depth (49). Zero tillage corn production showed higher average soil moisture (42). There was 0.07 to 1.2 inches more soil moisture at the root zone. The greatest difference in soil moisture occurred in the top 3 inches of the soil (10). Tillage had very little effect on soil moisture at depths below 24 inches.

2.4.2 Effect on soil aeration An analysis of the problem of soil aeration shows that diffusion of air from the soil into the atmosphere and vice versa is the key to soil aeration. Tillage operations make the soil loose, but excessive tillage produces small pore spaces which tend to retard seed germination and early growth. Implements, such as discs were found to contribute to soil compaction (9). Repeated tillage operations also lead to soil compaction.

Conventional tillage operations usually decreased soil porosity and the soil structure was less stable (44).

It was found that most field crops required an air-filled porosity of more than 10 percent (7, 45, 64). Many plants maintained good root growth if the soil had an oxygen diffusion rate (ODR) of at least 20×10^{-8} g cm^{-2} min^{-1}. Good plant emergence was obtained when the soil had an ODR of 50×10^{-8} to 70×10^{-8} g cm^{-2} min^{-1} (48).

The results of an experiment with wheat seedling emergence indicated that when the oxygen diffusion rate was below 75×10^{-8} to 100×10^{-8} g cm^{-2} min^{-1} overall emergence was lower (32). This value of oxygen diffusion rate corresponded to about 16 percent air-filled porosity in silty clay loam and about 25 percent in fine sandy loam. The amount of air flow in moist silty clay soil was reduced to one-fourth when the soil was packed as compared to unpacked soil (9).

2.4.3 Effect on soil strength

There have been many field experiments which have indicated that severe soil compaction caused by repeated tillage operations resulted in lower crop yields. Most field studies have measured soil compaction using soil properties such as bulk density, air-filled porosity, hydraulic conductivity and soil strength (64).

Soil resistance as measured by a penetrometer was found to be a good indication of root penetration resistance

(64). The pressure acting on the penetrometer in the preceding experiments was found to be in the range of 116 to 725 psi. It was reported that cotton did not emerge when penetrometer resistance was 174 psi (70). The radicles of corn roots failed to penetrate the soil when the penetrometer resistance was found to be 522 psi. The bulk density was 1.5 to 1.7 g/cc. In a sandy soil barley root development ceased when penetrometer resistance was 174 psi (29). The corresponding bulk density was 1.4 to 1.65 g/cc.

Field observations and measurements of soil density have shown that soil compaction is a major cause of shallow rooting (18). Soil mechanical resistance in unusually strong soils retarded root and underground shoots growth but was not the limiting factor in growth (6).

Zero tillage practices resulted in less soil resistance to root penetration throughout the growing season and lower bulk density as compared to conventional tillage. Root penetration was prevented when the soil bulk density reached 1.9 g/cc (60). But contradictory results have also been obtained. A bulk density of 1.37 g/cc was measured at planting time under conventional seedbed preparation while the bulk density was 1.54 g/cc under a zero tillage seedbed preparation (49). The bulk density in the

0.5 to 3.6 inch depth under a zero tillage corn crop was also noticeably greater than under conventional tillage (72). There was no significant difference in the soil bulk density between conventional and zero tillage corn crops (63).

It was cited by Zrazhevskiy and Nazarenko (79) that the optimum soil bulk density for grain crops ranged from 1.1 to 1.4 g/cc. For root crops the soil bulk density usually did not exceed 1.15 to 1.2 g/cc.

A study of wheat seedling emergence reported that the rate of seedling emergence was related directly to moisture content and indirectly to bulk density (32).

2.4.4 Effect on soil temperature Tillage operations clearly influence soil temperature and consequently influence crop growth. Theoretical studies indicate that a soil with no cover becomes hotter in summer and colder in winter as compared to a soil with some type of covering.

A zero tillage experiment showed that the range of average daily soil temperature at the 2 inch depth was 4 F less during germination and 6 F less over the entire growing season when compared to conventional tillage (49). The lower soil temperature resulting from zero tillage was evidently due to the vegetative cover.

Much work has been done on the effect of mulch tillage on soil temperature. Large amounts of crop residue reduce soil temperature thus reducing early growth of crops and consequently decreasing crop yields. It was reported that a 1.5 ton/acre mulch could reduce the average soil temperature at the 4 inch depth by 1 F (16) Another report confirmed that average soil temperature during the first eight weeks after planting was reduced by as much as 6 F under minimum tillage practices (39). The greatest effect of tillage on soil temperature was realized in the 0 to 4 inch depth and range from 2 to 4 F (61). Compaction by press wheels increased the soil thermal conductivity (66).

Practical experience has shown that plant germination becomes more rapid as the soil temperature increases up to a certain optimum temperature. The optimum rate of activity of soil organisms occurs between 64 F and 86 F (37). The optimum temperature for maximum rate of germination and growth of many different crops has been found (44, 78). The optimum root temperature for many plants was found to be about 68 F. The best top growth of spring wheat was found to be at 68 F to 75 F (62). It is believed that water absorption by plant roots is decreased by the decreasing root temperature (62).

2.4.5 Effect on soil erosion Zero tillage practices have proved to be extremely effective in soil and water conservation. Soil erosion at the rate of 0.06 ton per acre was found with zero tillage while it was 2.8 ton per acre with conventional tillage (33). This resistance to soil erosion under zero tillage was due to the maintainance of existing vegetative cover on the soil surface. Soil erosion under conventional tillage was much higher due to reduced trash cover thus leaving the soil open to wind and water erosion (56). The top soil was then washed from the fields and created stream pollution problems.

In a three year study, it was found that under zero tillage 118 pounds of soil per acre was eroded compared to nearly 6,000 pounds per acre under conventional tillage (76). Another experiment showed that, shortly after planting, soil erosion was 16.7 tons per acre from conventional tillage and 8.6 tons per acre from reduced tillage (44). It was reported that reduced tillage operations reduced soil erosion almost fourfold (54). Pierre and Wischmeier (44) found that erosion loss could be reduced 40 percent by wheel-track or plow planting as compared with conventional tillage.

2.4.6 Effect on yield It has been recognized that overtilling not only increased operating costs of crop growing but also reduced crop yield due to soil compaction. Some data have indicated that the yield of sugar beets and wheat was reduced by 13 percent due to overtilling while potato yields were reduced by as much as 54 percent (1).

Corn grown under zero tillage yielded 1.6 tons per acre (dry weight basis) or 26 bushels per acre more than when grown under conventional tillage (61). Several studies have shown increased corn production with zero tillage as compared to conventional tillage (42, 63, 72). Another study recorded no cases where the yield was less on zero tillage when compared to conventional tillage (33). However, an Ohio study on corn reported that zero tillage did not always raise yields (74).

Minimum seedbed preparation for cotton increased the yield 145 to 260 pounds of lint cotton per acre above the yield from conventional seedbed preparation (22). It was also reported that cotton yields over a 7 year period averaged 1,932 pounds per experimental plot for zero cultivation as compared to 1,888 pounds per experimental plot for conventional cultivation (24).

Wheat yields in experiments in Alberta and Saskatchewan over a three year period were superior for zero tillage. Yields of rape, flax, oats and barley were also higher (56).

Another report indicated that reducing various tillage operations in seedbed preparation increased crop production in some cases by more than 25 percent (41).

CHAPTER 3

SOIL PHYSICAL PROPERTIES AND THEIR MEASUREMENT

3.1 Soil Moisture Content

Moisture content has a decisive influence on all soil properties and processes. It is the most important factor. The flow paths of soil moisture determine the loss and the accumulation of chemical substances.

One of the aims of tillage is to improve water relationships in the soil for plant growth. Tillage effects the rate of infiltration, redistribution and storage of water within the soil profile and hence may have a direct or indirect influence on evaporation and transpiration.

Arndt and Rose (4) presented a simple model for the different fractions of precipitation to help explain the interactions between soil compaction, tillage and water for subsequent crop use.

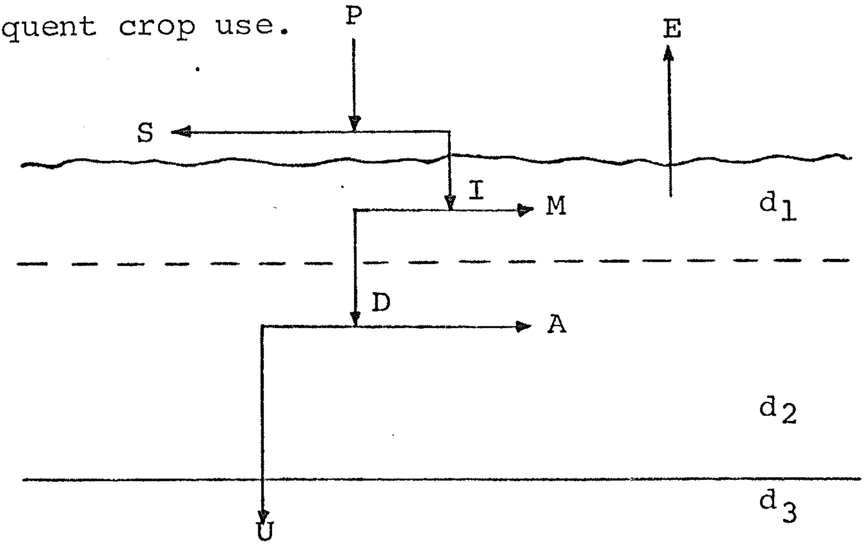

Fig. 1 A model for partitioning precipitation in tillage studies (Arndt and Rose (4)).

The model shows three soil layers: a tillage layer (d_1), a water storage layer (d_2) and a deep drainage layer (d_3). The precipitation (P) is separated into run-off water (S) and infiltrated water (I). Infiltrated water causes an increase in stored water (M) in the tillage layer and the amount of stored water depends on the amount of evaporation (E). The drainage (D) from the tillage layer will be the input water to the water storage layer and contribute to an accumulation of water (A). Some water will appear as deep drainage water (U), to the deep drainage layer.

