INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

ProQuest Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600

UMI®

University of Alberta

Longevity of Deep Ripping Effects on Solonetzic Soils

by

Melvin N. Mathison ©

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

Water and Land Resources

Department of *Renewable Resources*

Edmonton, Alberta

Fall 2000

National Library of Canada

Bibliothèque nationale du Canada

Acquisitions and Bibliographic Services

Acquisitions et services bibliographiques

395 Wellington Street
Ottawa ON K1A 0N4
Canada

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

Our file Notre référence

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

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

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

0-612-59845-4

Canada

University of Alberta

Library Release Form

Name of Author: *Melvin N. Mathison*

Title of Thesis: *Longevity of Deep Ripping Effects on Solonetzic Soils*

Degree: *Master of Science*

Year this Degree Granted: *2000*

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 herein before 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.

4542 Stewart Crescent
Vermilion, Alberta
T9X 1R3

Date: September 28/00

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 *Longevity of Deep Ripping Effects on Solonetzic Soils* submitted by *Melvin N. Mathison* in partial fulfillment of the requirements for the degree of *Master of Science* in *Water and Land Resources*.

Dr. D. S. Chanasyk (supervisor)

Dr. M. A. Naeth (co-supervisor)

Dr. D. J. Pluth

Dr. D. C. Sego

Dr. U. Silins

Date: Sept 25/00

ABSTRACT

The objective of this study was to determine if beneficial effects of deep ripping on Solonetzic soils were apparent after 15 to 20 years. Deep ripping is used as an amelioration method, with mixed results reported in the scientific literature on sustainability of the benefits. This study investigated select soil chemical and physical properties along with dryland yield data of wheat, barley, oats and canola from deep ripped sites in east-central Alberta. A significant yield advantage from deep ripping (for all crop species) was found for six of ten sites ($P \leq 0.10$), with all sites having an increase in mean yield. All sites showed yield increases for the majority of years evaluated. A significant reduction in penetration resistance was found in the deep ripped versus control treatments ($P \leq 0.05$). Beneficial effects of deep ripping were sustainable for up to 20 years at some sites.

ACKNOWLEDGEMENTS

Alberta Agricultural Research Institute (AARI) provided financial support for field research and lab analysis for this study. John Brown and Jerome Lickacz of Alberta Agriculture, Food and Rural Development provided yield data and information for the field plots. Lakeland College provided financial support, resource support and made time available for project completion. My appreciation extends to Dr. Emmanuel Mapfumo for his help during the entire project; and to my fellow grad students. I would like to thank my co-supervisors: Dr. David Chanasyk and Dr. Anne Naeth for their never ending encouragement, help and advice. I would like to acknowledge the support of my family throughout the course of my studies. Lastly, I would like to acknowledge the farm cooperators; their involvement and cooperation was greatly appreciated.

Mr. H. Bauer

Mr. V. Caskey

Mr. R. Christianson

Mr. D. Fried

Mr. G. Jorgenson

Mr. R. Klassen

Mr. L. Kneeland

Mr. G. Kuefler

Lone Pine Colony

Mr. P Madge

Mr. J. Schaffner

TABLE OF CONTENTS

PAGE

LIST OF TABLES

TABLE		PAGE

LIST OF FIGURES

I. INTRODUCTION

1.1 Introduction

The term Solonetz is of Russian origin (Peters 1973) and was used to describe a soil with a significant percentage of sodium salts. Solonetzic soils occur in many parts of the world including the southern portion of the former Soviet Union, the eastern region of the Balkans, Australia, the Argentine area in South America, the southwestern and north central part of the United States and in Western Canada (Peters 1973). In their natural state soils of the Solonetzic Order (Agriculture Canada Expert Committee on Soil Survey 1987) are considered to be marginal for crop production due to several adverse soil properties. Solonetzic areas in a field often exhibit more variation in topsoil depth, pH of the A horizon and hardness of the B-horizon compared to non-Solonetzic areas (Lickacz 1993). Solonetzic soils are characterized by having a Solonetzic B horizon or hard pan layer that is very hard when dry and impermeable to water when wet (Grevers and Taylor 1995). This hardpan layer occurs at approximately 5 to 30 cm below the soil surface and severely limits water and root penetration into the soil profile. Solonetzic soils often occur in a complex and very close association with non-hardpan soils (Hardy 1984). This discontinuous occurrence of Solonetzic soils in association with normal soils for the region often results in distinct Solonetzic patches in a given field. The soils on these Solonetzic patches are subject to wind and water erosion and often result in slight depressions with thin A horizons. In Western Canada Solonetzic soils were originally referred to as blowout or burnout soils due to this patchy appearance of the shallow pits that eroded in the native grasslands of the Brown and Dark Brown soil zones (Cairns and Bowser 1977).

