National Library of Canada

Bibliothèque nationale du Canada

Acquisitions and Bibliographic Services Branch

Direction des acquisitions et des services bibliographiques

395 Wellington Street
Ottawa, Ontario
K1A 0N4

395, rue Wellington
Ottawa (Ontario)
K1A 0N4

Your file Votre référence

Our file Notre référence

NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30, and subsequent amendments.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

La reproduction, même partielle, de cette microforme est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30, et ses amendements subséquents.

Canada

UNIVERSITY OF ALBERTA

CONSERVATION TILLAGE EFFECTS ON SELECTED SOIL PHYSICAL PROPERTIES OF A DARK GRAY SOLOD IN THE PEACE RIVER REGION OF ALBERTA

BY

ROGER ANDREIUK

©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

IN

SOIL SCIENCE

DEPARTMENT OF SOIL SCIENCE

EDMONTON, ALBERTA

SPRING 1993

National Library of Canada
Bibliothèque nationale du Canada

Acquisitions and Bibliographic Services Branch
Direction des acquisitions et des services bibliographiques

395 Wellington Street
Ottawa, Ontario
K1A 0N4

395, rue Wellington
Ottawa (Ontario)
K1A 0N4

Your file Votre référence

Our file Notre référence

The author has granted an irrevocable non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

L'auteur a accordé une licence irrévocable et non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without his/her permission.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

ISBN 0-315-82030-6

Canada

UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR: Roger Andreiuk

TITLE OF THESIS: Conservation Tillage Effects on Selected Soil Physical Properties of a Dark Gray Solod in the Peace River Region of Alberta

DEGREE: Master of Science

YEAR THIS DEGREE GRANTED: 1993

Permission is hereby granted to the University of Alberta Library to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly or scientific research purposes only.

The author reserves all other publication and other rights in association with the copyright in the thesis, and except as hereinbefore provided neither the thesis nor any substantial portion thereof may be printed or otherwise reproduced in any material form whatever without the author's prior written permission.

4220-42 Street
Leduc, Alberta
T9E-4S2

Date: April 19, 1993

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled CONSERVATION TILLAGE EFFECTS ON SELECTED SOIL PHYSICAL PROPERTIES OF A DARK GRAY SOLOD IN THE PEACE RIVER REGION OF ALBERTA submitted by ROGER ANDREIUK in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in SOIL SCIENCE.

D. S. Chanasyk

J. A. Robertson

K. W. Domier

Date: April 13, 1993

ABSTRACT

Reduced or zero tillage systems offer major advantages for soil and water conservation and for reducing farm labor and capital costs. Reports of conservation tillage effects on soil physical properties are divided and these effects are generally unquantified in the Peace River region of Alberta.

This study quantified the effects of three tillage systems on selected soil properties of a Dark Gray Solod in the Peace River region of Alberta. The tillage systems were: zero; minimum; and conventional. Soil parameters studied were bulk density, porosity, organic carbon, soil moisture, water retention, and soil strength. Special attention was paid to spatial and temporal variation of these parameters.

Bulk density and porosity generally did not vary among treatments throughout the season. Average (0-15 cm) bulk density under zero till did not change during the season, indicating an equilibrium bulk density.

Penetration resistance (PR), as a measure of soil strength, varied little among treatments at most times of measurement. However, differences of note among treatments occurred: three of six times in the surface 10 cm, in the between-pairs of rows position, where zero till had higher PR than the tilled treatments; and in July at depths below approximately 10 cm, in all row positions, where tilled treatments had higher PR than zero till. Large temporal and spatial variation in penetration resistance occurred.

Organic carbon in the surface 2.5 cm was significantly higher in the zero till treatment. This added carbon has implications for better surface soil structure and a less erodible soil under zero till. Organic carbon in depth increments below 2.5 cm, to a depth of 15 cm, did not differ among treatments.

Water retention at -33 and -1500 kPa, in the surface 2.5 cm, was significantly higher under zero till than under conventional till. Available water holding capacity of the 0-15 cm depth was not different among treatments and soil moisture generally did not vary among treatments.

Conservation tillage can be a viable alternative for the Peace River region of Alberta based on the similarity of soil physical properties among tillage treatments.

ACKNOWLEDGEMENTS

The author would like to gratefully acknowledge the Prairie Farm Rehabilitation Administration (J. Heinonen and R. Graw in Peace River) and the Molson family, as well as the Alberta Agriculture staff in Spirit River for recognizing the need for conservation tillage studies in the Peace River region. Farming For The Future (Alberta Agriculture) helped fund the Baytree conservation tillage study. The Natural Sciences and Engineering Research Council helped fund expenses for the 1989 study. Alberta Agriculture kindly allowed education leave and provided financial support to the author. Appreciation is extended to J. Heinonen and R. Graw for their help and suggestions during this research and the use of the conservation tillage field site for this study. Thanks to the Molson family for their friendliness and cooperation, as well as for the use of their land. The contributions of K. Ostermann, L. Salè and J. Arocena are gratefully acknowledged, especially their willingness to travel long distances and work under adverse conditions. The author is grateful to all members of the Department of Soil Science for providing support and a stimulating environment during the course of the project. My appreciation to members of the committee: Dr. J.A. Robertson and Dr. K.W. Domier as well as to Dr. R.T. Hardin for suggestions and guidance during this study. Special thanks to Dr. D.S. Chanasyk for his never ending optimism, faith, acceptance and encouragement throughout my studies and research. Thanks to Mrs. C. Andreiuk for her support and providing room and board to the research crew. Heartfelt gratitude to my family, Fern, Jess and Em, for their support, understanding and encouragement at all times.

TABLE OF CONTENTS

Chapter | Page

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

1.1 Background

Soil erosion has been occurring for a long time. The channels scoured by our river systems are easily seen evidence of this process. Man's impact upon the soil resources has often resulted in accelerating this process. In the Peace River region, accelerated, man-induced soil erosion has been recognized as a problem since 1917 (Albright, 1939). Albright (1939), superintendent of the Dominion Experimental station at Beaverlodge, Alberta, suggested that land contour, precipitation patterns, soil type and tillage practices all have a part to play in the propensity of Peace River soils to erode. He suggested modification of tillage practices towards a less intensive system as a way to prevent or reduce soil erosion on farm land.

More recently the propensity of Peace River region soils to erode has been reconfirmed: Novak and Van Vliet (1983 as cited by Van Vliet and Hall, 1991) identified the Peace River region as the highest erosion risk area of all the agricultural reporting areas in British Columbia. The severity of soil erosion in the Peace River region is influenced by several factors such as very long slopes, the occurrence of high intensity rainstorms (Van Vliet and Hall, 1991), rapid snowmelt on frozen soils (Chanasyk and Woytowich, 1987), poorly structured surface soils and slowly permeable subsoils (Odynsky et al., 1961).

Reduction of soil erosion in the Peace River region is essential to maintain long term productivity of the soils found there, and as suggested by Albright (1939) and by Van Vliet and Hall (1991) less intensive tillage methods must be adopted to preserve the soil resource. Van Vliet and Hall (1991) suggested that strategies to reduce soil erosion in the Peace River region should include: leaving the stubble and crop residue intact and at the surface after harvest, eliminating fall cultivation and providing a winter cover. In a study near Dawson Creek in the B.C. portion of the Peace River region, Van Vliet et al. (1991) found that zero till systems reduced soil erosion while maintaining crop yields.

The objectives of tillage are many and include: preparing a seedbed to allow the placement of seed in an environment that facilitates germination and growth, control of weeds and other pests, as well as incorporation of crop residues, fertilizers and herbicides. Excessive tillage can lead to destruction of stable soil structure, loss of topsoil due to wind and water erosion and eventual reduced crop productivity (Schertz et al., 1989). Improvements in crop varieties, seeding machinery and improved alternate methods of controlling weeds and other pests have reduced the need for intensive tillage in today's farming practices.

The need to reduce farm operating costs as well as control soil erosion by reducing the number of tillage operations has resulted in a change from intensive tillage to reduced or conservation tillage (Black and Siddoway, 1979). Conservation tillage is one of the most effective ways of controlling soil erosion (Papendick, 1984) and thus conserving the soil resource. Reduced and no-till systems can reduce total farm costs and dramatically reduce farm labor costs (Weersink et al., 1992).

The tillage systems that constitute conservation tillage vary from region to region. Papendick (1984) refers to the Conservation Tillage Information Center, Washington, D.C., as defining conservation tillage as methods of farming that maintain adequate plant cover or residue on the land to conserve soil and water while reducing labor, energy and capital. Conservation tillage is synonymous with reduced tillage and is variously termed zero tillage, no-tillage, direct drilling, reduced tillage, stubble mulching, etc.

Reduced mixing of the soil and reduced incorporation of crop residues under a reduced tillage system often results in a soil environment that is different from that under intensive cultivation. This modified environment influences crop growth in many ways, directly and indirectly, sometimes positively, sometimes negatively.

1.2 Changes in soil physical properties

The change from conventional intensive tillage to conservation tillage methods often results in a change in the soil environment. The properties and processes that may be altered by changing tillage systems include soil bulk density, soil strength, the soil moisture regime, residue cover, organic matter, the temperature regime, and others

Reported effects of tillage systems on the soil environment often indicate a higher bulk density under reduced tillage. The effects can be modified by other management practices and environmental factors such as freeze-thaw cycles, rainfall and wetting and drying cycles (Kay et al., 1985; Swan et al., 1987). A change in tillage systems may also result in a change in soil strength and may have an effect on plant growth, particularly root growth (Hill and Cruse, 1985). Increased bulk density under reduced tillage systems may or may not be root restricting since factors such as texture, structure, drainage and others determine the bulk density at which rooting is impaired.

Soil organic matter content and distribution vary under differing tillage systems (Blevins et al., 1977; Arshad et al., 1990). Increased contents of organic matter (Arshad et al., 1990; Campbell et al., 1989; Singh, 1991) as well as improved aggregation of surface soils (Arshad and Dobb, 1991; Sanborn, 1991) are generally reported under reduced tillage.

Bulk density of the soil surface influences movement of water into the soil profile. Excessively tilled soils may puddle in heavy rainstorms and subsequently reduce infiltration and increase runoff. Reduced macroporosity of surface soils under no-till systems may influence water movement and storage in the soil profile. A subsurface tillage-pan of high bulk density, which can affect water movement and impede root penetration, may result from excessive amounts of tillage.

Different tillage systems vary the level of crop residue on the soil surface which protects the soil from the erosive forces of wind and water. Residues levels also affect infiltration, runoff, and radiation balance which directly affect the soil moisture regime. Arshad and Dobb (1991) found higher soil moisture under zero tillage during the early part of the growing season as compared to conventional tillage in the Peace River region. Singh (1991) found that residue cover in tilled and no-tilled treatments resulted in higher soil moisture than in a tilled treatment with the straw removed. The effect of crop residue on soil moisture was also noted by Nyborg and Malhi (1989; as cited by Sanborn, 1991) where no significant difference in soil moisture was noted between zero tillage and conventional tillage plots that had straw removed; however, in plots with straw and stubble left, the zero tillage treatment had higher moisture contents than the conventional tillage

Contradictory reports on the extent and even direction of tillage-induced change in soil properties and processes indicate the need to take many factors into account when interpreting and applying results. Cropping patterns, climatic conditions, tillage equipment used, depth of tillage, time and method of measurement and antecedent values of soil properties all have some degree of influence on the measured changes in soil due to tillage.

Depth resolution of measurements is an important consideration in quantifying these changes. Effects of different tillage systems may be masked by a coarse resolution whereas the soil may exhibit very fine stratification of soil properties. Natural spatial variability as well as human-induced positional differences complicate the interpretation of measured results. Temporal variation in many properties warrants consideration in selecting time of measurements.

The properties of the soil environment interact in a complex manner with the crop through effects on seedling emergence, root growth and water use. Crop response to a given tillage system is modified by distribution and amount of rainfall, length of growing season and other factors. These complex interactions with the soil environment vary among climatic regions and soil types. Consequently tillage practices that cause a change in soil properties at one location may not cause that same change at another location.

1.3 Study objectives

Conservation tillage holds great promise in the Peace River region as a soil conservation measure. Conservation tillage, being one of the most effective ways of controlling soil erosion (Papendick, 1984), can play a valuable part in preserving the soil resources of the region. Conservation tillage can also reduce labor, energy, and capital costs on the farm.

The effects conservation tillage may have on soil physical properties such as soil strength, bulk density and soil moisture are largely unknown for the Peace River region, contributing to a reluctance amongst producers to adopt conservation tillage. However, such information is vital for a better understanding of tillage system behavior as well as assessing the suitability of tillage systems to the region and thus addressing producer concerns.

The objective of this research was to quantify the effects of three different tillage systems on soil bulk density, organic matter, soil moisture, and soil strength of a Dark Gray Solod in the Peace River region of Alberta. The tillage systems were zero tillage, minimum tillage and conventional tillage. The soil at the study site is of the Falher series which predominates in some 20,000 ha in the region. This soil is vulnerable to both wind and water erosion, has a relatively impermeable subsoil which is prone to waterlogging, and has poor soil structure (Odynsky et al., 1961).

The results of this study are presented in three chapters, each with its own specific objectives summarized below.

To determine the long term effects of three different tillage systems on:

1. Soil bulk density, porosity and organic matter with consideration to temporal and spatial variation (Chapter 2).
2. Available water holding capacity and soil moisture (Chapter 3).
3. Soil strength with consideration to temporal and spatial variability (Chapter 4).

The last chapter (Chapter 5) is a synthesis of the results reported in Chapters 2 through 4.

1.4 References

Albright, W. D. 1939. The menace of water erosion in the Peace. Sci. Agric. 19: 241-248.

Arshad, M. A. and Dobb, J. L. 1991. Tillage effects on soil physical properties in the Peace River region: Implications for sustainable agriculture. *in* Proc. 28th Annual Alberta Soil Science Workshop. pp. 190-199.

Arshad, M. A., Schnitzer, M., Angers, D. A. and Ripmeester, J. A. 1990. Effects of till vs no-till on the quality of soil organic matter. Soil Biol. Biochem. 22: 595-599.

Black, A. L. and Siddoway, F. H. 1979. Influence of tillage and wheat straw management on soil properties in the Great Plains. J. Soil and Water Cons. 34: 220-223.

Blevins, R. L., Thomas, G. W. and Cornelius, P. L. 1977. Influence of no-tillage and nitrogen fertilization on certain soil properties after five years of continuous corn. Agron. J. 69: 383-386.

Campbell, C. A., Biederbeck, V. O., Schnitzer, M., Selles, F. and Zentner, R. P. 1989. Effects of 6 years of zero tillage and N fertilizer management on changes in soil quality of an Orthic Brown Chernozem in Southwestern Saskatchewan. Soil Tillage Res. 14: 39-52.

Chanasyk, D. S. and Woytowich, C. P. 1987. Sediment yield as a result of snowmelt runoff in the Peace River region. Can. Agric. Eng. 29: 1-6.

Hill, R. L. and Cruse, R. M. 1985. Tillage effects on bulk density and soil strength of two Mollisols. Soil Sci. Soc. Am. J. 49: 1270-1273.

Kay, B. D., Grant, C. D. and Groenevelt, P. H. 1985. Significance of ground freezing on soil bulk density under zero tillage. Soil Sci. Soc. Am. J. 49: 973-978.

Novak, M. D. and van Vliet, L. J. P. 1983. Degradation effects of soil erosion by water and wind. *in* Proc. 8th B.C. Soil Science Workshop. pp. 46-47.

Nyborg, M. and Malhi, S. S. 1989. Effect of zero and conventional tillage on barley yield and nitrate nitrogen content, moisture and temperature of soil in north-central Alberta. Soil Tillage Res. 15: 1-9.

Odynsky, W., Lindsay, J. D., Reeder, S. W. and Wynnyk, A. 1961. Reconnaissance Soil Survey of the Beaverlodge and Blueberry Mountain Sheets. Alberta Soil Survey Report No. 20. University of Alberta, Edmonton, AB.

Papendick, R. I. 1984. Changing tillage and cropping systems: Impacts, recent developments, and emerging research needs. *in* G. Haas (ed.) The Optimum Tillage Challenge. Proc. of the Saskatchewan Institute of Agrologists Update Series, Nov. 6-8, 1984. Published by University of Saskatchewan Printing Services. Saskatoon, SK.

Sanborn, P. 1991. An evaluation of soil conservation under three tillage systems for the Peace River region of British Columbia: Soil physical properties. ARDSA Project 23011 final report.

Schertz, D. L., Moldenhauer, W. C., Livingston, S. J., Weesies, G. A. and Hintz. E. A. 1989. Effect of past soil erosion on crop productivity in Indiana. J. Soil Water Cons. 44: 604-608.

Singh, B. 1991. The long-term effects of tillage and residue management on the soil physical environment and on barley growth. University of Alberta, Department of Soil Science, Edmonton, AB. Ph.D. Dissertation. 213 pp.

Swan, J. B., Moncrief, J. F. and Voorhees, W. B. 1987. Soil compaction-causes, effects and control. Minnesota Extension Service, University of Minnesota, St. Paul, MN. Ag. Bu. 3115-1987, 12 pp.

Van Vliet, L. J. P. and Hall, J. W. 1991. Effects of two crop rotations on seasonal runoff and soil loss in the Peace River region. Can. J. Soil Sci. 71: 533-544.

Van Vliet, L. J. P., Kline, R., Sanborn, P. and Carroll, K. 1991. Soil loss and water runoff estimates, and barley yields from conventional, reduced, and zero tillage trials in the Peace River region of British Columbia. *in* Abstracts of Technical Papers. Can. J. Soil. Sci. 71: 280.

Weersink, A., Walker, M., Swanton, C. and Shaw, J. E. 1992. Costs of conventional and conservation tillage systems. J. Soil Water Cons. 47: 328-334.

Chapter 2

CONSERVATION TILLAGE EFFECTS ON BULK DENSITY, POROSITY AND ORGANIC MATTER OF A DARK GRAY SOLOD UNDER CONTINUOUS WHEAT IN THE PEACE RIVER REGION OF ALBERTA

2.1 Introduction

Soil bulk density has a profound effect on the air-water relations and crop productivity of a soil. Subsoil layers with high bulk density can interfere with movement of water into the soil. Plant root penetration is inversely affected by soil bulk density (Barley et al., 1965; Taylor and Gardner, 1963), which is typically altered by tillage and the incorporation of crop residues.

The reported effects of different tillage systems, particularly zero tillage, on bulk density are variable, often contradictory and do not allow for extrapolation to other agroclimatic regions. In a field study continuously cropped to barley in Scotland, Pidgeon and Soane (1977) found that soil bulk density to 15 cm was greater under zero-tillage as compared to moldboard plowing and chisel plowing. Gantzer and Blake (1978) showed that soil bulk density under zero-tillage was significantly greater than under conventional tillage, in both the spring and fall, in the surface 30 cm of a clay loam soil after six years in a continuous corn rotation. Treatment differences decreased from spring to fall but remained significant. Lindstrom and Onstad (1984) reported a statistically higher bulk density in the Ap horizon (0 - 15 cm) of the no-till treatment as compared to tilled treatments after planting in the third year of a continuous corn rotation on a fine loamy soil. Douglas et al. (1986) reported higher surface bulk density under direct drilled as compared to tilled treatments after ten years of tillage treatments on a silty soil.

In contrast, other reports indicate no significant difference in bulk density under conservation tillage as opposed to conventional tillage. These include: Hill and Cruse (1985) after eight years of tillage treatments under continuous corn where differences were not statistically significant but trends were that reduced tillage treatments had higher bulk density than no-tillage and conventional tillage; Sanborn (1991) who noted a higher bulk density in surface soils under zero tillage as compared to conventional tillage in each of four years studied, however the difference was not significant; Shear and Moschler (1969) where no significant difference in bulk density was observed between no-tillage and conventional tillage after six years of continuous corn production; Campbell et al. (1989) in a study in southwest Saskatchewan where no difference was found in surface bulk density between zero tillage and conventional tillage treatments sampled in the fall; Bauder et al. (1981) where soil bulk densities under four tillage treatments on a clay loam soil, were not significantly different but trends were that zero tillage had a higher bulk density than other treatments in the surface soil; Tollner et al. (1984) after seven years of a grain and soybean double cropping rotation under different tillage treatments where surface soils under no-tillage had a higher but not significantly different bulk density compared to conventional tillage. However, at a depth of 30-35 cm, the conventional tillage treatment had a significantly higher bulk density than the no-tillage treatment. Arshad and Dobb (1991) in their study in the Peace River region noted a similar effect where bulk density under zero tillage was higher compared to conventional tillage in the surface 7.5 cm while bulk density was higher throughout the growing season in the conventional tillage treatment at the 8-30 cm depth interval.

Temporal variation of bulk density under various tillage treatments is also noted by several researchers: Blevins et al. (1977) reported no significant difference in bulk density between no-tillage and conventional tillage treatments, after five years of continuous corn production on a silt loam soil. The measurements were made in March and the authors noted that the results did not reflect the seasonal variations that occur in conventional tillage immediately following tillage operations; Griffith et al. (1977) noted the temporary effect of tillage on bulk density referring to a study of no-till corn production compared to conventionally tilled treatments. In this study the no-till treatment exhibited the higher bulk density after planting, however, after harvest there was little difference among treatments. Arshad and Dobb (1991) observed a similar temporal effect where higher bulk density in the surface 7.5 cm under zero tillage as compared to conventional tillage was observed shortly after planting but there was no difference between treatments at the end of the growing season. Douglas et al. (1986) noted that bulk density under zero tillage did not change during the first month after seeding but bulk density under simple tillage and plowing had increased by 19 and 12 % respectively.

Voorhees and Lindstrom (1984) showed a difference in bulk density between conservation and conventional tillage that also was not constant with time. During the first three to four years of a nine-year study on a silty loam soil, bulk density of the 0-15 cm depth was higher under conservation tillage than under conventional moldboard plowing. This effect reversed after three to four years. A similar effect was also observed at the 15 - 30 cm layer where approximately seven years of conservation tillage were required to achieve a total porosity equal to that under conventional plowing. The authors suggested that the relative changes in bulk density between the two tillage treatments over time was due to a trend for soils under continuous fall moldboard plowing (conventional tillage) to become more dense with time while the bulk density of soils under fall chisel plow or disk treatments (conservation tillage) remained relatively constant with time.

Soil organic matter levels may be affected by differing tillage practices because of minimal soil mixing in a no-till system as compared to maximum mixing and redistribution in a conventional till system. Changes in the soil moisture regime, soil temperature, aeration, root growth and biological activities as a result of differing tillage practices are also likely to affect soil organic matter levels.