The water and nutrients carried to the deep drainage layer are lost to the crop and are limited by the amount of infiltrated water. Hence the water balance equation for the tillage layer can be presented as:

$$P = E+S+M+D \qquad (3.1)$$

Tillage operations which compact the soil have an adverse effect since they reduce the amount of available water in the water storage layer. The rate of seedling emergence is related directly to soil moisture content.

Soil moisture content can be determined by sampling at any desired depth. The samples are weighed and then dried at 105 to 110 C for about 48 hours. The moisture content is then calculated as a percentage of the oven-dry soil weight.

3.2 Soil Aeration

Much research has been done on the relation between soil aeration and plant growth. When evaluating tillage soil aeration appeared to be the most useful property (15). Root and top growth were found to be impeded by lack of oxygen in the soil. It was concluded that root respiration was the most sensitive plant activity related to soil aeration (45).

There are several methods which have been used to measure the soil aeration. Two states of soil aeration should be recognized: (i) air within the macro-pore space (air-filled porosity), and (ii) air in the micro-pore space, i.e. between the soil particle and the root surface (20). The air in the second state may be gaseous or dissolved in water.

Air-filled porosity is generally a reliable index of air availability for plant growth (45). It can be calculated as follows:

$$P_a = P_t - M_w D_b \tag{3.2}$$

$$P_t = 1 - D_b / \rho_s \tag{3.3}$$

where: P_a = air-filled porosity, percent

P_t = total soil porosity, percent

M_w = moisture content on dry weight basis, percent

D_b = dry bulk density, g/cc

ρ_s = soil particle density, g/cc

Moisture content, M_w is defined as:

$$M_w = (W_l/W_s)\ 100 \tag{3.4}$$

Dry bulk density, D_b is defined as:

$$D_b = W_s/V \tag{3.5}$$

where: W_l = weight of liquid, g

W_s = oven-dry weight of soil, g

V = total undisturbed soil volume, cc

Although the air-filled porosity of a soil may appear satisfactory for plant growth, the true aeration status may in fact be governed by the actual diffusion of oxygen in the micro-pore space. Lemon and Erickson (47) developed a method of measuring oxygen diffusion rate (ODR) in the micro-pore space by simulating the plant root with a small platinum wire. The apparatus is functional only in relatively wet soils. The principle of the simulation involves measurement of the electric current caused by reduction of oxygen at the surface of the wire electrode. A suitable mounted microelectrode is pushed into the soil with a working voltage between -0.4 and -0.8 volt to ensure that all the oxygen will be reduced. It usually requires 4 or 5 minutes (51) to standardize the apparatus before measuring the current. The equation for oxygen diffusion rate is:

$$f_{a,t} = \frac{60\ M\ i_t}{nFA} \times 10^{-6} \qquad (3.6)$$

where: $f_{a,t}$ = ODR (at time, t at the surface of an electrode radius, a), g cm^{-2} min^{-1}

M = molecular weight of oxygen (32 g/mole)

i_t = current, microamperes

n = number of equivalents per mole of oxygen (4)

F = Faraday's constant (96,500 coulombs/equivalent)

A = area of the electrode, cm^2

There are a number of physical and chemical factors influencing the accuracy of the measurement of ODR. Because of the great variation in soil environments, an average value of ODR should be used.

3.3 Soil Strength

Soil strenght can be studied by measuring the forces between individual particles. Published research has established which of the mechanical properties of the soil are concerned with the soil surface forces related to compaction.

Soil compaction has been used in both the dynamic and static sense: in the dynamic sense, it is the physical deformation of the soil increasing the dry bulk density, in the static sense, the soil resistance of penetration has been increased (19). The usual definition of dry bulk density is the weight of oven-dry soil per unit total undisturbed volume.

Increased tractor power as well as the increased use of farm machines has created problems in soil compaction. A number of experiments have been done to determine the influence of soil compaction on plant growth. It was concluded that soil compaction caused a reduction of soil permeability and soil aeration while increasing soil strength. These changes reduced the quality and quantity of food and fiber (28). In addition, disturbances in soil water and soil air due to compaction had an adverse effect on the biological processes in the soil.

Compaction occurred during cultivation, spraying and harvesting as well as during primary and secondary tillage (64). Changes in soil compaction due to tillage operations can be measured by changes in the dry bulk density. Many samples can be easily obtained.

A difficulty in determining dry bulk density is the accurate measurement of the undisturbed soil volume.

Many methods have been used but there is no best method for all situations (26). The core sampling method is not suited for detection of very abrupt changes in dry bulk density which may occur in the tilled soil. The sand-cone method is tedious and time consuming.

A rapid method used for measuring dry bulk density is the water balloon method. The basis of this method is the use of water to determine the volume of a test hole. A small amount of air pressure is applied to the surface of the fluid to cause the thin elastic membrane or balloon to fill the hole. The pressure should not be great enough to cause distortion or enlargement of the test hole. Usually a pressure 3 to 7 psi (20.7 to 48.3 kN/m^2) is adequate (26).

Soil resistance may be determined by measuring the penetration resistance of the soil. Soil penetration resistance can be used as a soil parameter in the evaluation of soil compaction and for comparison of tillage operations. The penetrating element is a circular (or rectangular) flat plate or a cone shaped tip. The cone penetrometer is frequently used in agricultural soil studies. It is applicable to a wide range of soil types although consistent and uniform test results are difficult to obtain in very stony soils. Use of a cone penetrometer permits a large number of tests. Consequently a sufficient amount of data can be collected in a reasonable time to obtain average results.

The American Society of Agricultural Engineers recommend for field use a 30 degree circular cone penetrometer driven through the soil at a rate of approximately 72 inches per minute. The results are quoted as a cone index. A description of this instrument is given in ASAE recommendation R313 (65).

The accuracy of a soil cone penetrometer depends greatly on the moisture content of the soil. The most accurate results are obtained when the soil moisture content is 20 percent (dry weight) (71).

3.4 Soil Temperature

Soil temperature is very important at planting time. Adverse soil temperatures cause, either directly or indirectly, crop failures (78). Seed germination and plant growth are dependent on an adequate soil temperature.

Soil temperature is effected by tillage primarily through changes in the thermal properties of the tillage layer. Most heat transfer in the soil is by conduction. Radiation and convection within the soil mass can be negligible (67).

The temperature in the upper soil layer fluctuates with alternating intervals of heat storage and heat loss. If the soil is covered with dense vegetation, the daily maximum temperature will be lower than that of uncovered soil. This is because of the shading effect. During the early growing season soil temperatures in the top layer of tilled soils have been found to be warmer than the soil temperatures in the top layer of untilled soils (75). There was a noticeable effect on seed germination.

Generally, the mercury-in-glass thermometer is the most common instrument for temperature measurement. Measuring soil temperature with a glass thermometer is not a suitable method. A thermocouple is a relatively simple method of temperature measurement. A potential difference is generated between the two ends of the thermocouple when they are placed at different temperatures. This potential difference is proportioned to the difference in temperature. A potentiometer is a device used to measure the potential difference. This potentiometer can be calibrated directly to measure temperature. Many potentiometers can read the potential difference within 1 μv. Copper-constantan thermocouples produce approximately 1.04 μv per degree Fahrenheit temperature difference.

In this study soil temperatures were measured with copper-constantan thermocouples in conjunction with a potentiometer. The readings were recorded directly in degrees Fahrenheit.

CHAPTER 4

INVESTIGATIONAL PROCEDURE AND APPARATUS

4.1 Details and Locations

A study to compare crops and weed growth under zero conventional tillage was begun in the spring of 1969 on a cropping area that had received no tillage since June 1968. Experimental sites were established by the Plant Science Department in co-operation with Chipman Chemical Company at three locations in Manitoba. Each location had 18 plots. The plot sizes were 120 feet by 350 feet at Carman and Sanford and 80 feet by 500 feet at Portage la Prairie. There were two zero tillage and one conventional tillage treatments established. The two zero tillage treatments received different chemical treatments for weed control (Table A-3).

The soil type at Carman was loamy sand, at Portage la Prairie sandy loam and at Sanford clay soil. The soil particle size analysis was done by the hydrometer method. The percentage of soil particle sizes is shown in Table B-2 (Appendix B).

The crops were wheat, barley, flax and rape. The crops were seeded with a Kirschmann double disc drill. An additional coulter was placed in front of the double disc to increase the cutting action (Fig. 3) The conventional tillage operations were discing and harrowing at Carman in 1970 and at all three locations in 1971. Cultivating and harrowing were used in 1970 at Portage la Prairie and Sanford (Table A-2).

This study was started in the summer of 1970 to determine the effect of zero and conventional tillage on the physical properties of the soil. The study was continued through the summer of 1971.

As far as this investigation was concerned, the two zero tillage treatments were no different and were considered as one treatment in comparison with the conventional tillage treatment.

4.2 Measurement and Sampling Technique

In the measurement and sampling of the soil parameters the same methods were used in both the zero tillage and the conventional tillage treatments. Samples were taken on the same day for each soil parameter at each location.

A computer program was written to do all repititious time-consuming calculations. The field data for each soil parameter were converted to the proper physical units. The statistical analysis was also done by computer.