1.2 Solonetzic Soils In Western Canada

Solonetzic soils are found mainly in the grassland and parkland regions. There are approximately 9 million hectares of Solonetzic soils in the Great Plains region of Canada and the United States (Carter and Pearen 1985). Grevers and Boehm (1994) estimated Solonetzic soils in Saskatchewan comprise approximately 1.8 million hectares. Alberta has the most Solonetzic soils in Western Canada with approximately 4 to 5 million hectares, which represents about 30% of the arable land. The majority are found in a low relief plain in the central part of the province that runs from near Vegreville in the north, down through Castor and Coronation, to Brooks in the south (Lickacz 1993).

1.2.1 Genesis of Solonetzic Soils

The classical thought on the formation of Solonetzic soils follows a sequence of pedogenic processes: first of salinization, then solonization and finally solodization (Miller and Pawluk 1994).

The process of salinization results in the accumulation of high levels of soluble salts near the soil surface. The long-term physical and chemical weathering of rocks and minerals releases salts into the soil, but this process in itself will not usually result in salinization. The salts are usually transported with groundwater and resurface in areas where there is a shallow water table, which allows capillary movement of salts and water to the surface. Capillary movement mainly occurs when the free water table is within approximately 2 meters of the soil surface, with the critical depth related to soil texture (Henry et al. 1987).

The salinization process in Western Canada is thought to have occurred from either local, intermediate or regional discharge areas of saline groundwater. Salts accumulate in the groundwater by dissolution from the geologic material along the flow path. Large areas of the Canadian prairies were at one time submerged under an ancient sea, and salts are often concentrated in areas where former saline water bodies such as these ancient seas were present. As the seas disappeared, marine shales remained, containing high concentrations of sodium salts. The movement of the glaciers mixed some of the marine shales with other surface deposits, resulting in material with high concentrations of sodium salts appearing at the surface in some locations (Henry et al. 1987). Bedrock and till material can both contribute to high levels of sodium salts. The salts are a mixture of various compounds, with sulfates of sodium, calcium and magnesium being most prevalent (Cairns and Bowser 1977). Fullerton and Pawluk (1987) indicated that Solonetzic soils likely developed from parent materials that are more or less uniformly salinized with sodium salts, or sodium salts introduced into the pedon due to capillary rise from groundwater. Carter (1984) also indicated that genesis of Solonetzic soils in Western Canada usually involves the presence of highly saline-sodic groundwater.

If the groundwater flow system is local in nature, then the recharge and discharge areas are relatively close to one another, within a distance of one kilometre (Vander Pluym 1987). Intermediate groundwater flow systems would be longer than one kilometre, with regional flow systems being much deeper and extending many kilometres. Groundwater moving from the recharge to the discharge area dissolves and transports the soluble ions present in the till or the marine shale. In a large regional flow system the discharge areas may appear random and unrelated to the slight depressions of the local topography.

Salinization of the present Solonetzic areas in Alberta, such as the large low relief plain in the central part of the Province, likely occurred immediately after the last glaciation. Meltwater from the glaciers in the Rocky Mountain region moved eastward as regional groundwater flow and came to the surface in areas where a shallow water table occurred. The water carried large amounts of sodium salts, picked up from the till material and underlying marine shale. Combined with local relief patterns and groundwater flow systems that were developing at the time, a rather sporadic discharge of salts occurred (Pawluk 1973).