Many studies indicate that near surface organic matter levels increase under reduced tillage practices. Arshad et al. (1990) reported a 26% increase in organic carbon in the surface 0-7.5 cm after 10 yr of no-tillage as compared to more intensive conventional tillage on a Donnelly series soil near Fort St. John, B.C. Carter (1991) noted an increase of 10-17 % in organic carbon in surface soils under direct drilled and reduced tillage as compared to moldboard plowing sites in Atlantic Canada. Several other studies show an increased level of organic matter near the soil surface of reduced tillage treatments as compared to conventional tillage treatments. These include; Douglas et al. (1986) in England, Archetti et al. (1989) in Italy, Campbell et al. (1989) in southwest Saskatchewan and Singh (1991) in central Alberta.

Organic matter tends to be concentrated near the surface in zero tillage treatments (Blevins et al. 1984; as cited by Sanborn, 1991). This is borne out by Singh (1991) and Campbell et al. (1989) who found that organic matter levels in the 10-15 cm depth and 7.5-15 cm depth respectively were not affected by tillage whereas the surface soils of the zero tillage treatments exhibited higher organic matter levels than conventional tillage.

Scientific information on the effects of tillage systems on soil bulk density, porosity and organic matter is scant under the soil and agroclimatic conditions of the Peace River region. The soil being studied has poor natural aggregation, is vulnerable to wind and water erosion and has a relatively impervious subsoil that may lead to waterlogged conditions during periods of heavy rainfall (Odynsky et al., 1961).

The objectives of this study were to determine the effects of three tillage treatments (zero, minimum, and conventional tillage) on the bulk density, porosity and organic matter of a Dark Gray Solod in the Peace River region of Alberta.

2.2 Materials and methods

2.2.1 Site and soil description

The study site is located on the SE 26-79-13-W6 in the Baytree-Bonanza area of the Peace River region of Alberta, 80 km west of Rycroft. The site has slopes less than 1% and a uniform aspect. This study, initiated by the Bill Molson family, the Prairie Farm Rehabilitation Administration and Alberta Agriculture at Spirit River, was established in the spring of 1986 on wheat stubble from the previous year. The site had been continually cropped and conventionally tilled since 1980. Prior to 1980 the site had been conventionally tilled with rotations including clover plowdown, cereal and summerfallow.

The soil (Falher series) was developed from fine textured lacustrine materials, gray and dark gray in color and usually free of stones. It is classified as a Dark Gray Solod with a good to very good arable rating (Odynsky et al., 1961). The soil is characterized by a well developed, dark colored surface horizon that usually ranges from 10 to 15 cm thick with an abrupt break between the A and B horizons.

The surface 15 cm of soil had an average clay content of 62% and soil below this depth had from greater than 60% to a maximum of 89% clay (< 2 μm), which places this soil in the heavy clay textural class (Agriculture Canada Expert Committee on Soil Survey, 1987). The hydrometer method was used for particle size determinations (McKeague, 1978).

2.2.2 Tillage systems

Four tillage treatments, replicated twice, were established in the spring of 1986 to study the long term effects of these treatments on soil properties and crop growth. Treatments were zero, minimum, and conventional tillage with banded fertilizer; a fourth treatment involving conventional tillage with broadcast fertilizer was not used in this study (Figure 2.1). Zero tillage consisted of no disturbance of the soil other than that caused by the seeding operation. Minimum tillage consisted of one disc cultivation in the fall and a light cultivation in the spring with sweeps. Conventional tillage consisted of chisel cultivation followed by one disc cultivation in the fall and two light cultivations in the spring with sweeps. The depth of tillage was generally 7-10 cm. All plots were diamond harrowed after seeding. Spring cultivation in 1989 was carried out on May 9.

A 6-m wide Haybuster 1000 double disc press drill with a 15 - 35 cm paired row configuration (15 cm between rows and 35 cm between pairs of rows) was used for seeding. The furrow openers were 45-cm offset double disc openers and the fertilizer knife banded fertilizer between the 15 cm rows (Figure 2.1). Starter fertilizer was applied with the seed on all treatments. The site was seeded to Katepwa spring wheat (Triticum aestivum L.) on May 12, 1989 at 133 kg ha^{-1}. Depth of seeding was 5-6 cm. The same fertilizer rates were applied to all treatments. Weed control was achieved by post-emergence application of herbicides across all treatments. The zero tilled treatments received pre-seeding applications of glyphosate tank-mixed with 2,4-D or dicamba.

All treatments were straight cut harvested using a combine equipped with attachments which spread the straw and chaff evenly across the full width of the threshing cut. Stubble height was approximately 10 cm.

2.2.3 Measurements and analyses

2.2.3.1 Soil bulk density, porosity and organic carbon

The bulk density of soil was measured several times during the 1989 growing season using soil cores and gamma ray attenuation techniques. On May 11, 1989, after spring cultivation but prior to seeding, a precalibrated surface moisture-density gauge (Model MC-1, Campbell Pacific Nuclear Corp., California) was used to determine the near-surface bulk density (0-10 cm depth) at five randomly selected locations per plot. In the tilled treatments three random sub-locations were selected at each of the five locations, while in the zero till treatment the three sublocations were in-row (IR), between-row (BR), and between-pairs of rows (BPR). For the 0-10 cm interval in all treatments, the three sublocation readings were averaged. A moisture-density combination probe (Model 501, Campbell Pacific Nuclear Corp., California) lowered down aluminum access tubes was used to determine soil bulk density at 10 cm increments from 10 to 80 cm in depth. Measurements were taken at five random locations per plot adjacent to the locations used for surface bulk density measurements, resulting in 10 measurements per treatment at a given depth increment. Bulk density was calculated as the difference between wet bulk density and fractional volumetric water content.

Soil cores, using a modified Uhland core sampler, were taken several times during the remainder of the year to determine bulk density in the 0-7.5 and 7.5-15 cm depths. Cores were taken at the in-row position at three or four randomly selected locations in each plot four times during the growing season (July 7, August 16, September 7, and October 6). Cores were also taken in the between-pairs of rows position on October 6. The cores collected in the between-pairs of rows position in October were also used for organic matter determination. The cores were sectioned carefully in the field using a scroll saw with a very fine blade to yield 2.5-cm increments. The 2.5-cm increments served to increase the resolution of the bulk density determinations. The 0-7.5 cm and 7.5-15 cm cores were taken from adjacent locations to avoid disturbance caused by taking the first core. The cores were stored at 4 ^{o}C prior to further use. Bulk density was calculated on an oven-dry (105 ^{o}C) basis.

Total soil porosity (n, %v/v) was computed using the relation: $n=100(1-Db/\rho s)$ where Db is the bulk density and ρs is the particle density of the soil. Measured values of ρs, determined using the pycnometer method (Blake and Hartge, 1986), were used to calculate porosity for the 0-15 cm depth and an assumed value of 2.65 Mg m^{-3} was used for depths below 15 cm.

Total carbon of soil samples collected in October from the between-pairs of rows position was determined by dry oxidation followed by infrared detection using the LECO CR 12 carbon analyzer (LECO Corporation, St. Joseph, MI 49085, USA). There were negligible carbonates in the 0-15 cm depth of soil, therefore total carbon was taken as organic carbon.

2.2.3.2 Statistical analysis

The bulk density, porosity and organic matter data were statistically analyzed to determine the effect of the treatments. Analysis of variance was performed for each depth using the GLM procedure of the Statistical Analysis System (SAS Institute Inc, 1991). The least squares means were calculated and used if an observation was missing. If F values for treatments were significant ($P \leq 0.10$), comparisons of means were conducted using the least significant difference test.

2.3 Results and discussion

2.3.1 Soil bulk density

2.3.1.1 Soil profile bulk density

Bulk densities of the three tillage treatments were significantly different in the surface 10 cm as measured on May 11, 1989, two days after spring tillage (Figure 2.2). There had been no precipitation between spring tillage and time of sampling so precipitation-induced recompaction of the soil disturbed by cultivation had not occurred. Bulk density was higher in the zero-till treatment than in the minimum-till treatment, and the bulk density in the minimum till treatment was higher than in the conventional-till treatment; however, the differences were small (0.05 and 0.04 Mg m^{-3} respectively). These differences reflect the relative intensity of the cultivations and their effect on surface soil bulk density.

There was no significant difference in bulk density among treatments in subsequent 10-cm increments for the 10 to 70 cm depth interval. A significant difference among treatments was noted in the 70-80 cm depth increment where bulk density under conventional-till was higher than under minimum and zero-till although this difference was not great (0.03 Mg m^{-3}). This may reflect compaction at depth brought about by the use of heavy tractors with large axle loads (Voorhees 1986; as cited by Rickman, 1988), as the conventional tillage requires more passes with the tractor than would the minimum or zero tillage treatments.

2.3.1.2 Surface bulk density (0-15 cm, by 2.5-cm increments, in-row position)

At all sampling times, the tilled treatments consistently had higher bulk density than the zero-till treatment in the 0-2.5 cm increment (Figure 2.3) although this difference was not significant. The greater compaction of the more bare surface soils in the tilled treatments was likely the result of seasonal precipitation, whereas accumulation of decomposed and undecomposed organic matter close to the soil surface in the zero-till treatment prevented densification. Appreciable amounts of precipitation occurred after seeding in May and before the sampling in July (129.7 mm precipitation) with one storm delivering 23.2 mm in a 24-hour period.

Measurements in the 2.5-cm increments from 2.5 to 15 cm in depth showed no significant difference among tillage treatments at each sampling time (Figure 2.3), with the exception of the 5-7.5 cm and 10-12.5 cm depths in August where the minimum-till treatment had significantly higher bulk density than the other two treatments. The reason for this difference is not known but may be due to few samples (n=3) being collected because of inclement weather at that time.

The general lack of significant difference among treatments may be due to several factors. These include: 1) the shallow depth of tillage in the tilled treatments; 2) the tillage operations performed resulted in less soil disturbance compared to other forms of tillage such as plowing or rototilling; and 3) reconsolidation of the soil due to intense rainstorms. Another factor may be the effect of the packing wheels on the double disc press drill causing post-seeding bulk densities to be similar even though initial bulk densities may have been different. Davies et al. (1973; as cited by Rickman; 1988) found that wheel-induced compaction was dependent on initial soil bulk density where lower initial densities resulted in greater change in density than did higher initial densities under the same compactive treatments. Cassel (1982) and Rickman (1988) suggested that crop root growth will decompact soils. Rickman found maximum decreases of 0.06 Mg m^{-3} for 5-cm increments over the growing season: in this study maximum decompaction from July to October was 0.07, -0.02, and 0.01 for zero, minimum, and conventional till respectively for the 0-15 cm depth. Bulk density also increased and decreased from July to October.

Wetting and drying and concomitant swelling and shrinking of this soil due to its high clay content (> 60%) may also contribute to the lack of difference in bulk density among treatments in the July to October time frame. Soil cracks were observed on the site many times throughout the season. Coefficient of linear extension was found to be highly correlated to clay content of soils (De Jong et al., 1991) and Swan et al. (1987) noted that wetting and drying may alleviate compaction.

Averaged over all depths (0-15 cm) and all sampling times throughout the season, bulk density in the zero-till, minimum-till and conventional-till treatments was 1.10, 1.13 and 1.11 Mg m^{-3} respectively (Table 2.1). The bulk densities averaged over all depths for each time of sampling (July, August, September and October) were: zero-till: 1.11, 1.10, 1.10 and 1.09 Mg m^{-3}; minimum-till: 1.09, 1.24, 1.11 and 1.10 Mg m^{-3}; and conventional-till; 1.11, 1.12, 1.12 and 1.09 Mg m^{-3}, respectively. The similarity of average bulk density under no-till throughout the season suggests that the soil has reached an equilibrium bulk density. Pidgeon and Soane (1977) concluded that surface soil under zero-tillage in their study had reached an equilibrium bulk density after three years of the imposed management practice.

2.3.1.3 Soil bulk density with respect to row position.

For the 0-2.5 cm depth in the between-pairs of rows position, bulk density under zero tillage was lower than that under the tilled treatments (Figure 2.4). This difference was not significant but the trend was similar to that observed at the same depth increment at all other times of sampling in the in-row position. The greater residue cover in the zero till treatment may have resulted in the soil surface being less prone to compaction from the beating action of rainfall as compared to the tilled treatments.

In contrast to the bulk density in the in-row position in October and at other sampling times, the bulk density in the between-pairs of rows position was significantly different among treatments in the 5-7.5 cm depth increment (Figure 2.4). Conventional tillage had a significantly lower bulk density in the 5-7.5 cm depth increment than the minimum and zero tillage treatments. Both tilled treatments had lower bulk density than zero tillage in the 2.5-5, 10-12.5, and 12.5-15 cm depth increments, but these did not test significant.

The similarity of bulk density between minimum and zero tillage for the 5-7.5 cm depth increment and the similarity of bulk density between the conventional and minimum tillage treatments at the 10-12.5 cm depth increment may be related to the organic matter contents of the respective treatments at these depths (Figure 2.5), bulk density being inversely related to organic matter. For the 5-7.5 cm depth increment, the zero and minimum tillage treatments had similar organic matter contents which were lower than under the conventional tillage treatment. For the 10-12.5 cm depth increment the zero tillage treatment had less organic matter than the two tilled treatments which had similar amounts of organic matter. However, the same trend was not evident at other depth increments.

In the between-pairs of rows position at all depths greater than 2.5 cm, with the exception of the 7.5-10 cm depth increment, the zero tillage treatment tended to have higher bulk density as compared to the tilled treatments (Figure 2.4). For the 7.5-10 cm depth increment, zero tillage had greater bulk density than the conventional tillage treatment but lower than that under minimum tillage; however, these differences were not significant. Because there was no packing of soil caused by the press wheels of the seed drill at this position and as root growth would have been less in this position as compared to the in-row position, this trend for the tilled treatments to exhibit lower bulk density than the zero tillage may be largely related to the amount of initial soil disturbance caused by cultivation.

The exception to this trend, namely the bulk density exhibited by the minimum tillage treatment exceeding even the bulk density under zero tillage in the 7.5-10 cm depth increment, may be due to minimum tillage being conducted with sweeps and discs whereas conventional tillage included cultivation with chisel points in the fall. The sweeps and discs may have resulted in an increased bulk density compared to conventional tillage, as well as zero tillage, just below the depth of cultivation which was approximately 7.5-10 cm.

A layer of higher bulk density for the 5-7.5 cm depth increment with a layer of lower bulk density below it, in the between-pairs of rows position, may be tillage induced. Cultivation with sweeps in the tilled treatments over the years could have caused densification immediately below the depth of cultivation. A similar trend in the zero tillage treatment may be a relic of past cultivation prior to initiation of the study.

2.3.1.4 Plant growth with respect to bulk density

Bulk density ranges that are optimum for plant and root growth are largely unknown for many soils (Cassel, 1982). Bulk density in itself is not the only factor that affects root penetration.

Other factors such as moisture content, porosity, size and continuity and tortuosity of pores, soil strength and texture affect root penetration and plant growth (Taylor and Gardner, 1963, Thacker and Johnson, 1988). In any case the bulk density that would limit crop growth is unknown for this soil-crop combination, however, it is worthy of note that bulk density generally was not significantly different among treatments in this study.

2.3.2 Soil porosity

The effects of tillage, or lack thereof, on total soil porosity were similar to those on soil bulk density. In May, the soil porosity of the 0-10 cm depth increment was highest under the conventional tillage treatment and least under the zero tillage (Figure 2.6). This reflects the relative intensity of the tillage operations which were carried out two days before the measurements. This difference between conventional and zero till, although very small (4% absolute), was significant. Porosity in the 10-cm increments from 10 to 70 cm was not significantly different among treatments. In the 70-80 cm depth increment porosity under the conventional tillage treatment was significantly lower than that under zero and minimum tillage but again the difference was very small ($< 2\%$).

Total soil porosity in the surface 0-2.5 cm at all other times of sampling was higher under the zero tillage treatment compared to the tilled treatments, although this difference was not significant (Table 2.2). Greater compaction of the soil surface under the tilled treatments was likely the result of seasonal precipitation. The accumulation of undecomposed and decomposed organic matter at the soil surface of the zero tillage treatment may have helped prevent densification and resultant reduction in porosity due to rainfall. The remaining 2.5-cm increments to a depth of 15 cm showed no significant difference among treatments with only one exception.

2.3.3 Soil organic carbon

The zero till treatment had the highest organic carbon content in the 0-2.5 cm depth increment which was significantly higher than either of the tilled treatments (Table 2.3). The relative increases were 15.6% and 16.5% over the minimum and conventional till treatments respectively. The tilled treatments did not differ in the amount of organic carbon in this depth increment. At all lower depths there was no significant difference among treatments. Thus, the distribution of organic matter with soil depth differed considerably between the tilled and zero till treatments with the difference occurring in the surface of the treatments. This could have implications for soil structural characteristics such as mean weight and geometric mean diameters of surface soil aggregates (Sanborn, 1991) and result in a soil surface that is more resistant to erosive forces under zero tillage. These results are similar to those noted by Blevins et al. (1977) where soil under zero till had significantly higher organic matter contents compared to that under conventional tillage in the 0-5 cm depth increment and minor differences below 5 cm with no difference below 10 cm. This is also similar to other studies in that the effects of zero till on organic matter are often limited to the extreme surface of the soil (Campbell et al., 1989; Sanborn, 1991; Singh, 1991).

The tilled treatments had a more uniform vertical distribution of organic carbon for the 0-10 cm depth interval as compared to the zero-till treatment (Figure 2.5). This conforms to the depth of cultivation (approximately 10 cm) in the tilled treatments and reflects the mixing of the soil resulting in a relatively uniform distribution of organic matter throughout the depth of cultivation. In the zero till treatment the soil remained largely undisturbed over four growing seasons and organic matter concentration could increase near the surface.

Averaged over all depth increments to 15 cm, the organic carbon levels were similar in all three tillage treatments; 3.42, 3.42 and 3.36% for the zero, minimum and conventional tillage treatments respectively. When this is converted to total mass of organic carbon in one square centimeter to a depth of 15 cm, taking into account the soil bulk density of each treatment, the results are 0.56, 0.55 and 0.52 g respectively. The mass of organic carbon to 15 cm is very similar among treatments and indicates that redistribution of organic matter is the major effect of tillage treatments. However, the trend of decreasing organic matter contents with increasing intensity of cultivation may be related to increased oxidative processes resulting from more soil stirring and residue incorporation which is the case in conventional tillage (Campbell et al., 1989).

2.4 Conclusions

Bulk density and porosity generally did not vary among the three tillage systems studied. Differences that occurred were largely restricted to the near surface and to the time period immediately after spring cultivation, where bulk densities reflected the effect and intensity of cultivation and were in the order of zero > minimum > conventional tillage. At other times of the season, bulk density did not vary among treatments. The lack of difference among treatments is likely due to relatively shallow cultivation, an already high bulk density, high clay content of the soil, seed drill configuration and seasonal precipitation. Spatial and temporal variation of bulk density was most evident in the tilled treatments early in the season and support the contention that spatial and temporal effects be considered in tillage studies.

Average (0-15 cm) bulk density under zero tillage did not change during the season, indicating an equilibrium bulk density. A tillage pan was noted in the between-pairs of rows position in all treatments. The effects on porosity were generally similar to those on bulk density.

Soil organic carbon was significantly higher under zero tillage in the surface 2.5 cm compared to the tilled treatments and did not differ among treatments below this depth. Minimal disturbance of the soil under zero till resulted in stratification of organic carbon.

Table 2.1 Soil bulk density (average 0-15 cm) as affected by tillage treatments during 1989. In-row position. ¶

Tillage system	Bulk density ($Mg\ m^{-3}$)				
	July 7	Aug. 16	Sept. 7	Oct. 6	Mean
Zero	1.11	1.10	1.10	1.09	1.10
Minimum	1.09	1.24	1.11	1.10	1.13
Conventional	1.11	1.12	1.12	1.09	1.11

¶ The only significant difference occurred on August 16, where minimum till had a significantly higher average bulk density than the other treatments.

Table 2.2 Total soil porosity (%, v/v) at different depths at the in-row position as affected by tillage treatment during 1989. ¶

Tillage system and soil depth increment (cm)	Time of measurement			
	July 7	Aug. 16	Sept. 7	Oct. 6
Zero tillage				
0-2.5	66.4	71.2	70.2	67.9
2.5-5	66.0	64.2	61.4	62.5
5-7.5	59.2	58.9	55.4	57.3
7.5-10	50.0	54.4	55.6	57.6
10-12.5	47.7	48.5	50.0	49.7
12.5-15	49.2	45.8	49.1	49.1
Minimum tillage				
0-2.5	66.2	64.9	67.4	63.9
2.5-5	67.7	58.4	62.8	64.9
5-7.5	62.1	47.2	56.2	57.7
7.5-10	49.7	47.8	57.8	58.0
10-12.5	49.1	43.0	48.9	50.3
12.5-15	50.6	47.5	46.4	46.9
Conventional tillage				
0-2.5	60.7	68.0	66.4	65.7
2.5-5	67.0	62.2	63.6	62.0
5-7.5	65.7	56.2	55.6	57.8
7.5-10	48.1	54.0	57.3	56.5
10-12.5	48.0	48.7	48.6	53.0
12.5-15	50.9	49.1	45.7	48.6

¶ The only significant difference among treatments was on August 16 where the minimum tillage treatment had lower porosity than the other treatments in the 5-7.5 and 10-12.5 cm increments ($P \leq 0.10$).

Table 2.3 Soil organic carbon (%, w/w) as affected by tillage treatment.

	Tillage treatment			
Soil depth (cm)	Zero	Minimum	Conventional	Mean
0-2.5	4.44 a†	3.84 b	3.81 b	4.03
2.5-5	3.80	3.75	3.83	3.79
5-7.5	3.60	3.60	3.76	3.65
7.5-10	3.29	3.50	3.58	3.46
10-12.5	2.96	3.14	3.10	3.06
12.5-15	2.46	2.71	2.11	2.42
Mean	3.42	3.42	3.36	

† For a given depth increment, treatment means followed by no letters are not significantly different ($P \leq 0.10$).