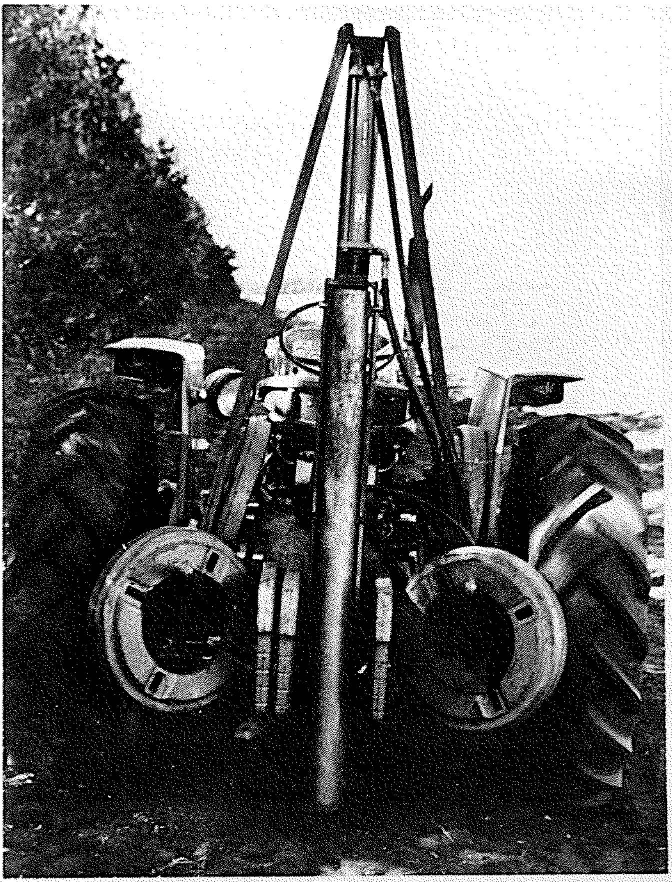

Fig. 2 Soil core sampler apparatus.

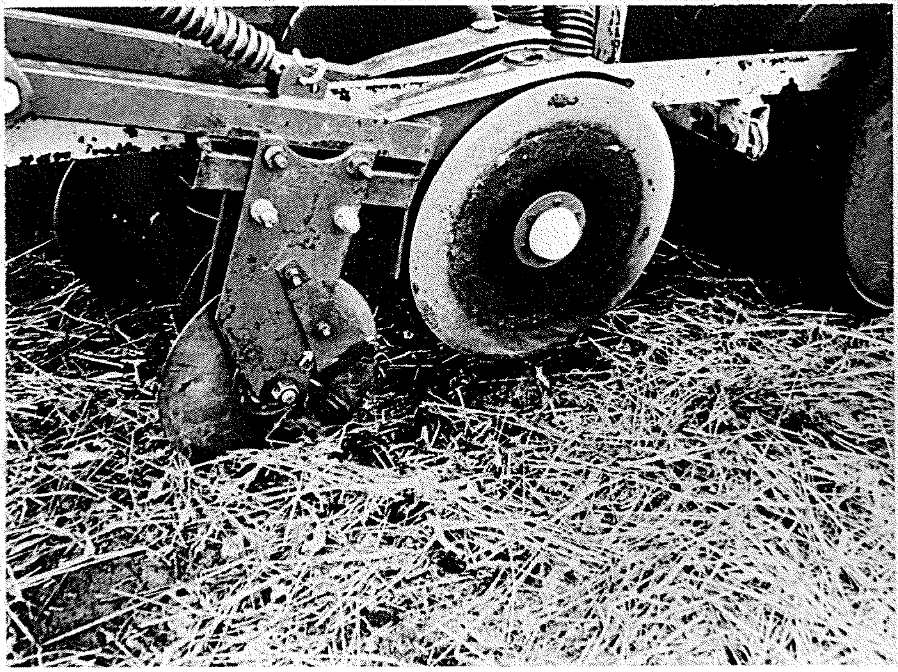

Fig. 3 Double disc drill with coulter.

4.2.1 Measurement of soil moisture Soil moisture was measured by the gravimetric method. The samples were taken weekly, in 3½ inch diameter cans. Two depth intervals, 0-2 inch and 2-4 inch were sampled in the summer of 1970. The depth intervals were 0-3 inch and 3-6 inch in the summer of 1971.

4.2.2 Measurement of oxygen diffusion rate The oxygen diffusion rate (ODR) was measured by the ODR apparatus (Fig. 4). The eight platinum 6 inch electrodes were inserted into the soil at any one point and the average value of the eight readings was used as the ODR value at that point. The length and diameter of the platinum wire tip of each electrode was measured. The diameters of all the wires were approximately the same and the average value of 0.64 mm was used. The length of the tips ranged between 3.3 mm and 4.5 mm. (The surface area of each platinum wire is shown in Appendix C.) The surface area values were need to calculate ODR values. Readings were taken after the apparatus stabilized. A voltage of -0.65 volt was supplied to insure the reduction of all the oxygen in the soil. The oxygen diffusion rate was measured at 0 to 3 inch depth in the summer of 1971.

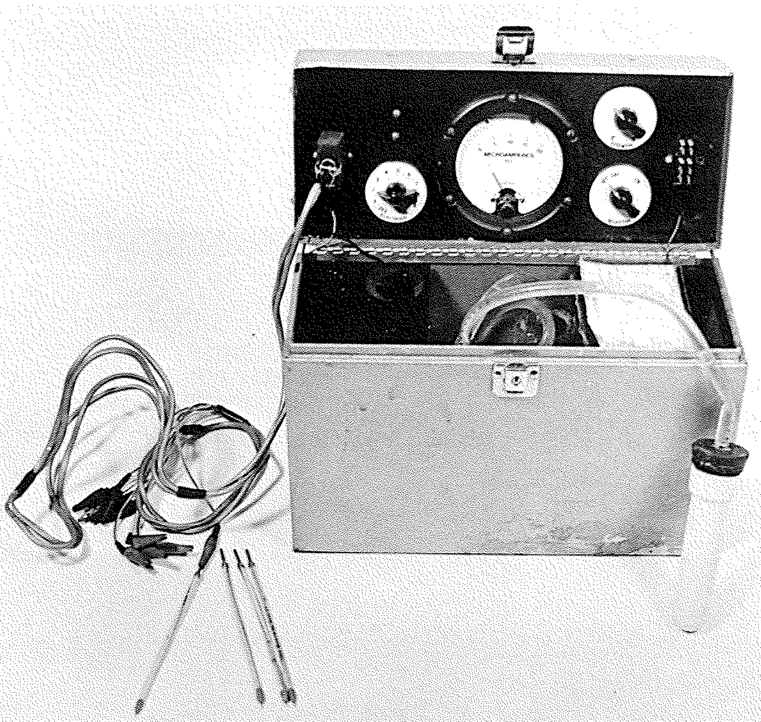

Fig. 4a Oxygen diffusion rate measuring apparatus.

Fig. 4b Field use of the oxygen diffusion rate measuring apparatus.

4.2.3 Measurement of air-filled porosity and total soil porosity Both air-filled porosity and total soil porosity were determined in the summer of 1971 at 0-3 inch and 3-6 inch depths. The particle density of the soil at each location was determined using a pycnometer. Approximately 5 grams of oven-dried soil were used each time. (The details of the calculations are shown in Table B-1, Appendix B). The average of particle density at each location, the moisture content, and the dry bulk density were used to determine the air-filled porosity and total soil porosity. Equations 3.2 and 3.3 were used.

4.2.4 Measurement of dry bulk density The bulk density was determined in the summer of 1971 with the water balloon method at 0-3 inch and 3-6 depths. The soil was carefully dug out and placed in a soil can for moisture determination. The volume of the holes was measured by the water balloon soil density apparatus (Fig. 5). The soil dry bulk density was determined from the values of soil dry weight and volume.

4.2.5 Measurement of soil resistance Soil resistance was measured by a hand operated cone penetrometer (Fig. 8). The cone penetrometer used in this study meets the ASAE recommendation. It was previously used by Feldman (24)

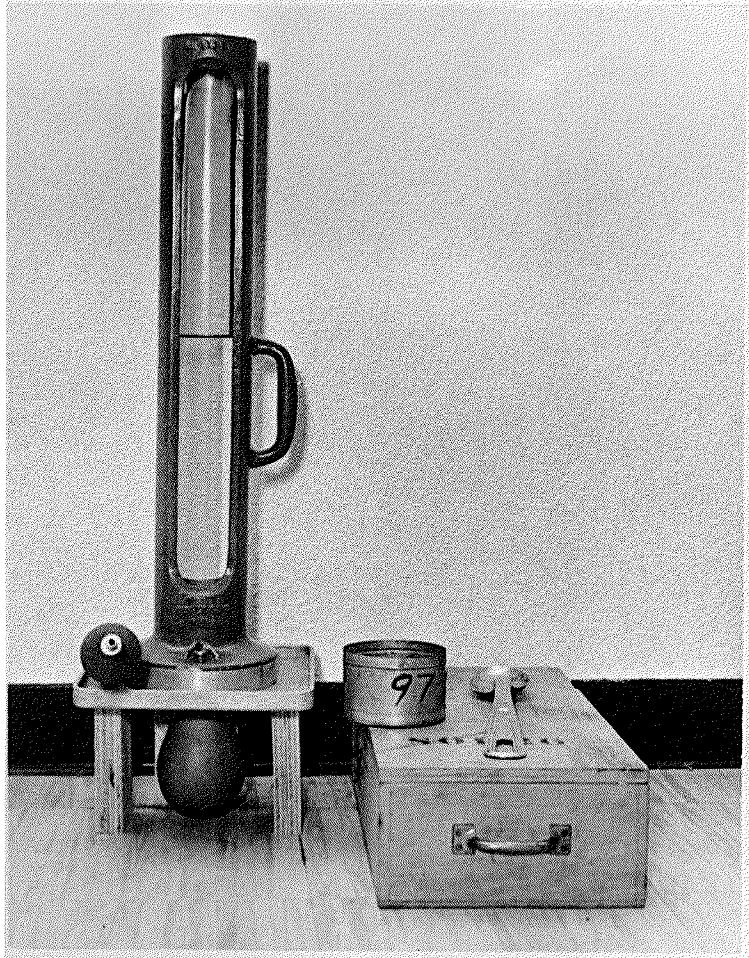

Fig. 5a Soil bulk density measuring apparatus (water balloon method).