The second stage in the development of Solonetzic soils is the process of solonizaton. For solonization to proceed there must be a desalinization period or a gradual reduction in the amount of soluble salts throughout the upper profile, along with the presence of clay minerals and sodium ions. The balance shifts from a net upward movement of salts to a net downward movement. In many areas the water table lowered rapidly after the meltwater from glaciation had raised them, permitting the salts to begin to leach (Pawluk 1973). Solonization is based on the theory of colloidal-chemical exchange where the formation of the Solonetzic profile is caused by high exchangeable sodium. Sodium levels increase until at least 10 to 15% of the exchange complex is occupied by sodium, and the total soluble salt content reduces to 0.10 to 0.15% or less (Miller and Pawluk

1994). The high amounts of sodium and low amounts of salt will cause clay to disperse; the clay begins to move downward in the profile and concentrates in what will become the B horizon (Peters 1973). Hydrolysis of sodium causes pH to increase (alkaline hydrolysis) and alkalization occurs. As the water table rises and falls during the year there is repeated salinization and desalinization occurring, which sustains the processes of alkalization and dispersion (Miller and Pawluk 1994). Under basic conditions some organic components also become mobile and leach into the B horizon with the fine clay, forming dark stains on the soil peds. The Bn or Bnt horizon develops over time, having a very hard consistence when dry and very sticky when wet. This horizon often develops so dense and compact that it becomes difficult for water to penetrate. The B horizon at this stage may be massive, breaking to an angular blocky structure (Juma 1999). A Bn horizon with a weak columnar structure and sharp upper boundary is also indicative of the early stages of solonization (Miller and Pawluk 1994). Solonetzic soils at this stage would belong to the Solonetz Great Group (Agriculture Canada Expert Committee on Soil Survey 1987). The hardpan Bnt horizon of a Solonetz usually occurs within approximately 20-cm of the surface (Lickacz 1993).

Solodization during the third stage results from a decrease or termination of groundwater influence on the solum. The formation of the slowly permeable B horizon and the change in texture from a coarser A horizon to finer B horizon (clay eluviation – illuviation) may reduce capillary movement of water beyond the top of the B horizon. The columnar structure becomes more pronounced as development occurs, and a Bnt horizon with dark staining on intact columnar or prismatic peds becomes characteristic. Some leaching of sodium from the Bnt horizon begins to occur with downward movement of water, and the rounded tops of columns begin to form. The columns vary in width from approximately 3 to 8 cm in diameter (Cairns and Bowser 1977). Root growth is restricted and tends to follow the natural cleavage lines at the outer edges of the columns where resistance to growth would be the least (Wetter et al. 1987). Eluviation and alkaline hydrolysis take place on top the B horizon (Miller and Pawluk 1994). Base cations are replaced over time by hydrogen and aluminum ions on the colloids and the A horizon becomes acidic. An ashy-white, acidic, Ae horizon with a platy structure develops. When the Ae horizon becomes continuous and 2-cm thick or greater, the profile has developed into a Solodized-Solonetz (Agriculture Canada Expert Committee on Soil Survey 1987). The Solonetzic soils in a large area in east-central Alberta are predominantly Solodized-Solonetz (Lickacz 1993).

If the Bnt horizon is no longer being resalinized by sodic ground water, which may occur with a continued drop in the water table, then alkaline hydrolysis of sodium clays can proceed. Leaching of sodium will continue from the B horizon, and some calcium and magnesium will be deposited at the top of the B horizon from decaying plant roots. The top of the columns in the B horizon begin to disintegrate and an AB or BA horizon forms. The columnar structure is not as strongly expressed and breaks more readily to blocky aggregates that are very hard when dry. Water and roots will be able to penetrate through the B horizon more readily, and the profile will now be classified as a Solod (Peters 1973; Agriculture Canada Expert Committee on Soil Survey 1987). The Solonetzic soils in the Peace River region of Alberta are mainly Solods (Lickacz 1993).

In Alberta, there is generally a zone of salt accumulation starting just below the B horizon (Cairns and Bowser 1977). The soluble salt concentration can vary substantially, and the zone usually contains sulfates and carbonates of sodium, calcium and magnesium. This is often referred to as the lime-salt layer of the C horizon. The salt crystals and white lime flecks are often visible and begin to occur at a depth of approximately 25 to 45 cm in the grassland regions of the Brown and Dark Brown soil zones, and slightly deeper in the parkland regions at 45 to 75 cm.

1.2.2 Agronomic Concerns

Webster and Nyborg (1986) noted that ponding of water on the soil surface, poor soil tilth and poor germination were all common problems with cropping of Solonetzic soils. Wetter et al. (1987) noted that an acidic Ap horizon and the hardpan layer that restricts rooting depth and downward movement of water and air into the profile may have the greatest effects on crop yield. Plant roots have a reduced soil volume to utilize for uptake of water and nutrients.