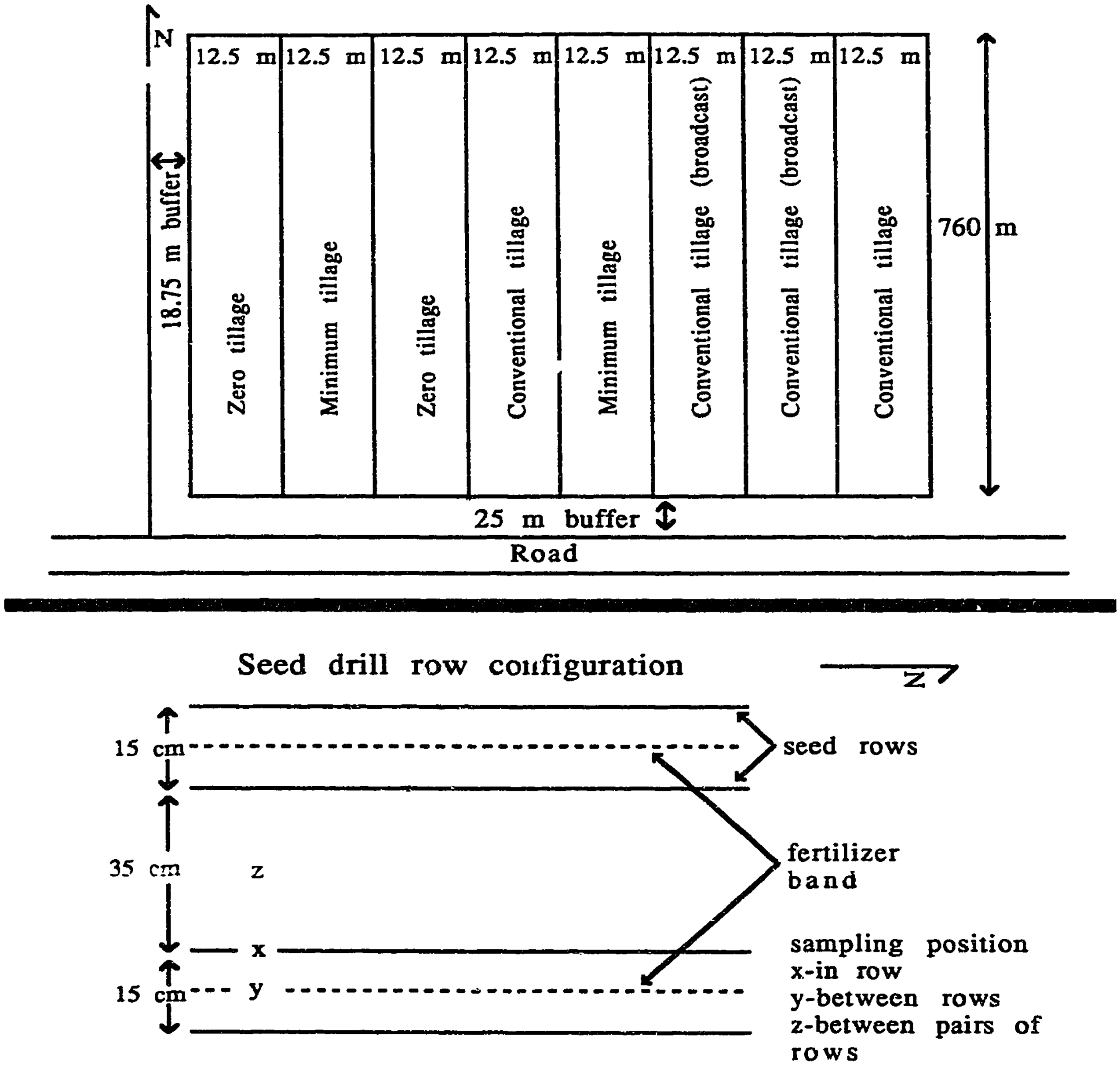


Figure 2.1 Schematic diagram of study site and sampling pattern with respect to seed rows.

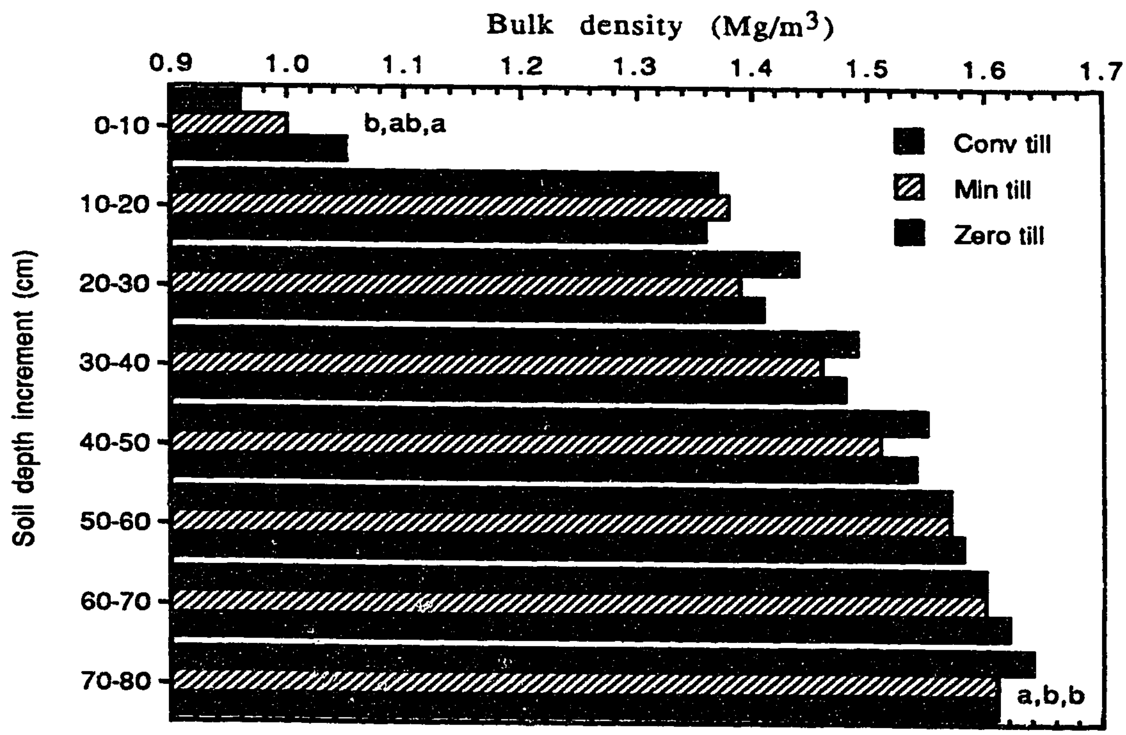


Figure 2.2 Soil bulk density with depth on May 11, 1989. Within a given depth increment, treatment means followed by no letters are not significantly different (P=0.10).

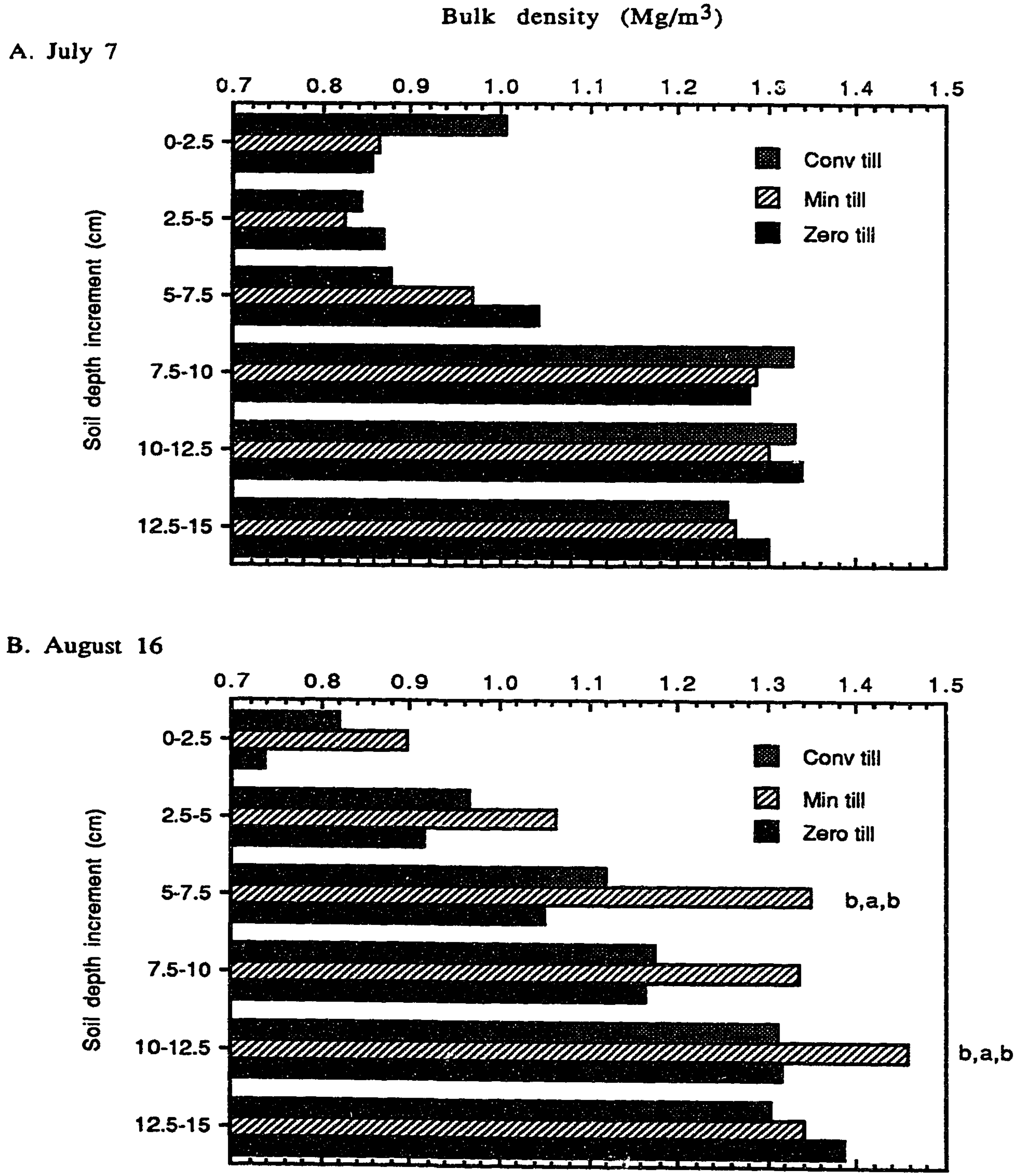


Figure 2.3 Soil bulk density (in-row position) with depth on (A) July 7 and (B) August 16, 1989. Within a given depth increment, treatment means followed by no letters are not significantly different (P=0.10).

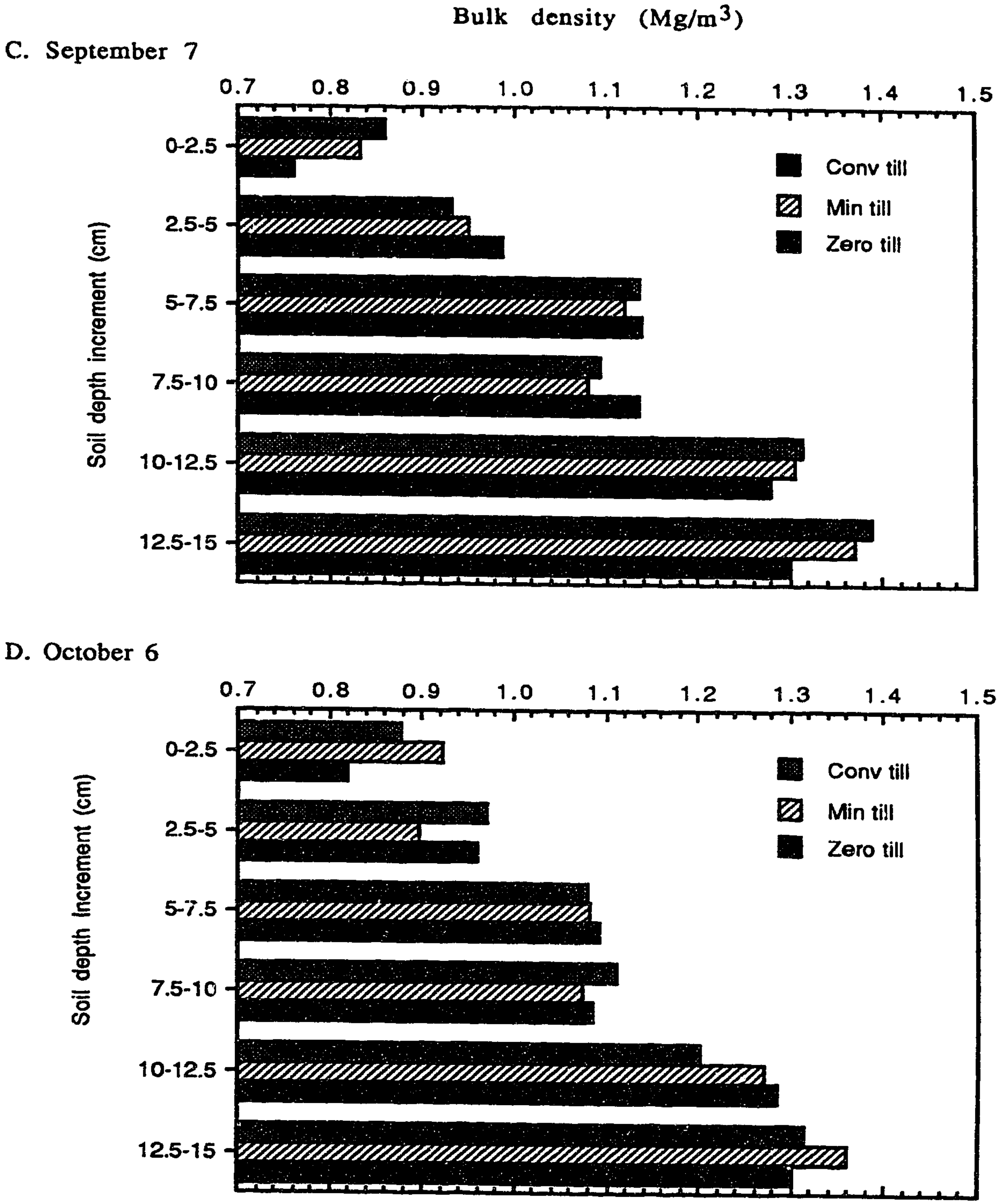


Figure 2.3 (cont'd) Soil bulk density (in-row position) with depth on (C) September 7 and (D) October 6, 1989. Within a given depth increment, treatment means followed by no letters are not significantly different (P=0.10).

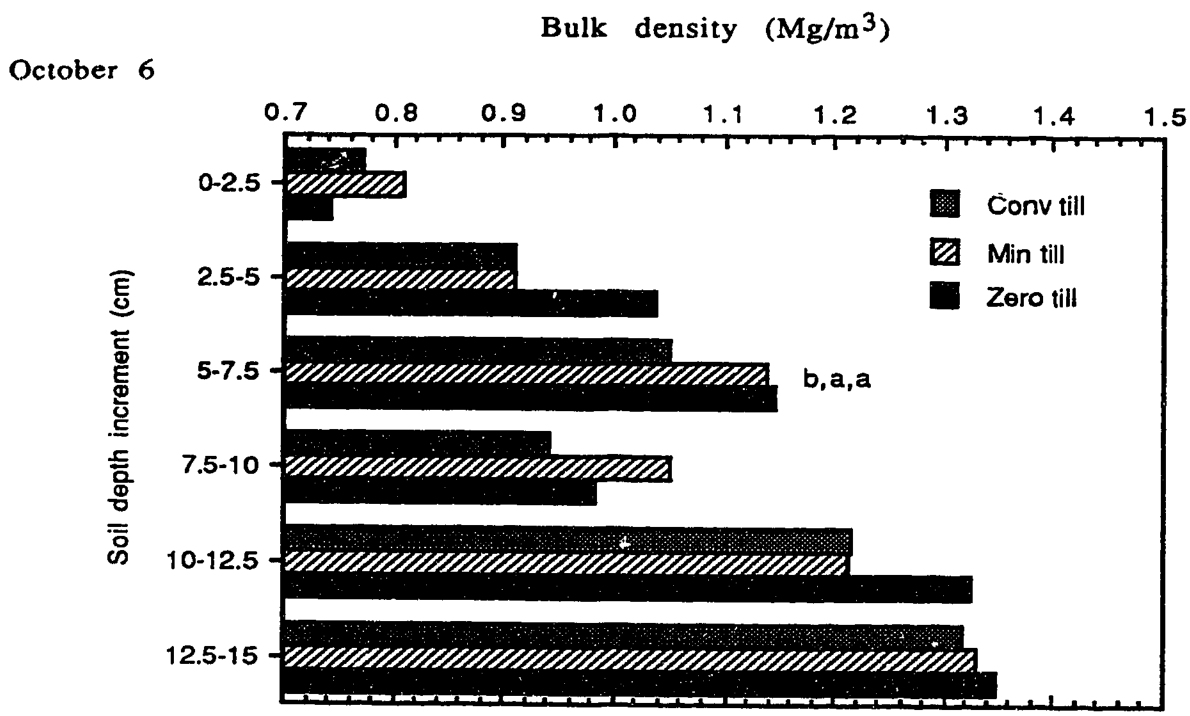


Figure 2.4 Soil bulk density (between-pairs of rows position) with depth on October 6, 1989. Within a given depth increment, treatment means followed by no letters are not significantly different (P=0.10).

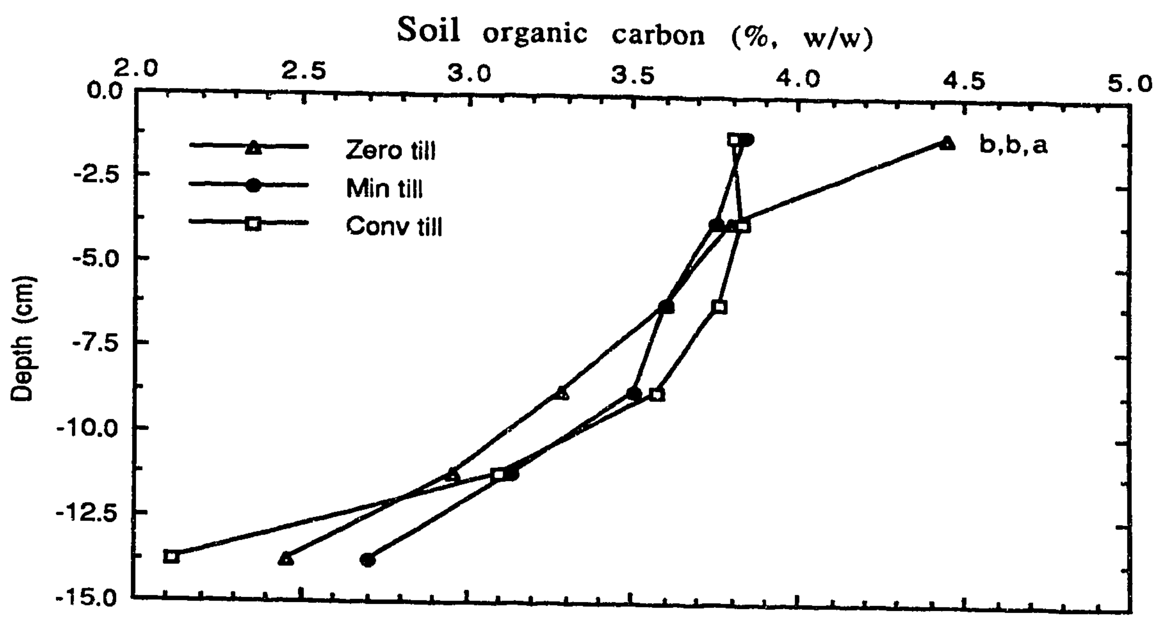


Figure 2.5 Soil organic carbon under three tillage systems in October 1989. Within a given depth increment, treatment means followed by no letters are not significantly different (P=0.10).

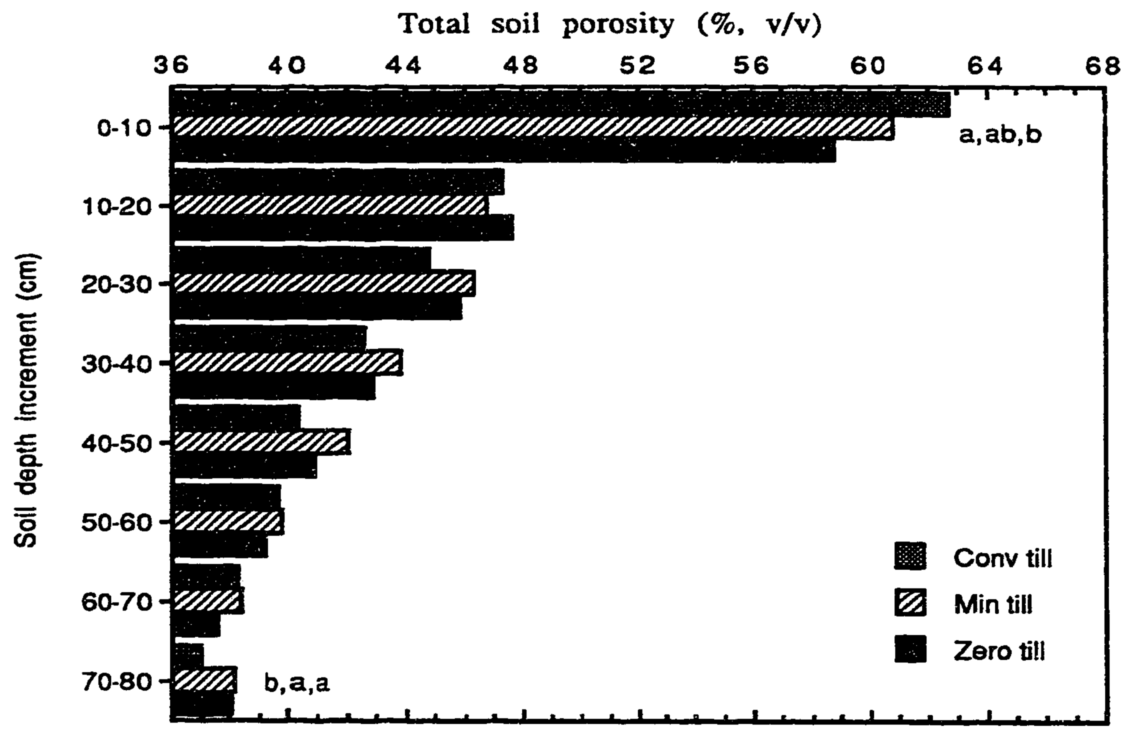


Figure 2.6 Total soil porosity with depth on May 11, 1989. Within a given depth increment, treatment means followed by no letters are not significantly different (P=0.10).

2.5 References

Agriculture Canada Expert Committee on Soil Survey. 1987. The Canadian system of soil classification. 2nd ed. Agric. Can. Publ. 1646. 164 pp.

Archetti, R., Bonciarelli, F. and Farina, G. 1989. Results of tillage trials carried out in 1981-1987 in Central Italy. Riv. di Ing.Agr. 1: 43-49.

Arshad, M. A. and Dobb, J. L. 1991. Tillage effects on soil physical properties in the Peace River region: Implications for sustainable agriculture. *in* Proc. 28th Annual Alberta Soil Science Workshop. pp. 190-199.