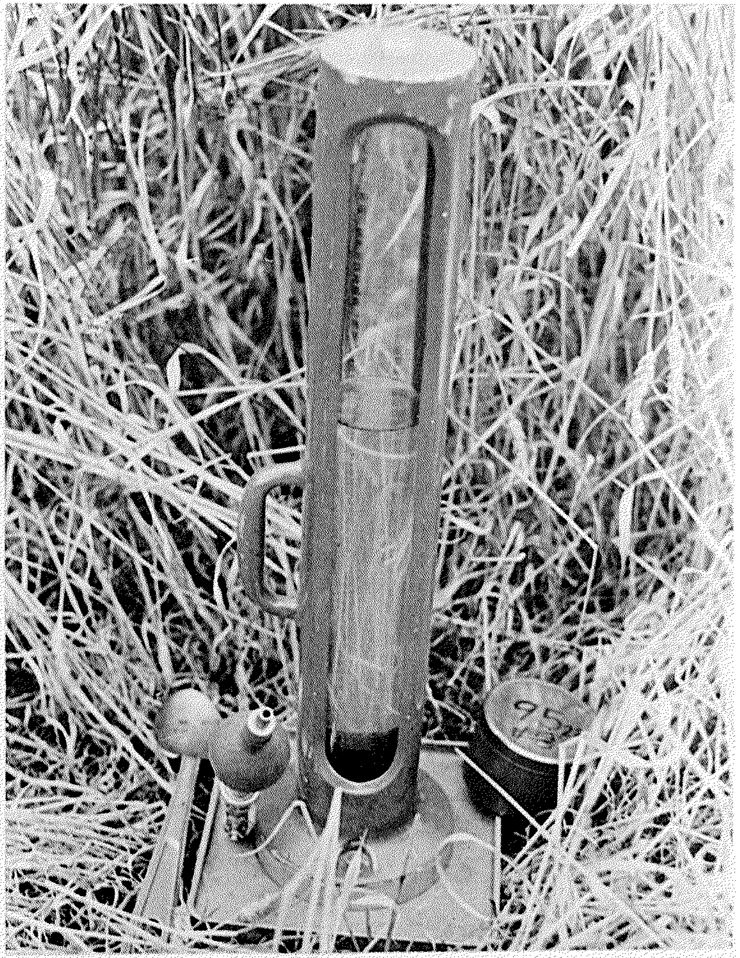

Fig. 5b Field use of the soil bulk density measuring apparatus (water balloon method).

in his studies of wheel traffic effect on soil compaction. The soil resistance was expressed as a cone index (C.I.) which is defined as pound force per square inch of cone area. The deflection recorded by the recording pen was measured in inches and converted to the cone index.

The cone penetrometer was calibrated by static loading to obtain a deflection versus load curve. The data points were fitted by a linear regression equation. The regression equation was found to be:

$$W = 32.77\,X + 3.96 \qquad (4.1)$$

where: W = force required to deflect penetrometer recording pen, lb.

X = penetrometer recording pen deflection, in.

The cone penetrometer could penetrate to a maximum depth of 16 inches. The deflection was measured at 2, 3, 4, 5, 6, 7, 8, 9, 10 and 12 inch depths from the soil surface.

Two different cones (Fig. 6) were used depending on the soil resistance encountered. The cone base areas were 0.5 in^2 or 0.2 in^2. The cone index was calculated by dividing equation 4.1 with the appropriate cone base area. The equation for cone index becomes:

$$C.I. = (32.77\,X + 3.96)/0.2 \qquad (4.2)$$

where the small cone was used or

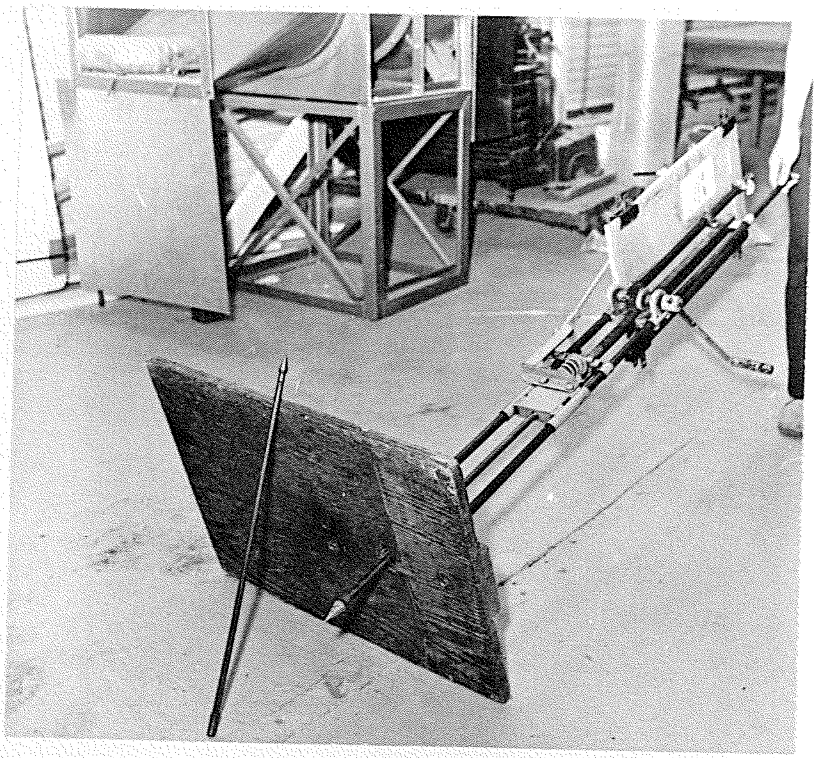

Fig. 6 Cone penetrometer illustrating the 0.5 in^2 and the 0.2 in^2 cones.

Fig. 7 Potentiometer used with thermocouples to measure temperature.

$$C.I. = (32.77\ X + 3.96)/0.5 \qquad (4.3)$$

where the large cone was used.

4.2.6 Measurement of soil temperatures In the summer of 1970 copper-constantan thermocouples were installed in zero tillage plots and in conventional tillage plots at 2, 4, 6, 8, 10, 12, 18, 24, 30, 36 and 48 inch depths. The soil temperature was measured once a week (Fig. 7).

In the summer of 1971 a temperature probe (Fig. 9) was designed to push horizontally into the soil from a hole which was made by a large core sampler (Fig. 2). The temperature probe was made from a 36 inch length of 3/4 inch by 3/4 inch angle iron with 3/16 inch by 3 inch steel tubes brazed in place at 2 inch intervals. The copper-constantan thermocouples were inserted into the steel tubes and held in place with epoxy cement. About 1/8 inch of the thermocouples protruded from the steel tube in order to contact the soil.

The temperature reading was taken within 10 minutes after the core sampler removed the soil from the hole. True soil temperature would not change significantly in 10 minutes or less due to warmer air in the hole (calculation shown in Appendix D). The readings were taken from plots planted to wheat.

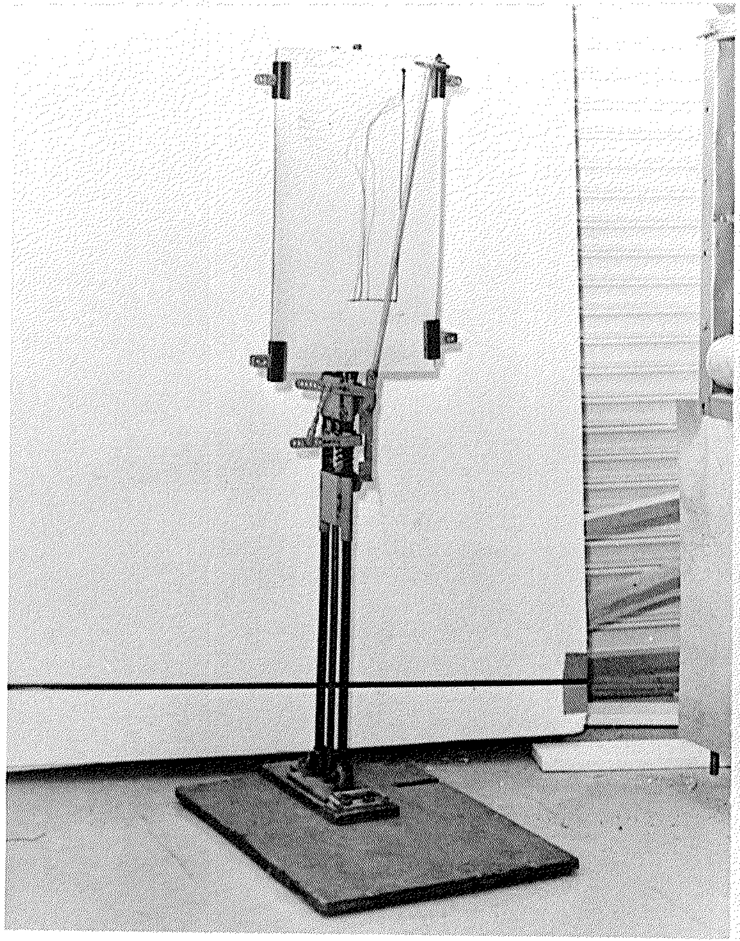

Fig. 8 Cone penetrometer illustrating a typical graphical record.