Management of Solonetzic soils for seedbed preparation requires timely operations with regard to soil moisture conditions. If Solonetzic soils are worked when they are too wet or too dry, they tend to form large clods. The occurrence of Solonetzic soils as patches in a field, often in close association with non-Solonetzic soils, makes optimum timing of field operations difficult for the entire area. After a rain the A horizon on the Solonetzic patches may remain wet compared to an adjacent Chernozemic area due to the shallower topsoil and the restricted movement of moisture down into the B horizon. If the Solonetzic patches are a smaller portion of the entire field, then tillage or seeding operations may be timed for the larger non–Solonetzic area. Large clods and poor soil tilth on the Solonetzic areas are often the result. This leads to poor or uneven seed germination and plant establishment.

During dry periods plant growth on the Solonetzic area will often be reduced due to a lack of soil moisture. Moisture from rainfall remains on the surface or in the A horizon, with more being lost to evaporation. The shallower topsoil and impermeable B horizon result in limited moisture storage capability. Plant roots have limited penetration through the columns of the Bnt horizon, thus limiting the soil volume available for uptake of available plant nutrients. The Solonetzic soil's shallower topsoil and therefore lower total volume results in organic matter and available nutrient content being lower on an area basis than non-Solonetzic soils.

The concentration of nitrogen, however, has in some instances been similar to adjacent Chernozemic soils. Soil samples from Ap horizons of Solonetzic and Chernozemic soils were analyzed by the Alberta Soil and Feed Testing Lab, and the Solonetzic soils could not be distinguished on the basis of nitrate nitrogen content from the Chernozems (Robertson 1982). Ponding of water in spring may result in denitrification occurring, which may also account for part of the decline in available nitrogen in some locations. Solonetzic soils generally release less total nitrogen to a growing crop than associated non-Solonetzic soils (Cairns and Bowser 1977).

Soil moisture is usually considered the major limiting factor for crop production on Solonetzic soils (Lickacz 1993). Differences in the hardpan layer occur over very short distances, often resulting in differences in crop height or a 'wavy crop pattern' developing during the growing season. The crops will mature unevenly, further complicating management at harvest time.

1.2.3 Agricultural Management Practices for Solonetzic Soils

Management of the seedbed is very important. The soil must be worked at optimum moisture conditions to prevent hard clods from forming, and the seedbed must be favorable for rapid germination and emergence. Surface drainage of ponded water may be beneficial to dry out the Solonetzic patches and allow for more timely tillage in accordance with the moisture content of the non-Solonetzic areas. When a heavy rain occurs after seeding, often a hard crust will form at the surface upon drying and prevent seedling emergence. Tillage must be done with caution on the shallow topsoil areas to prevent admixing part of the platy Ae or sodic B horizons into the Ap, which further reduces seedbed quality. Forage crops in the rotation can improve tilth on Solonetzic soils (Cairns 1973).

Deep plowing and deep ripping are two methods to improve the productivity of these soils that research scientists and agricultural producers have been examining. Chemical amendments such as calcium carbonate, gypsum and other calcium or sulfur containing compounds have been added with some of the deep ripping trials (Webster and Nyborg 1986). The cost of the treatment and the number of years that a yield advantage remains are major concerns of producers.

Deep plowing of Solonetzic soil is a soil mixing process with three potential benefits. First, the hardpan layer is physically broken to improve water and root penetration. Second, calcium in the form of lime [$CaCO_3$, $(CaMg)CO_3$] or gypsum ($CaSO_4 \cdot 2H_2O$) is brought up from the lime-salt layer in the C horizon and mixed with the sodium-rich B horizon. This may prevent the hardpan from reforming. Third, calcium may be brought to the surface during the plowing process and may have a beneficial effect on raising pH if the A horizon is acidic (Hardy 1984). The A, B and C horizons are generally mixed but not inverted as with an ordinary moldboard plow. One of the concerns of deep plowing is the potential mixing and dilution of the A horizon with other horizon material, and the subsequent loss of desirable physical and chemical properties of topsoil (Lavado and Cairns 1980). Several topsoil saving plows were designed and tested as prototypes but did not become readily available in Western Canada.