Arshad, M. A., Schnitzer, M., Angers, D. A. and Ripmeester, J. A. 1990. Effects of till vs no-till on the quality of soil organic matter. Soil Biol. Biochem. 22: 595-599.

Barley, K. P., Farrell, D. A. and Greacen, E.L. 1965. The influence of soil strength on the penetration of a loam by plant roots. Aust. J. Soil Res. 3: 69-79.

Bauder, J. W., Randall, G. W. and Swan, J. B. 1981. Effect of four continuous tillage systems on mechanical impedance of a clay loam soil. Soil Sci. Soc. Am. J. 45: 802-806.

Blake, G. R. and Hartge, K. H. 1986. Particle density. *in* A. Klute (ed.), Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods. 2nd edition. Am. Soc. Agron., Monograph 9, Madison, WI. pp 377-382.

Blevins, R. L., Smith, M. S. and Thomas, G. W. 1984. Changes in soil properties under no-tillage. *in* R. E. Philips and S. H. Philips (eds), No-Tillage Agriculture: Principles and Practices. Van Nostrand Reinhold, New York, pp.190-220.

Blevins, R. L., Thomas, G. W. and Cornelius, P. L. 1977. Influence of no-tillage and nitrogen fertilization on certain soil properties after five years of continuous corn. Agron. J. 69: 383-386.

Campbell, C. A., Biederbeck, V. O., Schnitzer, M., Selles, F. and Zentner, R. P. 1989. Effects of 6 years of zero tillage and N fertilizer management on changes in soil quality of an Orthic Brown Chernozem in Southwestern Saskatchewan. Soil Tillage Res. 14: 39-52.

Carter, M. R. 1991. Influence of organic matter and microbial biomass on the structural stability of the soil surface under reduced tillage systems. *in* Abstracts of Technical Papers. Can. J. Soil. Sci. 71: 263.

Cassel, D. K. 1982. Tillage effects on soil bulk density and mechanical impedance. *in* P. W. Unger and D. M. Van Doren (Editors), Predicting Tillage Effects on Soil Physical Properties and Processes. ASA Special Pub. No. 44. ASA, SSSA, Madison, WI. pp. 45-67.

Davies, R. B., Finely, J. B. and Richardson, S. J. 1973. Relative effects of tractor weight and wheelslip in causing soil compaction. J. Soil Sci. 24: 399-409.

De Jong. E., Kozak, L. M. and Stonehouse, H. B. 1991. A comparison of shrink swell indices. *in* Abstracts of Technical Papers. Can. J. Soil Sci. 71: 265.

Douglas, J. T., Jarvis, M. G., Howse, K. R. and Goss, M. J. 1986. Structure of a silty soil in relation to management. J. Soil Sci. 37: 137-151.

Gantzer, C. J. and Blake, G. R. 1978. Physical characteristics of Le Sueur clay loam soil following no-till and conventional tillage. Agron. J. 70: 853-857.

Griffith, D. R., Mannering, J.V. and Moldenhauer, W. C. 1977. Conservation tillage in the eastern corn belt. J. Soil Water Cons. 32: 20-28.

Hill, R. L. and Cruse, R. M. 1985. Tillage effects on bulk density and soil strength of two Mollisols. Soil Sci. Soc. Am. J. 49: 1270-1273.

Lindstrom, M. J. and Onstad, C. A. 1984. Influence of tillage systems on soil physical parameters and infiltration after planting. J. Soil Water Cons. 39: 149-152.

McKeague, J.A. (ed.) 1978. Manual on Soil Sampling and Methods of Analysis. 2nd edition. Canada Soil Survey Committee. Canadian Soc. Soil Sci. Ottawa, ON. pp. 212.

Odynsky, W., Lindsay, J. D., Reeder, S. W. and Wynnyk, A. 1961. Reconnaissance Soil Survey of the Beaverlodge and Blueberry Mountain Sheets. Alberta Soil Survey Report No. 20. University of Alberta, Edmonton, AB.

Pidgeon, J. D. and Soane, B.D. 1977. Effects of tillage and direct drilling on soil properties during the growing season in a long-term barley mono-culture system. J. Agri. Sci. 88: 431-442.

Rickman, J. F. 1988. Traction effects on soil compaction. University of Alberta, Department of Agricultural Engineering, Edmonton, AB. M.Sc. Thesis. 54 pp.

Sanborn, P. 1991. An evaluation of soil conservation under three tillage systems for the Peace River region of British Columbia: Soil physical properties. ARDSA Project 23011 final report.

SAS Institute Inc. 1991. SAS® Procedures Guide for Personal Computers, Version 6. Cary, NC: SAS Institute Inc. 373 pp.

Shear, G. M. and Moschler, W. W. 1969. Continuous corn by the no-tillage and conventional tillage methods: a six year comparison. Agron. J. 61: 524-526.

Singh, B. 1991. The long-term effects of tillage and residue management on the soil physical environment and on barley growth. University of Alberta, Department of Soil Science, Edmonton, AB. Ph.D. Dissertation. 213 pp.

Swan, J. B., Moncrief, J. F. and Voorhees, W. B. 1987. Soil compaction-causes, effects and control. Minnesota Extension Service, University of Minnesota, St. Paul, MN. Ag. Bu. 3115-1987, 12 pp.

Taylor, H. M. and Gardner, H. R. 1963. Penetration of cotton seedling taproots as influenced by bulk density, moisture content, and strength of soil. Soil Sci. 96: 153-156.

Thacker, D. J. and Johnson, R. L. 1988. The effect of soil compaction on plant root growth. *in* Proc. 25th Annual Alberta Soil Science Workshop. pp. 230-235.

Tollner, E. W., Hargrove, W. L. and Langdale, G. W. 1984. Influence of conventional and no-till practices on soil physical properties in the southern Piedmont. J. Soil Water Cons. 39: 73-76.

Voorhees, W. B. and Lindstrom,M J. 1984. Long-term effects of tillage method on soil tilth independent of wheel traffic compaction. Soil Sci. Soc. Am. J. 48: 152-156.

Voorhees, W. B. 1986. The effect of soil compaction on crop yield. ASAE Paper No. 860729. Am. Soc. Agric. Eng. St Joseph, MI 49085.

Chapter 3

CONSERVATION TILLAGE EFFECTS ON SOIL MOISTURE AND AVAILABLE WATER HOLDING CAPACITY OF A DARK GRAY SOLOD IN THE PEACE RIVER REGION OF ALBERTA

3.1 Introduction

The semiarid climate of the Peace River region, coupled with a growing season moisture deficit, necessitates a dependence on recharge of the soil profile moisture during the non-growing season to ensure adequate moisture for crop growth. Increased moisture through reduced evaporation would also help ensure adequate crop growth.

Springtime trafficability of the heavy clay soils in the region is an important consideration and high springtime soil moisture conditions can cause delays in seeding with subsequent increase of fall frost hazard (Hartman, 1992). Thus, concomitant with the need to improve soil moisture because of the growing season moisture deficit, higher surface soil moisture is a concern during the critical spring seeding period in the Peace River region where excessive moisture may lead to trafficability problems and delayed seeding operations.

In an effort to conserve soil and water resources and decrease farm operating and capital costs, reduced tillage and zero tillage have gained increased acceptance among agricultural producers in western Canada during the last decade. Soil moisture is often reported to be higher under zero tillage as compared to conventional tillage (Gantzer and Blake, 1978; Lindstrom et al., 1984; Unger, 1984; Douglas et al., 1986; Arshad and Dobb, 1991; Brandt, 1992) and, if such is the case, would help address the moisture needs for crop production in the Peace River region. Several other studies found no difference in soil moisture as a result of reducing or eliminating tillage (Bauder et al. 1981; Arshad and Coy, 1991; Sanborn, 1991; Brandt, 1992)

Regardless of whether reduced or zero tillage increases soil moisture, this change may or may not benefit plant growth. Tollner et al. (1984) observed a higher total water content in the top 60 cm of soil under zero tillage as compared to conventional tillage, however, zero tillage exhibited significantly less plant available water in the surface 5 cm. Similar observations were noted by Singh (1991) where the zero till treatment with straw had higher moisture content as compared to the tilled treatment with straw removed while plant available water content for the surface 15 cm was significantly lower for the zero till treatment. Conversely other studies have shown either no difference in available water between conventional, reduced or zero tillage (Chang and Lindwall, 1989; Sanborn, 1991) or an increased amount of available water under zero tillage as compared to tilled treatments (Nyborg and Malhi, 1989).

The soil moisture regime is dynamic and affected by evaporation, transpiration, infiltration, runoff and internal drainage. Tillage practices and their effect on pore geometry, which affects soil hydraulic properties, also affect the soil moisture regime (Klute, 1982). The complex interaction of these and other variables may change the soil moisture regime produced by various tillage systems. Greater infiltration rates under zero tillage are often reported (Arshad and Dobb, 1991; Singh, 1991; Campbell et al., 1992). Higher runoff volumes under zero tillage treatments compared to conventional tillage were noted by Van Vliet et al. (1991) on a study near Dawson Creek B.C. while soil loss was reported to be lower.

The direction and magnitude of tillage-induced effects on the soil moisture regime would seem to vary with soil type, length of imposed tillage practices, type of tillage practices, agroclimatic conditions, etc. As a consequence, results obtained in one location may not be applicable to other locations.

In view of their soil conserving effects and potential water conserving effects as well as economic benefits, conservation tillage systems hold promise for producers in the Peace River region of Alberta. However, information on the long term effects of such tillage systems on soil properties is lacking under the soil and agroclimatic conditions of that region. The effects of three tillage systems on soil bulk density, porosity and organic carbon under these conditions were previously reported (Chapter 2). The objectives of this study were to quantify the effects of zero, minimum and conventional tillage on the moisture regime and moisture retention properties of a Dark Gray Solod in the Peace River region of Alberta.

3.2 Materials and methods

3.2.1 Site and soil description

This study was conducted during the 1989 growing season on field scale plots located in the Baytree-Bonanza area of the Peace River region of northwestern Alberta. The climate of the area is semiarid. The soil was developed from fine textured lacustrine materials and is classified as a Dark Gray Solod according to the Canadian System of Soil Classification. Precipitation records were obtained for Dawson Creek, British Columbia, the nearest recording station to the study site, and reflect the precipitation patterns for the area. Other site details are given in Chapter 2.

3.2.2 Tillage systems

Three tillage treatments were established in the spring of 1986 to study the long term effects of these treatments on soil properties and crop growth. The tillage treatments were zero, minimum, and conventional tillage. Zero tillage consisted of no disturbance of the soil other than that caused by the seeding operation. Minimum tillage consisted of one disc cultivation in the fall and a light cultivation in the spring with sweeps. Conventional tillage consisted of chisel cultivation followed by one disc cultivation in the fall and two light cultivations in the spring with sweeps. The depth of tillage was generally 7-10 cm. Spring cultivation in 1989 was carried out on May 9.

Treatments were seeded with a 6-m wide Haybuster 1000 double disc press drill with a 15 - 35 cm paired row configuration (15 cm between rows and 35 cm between pairs of rows). The furrow openers were 45-cm offset double disc openers and the fertilizer knife banded fertilizer between the 15-cm rows. The site was seeded to Katepwa spring wheat (Triticum aestivum L.) on May 12, 1989 at 133 kg ha^{-1}. Depth of seeding was 5-6 cm. All plots were diamond harrowed after seeding. The same fertilizer rate was applied to all treatments. Weed control was achieved by post-emergence application of herbicides across all treatments. The zero tilled treatments received pre-seeding applications of glyphosate tank mixed with 2,4-D or dicamba.

All treatments were straight-cut harvested using a combine equipped with attachments which spread the straw and chaff evenly across the full width of the threshing cut. Stubble height was approximately 10 cm.

3.2.3 Measurements and calculations

3.2.3.1 Soil moisture and water filled pore space

Soil moisture was determined several times during the 1989 season using soil cores and gamma ray attenuation techniques. On May 11, 1989, after spring cultivation but prior to seeding, a pre-calibrated surface moisture-density gauge (Model MC-1, Campbell Pacific Nuclear Corp., California) was used to determine the near-surface moisture content (0-10 cm depth) at 5 randomly selected locations per plot. In the tilled treatments, 3 random sub-locations were selected at each of the 5 locations, while in the zero tillage treatment the three sub-locations were in-row, between-rows, and between-pairs of rows. For the 0-10 cm interval in all treatments, the three sublocation readings were averaged to determine the moisture content at each of the five locations. A moisture-density combination probe (Model 501, Campbell Pacific Nuclear Corp., California) lowered down aluminum access tubes was used to determine soil moisture below 10 cm in 10-cm increments to 80 cm near the 5 randomly selected locations per plot.

Soil cores, using a modified Uhland core sampler, were taken several times during the remainder of the year to determine soil moisture in the 0-7.5 and 7.5-15 cm depths. Cores were taken at the in-row position at three or four randomly selected locations in each plot four times during the season (July 7, August 16, September 7, and October 6). On August 16 cores were only taken from one plot per treatment due to inclement weather. Cores were also taken in the between-pairs of rows position on October 6. The cores collected from between-pairs of rows in October were also used for moisture retention determinations. The cores were sectioned carefully in the field using a scroll saw with a very fine blade to yield 2.5-cm increments. The 2.5-cm increments served to increase the resolution of the moisture determinations. The 0-7.5 cm and 7.5-15 cm cores were taken from adjacent locations to avoid disturbance caused by taking the first core. The core sections were stored at 4 ^{o}C prior to further use. Soil moisture was calculated on an oven-dry (105 ^{o}C) basis.

Water filled pore space (WFPS) was calculated as (volumetric water content/total porosity) x 100. Air filled porosity was calculated as total porosity - volumetric moisture.

3.2.3.2 Available water holding capacity

Soil cores taken from the between-pairs of rows position in October, 1989 were ground to pass a 2-mm screen. The ground soil was used to determine soil water retention at -33 and -1500 kPa, using a pressure-plate apparatus (Klute, 1986). Available water holding capacity (AWHC, %, g/g) was calculated as the difference between water contents at -33 and -1500 kPa corresponding to field capacity and permanent wilting point respectively (Cassel and Nielsen, 1986)

3.2.3.3 Statistical analysis

The soil moisture, water filled pore space and water retention data were statistically analyzed to determine the effect of the treatments. Analysis of variance was performed for each depth using the GLM procedure of the Statistical Analysis System (SAS Institute Inc, 1991). The least squares means were computed and used when an observation was missing. If F values for treatments were significant ($P \leq 0.10$), comparisons of means was conducted using the least significant difference test.

3.3 Results and discussion

3.3.1 Growing season precipitation

Precipitation in May was 75% of the 1951-80 average while precipitation in June and July was near normal (Table 3.1). August and September had 34% and 60% higher rainfall, respectively, than the long term average. Snowfall prior to the growing season was below normal, especially in February when precipitation was only 26% of the long term average.

3.3.2 Soil moisture

Soil moisture in May was not significantly different among the tillage treatments in all 10-cm increments to a depth of 80 cm with the exception of the 10-20 cm increment, where the zero till treatment had significantly lower soil moisture as compared to the minimum till treatment (Figure 3.1). In contrast, moisture in the surface 10 cm and the 20-30 cm increment was higher, though not significantly, under zero tillage as compared to the tilled treatments. Overall, the soil moisture for the 0-30 cm interval was the same among treatments, however, the distribution of moisture through this interval was different among treatments. This difference in moisture distribution down the soil profile may be due to the tilled treatments allowing better transmission of water from fall rains and spring snowmelt through the cultivated layer (approximately 10 cm) as compared to the zero tilled treatment, thus resulting in water moving deeper in the tilled treatments. This may be due to higher macroporosity in the surface 10 cm of the tilled treatments as compared to zero tillage during the fall and spring prior to the May 11 measurements. Total porosity was higher in the surface soil of the tilled treatments as compared to the zero till treatment on May 11 two days after spring tillage (Chapter 2) and would be expected to be higher in the surface of the tilled treatments shortly after fall cultivation. The water would pass more quickly through the tilled depth as compared to the untilled treatment and tend to accumulate below the depth of tillage (approximately 10 cm). Lindstrom and Onstad (1984) concluded that a higher volume of macropores in the Ap horizon under conventional and reduced tillage as compared to zero tillage would transmit more water into the soil profile. Singh (1991) in a study at Ellerslie, Alberta noted a similar effect of water moving deeper in tilled treatments compared to untilled treatments during a period of relatively high rainfall early in the growing season.

The trend to higher moisture content in the surface 10 cm under zero tillage may also be partially due to reduced evaporation as a result of the mulch covering of the zero tillage treatment. Other studies attribute greater surface moisture content under zero tillage to that factor (Jones et al., 1969; Pidgeon and Soane, 1977; Singh, 1991; Arshad and Dobb, 1991).

Higher water content in the 20-30 cm interval under zero tillage may be due to greater continuity of pores under zero tillage as compared to the tilled treatments, thus allowing movement of moisture deeper into the soil profile. Pore continuity in the tilled treatments would have been disrupted by cultivation to approximately 10 cm the prior fall. Tollner et al. (1984), in a chloride leaching experiment, noted higher throughput of water in zero till soil profiles as compared to tilled treatments.

Interestingly, the total soil water for the soil profile to 80 cm for the zero, minimum and conventional till treatments was very similar: 242, 240 and 237 mm respectively. The lack of a moisture conserving effect under zero tillage for the soil profile to 80 cm may be a result of weed growth. Any reduced evaporation under zero till may be offset by increased moisture use by weed growth during fall and spring. Foxtail barley (Hordeum jubatum L.) was observed to be a problem weed in the zero till treatments, while not a problem in the tilled treatments. Brandt (1992) noted that poor weed control under zero till treatments limited the potential of zero till to increase moisture during the non-growing season as well as to limit the potential of zero tillage to increase moisture use efficiency.

Soil moisture in the 2.5-cm increments in the in-row position for the surface 15 cm at all other times of measurement was generally not significantly different among treatments (Figure 3.2) with three exceptions: the 10-12.5 cm increment in August where minimum tillage exhibited significantly lower moisture than both the zero and conventionally tilled treatments; the 5-7.5 cm increment in September where zero tillage had significantly lower moisture than the tilled treatments; and the 0-2.5 cm increment in October where zero till had higher soil moisture as compared to the tilled treatments.

In the between-pairs of rows position sampled on October 6, two depth increments exhibited significantly different soil moisture among treatments (Figure 3.3). These were the surface 2.5 cm where zero till had significantly higher soil moisture than the conventional till treatment, as well as the 7.5-10 cm increment where minimum till had higher soil moisture than both the other treatments.

Taken as total soil moisture for the 0-15 cm depth (Figure 3.4), moisture under the zero till treatment had the following trend: higher soil moisture on July 7 as compared to the minimum and conventionally tilled treatments (10% and 7% respectively); similar soil moisture to the tilled treatments on August 16; lower soil moisture than the tilled treatments on September 7 (5%); and similar moisture to the tilled treatments on October 6. Note that percentage values in brackets are relative differences. Soil moisture for the surface 15 cm may well be related to the weed populations present at the respective sampling times. Although the zero till treatment received preseeding applications of glyphosate, foxtail barley (Hordeum jubatum L.) increased throughout the season and was quite noticeable near the end of the season, whereas in the tilled treatments foxtail barley was not evident. Other studies have noted that foxtail barley was a difficult weed to control under zero till conditions, but was readily controlled by tillage (Brandt, 1992).

In July the weed population had not yet recovered from the spring application of herbicide on the zero tilled plots and the plant population was largely composed of the wheat crop on all the treatments. With similar plant species and populations present up to July 7 in all treatments, water use by plants can be assumed to be similar in all treatments, thus the higher moisture content under zero till may be a reflection of the reduced evaporation brought about by the greater residue cover under zero till conditions. Singh (1991) noted the water conserving effect of mulch under zero tillage up to 77 days after seeding during one year of his study. Numerous other studies have attributed higher soil moisture under zero till to reduced evaporation due to residue cover (Pidgeon and Soane, 1977; Gantzer and Blake, 1978; Arshad and Coy, 1990).

Between July 7 and August 16, canopy shading would have reduced evaporation losses and by August 16 crop transpiration would have been reduced by the onset of crop maturity. However, the foxtail barley infestation continued to increase between July and August and likely continued to deplete soil moisture in the zero till treatment.

On September 7, when the wheat crop neared final maturity foxtail barley in the zero till treatment was still actively growing. This may explain why the zero till treatment had lower soil moisture in the 0-15 cm interval as compared to the tilled treatments at this time. However on October 6, by which time essentially all plant growth had stopped (both crop and weeds), the soil moisture for the 0-15 cm interval was once again similar among all treatments.

Soil moisture below 15 cm was not measured throughout the season, however, due to near normal precipitation in June and July and a relatively dense subsoil, rooting beyond 15 cm would not be extensive. Thus changes in soil moisture as a result of plant uptake would likely be reflected, to some degree, in the surface 15 cm of soil. Singh (1991), in a study at Ellerslie involving barley, noted that 51% of total root mass and 43% of total root length was in the surface 7.5 cm. For the surface 15 cm, the values were 67 and 62% respectively. Xu and Juma (1991), in a study also at Ellerslie, found that more than 90% of barley root mass was concentrated in the surface 20 cm. The soil at Ellerslie is much less restrictive to root penetration than that at Baytree and so the observations in the studies by Singh, and Xu and Juma, support those of this study.

3.3.3 Water filled pore space and air filled porosity

Generally water filled pore space differed little among treatments at all times of measurement (Tables 3.2 and 3.3). This is not surprising as there was little difference in volumetric moisture and bulk density among treatments. Differences that were significant occurred on May 12 at three depth increments and on September 7 in one depth increment.

Sampling after May generally occurred shortly after appreciable rains and the high values for water filled pore space below 7.5 cm indicate that this soil does become waterlogged during periods of heavy precipitation.

In a year with high precipitation, root growth in this soil could be adversely affected by low air filled porosity. Several times during 1989 air filled porosity (Table 3.4) of several depth increments in the 7.5-15 cm interval fell below 10%, a level at which aeration may be inadequate for plant growth (Hausenbuiller, 1985).

3.3.4 Field capacity, permanent wilting point and available water holding capacity

Soil moisture at -33 kPa was not significantly different in the 2.5-cm increments for the surface 15 cm, with the exception of the 0-2.5 cm interval, where the conventional till treatment had a significantly lower moisture content than the zero till treatment (Table 3.5). Below 2.5 cm, the minimum till treatment retained more moisture than either the zero or conventional till treatments, but not significantly so.

Soil moisture retained at -1500 kPa was also not significantly different among treatments through the 0-15 cm interval, again with the exception of the 0-2.5 cm increment, where the conventional till treatment had significantly lower moisture than did either the zero or minimum till treatments.