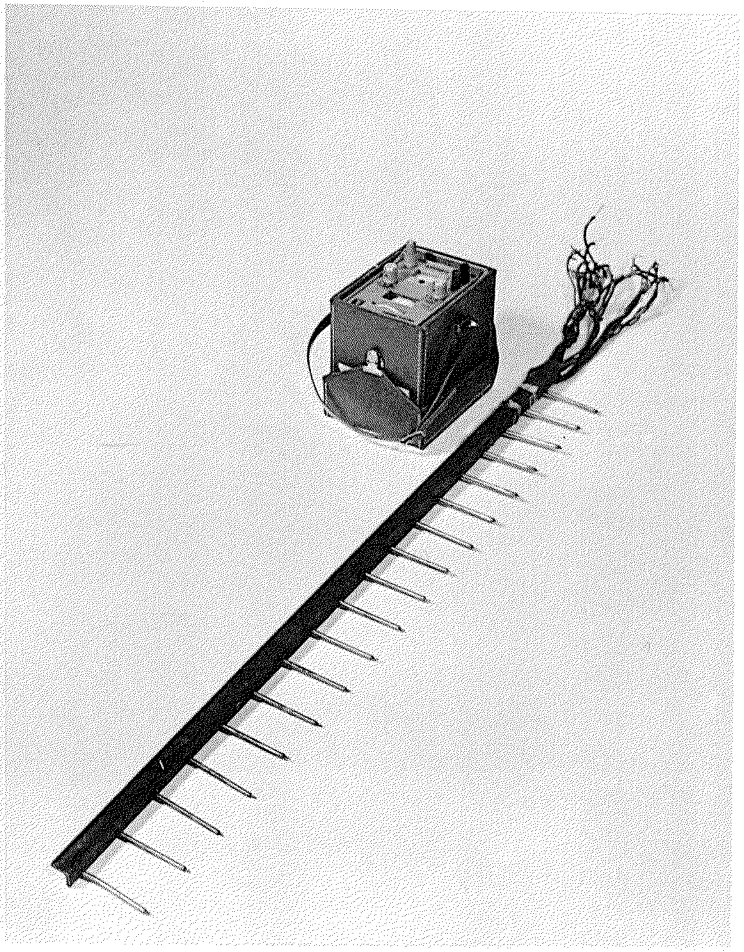

Fig. 9 Soil temperature probe and potentiometer.

The core sampler (Fig. 2) was patterned after one built by Boehle, et al. (11). The steel tubing was 4¼ inch outside diameter, 0.12 inch thick and 60 inches long. It was driven into the soil by a hydraulic cylinder. The core sampler was mounted on the rear of a Massey Ferguson model 150 tractor.

4.2.7 Statistical analyses Three types of analyses of variance were used for analyzing the soil parameters. The proportional subclass frequencies with three-way classifications was used for soil temperature, soil moisture, air-filled porosity, total soil porosity and dry bulk density. All of these soil parameters were measured in 1971. In addition soil moisture and soil strength were measured in 1970.

The equal subclass frequencies with two-way classification was used in the analysis of the temperature data obtained in 1970. The reason for using this type of analysis was because the soil temperature for that year was measured only once a week without replication, and only over two profiles at each location. The soil temperature profile was important so the temperatures for each depth were averaged for the season.

The third type used for the analysis of the oxygen diffusion rate data was the proportional subclass frequencies with two-way classification. This type was used in this analysis because only the ODR data for the 0 to 3 inch depth was used.

Sample analysis of variance tables are shown in Appendix E.

CHAPTER 5

RESULTS AND DISCUSSION

Experiments were conducted to compare the effect of zero and conventional tillage on the physical properties of the soil. Soil physical properties studied were soil moisture, soil aeration, soil strength and soil temperature.

Crop emergence and yield were used to compare crop response with soil physical properties.

5.1 Soil Moisture Content

The results of soil moisture content are shown in Tables 5.1 to 5.6.

Carman The 1970 results indicated that soil moisture content was higher under zero tillage than under conventional tillage at the 0 to 2 and 2 to 4 inch depth (Table 5.1). However, there were no significant differences. In the early growing season in June, the soil moisture content was noticeably greater under zero tillage at 0 to 2 and 2 to 4 inch depth. The soil moisture content in the early growing season is an important factor for seed germination and for initial plant growth. In 1971 there was a higher soil moisture content under zero tillage as compared to conventional tillage (Table 5.2). A significant

Table 5.1 Mean Soil Moisture Content (Percent Dry Weight) Carman 1970

Date	Zero		Conventional	
	0-2 in.	2-4 in.	0-2 in.	2-4 in.
19 June	29.3	30.7	16.2	21.2
25 June	22.8	32.6	17.9	20.3
2 July	13.2	17.3	13.9	17.9
16 July	18.5	19.8	15.9	19.0
30 July	13.7	15.8	9.5	15.9
6 August	11.0	14.9	9.8	12.3
20 August	5.9	9.3	8.1	10.3
10 September	21.9	22.3	19.0	21.4
18 September	17.4	19.6	16.1	19.7
Growing season average	17.1	20.3	14.1	17.6

Table 5.2 Mean Soil Moisture Content (Percent Dry Weight) Carman 1971

Date	Zero		Conventional	
	0-3 in.	3-6 in.	0-3 in.	3-6 in.
8 July	25.2	23.6	21.2	22.2
13 July	27.0	24.8	25.1	24.8
28 July	24.8	22.6	21.9	19.9
13 August	14.1	17.3	9.8	13.7
Growing season average	22.9*	22.2	19.7	20.4

* Significantly different at the 5 percent level.

** Significantly different at the 1 percent level.

difference was found at the 0 to 3 inch depth.

The significant differences found in 1971 were probably due to the higher precipitation received in this year and the higher permeability of the tilled layer of soil under conventional tillage (Table A-1).

Portage la Prairie The results of soil moisture content in 1970 showed a little higher precentages under zero tillage in the 0 to 2 inch and in the 2 to 4 inch depth (Table 5.3). None of the differences were significant. In 1971 the soil moisture content was less under zero tillage but it was not significantly different (Table 5.4).

The 1971 average soil moisture content under zero tillage was slightly less than under conventional tillage. This difference, although not significant, might not have shown if early season soil moisture content data had been available.

Sanford The results in 1970 and 1971 showed higher soil moisture content under zero tillage in the 0 to 2 inch depth (Tables 5.5 and 5.6). The differences were not significant.

The soil moisture content under zero tillage was found to be higher than under conventional tillage as was expected. In the early growing season zero tillage resulted in higher soil moisture content but these

Table 5.3 Mean Soil Moisture Content (Percent Dry Weight) Portage la Prairie 1970

Date	Zero		Conventional	
	0-2 in.	2-4 in.	0-2 in.	2-4 in.
19 June	24.1	32.4	19.4	30.7
25 June	17.9	14.4	18.9	17.3
2 July	6.8	10.4	6.0	10.5
16 July	16.3	17.1	14.7	16.2
30 July	5.9	8.7	5.1	7.8
6 August	4.3	7.1	3.6	5.6
13 August	2.8	5.2	2.7	5.0
20 August	4.2	5.9	4.0	5.7
31 August	14.9	14.7	16.3	15.4
10 September	9.6	10.4	9.9	10.2
18 September	15.8	16.7	15.3	16.4
Growing season average	11.2	13.0	10.6	12.9

Table 5.4 Mean Soil Moisture Content (Percent Dry Weight) Portage la Prairie 1971

Date	Zero		Conventional	
	0-3 in.	3-6 in.	0-3 in.	3-6 in.
20 July	24.1	24.7	19.8	22.3
23 August	13.0	12.9	15.4	16.0
24 August	13.5	14.3	16.8	17.6
Growing season average	16.9	17.3	17.3	18.6

Table 5.5 Mean Soil Moisture Content (Percent Dry Weight) Sanford 1970

Date	Zero		Conventional	
	0-2 in.	2-4 in.	0-2 in.	2-4 in.
16 June	30.9	42.6	48.7	44.6
19 June	29.5	60.5	26.8	44.6
25 June	28.5	35.1	24.3	32.5
16 July	31.1	40.2	28.5	41.9
30 July	29.1	34.7	21.5	29.2
6 August	17.7	26.4	13.8	24.8
13 August	14.2	23.2	12.7	23.6
20 August	21.1	23.8	19.0	25.3
27 August	15.2	21.4	13.7	24.4
10 September	43.9	43.9	44.4	45.7
18 September	36.8	44.4	37.6	46.7
Growing season average	27.1	36.0	26.5	34.8

Table 5.6 Mean Soil Moisture Content (Percent Dry Weight) Sanford 1971

Date	Zero		Conventional	
	0-3 in.	3-6 in.	0-3 in.	3-6 in.
9 July	39.8	38.2	38.9	39.6
3 August	47.2	41.3	43.8	38.8
20 August	46.1	38.3	46.2	35.2
Growing season average	44.3	39.3	42.8	38.0

differences were not observed by the end of the growing season. Under zero tillage, the tillage layer (Fig. 1) was eliminated resulting in larger water storage layer, therefore more moisture was available for crop use. The slightly higher average soil moisture content over the growing season was in agreement with other reports (10, 27, 42, 49, 58).

5.2 Soil Aeration

The oxygen diffusion rate (ODR), air-filled porosity and total soil porosity were the three indexes of soil aeration investigated in the 1971 season. The ODR was measured in the 0 to 3 inch layer only. The soil was dry and hard below the 3 inch depth which damaged the platinum electrodes. The results are presented in Tables 5.7, 5.8 and 5.9.

Carman The ODR, air-filled porosity and total soil porosity had lower values under the zero tillage (Table 5.7). The ODR and the air-filled porosity for the growing season were significantly different, but not the total soil porosity.

The average ODR value obtained (28×10^{-8} g cm^{-2} min^{-1}) was higher than the value given by Letey, et al. (48) who found that an ODR value of 20×10^{-8} g cm^{-2}min^{-1} was

Table 5.7 Mean Soil Aeration Carman 1971

Index	Date	Zero		Conventional	
		0-3 in.	3-6 in.	0-3 in.	3-6 in.
ODR	13 July	14.8	-[a]	31.9	-[a]
(10^{-8}g cm^{-2}min^{-1})	13 Aug.	24.6	-	23.2	-
	20 Aug.	53.3	-	63.6	-
Growing season average		28.3*	-	37.4	-
Air-filled Porosity (Percent by Volume)	8 July	30.8	21.3	27.7	19.8
	13 July	20.0	17.4	30.7	18.5
	28 July	16.1	12.1	29.8	23.2
	13 Aug.	37.3	23.4	42.0	31.7
Growing season average		26.2*	18.8*	32.6	23.0
Total soil Porosity (Percent by Volume)	8 July	57.2	50.3	52.6	48.2
	13 July	52.0	48.8	57.4	49.4
	28 July	48.3	43.8	54.6	48.7
	13 Aug.	53.7	46.4	53.5	49.0
Growing season average		53.0	47.6	54.6	48.8

[a] Not available.

sufficient to maintain good root growth. The air-filled porosity was also higher than the value that most field crops require (7, 45, 64).