McAndrew and Malhi (1990) examined the long-term effects of deep plowing, and concluded that long-term beneficial effects were present for both crop yield and soil chemical properties. Agricultural producers in Western Canada have been concerned about the high initial capital cost of deep plowing, the time required to complete the operation, the potential dilution of topsoil and the potential for adverse seedbed conditions that initially result. Yield can be reduced substantially the first year and several secondary tillage operations are required after plowing to adequately prepare a seedbed. Deep plowing costs between $247 and $370 per hectare (Grevers and Boehm 1994, Lickacz 1993). Deep plowing will not be effective if the plowing depth is too shallow to adequately reach the lime-salt layer, or the calcium in the lime-salt layer is not in sufficient concentration. Solonetzic soils are not all suitable for deep plowing. Soil sampling should be undertaken prior to starting to determine if the area is suitable and the plowing depth that will be required (Lickacz 1993).

Deep ripping of Solonetzic soils is intended to physically shatter the hardpan layer with limited soil mixing compared to deep plowing. Deep ripping is faster than deep plowing and the estimated cost is substantially lower. Grevers and Boehm (1994) estimated the cost of deep ripping from $37 to $148 per hectare, with the greater the density of the hardpan, the higher the cost. Lickacz (1993) estimated deep ripping cost at between $100 and $110 per hectare including the cost of tilling the soil for seedbed preparation. Grevers and Taylor (1995) estimated the cost of deep ripping at approximately $80 to $106 per hectare, with secondary tillage costs between $30 and $57 per hectare.

1.3 Research Objectives

With approximately 30% of the arable land in Alberta Solonetzic, there remains considerable interest in finding an amelioration method to deal with these soils. Deep ripping is less costly than deep plowing, and would be preferred by many producers if the beneficial effects remain for a considerable period of time. Deep ripping is intended as a physical process to shatter the hardpan B horizon and increase water and root penetration down into the soil profile. If there are no chemical changes occurring, the beneficial effects may or may not last. Low commodity prices in the 1990's have made it more critical for producers to have relevant information in order to make informed decisions regarding the long term effects of deep ripping on Solonetzic soils. Most scientific studies have occurred within a few years after ripping.

This study assesses the longevity of the effects of deep ripping at sites that were ripped in the late 1970s and early 1980s. Evaluation after this time frame is aimed at providing agricultural producers with information about whether the effects remain after a period of up to 20 years. The assessment includes evaluation of select soil chemical and physical properties for deep ripped and adjacent unripped areas. The study will determine if changes in chemical or physical properties due to deep ripping are apparent. Crop yield data collected over varying numbers of years from the deep ripped and unripped areas will be compared for each site. Finally the yield data will be evaluated in conjunction with the soil data to determine if relationships exist.

1.4 References

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

Cairns, R.R. 1973. Cultural practices for Solonetzic soils. Pp. 50-61 in J.A. Toogood and R.R. Cairns (eds.). Solonetzic soils technology and management. Department of Extension Bulletin B-73-1, University of Alberta. Edmonton, Alberta. 92 pp.

Cairns, R.R. and W.E. Bowser. 1977. Solonetzic soils and their management. Publication 1391. Information Services, Agriculture Canada. Ottawa, Ontario. 37 pp.

Carter, M.R. 1984. Effect of soil management on some chemical, physical, and biological properties of a Solonetzic soil. Soil Sci. 138: 411-416.

Carter, M.R. and J.R. Pearen. 1985. General and spatial variability of Solonetzic soils in north central Alberta. Can. J. Soil Sci. 65: 157-167.

Fullerton, S. and S. Pawluk. 1987. The role of seasonal salt and water fluxes in the genesis of Solonetzic B horizons. Can. J. Soil Sci. 67: 719-730.

Grevers, M.J.C. and M.M. Boehm. (1994-Updated). Deep tillage of Saskatchewan soils. [Homepage of Saskatchewan Agriculture and Food], [Online]. Available: http://www.agr.gov.sk.ca/land_wat_clim/soil/Scd0294.asp [17 June 1999].

Grevers, M.J.C. and J. Taylor. 1995. The economic feasibility of subsoiling Solonetzic soils in Saskatchewan. J. Prod. Agric. 8: 557-561.

Hardy, J.R. 1984. Solonetzic soils in Alberta-a review. Regional Development Branch (Alberta), Agriculture Canada. Edmonton, Alberta. 12 pp.

Henry, L., B. Harron and D. Flaten. 1987. The nature and management of salt-affected land in Saskatchewan. Agdex 518. Soils and Crops Branch, Saskatchewan Agriculture. Regina, Saskatchewan. 23 pp.

Juma, N.G. 1999. The pedosphere and its dynamics: a systems approach in soil science: 1. Salman Productions. Edmonton, Alberta. 315 pp.