Available water holding capacity was not significantly different among treatments in all 2.5-cm increments to 15 cm. However, in the surface 2.5 cm, where zero till had the highest available water holding capacity and conventional till the lowest (Table 3.5), the probability of a greater F statistic was 11%. This possibly indicates that a significant difference may be noted if this study was of longer duration thus allowing differences to become apparent. The general lack of significant difference among treatments may be due to several reasons: the available water holding capacity was determined on ground samples and thus any differences in pore size distribution would have been obliterated; water retention is dependent to a large degree on texture and the texture likely did not vary among treatments; the short duration of the study may not have allowed for changes in this property to become apparent.

Averaged over the 0-15 cm interval, the available water holding capacity of the conventional tillage treatment was lower than the minimum and zero till treatments, but not significantly so (Table 3.5). Other studies have also shown no difference in available water holding capacity in the surface soil between tilled and no till treatments (Sanborn, 1991; Chang and Lindwall, 1989). Conversely Singh (1991) and Tollner et al. (1984) observed a significantly lower near-surface available water holding capacity under zero till as compared to tilled treatments.

3.4 Conclusions

The tillage systems, in effect for 4 years, differed little in their soil moisture regimes. Volumetric moisture in individual depth increments was generally the same for the soil profiles studied at various times during the season. Water filled pore space exhibited the same general lack of significant difference among treatments. High water filled pore space and low air filled porosity at several times during the season indicates that this soil is prone to waterlogging and plant growth may be restricted following high precipitation. Similarity of these properties among treatments indicates similar hydrological properties of the soil under the different treatments.

Water retention properties or available water holding capacity of the soil generally did not differ among tillage treatments. Differences were restricted to the surface 2.5 cm as a result of higher organic matter contents in this increment under zero tillage.

This study identified the need for adequate weed control under zero till systems in order to reap the moisture conserving benefits of zero tillage. The moisture conserving effect of mulch on the zero till plots resulted in higher soil moisture under this treatment during the early part of the season when weed growth was minimal. Later in the season, when crop growth had slowed, continued weed growth on the zero till plots resulted in lower soil moisture in the surface 15 cm as compared to the tilled treatments.

Table 3.1 Monthly and total precipitation in 1989, (January-October) and the 1951-1980 long term normals (LTN) for the same months at Dawson Creek, British Columbia. †

Total Precipitation (mm)			
Month	1989	1951-1980 LTN	Difference between 1989 and the LTN
January	19.0	36.1	-17.1
February	7.4	28.9	-21.5
March	34.2	30.6	+3.6
April	8.8	19.0	-10.2
May	26.6	35.2	-8.6
June	70.2	72.8	-2.6
July	79.4	70.8	+8.6
August	92.2	68.9	+23.3
September	66.4	41.5	+24.9
October	22.8	30.9	-8.1
Total ppt. Jan-Oct	427.0	434.7	-7.7

† 20 km west of the study site

Table 3.2 Water filled pore space (%, v/v)¶ of the soil profile on May 11, 1989.

	Tillage Treatments		
Depth increment (cm)	Zero	Minimum	Conventional
0-10	42.4	36.2	36.4
10-20	66.7 b†	73.2 a	70.6 ab
20-30	75.7 a	72.6 b	75.2 a
30-40	74.0	72.3	74.3
40-50	75.7	74.7	75.0
50-60	76.2 a	75.9 a	73.9 b
60-70	77.6	76.0	75.4
70-80	74.9	74.5	74.5

¶ Water filled pore space = $\frac{\text{volumetric water content}}{\text{total porosity}} \times 100$

† In a given depth increment, treatment means followed by no letters are not significantly different (P=0.10).

Table 3.3 Water filled pore space (%, v/v)¶ for 2.5-cm increments to 15 cm at four times during the growing season (in-row position).

Depth increment (cm)	Tillage treatment Zero	Minimum	Conventional
	July 7		
0-2.5	34.6	30.1	40.4
2.5-5	41.3	35.6	38.0
5-7.5	54.0	45.9	40.5
7.5-10	78.0	74.5	81.0
10-12.5	81.1	72.8	76.7
12.5-15	76.3	67.6	66.3
	August 16		
0-2.5	43.5	59.5	47.3
2.5-5	56.9	74.3	62.2
5-7.5	67.3	90.4	77.0
7.5-10	76.4	87.9	79.5
10-12.5	89.7	87.1	84.8
12.5-15	89.9	67.7	75.9
	September 7		
0-2.5	48.5	51.2	51.8
2.5-5	64.4	66.3	63.3
5-7.5	77.3	82.5	85.6
7.5-10	73.5	73.4	73.3
10-12.5	86.4 c†	92.2 b	95.8 a
12.5-15	84.0	91.4	94.1
	October 6		
0-2.5	49.5	49.1	48.5
2.5-5	63.0	56.1	64.5
5-7.5	77.1	78.2	79.2
7.5-10	72.4	75.6	74.1
10-12.5	92.3	90.1	85.5
12.5-15	93.9	95.0	90.7

¶ Water filled pore space = $\frac{\text{volumetric water content}}{\text{total porosity}} \times 100$

† In a given depth increment, treatment means followed by no letters are not significantly different (P=0.10).

Table 3.4 Air filled porosity (%, v/v) † at four times during the 1989 season(in-row position).

Depth increment (cm)	Tillage treatment		
	Zero	Minimum	Conventional
		July 7	
0-2.5	43.7	46.5	36.2
2.5-5	38.8	43.7	41.8
5-7.5	27.4	33.9	39.5
7.5-10	11.5	13.5	10.1
10-12.5	9.3	13.7	11.8
12.5-15	12.4	17.1	18.1
		August 16	
0-2.5	40.7	26.8	36.0
2.5-5	27.9	15.1	24.0
5-7.5	19.3	4.6	13.8
7.5-10	12.9	6.0	11.6
10-12.5	5.0	5.5	7.5
12.5-15	4.8	16.2	12.0
		September 7	
0-2.5	36.6	33.2	32.2
2.5-5	22.3	21.4	23.6
5-7.5	12.7	9.9	8.1
7.5-10	15.3	15.9	16.0
10-12.5	7.1	3.9	2.0
12.5-15	8.1	4.2	2.7
		October 6	
0-2.5	35.0	32.9	34.0
2.5-5	23.3	28.8	22.3
5-7.5	13.2	12.9	12.1
7.5-10	17.0	16.1	14.6
10-12.5	3.4	4.9	7.9
12.5-15	3.7	2.3	4.8

† Air filled porosity = total porosity - volumetric water.

Table 3.5 Soil water retention properties and available water holding capacity (AWHC) as affected by tillage treatments.

	Soil water (%, g/g x 100)						AWHC¶ (%,g/g x 100)		
	-33 kPa			-1500 kPa					
Depth increment (cm)	Zero Till	Min Till	Conv Till	Zero Till	Min Till	Conv Till	Zero Till	Min Till	Conv Till
0-2.5	38.1a†	36.4ab	34.9b	21.8a	21.8a	21.3b	16.3	14.6	13.6
2.5-5	37.5	38.3	37.1	22.3	22.6	22.2	15.2	15.7	14.9
5-7.5	37.7	38.3	37.8	22.7	22.9	22.4	15.0	15.4	15.4
7.5-10	36.8	37.8	37.2	22.4	22.8	22.5	14.4	15.0	14.7
10-12.5	36.8	37.2	36.5	22.2	22.4	22.3	14.6	14.8	14.2
12.5-15	36.1	36.3	35.6	21.9	21.9	21.7	14.2	14.4	13.9
Mean (0-15 cm)	37.1	37.4	36.5	22.2	22.4	22.1	14.9	15.0	14.4

† In a given depth increment, treatment means followed by no letters are not significantly different (P=0.10).

¶ AWHC = the difference in soil water retained at -33 and -1500 kPa.

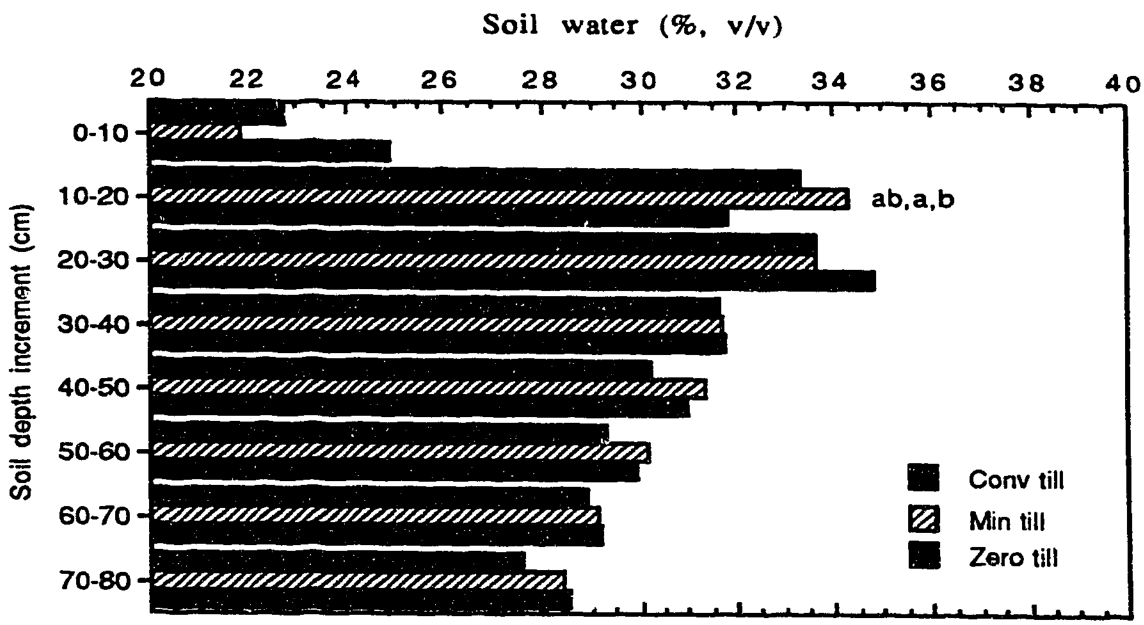


Figure 3.1 Soil water profile on May 12, 1989. Within a given depth increment, treatment means followed by no letters are not significantly different (P=0.10).

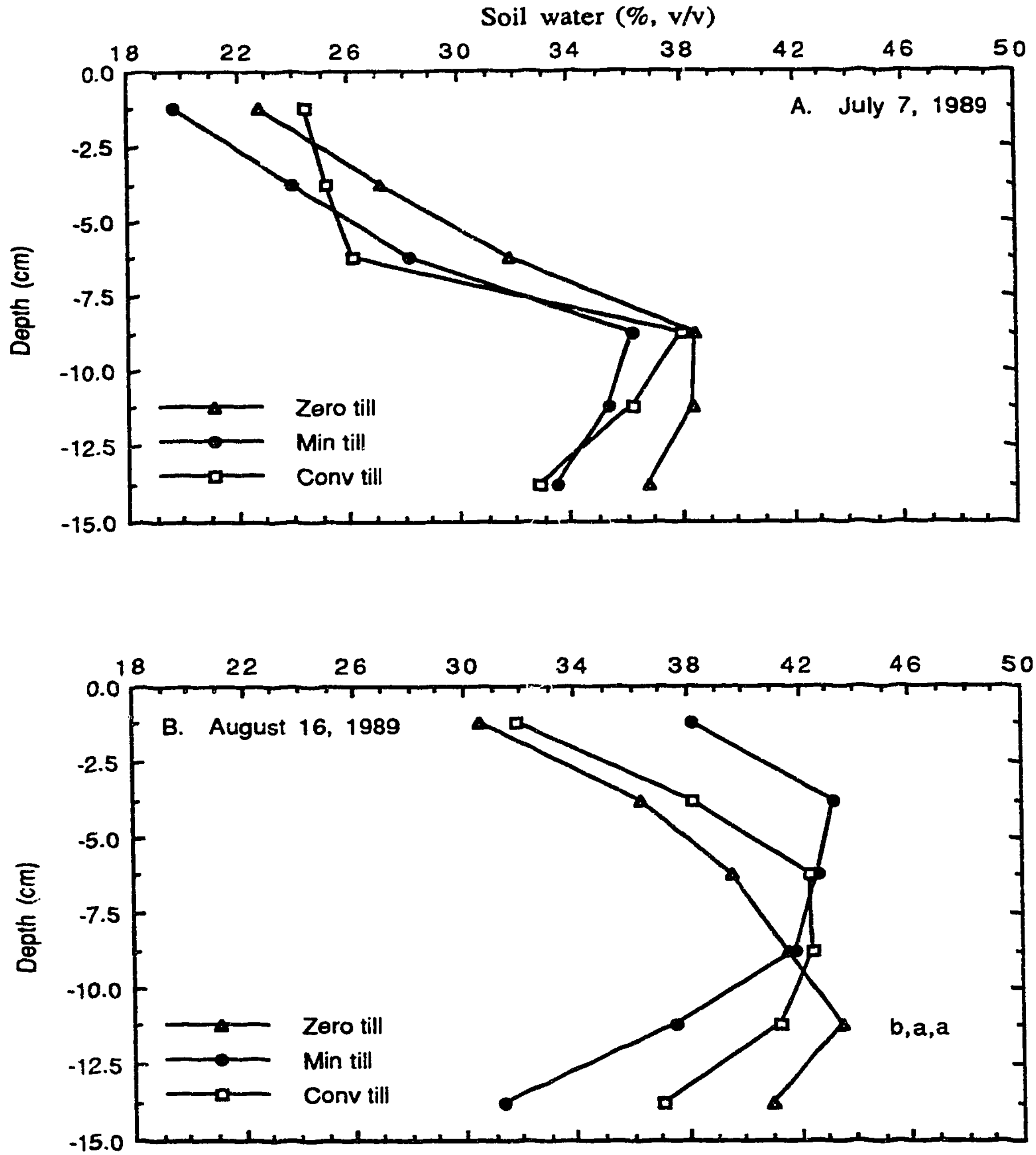


Figure 3.2 Soil water profiles on (A) July 7 and (B) August 16, 1989 (in-row position). Within a given depth increment, treatment means followed by no letters are not significantly different (P=0.10).

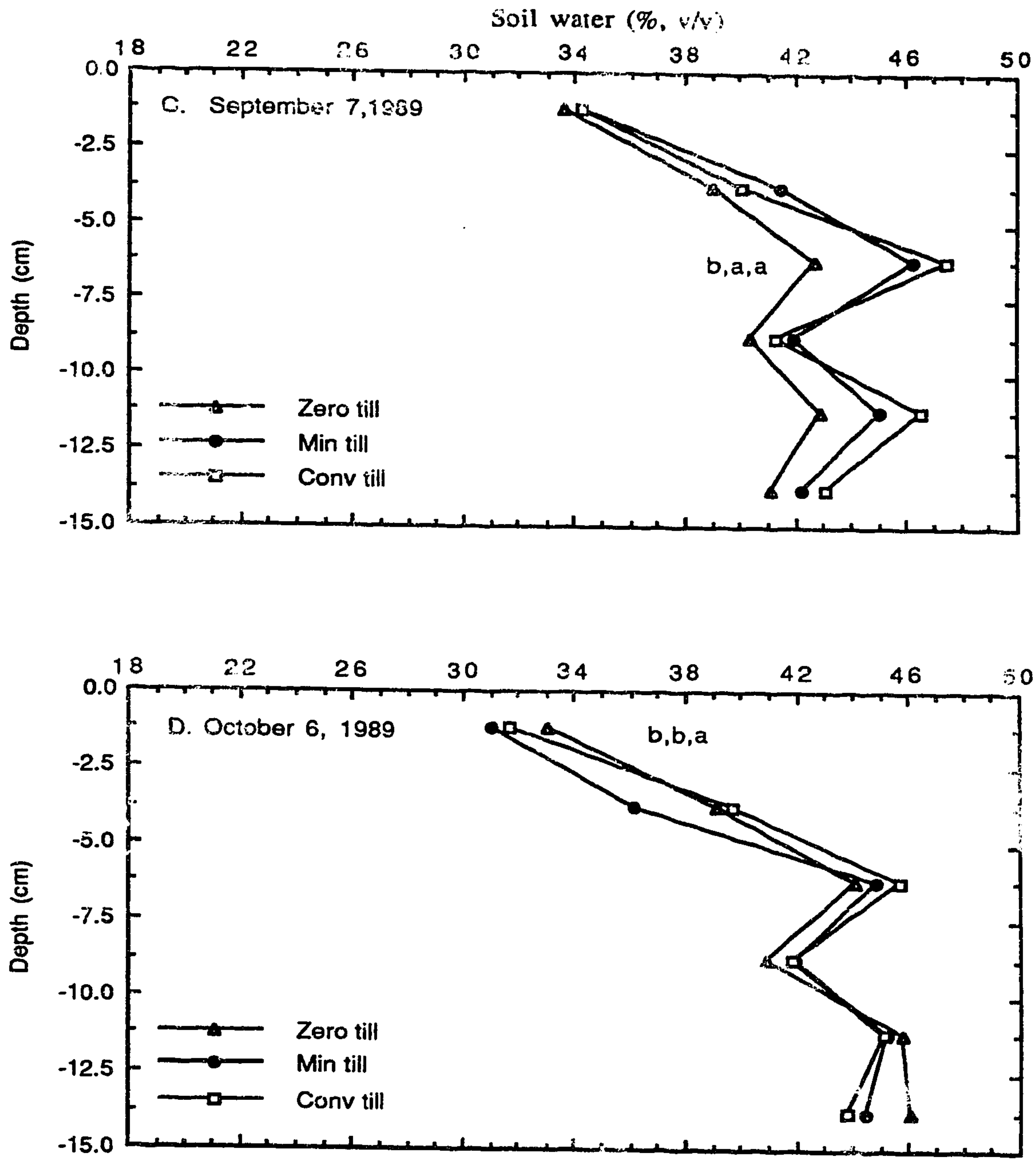


Figure 3.2 (cont'd) Soil water profiles on (C) September 7 and (D) October 6, 1989 (in-row position). Within a given depth increment, treatment means followed by no letters are not significantly different (P=0.10).

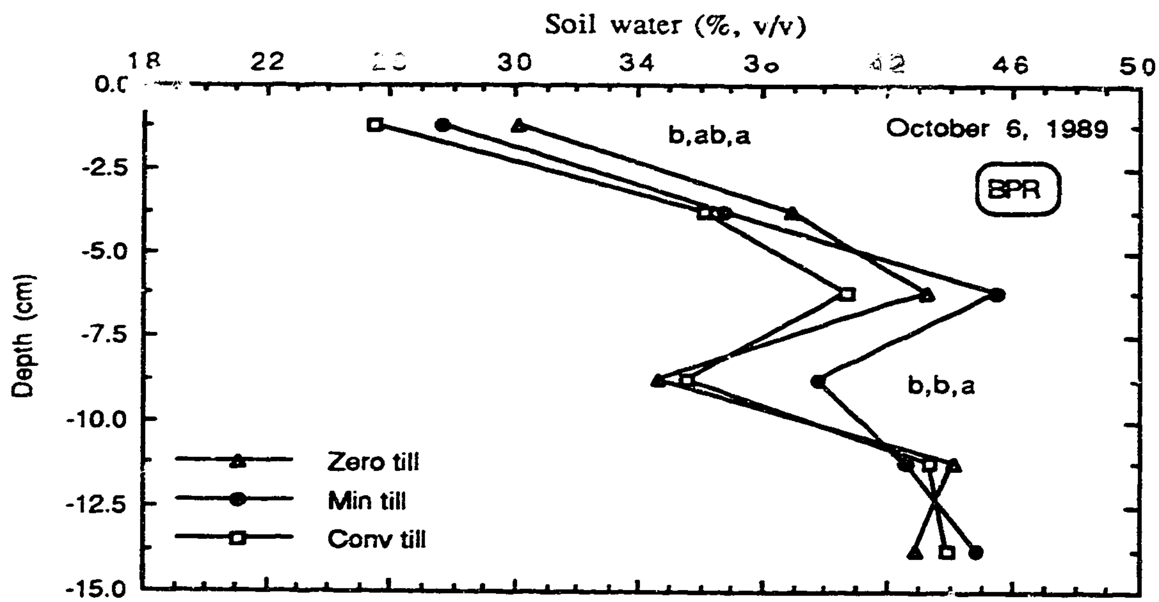


Figure 3.3 Soil water profile on October 6, 1989 in the between-pairs of rows (BPR) position. Within a given depth increment, treatment means followed by no letters are not significantly different (P=0.10).

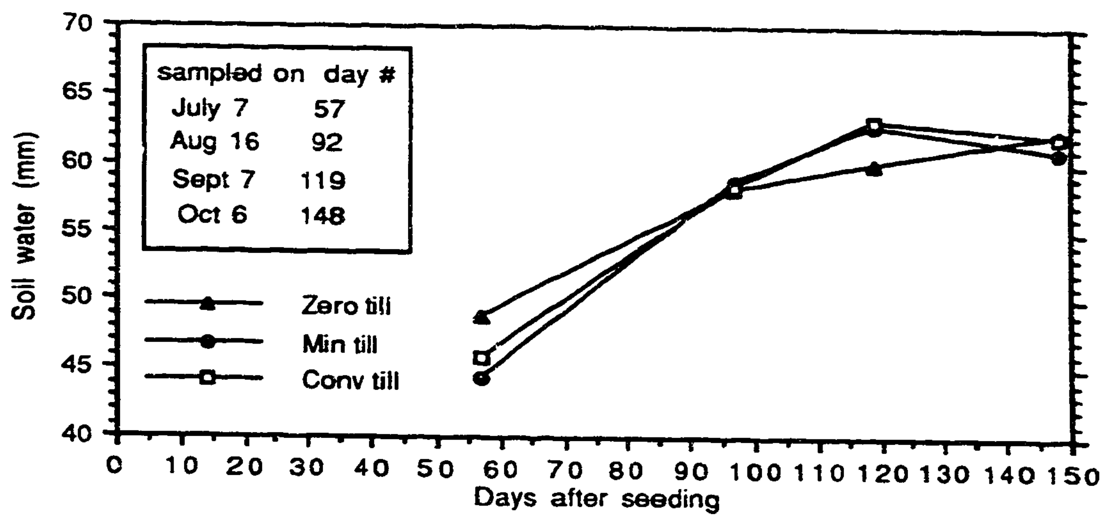


Figure 3.4 Total soil water in the surface 15 cm during the 1989 growing season (in-row position). Treatment means were not significantly different on any given date (P=0.10). Treatments were seeded on May 12, 1989 and harvested on October 10, 1989.

3.5 References

Arshad, M. A. and Coy, G. R. 1990. Tillage and cropping systems for soil conservation and sustained crop production in the Peace River region. CARTT Project #88-007 progress report.