Portage la Prairie Zero tillage had less soil aeration as measured by ODR, air-filled porosity and total soil porosity in the 0 to 3 inch depth as compared to conventional tillage. A significant difference showed only for air-filled porosity. The air-filled porosity and total soil porosity were higher under zero tillage in the 3 to 6 inch depth. However, no significant differences were found (Table 5.8)

Soil aeration (ODR, air-filled porosity, total soil porosity) in this area was higher than the critical value (7, 45, 48, 64) for plants to maintain the good root growth.

Sanford While the ODR was higher, but not significantly, under zero tillage, the results for air-filled porosity and total soil porosity indicated that soil aeration was significantly less under zero tillage (Table 5.9).

It should be noted that in the 0 to 3 inch depth, the three indexes of soil aeration indicated less soil aeration under zero tillage at all locations except ODR at Sanford. The ODR value at Sanford was nearly at the critical value. However, the air-filled porosity at all locations showed that there was adequate aeration for

Table 5.8 Mean Soil Aeration Portage la Prairie 1971

Index	Date	Zero		Conventional	
		0-3 in.	3-6 in.	0-3 in.	3-6 in.
ODR	23 July	32.0	-[a]	28.8	-[a]
(10^{-8}g cm^{-2}min^{-1})	23 Aug.	23.4	-	29.1	-
	26 Aug.	22.9	-	24.7	-
Growing season average		26.1	-	27.8	-
Air-filled Porosity (Percent by Volume)	20 July	36.7	22.9	37.1	20.4
	23 Aug.	40.6	36.3	46.6	32.8
	24 Aug.	39.1	32.6	45.5	31.8
Growing season average		38.8*	30.6	43.1	28.4
Total Soil Porosity (Percent by Volume)	20 July	60.1	52.0	57.8	49.1
	23 Aug.	54.8	51.5	61.4	52.2
	24 Aug.	54.4	50.2	61.4	52.3
Growing season average		56.4	51.3	60.2	51.2

[a] Not available

Table 5.9 Mean Soil Aeration Sanford 1971

Index	Date	Zero		Conventional	
		0-3 in.	3-6 in.	0-3 in.	3-6 in.
ODR	9 July	31.5	[a]	25.6	[a]
(10^{-8}g cm^{-2}min^{-1})	3 Aug.	14.7	-	15.7	-
	4 Aug.	15.6	-	20.8	-
Growing season average		21.2	-	20.7	-
Air-filled Porosity (Percent by Volume	9 July	39.2	27.5	44.6	30.6
	3 Aug.	34.0	17.9	41.9	18.0
	20 Aug.	35.8	23.5	44.9	25.4
Growing season average		36.4*	23.0	43.7	24.6
Total soil Porosity (Percent by Volume)	9 July	69.3	62.6	71.7	64.7
	3 Aug.	69.6	59.3	72.1	57.8
	20 Aug.	70.0	60.6	74.2	60.2
Growing season average		69.6*	60.9	72.6	60.9

[a] Not available.

maintaining good plant growth.

5.3 Soil Strength

Two indexes of soil strength were used to compare zero and conventional tillage. One was a soil resistance expressed as a cone index. The other was soil compaction expressed as bulk density. Soil resistance was measured in 1970 and soil compaction was measured in 1971.

The soil resistance results were calculated as follows: the 0 to 3 inch interval the average cone index was calculated from the cone index values at 2 inch and 3 inch depths, the 0 to 6 inch interval the average cone index was calculated from the cone index values at 2, 3, 4, 5 and 6 inch depths and the 0 to 12 inch interval was calculated similarly. These three intervals were used to compare the two tillage treatments. The results are shown in Tables 5.10, 5.11 and 5.12.

Carman The cone index showed that the strength of the soil was low in the early growing season (Table 5.10). The strength of the soil increased up to a maximum value in the third week of August. After this week the strength decreased. The highest average cone index over the growing season occurred in the 0 to 12 interval. It was found that the cone index was higher under zero tillage in all three selected intervals and the differences were

Table 5.10 Mean Soil Strength Carman 1970-1971

Index	Date	Zero				Conventional			
		0-3	3-6	0-6	0-12	0-3	3-6	0-6	0-12
		(inches)				(inches)			
Cone Index (psi)	19/6/70	91		110	124	27		50	74
	25/6/70	73		115	141	46		72	108
	2/7/70	138		173	179	72		108	126
	16/7/70	149		181	208	80		108	173
	24/7/70	136		175	207	68		109	171
	30/7/70	277		323	349	178		228	284
	6/8/70	147		155	154	81		92	108
	20/8/70	523		469	433	405		375	425
	10/9/70	197		238	268	212		202	245
	18/9/70	214		243	273	151		188	245
Growing season average		195**		218**	234**	132		153	196
Bulk Density (g/cc)	8/7/71	1.07	1.24			1.18	1.31		
	13/7/71	1.20	1.28			1.06	1.26		
	28/7/71	1.29	1.40			1.13	1.28		
	13/8/71	1.16	1.34			1.16	1.28		
Growing season average		1.17	1.31			1.13	1.28		

significant.

The soil bulk density under zero tillage was greater in the 0 to 3 inch depth and in the 3 to 6 inch depth than under conventional tillage. The differences were small and not significant.

The results of higher soil strength under zero tillage agreed with other reports (49, 72). The soil strength under conventional tillage was not higher than under zero tillage as reported by another worker (63). This result was probably due to less wheel traffic received during the growing season under conventional tillage in this study than the previous work (63). It was also reported that increased soil compaction was due to a variety of factors (28).

Portage la Prairie The cone index was higher under zero tillage in all three depth intervals (Table 5.11). The differences were not significant. However, the average cone index was highest in the 0 to 12 inch interval as it was in Carman.

The soil bulk density was higher under zero tillage. The differences were small and not significant.

No significant differences were found in the two soil strength indexes at this location. The differences in soil moisture content and aeration were also small

Table 5.11 Mean Soil Strength Portage la Prairie 1970-1971

Index	Date	Zero 0-3	Zero 3-6	Zero 0-6	Zero 0-12	Conventional 0-3	Conventional 3-6	Conventional 0-6	Conventional 0-12
		(inches)				(inches)			
Cone Index (psi)	10/6/70	56		82	99	22		61	90
	19/6/70	86		116	131	87		118	133
	25/6/70	62		120	139	58		101	123
	2/7/70	148		230	234	213		255	250
	9/7/70	192		309	332	124		186	235
	16/7/70	138		192	261	154		195	238
	30/7/70	332		414	436	273		368	444
	6/8/70	156		191	207	153		196	213
	13/8/70	427		564	591	285		390	449
	20/8/70	491		602	616	528		609	675
	31/8/70	159		296	398	193		372	492
	10/9/70	228		327	443	274		406	478
	18/9/70	70		86	112	68		81	110
Growing season average		196		271	308	187		257	303
Bulk Density (g/cc)	20/7/71	1.01	1.22			1.07	1.29		
	23/8/71	1.14	1.23			0.98	1.21		
	24/8/71	1.16	1.26			0.98	1.21		
Growing season average		1.10	1.24			1.01	1.24		

(Tables 5.3, 5.4 and 5.8) and therefore little difference in soil strength would be expected.

Sanford In 1970 the cone index was significantly higher in the 0 to 3 inch layers (Table 5.12). The soil bulk density in 1971 was higher in both the 0 to 3 inch and 3 to 6 inch layers. Both cone index and soil bulk density indicated significantly higher values of soil strength in the top soil layer under zero tillage as compared to conventional tillage.

The values of soil bulk density in this area were low probably due to errors in measurement of original soil volume. The soil was fine clay and the moisture content in the soil was high. Distortion of the test hole could be easily caused by the pressure that was applied during measurement.

5.4 Soil Temperature

Soil temperatures were measured both years. The results as presented in Tables 5.13 to 5.17 were calculated as follows: the 0 to 4 inch interval the average soil temperature was calculated from the soil temperature at the 2 inch and the 4 inch depth, the 0 to 6 inch interval the average soil temperature was calculated from the soil temperature at the 2, 4 and 6 inch depth and the 0 to 12, 0 to 24 and 0 to 48 inch intervals were calculated similarly.

Table 5.12 Mean Soil Strength Sanford 1970-1971

Index	Date	Zero				Conventional			
		0-3	3-6	0-6	0-12	0-3	3-6	0-6	0-12
		(inches)				(inches)			
Cone Index (psi)	16/6/70	56		73	79	26		59	75
	19/6/70	62		86	93	40		74	88
	25/6/70	128		146	138	92		119	124
	16/7/70	70		99	129	67		100	122
	24/7/70	115		164	190	109		155	179
	6/8/70	64		97	131	78		124	152
	13/8/70	241		329	389	131		283	413
	20/8/70	364		480	521	215		347	476
	27/8/70	405		477	540	464		586	633
	31/8/70	141		233	338	94		173	275
	10/9/70	125		167	249	190		185	265
	18/9/70	37		54	79	31		52	80
Growing season average		178*		201	240	128		188	240
Bulk Density (g/cc)	9/7/71	0.76	0.92			0.70	0.87		
	3/8/71	0.75	1.00			0.70	1.04		
	20/8/71	0.74	0.97			0.64	0.98		
Growing season average		0.75*	0.97			0.68	0.96		

These five intervals were used to compare the two tillage treatments.

<u>Carman</u> The average soil temperatures in 1970 show that there were no differences in temperature between zero tillage and conventional tillage down to 48 inches (Table 5.13).

In 1971 there were no significant differences in temperature of the 0 to 4, 0 to 6 and 0 to 24 inch intervals between the two tillage treatments (Table 5.14). There were significant differences in the 0 to 12 and 0 to 30 inch layers.