Lavado, R.S. and R.R. Cairns. 1980. Solonetzic soil properties and yields of wheat, oats and barley affected by deep plowing and ripping. Soil Tillage Res. 1: 69-79.

Lickacz, J. (1993-Revised). Management of Solonetzic soils. Adapted from Agdex 518-8 [Homepage of Alberta Agriculture, Food and Rural Development], [Online]. Available: http://www.agric.gov.ab.ca/agdex/500/1800008.html [14 Feb 2000].

Miller, J.J. and S. Pawluk. 1994. Genesis of Solonetzic soils as a function of topography and seasonal dynamics. Can. J. Soil Sci. 74: 207-217.

McAndrew, D.W. and S.S. Malhi. 1990. Long-term effect of deep plowing Solonetzic soil on chemical characteristics and crop yield. Can. J. Soil Sci. 70: 565-570.

Pawluk, S. 1973. Groundwater as related to Solonetzic soils. Pp. 27-32 in J.A. Toogood and R.R. Cairns (eds.). Solonetzic soils technology and management. Department of Extension Bulletin B-73-1, University of Alberta. Edmonton, Alberta. 92 pp.

Peters, T.W. 1973. Introduction. Pp. 8-22 in J.A. Toogood and R.R. Cairns (eds.). Solonetzic soils technology and management. Department of Extension Bulletin B-73-1, University of Alberta. Edmonton, Alberta. 92 pp.

Robertson, J.A. 1982. Fertility status of Solonetzic soils: a review. Pp. 116-130 in J.C. Hermans (ed.). Proceedings of the Solonetzic working Group. Alberta Agriculture. Edmonton, Alberta.

Vander Pluym, H.S.A. 1987. Dryland saline seep control. Agdex 518-11, Alberta Agriculture. Print Media Branch. Edmonton, Alberta. 12 pp.

Webster, G.R. and M. Nyborg. 1986. Effects of tillage and amendments on yields and selected soil properties of two Solonetzic soils. Can. J. Soil Sci. 66: 455-470.

Wetter, L.G., G.R. Webster and J. Lickacz. 1987. Amelioration of a Solonetzic soil by subsoiling and liming. Can. J. Soil Sci. 67: 919-930.

II. SITE CHARACTERIZATION

2.1 Introduction

This study was conducted in what is described mainly as the east-central region of Alberta on plots established in the 1970s and early 1980s by the Soil and Crop Management Branch of Alberta Agriculture, prior to Alberta Agriculture becoming Alberta Agriculture, Food and Rural Development (AAFRD). The plots were established on farms whose owners were interested in cooperating on this field research and comprised various physical and chemical treatments. In some locations additional treatments were added after initial plot establishment. The physical treatments included deep ripping and deep plowing, with some locations including more than one type of ripper or plow. The chemical treatments comprised various gypsum or lime application rates alone or in combination with physical treatments. The Soil and Crop Management Branch collected yield data from the sites for varying numbers of years after establishment until monitoring was discontinued in 1993 (Soil And Crop Management Branch 1994). Yield data for the sites were not comparable in years of collection due to different plot establishment dates, differing number of years of data collection and the absence of yield data for summerfallow years. The plots were managed after establishment as part of the normal cropping practices of the individual farm cooperators.

2.2 Field Plots

2.2.1 AAFRD Plots Sampled

Eleven field sites were selected where deep ripping treatments were present, plot markers were visible and unripped (check) strips remained with no alterations. Farmer cooperators were contacted for permission to resample their sites for soil physical and chemical properties. Soil sampling was conducted in spring 1998 and 1999. Deep ripping trials and check strips were the only treatments sampled at the selected sites. The rectangular treatment plots varied in width and length, and along with the varying number of treatments at a site, resulted in large differences in overall plot size among sites. The width of the treatments ranged from approximately 20 m for the narrowest to most of a quarter section (64 ha). The plots also varied in length from approximately 169 m for the shortest, to a quarter section (approximately 812 m); one site had treatments extending a full half section (Lickacz and Kastelic 1989).