Arshad, M. A. and Coy, G. R. 1991. Tillage and cropping systems for soil conservation and sustained crop production in the Peace River region. CARTT Project #600790 progress report.

Arshad, M. A. and Dobb, J. L. 1991. Tillage effects on soil physical properties in the Peace River region: Implications for sustainable agriculture. *in* Proc. 28th Annual Alberta Soil Science Workshop. pp. 190-199.

Bauder, J. W., Randall, G. W. and Swan, J. B. 1981. Effect of four continuous tillage systems on mechanical impedance of a clay loam soil. Soil Sci. Soc. Am. J. 45: 802-806.

Brandt, S. A. 1992. Zero vs conventional tillage and their effects on crop yield and soil moisture. Can. J. Plant Sci. 72: 679-688.

Campbell, C. A., McKonkey, B. G., Zentner, R. P.,Selles, F. and Dyck, F. B. 1992. Benefits of wheat stubble strips for conserving snow in southwestern Saskatchewan. J. Soil and Water Cons. 47(1): 112-115.

Cassel, D. K. and Nielsen, D. R. 1986. Field capacity and available water capacity. *in* A. Klute (ed.), Methods of Soil Analysis, Part 1. Agronomy. 2nd edition. Am. Soc. Agron. Monogram 9: 901-926. Madison, WI.

Chang, C. and Lindwall, C. W. 1989. Effects of minimum tillage practices on some physical properties of a Chernozemic clay loam. Can. J. Soil Sci. 69: 443-449.

Douglas, J. T., Jarvis, M. G., Howse, K. R. and Goss, M. J. 1986. Structure of a silty soil in relation to management. J. Soil Sci. 37: 137-151.

Gantzer, C. J. and Blake, G. R. 1978. Physical characteristics of Le Sueur clay loam soil following no-till and conventional tillage. Agron. J. 70: 853-857.

Hartman, M. 1992. I. D. #22 Applied Research Association, Fourth annual report. Manning, AB.

Hausenbuiller, R. L. 1985 Soil Science: Principles and Practices. 3rd edition. Wm. C. Brown Publishers, Dubuque, IA. pp. 610.

Jones, N. J., Moody, J. E. and Lilland, J. H. 1969. Effects of tillage, no tillage and mulch on soil water and plant growth. Agron. J. 61: 719-721.

Klute, A. 1982. Tillage effects on the hydraulic properties of soil: A Review. *in* P. W. Unger and D. M. Van Doren (eds.), Predicting Tillage Effects on Soil Physical Properties and Processes. ASA Special Pub. No. 44. ASA, SSSA, Madison, WI. pp. 29-43.

Klute, A. 1986. Water retention: laboratory methods. *in* A. Klute (ed.) Methods of Soil Analysis, Part 1. Agronomy 9: 635-662. Am. Soc. Agron., Madison, WI.

Lindstrom, M. J. and Onstad, C. A. 1984. Influence of tillage systems on soil physical parameters and infiltration after planting. J. Soil Water Cons. 39: 149-152.

Lindstrom, M J., Voorhees, W. B. and Onstad, C.A. 1984. Tillage system and residue cover effects on infiltration in northwest Corn Belt soils. J. Soil Water Cons. 39: 64-68.

Nyborg, M. and Malhi, S. S. 1989. Effect of zero and conventional tillage on barley yield and nitrate nitrogen content, moisture and temperature of soil in north-central Alberta. Soil Tillage Res. 15: 1-9.

Pidgeon, J. D. and Soane, B.D. 1977. Effects of tillage and direct drilling on soil properties during the growing season in a long-term barley mono-culture system. Agri. Sci. 88: 431-442.

Sanborn, P. 1991. An evaluation of soil conservation under three tillage systems for the Peace River region of British Columbia: Soil physical properties. ARDSA Project 23011 final report.

SAS Institute Inc. 1991. SAS® Procedures Guide for Personal Computers, Version 6. Cary, NC: SAS Institute Inc. 373 pp.

Singh, B. 1991. The long-term effects of tillage and residue management on the soil physical environment and on barley growth. University of Alberta, Department of Soil Science, Edmonton, AB. Ph.D. Dissertation. 213 pp.

Tollner, E. W., Hargrove, W. L. and Langdale, G. W. 1984. Influence of conventional and no-till practices on soil physical properties in the southern Piedmont. J. Soil Water Cons. 39: 73-76.

Unger, P. W. 1984. Tillage effects on surface soil physical conditions and sorghum emergence. Soil Sci. Soc. Am. J. 48: 1423-1432.

Van Vliet, L. J. P., Kline, R., Sanborn, P. and Carroll, K. 1991. Soil loss and water runoff estimates, and barley yields from conventional, reduced, and zero tillage trials in the Peace River region of British Columbia. *in* Abstracts of Technical Papers. Can. J. Soil. Sci. 71: 280.

Xu, J. G. and Juma, N. G. 1991. Shoot, root mass, and shoot/root ratios of four varieties of barley grown in North Central Alberta. *in* Abstracts of Technical Papers. Can. J. Soil Sci. 71: 282.

Chapter 4

SOIL STRENGTH UNDER THREE TILLAGE SYSTEMS IN THE PEACE RIVER REGION

4.1 Introduction

Conservation tillage systems hold great potential for soil erosion control, increasing or preserving soil moisture and for reducing farm labor and capital costs. There has been increased adoption of conservation or reduced tillage crop production in western Canada during the last decade, however, producers still have many questions regarding the long term effects these tillage systems may have on soil physical properties. One paramount concern of producers is that under reduced or zero tillage systems the soil may become excessively compacted due to the absence of tillage and adversely affect crop growth. Another concern is that these tillage systems may adversely affect the soil moisture regime and trafficability of fields.

Excess compaction and concomitant increase in soil strength can be deleterious to root penetration and crop yields (Taylor and Gardner, 1963; Taylor and Ratliff, 1969; Tollner et al., 1984; Thacker and Johnson, 1988; Cannon and Landsburg, 1990). Taylor and Gardner (1963) found a highly significant negative linear correlation between soil strength and root penetration percentage. The authors also noted that root penetration was more closely related to soil strength than it was to bulk density and soil moisture. This observation was also noted by Barley et al. (1965). Not all instances of soil compaction are harmful to crop production as the use of packer wheels on seed drills has long been known to enhance seed germination (Dasberg et al., (1966) as cited by Hillel, 1982) and there is some optimum level of soil compaction where crop production will be maximized (Eriksson et al., (1974) as cited by Rickman, 1988).

The penetrometer, which measures mechanical impedance or soil strength, is a useful tool to rapidly assess soil conditions over large areas and to detect compacted soil layers which may present barriers to root growth and water movement (Sanborn, 1991) and has been used in studies of root penetration, traction and trafficability prediction, and stratification of soils (Greacen, (1986) as cited by [illegible] et al., 1991; Hillel, 1982)

Many studies indicate that penetration resistance increases in the upper portion of the soil profile under reduced or zero tillage systems as compared to conventional tillage (Jones et al., 1969; Pidgeon and Soane, 1977; Bauder et al., 1981; Lindstrom and Onstad, 1984; Tollner et al., 1984; Hill and Cruse, 1985; Burch et al., 1986; Douglas et al., 1986; Archetti et al., 1989; Singh, 1991; Sanborn, 1991). Conversely Hill and Cruse (1985) found no significant difference in penetration resistance between zero tillage and conventional tillage on one of their study sites, although the trend was for penetration resistance to be higher under zero tillage.

Penetration resistance is influenced by many factors and these must be considered when interpreting penetrometer data. Penetration resistance and soil strength are strongly influenced by soil moisture and bulk density (Taylor and Gardner, 1963; Mirreh and Ketcheson, 1972; Williams and Shaykewich, 1970). Generally as bulk density and moisture tension increases so does soil strength.

Other factors such as soil texture, organic matter, soil structure and soil salinity also affect penetration resistance (Cassel, 1982; Thacker and Johnson, 1989). Thacker and Johnson (1989) found that penetration resistance in a soil with 33% clay was 2.5 times higher than in a soil with 8% clay.

Soil penetration resistance is considered a more sensitive indicator of tillage-induced changes in the soil and root response to these changes than is bulk density (Barley et al., 1965; Pidgeon and Soane, 1977; Bauder et al., 1981; Radcliffe et al., 1989). Radcliffe et al. (1989) observed that the mean bulk densities of the Ap2 and Bt1 horizons were identical while high values of penetration resistance coincided with the Ap2 horizon. Likewise, Bauder et al. (1981) found no difference in bulk density as a result of tillage treatments, while penetration resistance was significantly higher near the soil surface in the zero till treatment.

Temporal variation of penetration resistance due to changes in bulk density over time as well as changes in moisture content over time as a result of precipitation, evaporation, plant use and drainage further complicate the interpretation of data and may mask treatment differences (Cassel, 1982). Spatial variation of penetration resistance due in part to the natural variability of soil properties such as bulk density as well as spatial variation of penetration resistance with respect to crop row position and wheel track position may also complicate interpretation of penetration resistance data (Cassel et al. 1978; Cassel, 1982; Radcliffe et al. 1989).

As mentioned earlier, conservation or reduced tillage holds great potential for agricultural production through soil and water conservation as well as reduced farm labor and capital costs, however, information on the effects of tillage treatments or lack of tillage on soil strength under the soil and agroclimatic conditions of the Peace River region is generally lacking. Furthermore the literature is divided as to the effects of tillage systems on soil strength. The effects of three tillage systems (zero, minimum and conventional) on bulk density, organic carbon, soil moisture regime and some other properties of a Dark Gray Solod under continuous wheat production in the Peace River region have been previously reported (Chapters 2 and 3). The objective of the research reported in this chapter was to quantify the effects of these tillage practices on soil strength.

4.2 Materials and methods

4.2.1 Site and soil description

This research was conducted during the 1989 growing season on field scale plots located in the Baytree-Bonanza area of the Peace River region. The heavy clay soil (Falher series) at the research site was developed from fine textured lacustrine materials and has a relatively impermeable subsoil which may lead to waterlogged conditions during periods of high precipitation.

The tillage treatment study was established in the spring of 1986 and the site had previously been continuously cropped and conventionally tilled since 1980. Prior to that, the site had been conventionally tilled with rotations including cereal, clover plowdown and summerfallow. Other site details are reported in Chapters 2 and 3.

4.2.2 Tillage systems

In the spring of 1986, three tillage systems were established on crop stubble to study the long term effects of these systems on soil properties and crop growth in the Peace River region. The tillage systems were zero, minimum and conventional tillage. Minimum tillage consisted of one disc cultivation in the fall and a light cultivation in the spring with sweeps. Conventional tillage consisted of chisel cultivation followed by disc cultivation in the fall and two light sweep cultivations in the spring. Depth of tillage was generally 7-10 cm. Spring cultivation in 1989 was carried out on May 9.

The treatments were seeded with a 6-m wide Haybuster 1000 double disc press drill with a 15 - 35 cm paired row configuration (15 cm between rows and 35 cm between pairs of rows). The furrow openers were 45-cm offset double disc openers and the fertilizer was banded between the 15-cm rows with a fertilizer knife. Katepwa spring wheat (Triticum aestivum L.) was seeded on May 12, 1989 at the rate of 133 kg ha^{-1}. Seeding depth was 5-6 cm. All plots were diamond harrowed after seeding to smooth the field and ensure good seed soil contact. Weed control was achieved by post-emergent application of herbicides across all treatments. The zero till plots received pre-seeding applications of glyphosate tank mixed with 2,4-D or dicamba.

All treatments were straight cut harvested with a combine equipped with attachments that spread the straw and chaff evenly across the full width of the threshing cut. Stubble height was approximately 10 cm.

4.2.3 Measurements and analysis

4.2.3.1 Soil penetration resistance

Soil penetration resistance (PR) was measured six times during the growing season in 1989: May 11 (one day before seeding), June 9, July 7, August 16, September 7 and October 6. PR on each of the dates was measured at five randomly selected locations in each of the two plots per tillage treatment (ten locations per treatment). Duplicate measurements were made at each of three positions relative to the crop row at each of the ten locations per treatment on each sampling date; these positions being in the crop row (IR), centered between the crop rows (BR) and centered between the pairs of crop rows (BPR). On May 11, the same number of measurements were made in the tilled treatments as were made in the zero till treatment, however, they were not relative to row position because tillage had obliterated the crop rows. This sampling pattern resulted in 20 penetrometer insertions for each position in each treatment for each sampling date. The duplicate measurements were made approximately 10 cm apart and averaged for the purpose of statistical analysis.

All PR measurements on May 11 were made within 1 m of measurement locations used for bulk density and moisture. On other sampling dates there were three or four measurement locations for bulk density and moisture, consequently, only three or four of the five PR measurement locations were within 1 m of the bulk density/moisture locations. On July 7 there were three bulk density/moisture measurement locations per plot; on August 16 there were three locations on one plot per treatment; on September 7 there were four locations per plot; on October 6 there were three locations per plot in both IR and BPR positions. Bulk density and moisture was measured in the IR position on July 7, August 16 and September 7.

Penetration resistance was measured using a manually operated, recording penetrometer equipped with a 30° cone having a 0.95 cm^2 basal area (11 mm diameter) and a 45-cm long extension rod (Model CP-10, RIMIK PTY LTD, Toowoomba, Australia). This penetrometer is preset to measure and record penetration resistance at 15-mm increments to a maximum depth of 45 cm. Penetration resistance was measured by the same operator throughout the study to avoid possible differences due to different operators (Cassel, 1982).

4.2.3.2 Statistical analysis

The PR data was statistically analyzed to determine treatment effects. PR measured on May 11 in the zero till treatment was averaged across position for comparison to the tilled treatments, whereas on other dates, it was not. Data or each depth were tested for fulfillment of the the assumptions of analysis of variance. These tests suggested that PR data did not need transformation. Log transformation of a partial data set did not result in different conclusions regarding treatment effects on soil strength, therefore statistical analysis was carried out on the original non-transformed data. Analysis of variance was performed for each position and depth for each sampling time using the GLM procedure of the

Statistical Analysis System (SAS Institute Inc., 1991) The least squares means were computed and used when an observation was missing. If F values for treatment effects were significant ($P \leq 0.10$), comparisons of means were conducted using the least significant difference test.

4.3 Results and discussion

4.3.1 Soil penetration resistance on May 11, 1989

PR on May 11 was higher under zero tillage in the surface 10 cm but not significantly so (Figure 4.1). Soil moisture in the surface 10 cm was also higher under zero tillage (Table 4.1), thus, PR differences in this increment cannot be attributed to moisture content. However, bulk density of the surface 10 cm (Table 4.2) was higher in the zero till treatment and may have resulted in the observed PR differences.

In the 10-20 cm depth increment PR was lowest in the minimum till treatment while zero and conventional tillage exhibited similar PR values. Again these differences were not significant. Soil moisture appears to have more of an influence on PR in this depth increment as the minimum till treatment had the highest moisture of the three treatments as well as the highest bulk density (Tables 4.1 and 4.2).

From 20 cm to approximately 40 cm, minimum and zero tillage exhibited similar PR values which were lower than those under conventional tillage (Figure 4.1). This difference was significant for depths of 31.5 to 39 cm. For depths of 40.5 to 43.5 cm, all three treatments were significantly different from each other with minimum tillage having the lowest PR values and conventional till having the highest. This same trend occurred at a depth of 45 cm, however, the significant difference was between minimum and conventional till. This pattern of PR under conventional tillage being highest is consistent with both moisture and bulk density: conventional tillage had the highest bulk density and the lowest moisture below 20 cm (Tables 4.1 and 4.2).

Treatment differences were generally explained by bulk density near the surface and by moisture contents in the lower depths. Singh (1991) observed similar relations among bulk density, moisture and PR with respect to depth.

4.3.2 Soil penetration resistance: in-row (IR) position

Differences among treatments for the IR position were generally not significant (Figure 4.2). Temporal variation, however, was considerable and likely reflects, to a large degree, crop use of soil moisture during the growing season as evidenced by the large increase in PR from the May/June time period to the July/August time period. A subsequent decrease in PR occurred during the September/October time period, likely due to precipitation just prior to and during that time period (Chapter 3).

Zero till had lower PR than the tilled treatments at all depths greater than 12 cm on July 7 (Figure 4.2), but not significantly so. This may be a reflection of the moisture conserving effect of zero till. The lack of significant difference in the in-row position among treatments may be attributed to the effects of the furrow openers and packing wheels of the seed drill, seasonal precipitation, plant root growth and moisture use, as well as the high clay content of the soil: all contributing to a re-homogenization of soil properties, such as bulk density and moisture content, which affect PR.

4.3.3 Soil penetration resistance: between-rows (BR) position

The trend of PR in the between-rows position (Figure 4.3) was very similar to that in the in-row position. Temporal variation again reflected moisture use by the crop coupled with the growing season moisture deficit. The water conserving effect of zero till was again evident on July 7 where below approximately 10 cm, the PR values were lower under zero till as compared to the tilled treatments, which were similar. However, as opposed to the IR position this difference in PR was significant at 31.5 cm and at depths greater than 36 cm. PR at other sampling times during the season was generally not significantly different among treatments.

Maximum PR on July 7, for each treatment, occurred at depths from 12 to 15 cm. These maximum values in the between-row position were appreciably higher than the maximum values in the in-row position at similar depths. This may be related to the placement of the fertilizer band in the between-row position. As a consequence, plant roots, in the presence of adequate moisture to allow for growth, would have proliferated around the fertilizer band and utilized more moisture than in the in-row position, resulting in higher PR in the between-rows position.

4.3.4 Soil penetration resistance: between-pairs of rows (BPR) position

There were more significant differences in PR among tillage treatments in the BPR position than in the IR and BR positions (Figure 4.4). Most evident was a significantly higher PR under zero tillage as compared to the tilled treatments at some depths in the cultivation zone (0-10 cm). This occurred on June 9, August 16, and September 7, being most pronounced on June 9.

On June 9, soil moisture in the BPR position to 15 cm was lower in the zero till treatment as compared to the tilled treatments (data not shown) and may have caused the higher PR noted at some depths in this increment. However, moisture content to 15 cm in the IR position on June 9 was also lower under zero till as compared to the tilled treatments and PR in the IR position to 15 cm on June 9 (Figure 4.2) was similar among treatments. Excess soil moisture prevented measurement of bulk density on June 9, however, PR and moisture measurements indicate that bulk density in the BPR position on this date may have been higher under zero tillage than the tilled treatments. Thus, reconsolidation of the surface soil in the BPR position under the tilled treatments due to rainfall and soil subsidence had likely not progressed to the extent that it had by July 7.

Once again, as in the IR and BR positions, on July 7 the moisture conserving effect of zero till was evident by lower PR values under the zero till treatment as compared to the tilled treatments at depths greater than 9 cm, with significant differences from 28.5 to 42 cm.

The minimum till treatment also exhibited lower PR on July 7 as compared to conventional tillage at depths greater than 10.5 cm with significant differences from 30 to 39 cm. With the relative lack of plant growth in the BPR position on July 7, this suggests that minimum tillage may also exhibit more of a moisture conserving effect than conventional tillage due to greater crop residue cover.

On August 16, PR was greater in the surface 10 cm of the zero till treatment as compared to the tilled treatments (Figure 4.4); however, this difference was significant only at depths of 1.5, 3 and 4.5 cm. Surprisingly, a small difference of only 81 kPa between zero till and minimum till at the 1.5 cm depth tested significant. A similar pattern was evident on September 7 to a depth of 13.5 cm with the significant differences evident only at 6, 7.5, and 9 cm.

As in the IR and BR positions on October 6, PR in the BPR position was not significantly different among treatments. By this time, weed growth had ceased, the crop was fully mature and soon to be harvested and precipitation had recharged the soil moisture profile to some degree, so that PR approached that observed at the beginning of the season in May and June.

4.3.5 Soil penetration resistance with respect to position.

On May 11, positional differences in the zero till treatment were generally not significant, with the exception of the 1.5, 3, and 45 cm depths; where the BPR position had higher PR than the BR and IR position at 1.5 cm and higher PR than the IR position at 3 cm, while at 45 cm the IR position had higher PR than the BPR position. PR in the BPR position was also slightly higher than in the IR or BR positions from 4.5 to 7.5 cm but not significantly so. This lack of significant difference was likely the result of the prior season's precipitation, natural soil settling and root growth. The tilled treatments were not analyzed for positional differences in PR on May 11 because of cultivation the prior fall and two days before sampling.

Positional differences in PR were observed during the remainder of the season. On June 9, PR to a depth of 15 cm was higher in the BPR position of the zero till treatment as compared to the BR and IR positions. There was little difference in PR in the tilled treatments with respect to position at this time. The increase in positional differences in the zero till treatment from May 11 to June 9 was attributed to the seeding operation which, due to the drill's unique opener and bander configuration, loosens the soil in the IR and BR positions to seeding depth and banding depth respectively, but has little influence in the BPR position. The lack of difference among positions for the tilled treatments on June 9 likely resulted from a combination of spring cultivation, the loosening action of the drill openers, the harrowing operation after seeding which would have firmed the soil regardless of position location, natural soil settling as a result of precipitation between seeding and June 9, and wet soil conditions at the time of PR measurement.

On July 7, a time of active plant growth and high water consumption, differences in PR among positions reflect, to a large degree, water use by plants. PR was higher in the BR position, in which the fertilizer was banded, than in the other positions from depths of 9 to 18 cm for all treatments. Below this, PR in the BR and IR positions was similar to a depth of 45 cm. PR was lower in the

BPR position than in the IR and BR positions from depths of 12 to 45 cm, the maximum depth of measurement. This pattern of PR was attributed to a proliferation of roots around the fertilizer band in the BR position, which would have utilized soil moisture to a greater extent than in the other positions and resulted in higher PR, and below approximately 18 cm to greater root growth in the IR and BR position as compared to the BPR position. Root growth and subsequent moisture use resulting in higher PR in the IR position as compared to other positions was also noted by Cassel et al. (1978).

On August 16, positional difference in PR was most notable under zero till where the BPR position had higher PR than the IR and BR positions in the surface 15 cm. This was attributed partly to weed growth being greater in the BPR position as compared to the other positions as well as a possibly higher bulk density in the BPR position, as the BPR position would not have been disturbed by the seeding operation.

On September 7, positional PR throughout most of the soil profile depth probed followed the general trend of BPR > BR > IR for all treatments. This may be a result of greater water infiltration in the IR position due to soil loosening by roots and water transmission along root channels. Crop water use at this time in the IR and BR positions would have decreased as the crop was near maturity; however, weed growth in the BPR position was greater at this time, especially in the zero till treatment. The resultant water use by weeds contributed to higher PR values in the BPR position.