The temperature was slightly higher under zero tillage. The soil under zero tillage has greater capacity for more heat storage than the soil under conventional tillage. The reduction in air-filled porosity in the soil under zero tillage would increase the specific heat of the soil. Once the soil has been heated the trash cover could prevent loss of heat.

<u>Portage la Prairie</u> The 1970 temperature measurements indicated there were no significant differences in the soil temperature between zero and conventional tillage at all intervals (Table 5.15). Although not significant the zero tillage had the lower temperature in the 0 to 4 inch and 0 to 12 inch intervals.

<u>Sanford</u> The 1970 temperature data indicated that there

Table 5.13 Mean Soil Temperature (F) Carman 1970

Date	Zero					Conventional				
	0-4	0-6	0-12	0-24	0-48	0-4	0-6	0-12	0-24	0-48
	(inches)					(inches)				
19 June	60	59	58	58	56	62	60	58	58	56
25 June	68	66	65	64	61	67	66	64	63	60
2 July	72	70	68	67	64	70	69	68	66	64
9 July	81	78	73	70	67	80	78	74	72	68
16 July	71	69	68	66	64	70	69	67	66	64
24 July	66	65	64	64	62	64	64	64	63	62
30 July	82	78	74	72	69	76	75	73	72	68
6 August	76	74	71	69	67	76	75	72	71	68
Growing season average	72	70	68	66	64	71	70	68	66	64

Table 5.14 Mean Soil Temperature (F) Carman 1971

Date	Zero					Conventional				
	0-4	0-6	0-12	0-24	0-30	0-4	0-6	0-12	0-24	0-30
	(inches)					(inches)				
10 August	69	69	67	66	65	68	67	66	65	64
11 August	69	68	67	67	66	67	66	65	64	64
18 August	67	67	66	65	65	67	67	66	65	64
Growing season average	68	68	67**	65	65**	68	67	66	65	64

Table 5.15 Mean Soil Temperature (F) Portage la Prairie 1970

Date	Zero					Conventional				
	0-4	0-6	0-12	0-24	0-48	0-4	0-6	0-12	0-24	0-48
	(inches)					(inches)				
10 June	70	68	65	64	62	70	68	66	64	62
19 June	63	63	62	61	60	64	64	63	62	60
25 June	64	64	64	64	62	64	65	65	65	63
2 July	68	68	68	68	66	68	68	68	68	66
9 July	79	77	74	73	70	74	73	71	70	68
16 July	68	68	68	67	66	66	66	66	66	64
30 July	72	71	71	70	67	68	68	68	67	65
6 August	69	69	68	67	65	70	70	69	68	66
13 August	80	78	76	74	71	88	85	79	77	73
20 August	65	65	65	65	65	67	67	67	67	66
27 August	66	65	65	65	64	69	68	68	67	66
31 August	59	59	60	61	61	62	61	61	62	62
10 September	54	55	57	58	59	54	54	57	58	59
18 September	51	51	52	52	52	53	53	52	53	53
Growing season average	66	66	65	65	64	67	66	66	65	64

were no significant differences except in the 0 to 48 inch layers (Table 5.16). The soil temperature was slightly higher under zero tillage.

In 1971 the temperatures were not different in the 0 to 4, o to 6 and 0 to 12 inch layers (Table 5.17). Significant differences of higher temperature under zero tillage were found in the 0 to 24 inch and 0 to 36 inch layers.

5.5 Crop Emergence

The emergence data was supplied by the Plant Science Department who performed statistical analyses on data recorded by Chipman Chemicals Limited. Emergence data (Table 5.18) is presented here in order to compare the crop response to the tillage treatments. Only one of the zero tillage treatments was used for comparison to the conventional tillage treatment.

Carman All crops had significantly higher emergence under zero tillage than under conventional tillage.

The higher emergence obtained from zero tillage was probably due to the higher soil moisture content in the early growing season (Table 5.1). The soil strength was higher under zero tillage, but seedling emergence has been more closely correlated with soil moisture than with soil strength (32).

Table 5.16 Mean Soil Temperature (F) Sanford 1970

Date	Zero					Conventional				
	0-4	0-6	0-12	0-24	0-48	0-4	0-6	0-12	0-24	0-48
	(inches)					(inches)				
16 June	62	61	60	58	55	62	61	60	58	54
19 June	58	58	57	57	54	59	58	57	56	53
25 June	66	65	64	62	58	68	66	64	62	58
2 July	70	69	67	65	61	70	69	68	66	62
9 July	78	76	72	69	65	80	76	70	67	63
16 July	74	73	70	68	64	74	72	68	66	62
24 July	65	65	64	63	60	64	63	63	62	60
30 July	72	71	68	67	63	72	70	68	66	63
6 August	72	70	68	66	63	60	68	66	64	61
13 August	68	67	67	66	64	66	65	65	64	61
20 August	67	66	64	64	62	64	63	62	62	60
27 August	66	65	63	62	60	64	63	61	60	59
31 August	62	61	60	60	59	59	58	57	57	57
10 September	56	57	58	59	59	57	57	57	58	58
18 September	56	55	55	54	54	54	53	52	52	52
Growing season average	66	65	64	63	60*	65	64	62	61	59

Table 5.17 Mean Soil Temperature (F) Sanford 1971

	Zero					Conventional				
Date	0-4	0-6	0-12	0-24	0-36	0-4	0-6	0-12	0-24	0-36
	(inches)					(inches)				
4 August	61	60	60	59	58	62	62	61	59	58
6 August	66	65	63	61	59	65	64	62	59	58
Growing season average	64	63	62	60**	59**	64	63	62	59	58

Table 5.18 Crop Emergence (Counts per ¼ Square Meter) 1970

Crop	Carman		Portage la Prairie		Sanford	
	Zero	Conv.	Zero	Conv.	Zero	Conv.
Wheat	60**	49	61**	52	34*	28
Barley	27**	22	27	26	52**	45
Flax	118**	87	132**	90	108**	75
Rape	11*	8	24**	16	49**	33

Table 5.19 Crop Yields (Bushel Per Acre) 1970-1971

Year	Crop	Carman		Portage la Prairie		Sanford	
		Zero	Conv.	Zero	Conv.	Zero	Conv.
1970	Wheat	-[a]	-	29.7	28.7	30.9	29.8
	Barley	-	-	39.8	33.8	52.3	61.1
	Flax	-	-	7.9	6.9	15.8**	13.6
	Rape	-	-	11.0	6.3	16.9*	8.5
1971	Wheat	39.2	37.9	24.1	21.4	26.5	29.7
	Barley	45.5**	57.0	36.3	36.3	54.1	60.0
	Flax	13.8	12.1	15.7*	12.5	18.1*	13.9
	Rape	14.4	18.0	27.5	24.0	-[b]	-

[a] No data due to hail.

[b] No data due to shattering.

Portage la Prairie Wheat, flax and rape had significantly higher emergence under zero tillage. Barley emergence counts were not significantly different.

Sanford The four crops had significantly higher emergence under zero tillage. The average soil moisture content over the growing season and in the early growing season were also higher under zero tillage.

It is believed that the higher crop emergence obtained under zero tillage was influenced by the four soil parameters. The soil strength was higher under zero tillage. The cone indexes at all locations in the early growing season were not sufficient to restrict seed germination. The values of soil bulk density were in the optimum range for grain crops (32). Higher soil strength under zero tillage in the early growing season is beneficial to ensuring good contact between seed and soil.

5.6 Crop Yields

The crop yield results were supplied by the Plant Science Department (Table 5.19). These data were used to compare the effect of zero and conventional tillage on crop yields.

Carman No yields were available in 1970 due to damage prior to harvesting. The 1971 data showed higher yields from wheat and flax under zero tillage and lower yields from barley and rape. The differences were significant only on the barley.

Portage la Prairie In 1970 all crop yields were higher under zero tillage but not significantly higher. In 1971 the higher yields from wheat, flax and rape were obtained. The same yield was obtained from barley under zero and conventional tillage. Significant differences were detected in the flax yields.

Sanford In 1970 wheat, flax and rape yielded higher amounts under zero tillage while barley yield was reduced. Only flax and rape had significantly different yields. In 1971 wheat and barley yielded lower while flax yielded higher under zero tillage. No rape yield was available due to excessive shattering. Only flax yields were significantly different.

The higher yields were obtained under zero tillage as compared to conventional tillage were the result of good soil moisture content, adequate soil aeration, higher soil temperature and good seed-to-soil contact. High soil strength did not prevent good root growth and therefore did not effect yields. The lower crop yields under zero tillage probably were due to other factors such as chemical or fertilizer effects.

CHAPTER 6

CONCLUSIONS

Zero tillage was evaluated in comparison with conventional tillage. Conventional tillage in this study consisted of discing or cultivating followed by harrowing before seeding. The comparions were made by measuring, for both tillage methods, soil moisture content, soil aeration, soil strength and soil temperature.

Based on the results of this study the following general conclusions are made:

1. Soil moisture content was higher under zero tillage.

2. Soil aeration as measured by oxygen diffusion rate, air-filled porosity and total soil porosity was lower under zero tillage. The lower values did not approach critical levels and there was no evidence that plant growth was effected.

3. Soil strength as measured by cone penetrometer and by bulk density was higher under zero tillage.

4. Soil temperature was higher under zero tillage.

A full evaluation of a tillage system can not be made without mention of crop yields. Generally in this study both crop emergence and yields were equal or higher under zero tillage.

CHAPTER 7

RECOMMENDATIONS

In a study of tillage and other soil-machine problems, all the environmental conditions should be considered. The limited parameters measured in this study may not be sufficient at other locations. Differences in soil, tillage tools, instruments, facilities and errors can effect the results and may lead to different conclusions.