On October 6 PR did not vary among positions. Plant growth had ceased, precipitation had recharged the soil profile to a large degree, and PR values approached those in May and June.

4.3.6 Soil penetration resistance and plant growth considerations.

Soil strength measured with a penetrometer cannot be easily compared to the forces experienced by a growing root; however penetration resistance is a valid measurement to assess changes in soil strength brought about by different tillage operations in a given soil (Cassel, 1982).

The relation of soil strength as measured by penetrometer to root growth is still not clearly understood. Many authors refer to or report root limiting penetration resistance in the range of 2-4 MPa (Taylor and Gardner, 1963; Radcliffe et al., 1989; Thacker and Johnson, 1988; Naeth et al., 1991). Assuming validity of these limits, soil strength was in this range in July, August and September (Figures 4.2-4.4). However, porosity, size and continuity of pores, and structural voids all affect root growth and penetration (Taylor and Gardner, 1963; Veprakas et al., 1986; Ehlers et al., 1983 as cited by Sanborn, 1991). Fine, flattened, exped roots were observed to 70 cm at the study site indicating that at times some roots were able to utilize structural or biological channels to access the soil profile.

4.4 Conclusions

Penetration resistance, measured to a depth of 45 cm, generally did not vary among treatments at most times of measurement, but exhibited large temporal and spatial variation. Differences in PR among treatments, that occurred, were largely restricted to the surface 10 cm in the BPR position, three of the six sampling times during the season, and to depths below 30 cm in May and below 10 cm in July in the BR and BPR positions. In the surface 10 cm in the BPR position, zero till had higher PR as compared to the tilled treatments, largely as a result of the lack of tillage. This was most pronounced for the period from seeding until early July. The differences near the soil surface were attributed largely to differences in bulk density.

Significantly lower PR, at depths greater than 30 cm, in the zero till treatment in July was attributed to enhanced moisture under zero till.

The penetrometer was a useful tool to: (1) assess soil strength as affected by different tillage systems (2) rapidly assess soil conditions over a wide area, and (3) detect changes in PR spatially and temporally. Large temporal and spatial (position and depth) variation in penetration resistance noted in this study support the contention that it is essential to incorporate these considerations in any measurement and interpretation of penetration resistance in field studies.

Table 4.1 Percent soil moisture content (%, v/v) at the time of penetration resistance measurements during 1989.

Depth (cm)	Date ¶ May 11	Depth (cm)	Date † July 7	Aug. 16	Sept. 7	Oct. 6 IR	Oct. 6 BPR
			Zero till				
0-10	24.9	0-2.5	22.8	30.5	33.6	33.0	30.1
10-20	31.8	2.5-5	27.2	36.3	39.1	39.1	38.9
20-30	34.8	5-7.5	31.8	39.5	42.7	44.1	43.3
30-40	31.8	7.5-10	38.5	41.5	40.3	40.8	34.6
40-50	31.0	10-12.5	38.4	43.5	42.9	45.8	44.1
		12.5-15	36.7	41.0	41.1	46.1	42.8
			Minimum till				
0-10	21.9	0-2.5	19.7	38.1	34.3	31.0	27.7
10-20	34.3	2.5-5	24.1	43.2	41.5	36.2	36.8
20-30	33.6	5-7.5	28.2	42.6	46.3	44.8	45.5
30-40	31.7	7.5-10	36.2	41.8	41.9	41.9	39.8
40-50	31.4	10-12.5	35.4	37.5	45.0	45.2	42.6
		12.5-15	33.5	31.3	42.2	44.5	44.8
			Conventional till				
0-10	22.8	0 -2.5	24.5	31.9	34.3	31.7	25.5
10-20	33.3	2.5-5	25.2	38.2	40.0	39.7	36.1
20-30	33.6	5-7.5	26.2	42.4	47.5	45.7	40.7
30-40	31.6	7.5-10	38.0	42.5	41.3	41.9	34.5
40-50	30.2	10-12.5	36.2	41.3	46.5	45.1	43.4
		12.5-15	32.8	37.0	43.0	43.8	43.9

¶ Measured with surface and down hole moisture/density gauges. Averaged across position in the Zero till treatment: no position in the tilled treatments prior to seeding.

† Measured with 2.5 cm high & 7.5 cm diameter soil cores at the in-row (IR) position in July, August and September: in-row (IR) and between-pairs of rows (BPR) positions in October.

Table 4.2 Soil bulk density (Mg/m^3) at the time of penetration resistance measurements during 1989.

	Date ¶		Date †				
Depth (cm)	May	Depth (cm)	July 7	Aug. 16	Sept. 7	Oct. 6 IR	Oct. 6 BPR
			Zero till				
0-10	1.05	0-2.5	0.86	0.74	0.76	0.82	0.74
10-20	1.36	2.5-5	0.87	0.91	0.99	0.96	1.04
20-30	1.41	5-7.5	1.04	1.05	1.14	1.09	1.15
30-40	1.48	7.5-10	1.28	1.17	1.14	1.08	0.99
40-50	1.54	10-12.5	1.34	1.32	1.28	1.29	1.33
		12.5-15	1.30	1.39	1.30	1.30	1.35
			Minimum till				
0-10	1.00	0-2.5	0.86	0.90	0.83	0.92	0.81
10-20	1.38	2.5-5	0.83	1.06	0.95	0.90	0.91
20-30	1.39	5-7.5	0.97	1.35	1.12	1.08	1.14
30-40	1.46	7.5-10	1.29	1.33	1.08	1.07	1.05
40-50	1.51	10-12.5	1.30	1.46	1.31	1.27	1.21
		12.5-15	1.26	1.34	1.37	1.36	1.33
			Conventional till				
0-10	0.96	0-2.5	1.00	0.82	0.86	0.88	0.77
10-20	1.37	2.5-5	0.84	0.97	0.93	0.97	0.91
20-30	1.44	5-7.5	0.88	1.12	1.14	1.08	1.05
30-40	1.49	7.5-10	1.33	1.18	1.09	1.11	0.94
40-50	1.55	10-12.5	1.33	1.31	1.32	1.20	1.21
		12.5-15	1.25	1.30	1.39	1.31	1.32

¶ Measured with surface and down hole moisture/density gauges. Averaged across position in the Zero till treatment: no position in the tilled treatments prior to seeding.

† Measured with 2.5 cm high & 7.5 cm diameter soil cores at the in-row (IR) position in July, August and September: in-row (IR) and between-pairs of rows (BPR) positions in October.

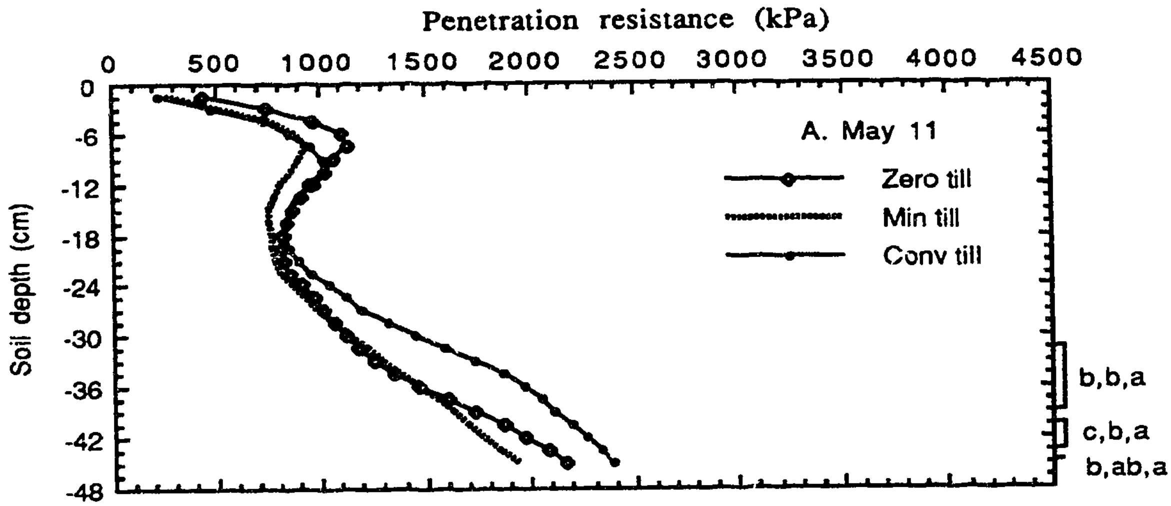


Figure 4.1 Soil penetration resistance on May 11, 1989. At a given depth, treatment means followed by no letters are not significantly different (P=0.10). PR was averaged across position in the Zero till treatment. There were no positions in the tilled treatments.

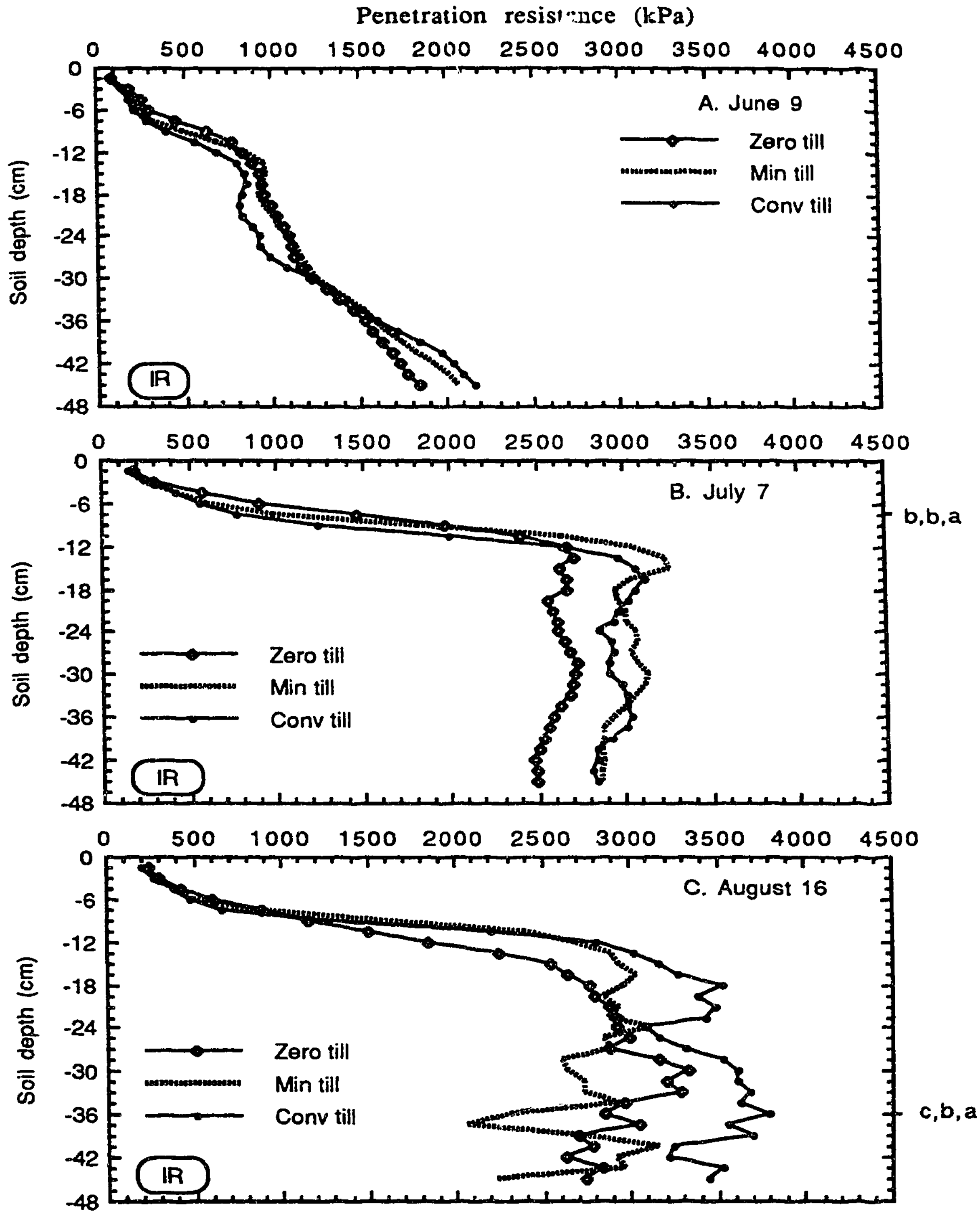
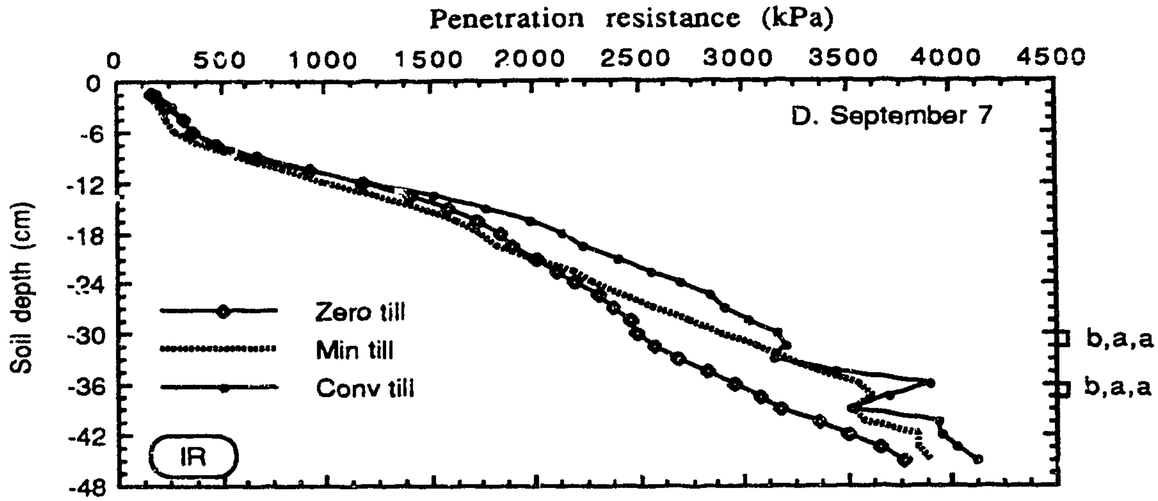


Figure 4.2 Soil penetration resistance on (A) June 9, (B) July 7 and (C) August 16, 1989 in the in-row (IR) position. At a given depth, treatment means followed by no letters are not significantly different (P=0.10).



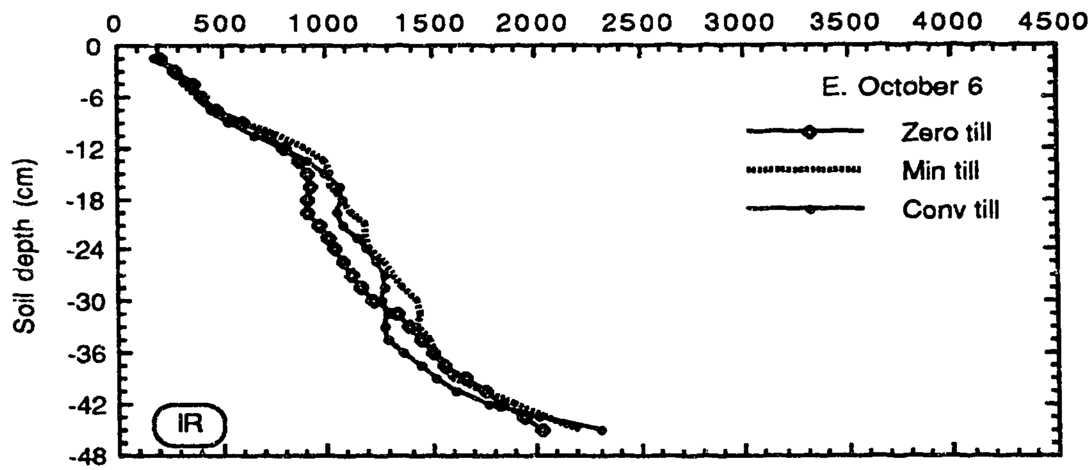


Figure 4.2 (cont'd) Soil penetration resistance on (D) September 7, and (E) October 6, 1989 in the in-row (IR) position. At a given depth, treatment means followed by no letters are not significantly different (P=0.10).

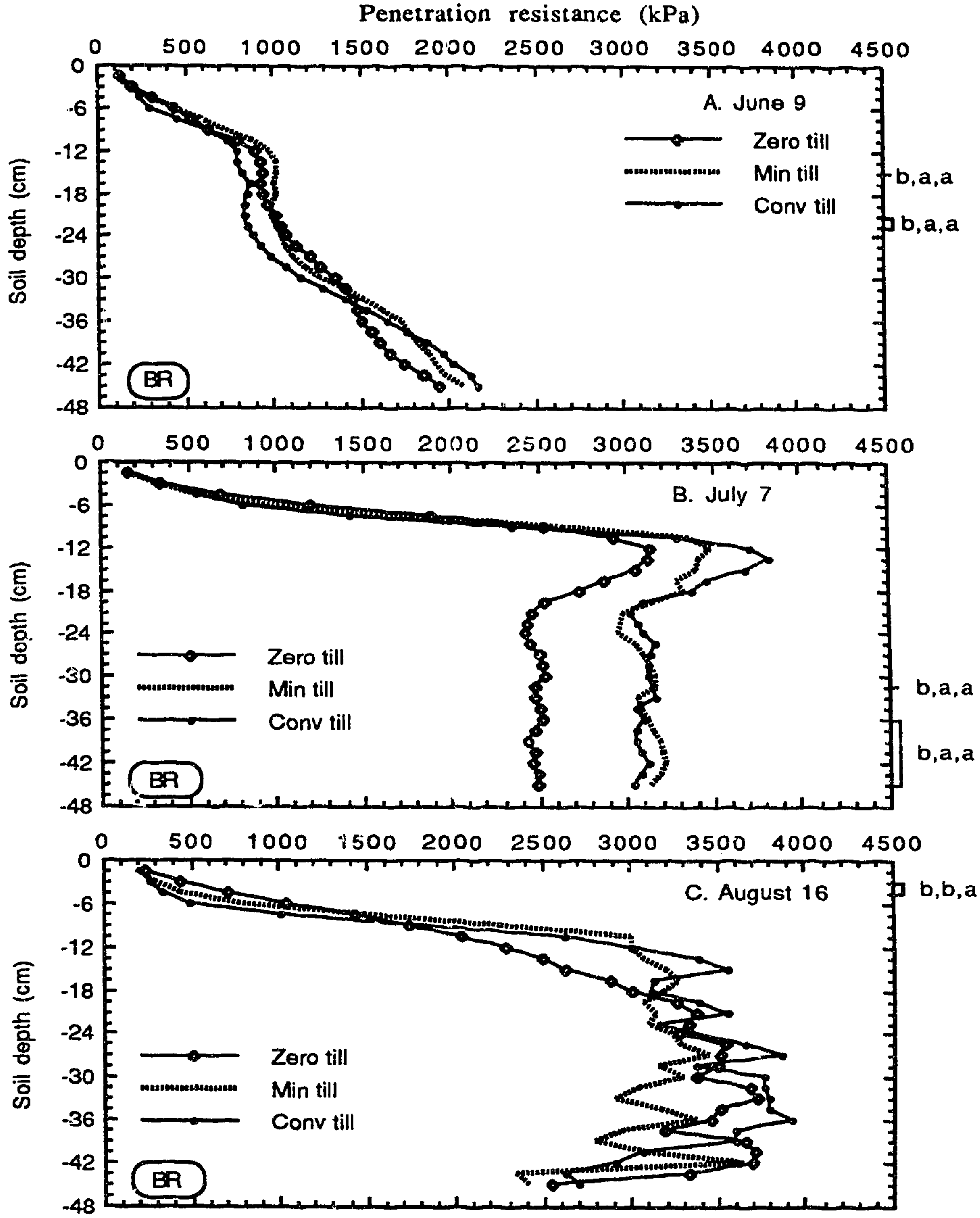
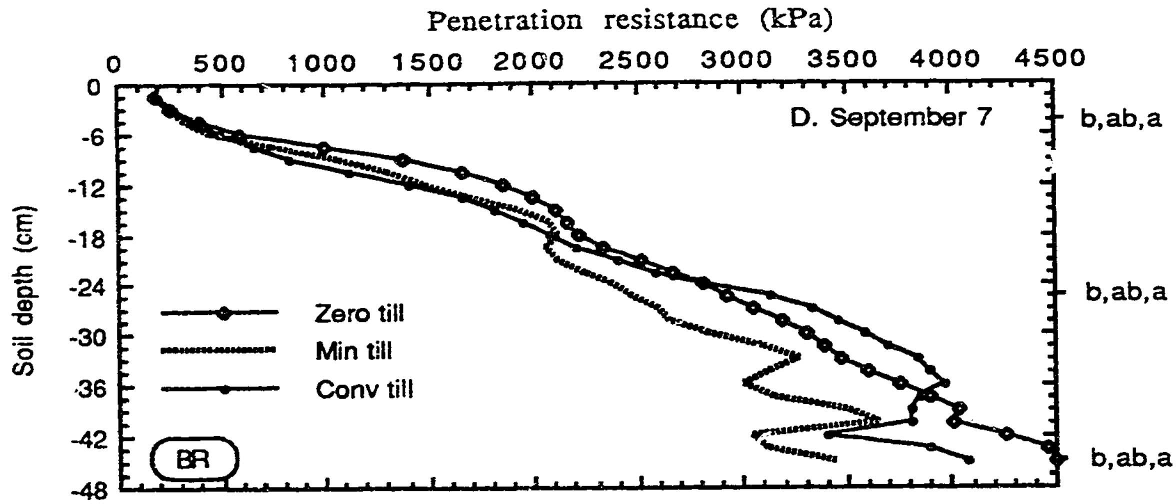


Figure 4.3 Soil penetration resistance on (A) June 9, (B) July 7 and (C) August 16, 1989 in the between-rows (BR) position. At a given depth, treatment means followed by no letters are not significantly diffe.ent (P=0.10).