Recommendations for further studies are as follows:

- The long-term effects should be evaluated for the two tillage systems.
- The cost of each tillage system should be studied.
- The development of instruments for efficient field use would be desirable.
- The optimum number of tillage operations should be determined for each year as well as over successive years.
- The results, methods and other problems of different experimental stations should be compared and discussed. This comparison will lead to the best way of evaluating tillage performance.
- Similitude studies could be needed to find a "tillage index" which would be related to the

soil properties.

- Finally, zero tillage should not be recommended to all farmers unless all the factors which effect tillage performance are considered.

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APPENDIX A

Table A-1 Meteorological Data[a]

Location	Month	Mean Daily Temperature (F)		Total Precipitation (in)	
		1970	1971	1970	1971
Carman	May	--[b]	--[b]	2.56	2.07
	June	--	--	2.62	3.86
	July	--	--	2.72	2.95
	August	--	--	1.62	1.21
	September	--	--	2.37	4.87
	Total			11.89	14.96
Portage la Prairie	May	48.7	52.1	1.92	0.67
	June	67.0	63.9	1.89	4.27
	July	69.4	62.7	2.29	3.45
	August	65.5	66.1	1.46	0.48
	September	55.2	55.5	2.57	1.68
	Total			10.13	10.55
Starbuck[c]	May	49.6	51.8	2.41	2.03
	June	67.3	64.4	2.36	5.83
	July	70.0	62.6	2.92	5.07
	August	66.2	66.3	2.09	0.79
	September	56	56.6	3.07	1.38
	Total			12.85	15.1
Glenlea[c]	May	47.8	50.8	4.03	1.13
	June	66.9	64.2	3.74	2.08
	July	68.8	62.4	3.12	3.28
	August	64.7	65.5	1.03	1.32
	September	54.8	55.1	3.20	2.68
	Total			15.12	10.49

TABLE A-1 continued...

[a] Extracted from Monthly Record Meteorological Observations in Canada Department of Transport.

[b] Not available.

[c] Two closest weather stations to Sanford.

Table A-2 History of Tillage Operations on Conventional Tillage Plots

Location	1969	1970	1971
Carman	Disced twice	Disced and harrowed	Disced and harrowed
Portage la Prairie	Cultivated and harrowed	Cultivated and harrowed	Disced and harrowed
Sanford	Cultivated and harrowed	Cultivated and harrowed	Disced and harrowed

Table A-3 Herbicide Applications on Zero Tillage Plots

Year	Zero 1	Zero 2
1969	12 oz. Paraquat (Gramoxone) and 4 oz. Diquat (Reglone)	12.02 Paraquat (Gramoxone) and 16 oz. 2,4-D Ester
1970	12 oz. Paraquat and 4 oz. Diquat	12 oz. Paraquat and 16 oz. 2,4-D Ester
1971	12 oz. Paraquat and 4 oz. Diquat	4 oz. Paraquat and 8 oz. Brominal M.

APPENDIX B

Table B-1 Soil Specific Gravity Test

Project: Zero Tillage
Location: Carman, Manitoba
Soil: Loamy Sand
Sample: 0-6 Inches Mixed

Sample	I	II	III
Wt. Bottle + Water (Full), g	64.4775	66.4461	68.6655
Wt. Bottle + Partly full of water, g	44.1365	46.7610	50.0455
Wt. Bottle + Partly full of water + Soil, g	48.7090	51.9206	54.8019
Wt. Bottle + Soil + Water (Full), g	67.2056	69.5447	71.5276
Wt. Soil, g	4.5725	5.1596	4.7564
Vol. Soil, cc	1.8444	2.0610	1.8943
Specific gravity	2.4791	2.5034	2.5109
Average specific gravity [a/]		2.4978	

Project: Zero Tillage
Location: Portage la Prairie, Manitoba
Soil: Sand Loam
Sample: 0-6 Inches Mixed

Sample	I	II
Wt. Bottle + Water (Full), g	64.3800	66.3988
Wt. Bottle + Partly full of water, g	45.8658	46.4900
Wt. Bottle + Partly full of water + Soil, g	50.2525	50.8978
Wt. Bottle + Soil + Water (Full), g	67.0508	69.0528
Wt. Soil, g	4.3867	4.4078
Vol. Soil, cc	1.7159	1.7538
Specific gravity [a/]	2.5565	2.5133
Average specific gravity	2.5349	

Table B-1 continued...

Project: Zero tillage Location: Sanford, Manitoba
Soil: Clay Sample: 0-6 Inches Mixed

Sample	I	II	III
Wt. Bottle + Water (Full), g	64.4860	66.4556	68.6708
Wt. Bottle + Partly full of water, g	46.7153	46.8939	47.0024
Wt. Bottle + Partly full of water + Soil, g	51.5826	51.9376	52.0879
Wt. Bottle + Soil + Water (Full), g	67.3786	69.4463	71.7068
Wt. Soil, g	4.8673	5.0437	5.0755
Vol. Soil, cc	1.9747	2.0530	2.0495
Specific gravity	2.4648	2.4567	2.4813
Average specific gravity[a]		2.4676	

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[a] Soil particle density is numerically equal to soil specific gravity but has units of g/cc.

Table B-2 Soil Particles Analysis (Hydrometer Method)

Location	Clay, %	Silt, %	Sand, %	Specific Gravity
Carman (loamy sand)	7	12	81	2.4978
Portage la Prairie (sandy loam)	11	24	65	2.5349
Sanford (clay)	61	28	11	2.4676

APPENDIX C

Table C-1 Surface Area of Platinum Electrodes (cm^2)

Short (6 inch) Electrode No.	Short (6 inch) Surface Area	Long (12 inch) Electrode No.	Long (12 inch) Surface Area
1	0.0836	1	0.0776
3	0.0736	2	0.0836
5	0.0776	3	0.0796
6	0.0796	4	0.0756
7	0.0856	5	0.0836
8	0.0696	6	0.0796
9	0.0877	7	0.0816
11	0.0836	8	0.0796
14	0.0856		
18	0.0937		

APPENDIX D

Time Limitation for Temperature Measurement with the Core Sampler

This calculation was performed to find the time that would be required for a surface temperature change to effect the temperature at a given point within the soil.

Consider the soil as a semi-infinite solid. The following assumptions were made:

(i) The soil is homogeneous and isotropic.

(ii) The heat transfer in the soil takes place only through conduction.

(iii) Consider only the unsteady one-dimensional case.

(iv) No heat source, i.e. no heat produced in the soil.

With these assumptions the following general equation was obtained (38):

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha} \frac{\partial T}{\partial t} \qquad (1)$$

where: T = temperature, F

t = time, hr.

x = distance, ft.

α = thermal diffusivity, ft^2/hr

With the following boundary conditions and the assumptions adopted, the problem can be solved. The solution is given by equation 2.

$$\frac{T(x,t) - T_o}{T_i - T_o} = \text{erf}\left(\frac{x}{2\sqrt{\alpha t}}\right) \qquad (2)$$

The boundary conditions are:

$$T(x,o) = T_i$$

$$T(o,t) = T_o \text{ for } t > o$$

where: T_i = original temperature at $t = o$, and at distance x

T_o = surface temperature changed suddenly at $x = o$ and time t

$T(x,t)$ = the temperature at the distance x from the surface and at the time t after the sudden temperature change of the surface

$\text{erf}\left(\frac{x}{2\sqrt{\alpha t}}\right)$ = Gauss' error function

To solve this problem some numerical values have to be assumed. The following values were assumed:

x = 2.5 in., the length of thermocouple to be inserted

T_i = 50 F, assumed initial soil temperature

T_o = 90 F, assumed soil surface temperature after the sudden change (air temperature) at distance x and at time t

$T(x,t)$ = 51.5 F assumed temperature

The temperature $T(x,t)$ was assumed by considering the accuracy of a thermocouple which can detect temperatures with ± 1.5 F. The assumed numerical values were substituted into equation 2. Solving for the error function gave:

$$\text{erf}\left(\frac{2.5}{2\sqrt{\alpha t}}\right) = 0.9$$

From tabulated values (38) the argument of the error function was:

$$\frac{2.5}{2\sqrt{\alpha t}} = 1.471$$

Substituting the value $\alpha = 0.03$ ft^2/hr. (43) and solving for t gave:

$$t = 10.025 \text{ min.}$$

Hence the soil temperature reading should be taken in less than 10 minutes after removal of the soil with the core ampler in order to minimize errors.

APPENDIX E

Table E-1 Final AOV Table, Moisture Content, at Portage la Prairie. Overall depth. (Proportional subclass frequencies, three-way classification)

Source	DF	SS	MS	F
A	1	4.543	4.543	2.04
B	1	129.594	129.594	58.24**
C	10	5971.793	59.718	26.84**
AB	1	1.262	1.262	0.56
AC	10	45.644	4.564	2.05*
BC	10	275.352	227.535	12.38**
ABC	10	9.031	0.903	0.41
Within	88	195.840	2.225	
Total	131	6633.059		

A - Tillage treatment; B - Depth; C - Days

Mean value: Zero - 12.072; Conventional - 11.678

* Significantly different at 5 percent level.

** Significantly different at 1 percent level.

Table E-2 Final AOV Table, Temperature at Carman 1970. Overall depth. (Equal subclass frequencies, two-way classification)

Source	DF	SS	MS	F
A	1	0.500	0.500	0.02
B	10	4606.813	460.681	20.59**
AB	10	52.875	5.288	0.24
Within	154	3446.000	22.377	
Total	175	8106.188		

A - Tillage treatment; B - Depth

Mean value: Zero - 63.91; Conventional - 63.81

Table E-3 Final AOV Table, Oxygen Diffusion Rate at Carman 1971. 0-3 inch. (Proportional subclass frequencies, two-way classification)

Source	DF	SS	MS	F
A	1	626.754	626.754	7.02*
B	2	7113.613	3556.806	39.82**
AB	2	471.168	235.584	2.64
Within	25	2233.035	89.321	
Total	30	10444.570		

A - Tillage treatment; B - Days

Mean value: Zero - 28.309; Conventional - 37.451