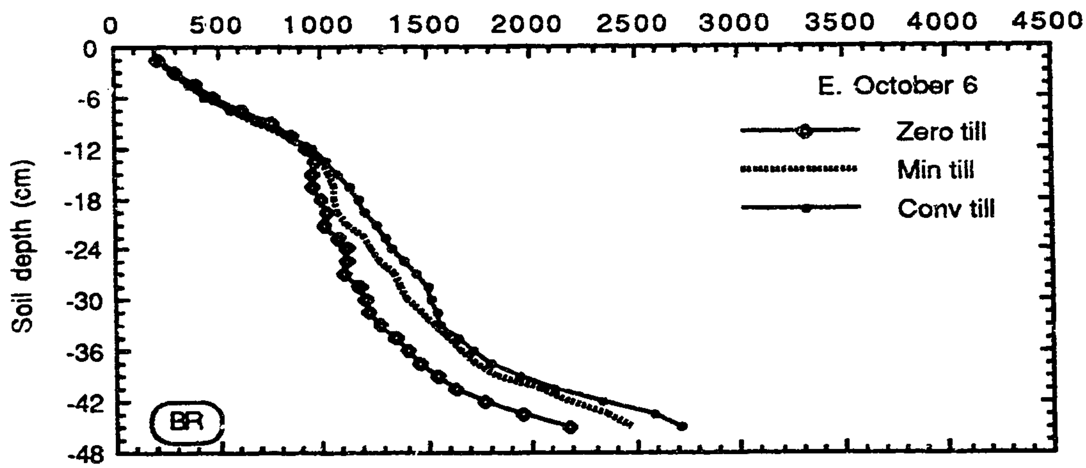


Figure 4.3 (cont'd) Soil penetration resistance on (D) September 7, and (E) October 6, 1989 in the between-rows (BR) position. At a given depth, treatment means followed by no letters are not significantly different (P=0.10).

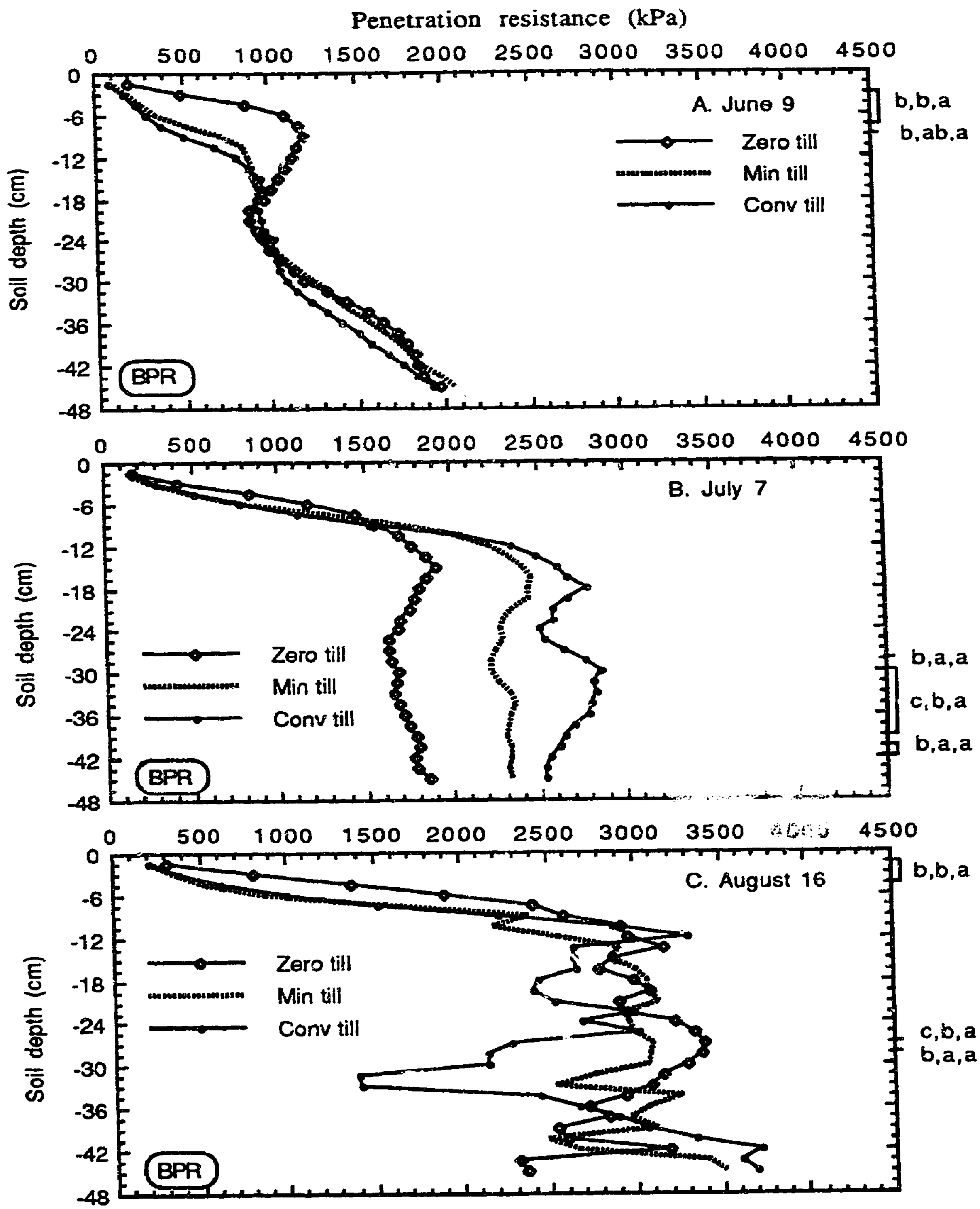
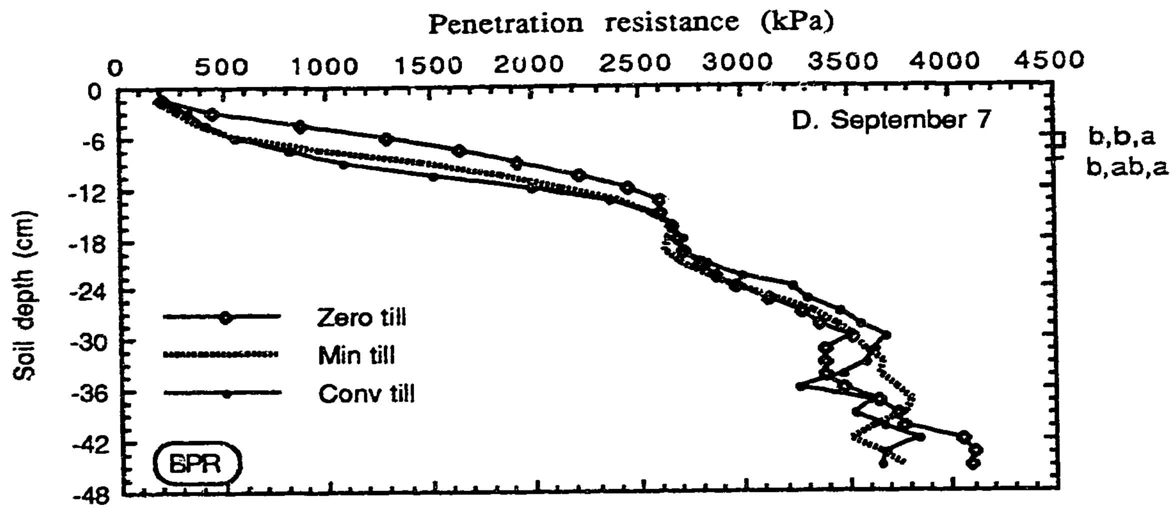


Figure 4.4 Soil penetration resistance on (A) June 9, (B) July 7 and (C) August 16, 1989 in the between-pairs-of-rows (BPR) position. At a given depth, treatment means followed by no letters are not significantly different (P=0.10).



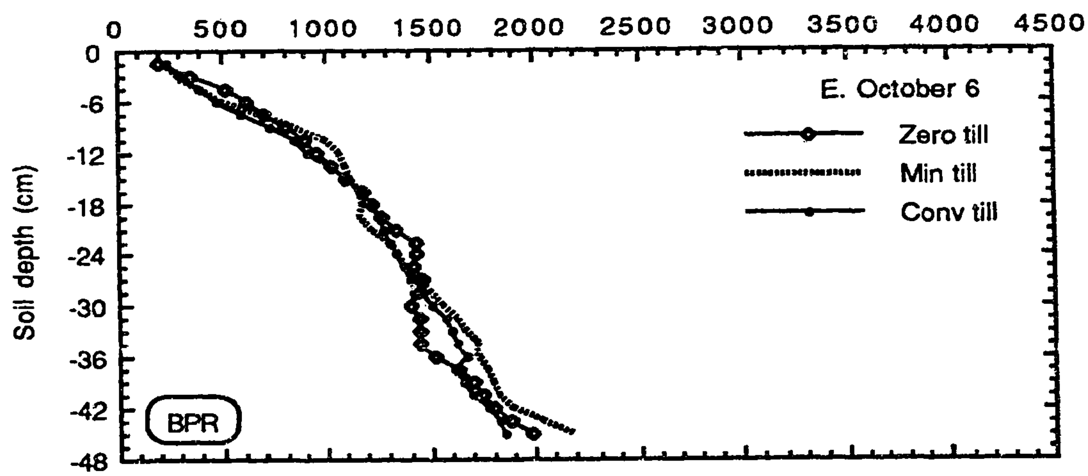


Figure 4.4 (cont'd) Soil penetration resistance on (D) September 7, and (E) October 6, 1989 in the between-pairs-of-rows (BPR)position. At a given depth, treatment means followed by no letters are not significantly different (P=0.10).

4.5 References

Archetti, R., Bonciarelli, F. and Farina, G. 1989. Results of tillage trials carried out in 1981-1987 in Central Italy. Riv. di Ing.Agr. 1: 43-49.

Barley, K. P., Farrell, D. A. and Greacen, E.L. 1965. The influence of soil strength on the penetration of a loam by plant roots. Aust. J. Soil Res. 3: 69-79.

Bauder, J. W., Randall, G. W. and Swan, J. B. 1981. Effect of four continuous tillage systems on mechanical impedance of a clay loam soil. Soil Sci. Soc. Am. J. 45: 802-806.

Burch, G. A., Mason, I. B., Fischer,R. A. and Moore, I. D. 1986. Tillage effects on soils-physical and hydraulic responses to direct drilling at Lockhart, N.S.W. Aust. J. Soil Res. 24: 377-391.

Cannon, K. R. and Landsburg, S. 1990. Soil Compaction: A Literature Review. AGTD Environmental Research Monograph 1990-1. NOVA Corporation of Alberta, Calgary, AB. 48 pp.

Cassel, D. K., Bowen, H. D. and Nelson, L. A. 1978. An evaluation of mechanical impedance for three tillage treatments on Norfolk sandy loam. Soil Sci. Soc. Am. J. 42: 116-120.

Cassel, D. K. 1982. Tillage effects on soil bulk density and mechanical impedance. *in* P. W. Unger and D. M. Van Doren (Editors), Predicting Tillage Effects on Soil Physical Properties and Processes. ASA Special Pub. No. 44. ASA, SSSA, Madison, WI. pp. 45-67.

Dasberg, S., Hillel, D. and Arnon, I. 1966. Response of grain sorghum to seedbed compaction. Agron. J. 58: 199-201.

Douglas, J. T., Jarvis, M. G., Howse, K. R. and Goss, M. J. 1986. Structure of a silty soil in relation to management. J. Soil Sci. 37: 137-151.

Ehlers, W., Kopke, W., Hesse, F. and Bohm, W. 1983. Penetration resistance and root growth of oats in tilled and untilled loess soil. Soil Tillage Res. 3: 261-275.

Eriksson, J., Hakansson I. and Danfors, B. 1974. Effects of soil compaction on soil structure and crop yields. Swedish Institute of Agricultural Engineering Bull. 554: pp 45-180.

Greacen, E. L. 1986. Root response to soil mechanical properties. *in* transactions of the XIII Congress of the International Society of Soil Science. Hamburg, Germany. pp. 20-47.

Hill, R. L. and Cruse, R. M. 1985. Tillage effects on bulk density and soil strength of two Mollisols. Soil Sci. Soc. Am. J. 49: 1270-1273.

Hillel, D. 1982. Introduction to Soil Physics. Academic Press, San Diego, CA. 364 pp.

Jones, N. J., Moody, J. E. and Lilland, J. H. 1969. Effects of tillage, no tillage and mulch on soil water and plant growth. Agron. J. 61: 719-721.

Lindstrom, M. J. and Onstad, C. A. 1984. Influence of tillage systems on soil physical parameters and infiltration after planting. J. Soil Water Cons. 39: 149-152.

Mirreh, H. F. and Ketcheson, J. W. 1972. Influence of soil bulk density and matric pressure on soil resistance to penetration. Can. J. Soil Sci. 52: 477-483.

Naeth, M. A., White, D. J., Chanasyk, D. S., Macyk, T. M., Powter, C. B. and Thacker, D. J. 1991. Soil physical properties in reclamation. Alberta Land Conservation and Reclamation Council Report No. RRTAC 91-4. ISBN 0-7732-0880-1. pp. 216.

Pidgeon, J. D. and Soane, B.D. 1977. Effects of tillage and direct drilling on soil properties during the growing season in a long-term barley mono-culture system. J. Agri. Sci. 88: 431-442.

Radcliffe, D. E., Manor, G., Clark, R. L., West, L. T., Langdale, G. W. and Bruce, R. R. 1989. Effect of traffic and in-row chiseling on mechanical impedance. Soil Sci. Soc. Am. J. 53: 1197-1201.

Rickman, J. F. 1988. Traction effects on soil compaction. University of Alberta, Department of Agricultural Engineering, Edmonton, AB. M.Sc. Thesis. 54 pp.

Sanborn, P. 1991. An evaluation of soil conservation under three tillage systems for the Peace River region of British Columbia: Soil physical properties. ARDSA Project 23011 final report.

SAS Institute Inc. 1991. SAS® Procedures Guide for Personal Computers, Version 6. Cary, NC: SAS Institute Inc. 373 pp.

Singh, B. 1991. The long-term effects of tillage and residue management on the soil physical environment and on barley growth. University of Alberta, Department of Soil Science, Edmonton, AB. Ph.D. Dissertation. 213 pp.

Taylor, H. M. and Gardner, H. R. 1963. Penetration of cotton seedling taproots as influenced by bulk density, moisture content, and strength of soil. Soil Sci. 96: 153-156.

Taylor, H. M. and Ratliff, L.F. 1969. Root elongation rates of cotton and peanuts as a function of soil strength and soil water content. Soil Sci. 108: 113-119.

Thacker, D. J. and Johnson, R. L. 1988. The effect of soil compaction on plant root growth. *in* Proc. 25th Annual Alberta Soil Science Workshop. pp. 230-235.

Thacker, D. J. and Johnson, R.L. 1989. Factors influencing cone penetration resistance as a measure of compaction in minespoils. *in* Proc. Reclamation, A Global Perspective. Alberta Land Conservation and Reclamation Council Report # RRTAC 89-2. 2 Vols. pp. 617-625.

Tollner, E. W., Hargrove, W. L. and Langdale, G. W. 1984. Influence of conventional and no-till practices on soil physical properties in the southern Piedmont. J. Soil Water Cons. 39: 73-76.

Veprakas, M. J., Miner, G. S. and Peedin, G. F. 1986. Relationships of dense tillage pans, soil properties, and subsoiling to tobacco root growth. Soil Sci. Soc. Am J. 50: 1541-1546.

Williams, J and Shaykewich, C. F. 1970. The influence of soil matric potential on the strength properties of unsaturated soil. Soil Sci. Soc. Am. J.34; 835-840.

Chapter 5

SYNTHESIS

5.1 Introduction

Conservation tillage holds great promise in the Peace River region as a soil and water conservation measure, as well as a means of reducing farm labor, energy and capital inputs. For these reasons conservation tillage systems are being intensively studied world wide and producers are interested in adopting these systems. Reluctance among producers to the wholehearted adoption of conservation tillage systems remains, due in part, to concerns about soil compactness and poor field trafficability under reduced or zero till management. The focus of this study was to quantify changes in the soil physical environment brought about by medium term tillage systems.

5.2 Effects of tillage management systems on the soil physical environment.

One goal of conservation tillage is to create soil surface conditions that reduce wind and water erosion. Increased plant residue on the surface, as a result of reducing or eliminating tillage, helps protect the soil from erosive forces. As well, higher organic matter associated with increased surface residue can lead to larger and more stable soil aggregates which are less prone to erosion and surface sealing from rainfall.

This study revealed that soil organic carbon varied among the different tillage systems; the effect largely being a redistribution of organic carbon in the soil profile, such that organic carbon in the near surface of the zero tillage treatment was significantly higher than in the tilled treatments. This increase may result in reduced soil erosion as well as a reduction in surface sealing during rainfall because of improved quality of the organic matter and better soil aggregation or structure. Arshad and Dobb (1991) attributed better aggregation of surface soils under zero tillage to increased organic matter levels and Sanborn (1991) noted a significant direct relationship between organic matter and aggregate stability.

Typically, tillage results in lower bulk density of the tilled soil layer, however, the magnitude and persistence of changes in bulk density vary with tillage and other management practices, as well as with soil and environmental factors.

Soil bulk density varied little among tillage management systems in this study. A significant, but small, difference occurred in the soil surface (0-10 cm) immediately after spring tillage (May 11) where bulk density was in the order of zero > minimum > conventional tillage, and reflected the effect of cultivation on reducing bulk density. At other times during the season, bulk density did not vary among treatments, likely due to a relatively shallow cultivation depth, an already high bulk density, high clay content of the soil, seasonal precipitation, natural soil settling, seed drill packing wheels, and harrowing of all treatments after seeding. Similarity of average surface bulk density throughout the season under zero till indicates that an equilibrium bulk density has been attained under this tillage management system.

The bulk densities measured in this study may be in the range where they would affect plant growth, however, the root limiting bulk density for this soil-crop combination is unknown. It is noteworthy that bulk density generally did not vary among tillage systems. Considerable temporal and spatial variation of bulk density was evident in this study, thus, a random sampling technique without consideration to time of season and position would limit the usefulness of data collected.

Soil properties which are modified by tillage management practices (such as water transmission and retention characteristics, size and stability of aggregates), in turn, influence the soil moisture regime. Surface residue affects soil moisture by changing evaporation patterns and reducing the surface sealing effects of raindrop impact, thus reducing runoff.

This study revealed small differences in water retention properties among tillage treatments. Significant differences only occurred in the 0-2.5 cm depth increment at both -33 and -1500 kPa. At -33 kPa the zero till treatment retained significantly more water than the conventional tillage treatment while at -1500 kPa both zero and minimum till retained significantly more water than conventional till. Available water holding capacity of the soils was not significantly different among treatments. Water retention at relatively low suctions is largely attributed to structure and at high suctions to texture and surface area of the soil material (Hillel, 1982). The samples used to determine water retention were ground, thus limiting soil structure influence. The tillage treatments were in place for a short time thus likely having very little, if any, effect on particle size distribution. Therefore, higher water retention under zero till in the 0-2.5 cm depth increment may be related to the higher organic matter found under zero till in this increment. Organic matter can hold large volumes of water but its water content-potential relations are little known and need further investigation.

In this study, soil moisture varied little among treatments. A trend for zero till to exhibit a moisture conserving effect was observed early in the season but differences in soil moisture were not significant. Inadequate weed control under zero till may have masked any significant soil moisture advantage under this tillage system.

Air filled porosity fell below 10% in the near surface soil shortly after appreciable rains and indicates that following periods of high rainfall, water-logged soil conditions may occur which could adversely affect plant growth. However, low air filled porosity was observed in all the tillage treatments and thus no one tillage system could be identified as having a propensity for water-logging.

Penetration resistance generally did not vary among treatments at most times of measurement. However, differences of note, among treatments, occurred in: the surface 10 cm in the BPR position three of six sampling times during the growing season, where zero till had higher PR than the tilled treatments; and as well, at depths below 30 cm in May and below 10 cm in July where conventional tillage had the highest PR. Differences in PR in the surface were mainly explained by differences in bulk density while the differences in PR at greater depths were largely attributed to differences in soil moisture.

PR was in the range considered to be root limiting several times during the season. As these high values occurred after mid-season, when the crop would have already established an extensive root system, and because roots are able to utilize structural and biological channels to access the soil profile, it is unknown if the high soil strength limited root growth. In the event of drier soil conditions earlier in the season, soil strength may be root restricting and be reflected in lower crop production.

The penetrometer was a useful tool to rapidly assess soil conditions over a wide area and was a sensitive indicator of tillage-induced changes in soil conditions as it combines changes in soil moisture and bulk density. However, large temporal and spatial variation in PR noted in this study indicate that temporal and spatial consideration should be included in any PR measurements.

5.3 Management implications

The general lack difference for selected soil properties among tillage treatments indicates that conservation tillage can be an acceptable alternate tillage method for the Peace River region. Producer concerns with respect to soil compactness and poor field trafficability under conservation tillage systems appear to be unfounded under the soil-crop-environment conditions as represented by this study. With attention to adequate weed control and other crop management considerations (such as fertility, diseases, etc.) conservation tillage systems can be a successful management alternative with advantages for soil and moisture conservation as well as for reducing farm input costs.

5.4 Future research efforts

A) Soil considerations

The soil environment needs to be monitored in greater detail in the early part of the growing season as effects on plant growth during this time are often reflected in later crop yields.

Future studies involving tillage systems should be conducted over several years to observe the influence of different weather conditions (wet vs dry years) and to incorporate the winter period and its effects on soil properties.

Studies on longer term treatments should be undertaken as some soil properties may take a long time to change (e.g. organic matter).

Origin, size, tortuosity and continuity of pores and the effects on water transmission need to be studied in greater detail under zero till systems in the Peace River region as earthworm activity is very low or nonexistent in parts of that region.

B) Plant considerations

Critical plant growth limits for bulk density and soil strength need to be established for different soil types and plant species, preferably in field situations to incorporate structural and biological channels.

Future studies should place emphasis on weed growth in relation to tillage practices and water use by weeds.

Soil fertility and fertilizer placement with respect to drill configuration need to be studied in relation to rooting behavior as rooting patterns may affect soil properties such as bulk density and moisture and confuse interpretation of data.

Various biological considerations with respect to tillage systems should be studied in the future. For example, leaf diseases which are harbored on leaf litter, may have different effects on crop yields under different tillage systems.

C) Equipment considerations

Particular attention should be paid to sampling position, especially with drills having a unique configuration such as the one used in this study. For instance, when using drills with a paired row configuration, the BPR position represents a relatively large proportion of the field surface and could be expected to have a large influence on the soil moisture regime

Different seed drill configurations, opener types (hoe vs disc), packing wheel arrangements, etc. need to be studied with respect to seed placement, weed response, and disturbance of the soil under zero till systems.

D) Economic considerations

Concurrent with studies of tillage system effects on the the soil and plant environment an economic analysis should be conducted to allow producers to assess the relative economies of different tillage management systems.

5.5 References

Arshad, M. A. and Dobb, J. L. 1991. Tillage effects on soil physical properties in the Peace River region: Implications for sustainable agriculture. *in* Proc., 28th Annual Alberta Soil Science Workshop. pp. 190-199.

Hillel, D. 1982. Introduction to Soil Physics. Academic Press, San Diego, CA. 364 pp.

Sanborn, P. 1991. An evaluation of soil conservation under three tillage systems for the Peace River region of British Columbia: Soil physical properties. ARDSA Project 23011 Final report.