2.2.2 Location, Soil Types and Climate of Plots Sampled

The 11 sites are located from near Vegreville in the north to near Oyen in the south, with mainly Solodized Solonetz soils (Figure 2.1) in the Brown, Dark Brown and Black Soil zones (Conservation and Development Branch 1995). Large climatic differences occur over this geographic area, along with wide annual variations in precipitation. The majority of the sites are in the Aspen Parkland ecoregion (Strong and Leggat 1992) with an annual average summer (May-August) precipitation of 259 mm. One site is located in the Mixed Grass Ecoregion, where total average summer precipitation is 176 mm. Three sites at the south end are in the Dry Mixed Grass Ecoregion where the annual summer average precipitation is only 156 mm. The summer climatic moisture balance for the region are negative: Aspen Parkland 199 mm, Mixed Grass 360 mm and Dry Mixed Grass 401 mm. A brief description of the field plots indicating legal location, County or Improvement District, Ecoregion, plot establishment date, Soil Zone and soil description follow the end of this chapter (Table 2.1).

2.3 Overview of Analyses Completed

Soil cores were collected in spring 1998 from both ripped and unripped treatments at all sites. The 0 to 15 cm and 15 to 30 cm cores were analyzed for soil chemical properties and textural analysis. Bulk density was evaluated using a moisture density probe (501) mounted on aluminum access tubes in the core holes. Penetrometer readings were taken at all sites in spring 1998 and 1999. Soil moisture was very limiting to crop growth at the time of sampling in 1998. This resulted in very high PR readings with many samples being recorded as the maximum value of the penetrometer. Moisture conditions were more favorable at sampling in spring 1999.

2.4 Site Observations

The 11 sites exhibited large differences in visual surface cloddiness and the degree of difficulty required to obtain core samples and penetration resistance readings. A very hard layer was encountered at many of the sample locations. High variability in physical and chemical properties is expected from one site to the other due to the differences in parent material that exist and the nature of Solonetzic soils versus non-Solonetzic soils. Yield data from site to site would also be expected to be highly variable due to the large differences in climatic regions. Ten of the eleven sites had at least five years of yield data available for evaluation.

2.5 References

Bowser, W.E., T.W. Peters and J.D. Newton. 1951. Soil survey of Red Deer sheet. Report No. 16 of the Alberta Soil Survey. Department of Extension, University of Alberta. Edmonton, Alberta. 86 pp.

Bowser, W.E., A.A. Kjearsgaard, T.W. Peters and R.E. Wells. 1962. Soil survey of Edmonton sheet. Alberta Soil Survey Report No. 21. Department of Extension, University of Alberta. Edmonton, Alberta. 66 pp.

Conservation and Development Branch. 1995. Soil group map of Alberta. Alberta Agriculture, Food and Rural Development. Edmonton, Alberta. 1 pp.

Kjearsgaard, A.A. 1976. Reconnaissance soil survey of the Oyen Map Sheet – 72M. Alberta Institute of Pedology, Report No. S-76-36. University of Alberta. Edmonton, Alberta. 85 pp.

Lickacz, J. and E. Kastelic. 1989. Compendium of deep tillage trials on Solonetzic soils in Alberta. Soils Branch, Alberta Agriculture. Edmonton, Alberta. 27 pp.

MacMillan, R.A., W.L. Nikiforuk and A.T. Rodvang. 1988. Soil survey of the County of Flagstaff, Alberta. Alberta soil survey report No. 51. Research Branch, Agriculture Canada; Terrain Sciences Department, Alberta Research Council. Edmonton, Alberta. 88 pp.

Soil and Crop Management Branch. 1994. Solonetzic soils deep tillage feasibility study-cumulative yield data. Unpublished. Alberta Agriculture. Edmonton, Alberta. 20 pp.

Strong, W.L. and K.R. Leggat. 1992. Ecoregions of Alberta. Alberta Forestry, Lands and Wildlife. Land Information Services Division, Resource Information Branch. Edmonton, Alberta. 59 pp.

Wells, R.E. and W.L Nikiforuk. 1988. Soil survey of the County of Paintearth, Alberta. Alberta soil survey report No. 49. Terrain Sciences Department, Alberta Research Council. Edmonton, Alberta. 78 pp.

Wyatt, F.A., J.D. Newton, J.A. Allen, W.E. Bowser and W. Odynsky. 1938. Soil survey of the Sullivan Lake sheet. Bulletin No. 31. Department of Extension, University of Alberta. Edmonton, Alberta. 102 pp.

Table 2.1 Description of field plots.

Site A
Legal location NE 20-30-11-4
Special Area #2 (Hanna)
Dry Mixed Grass ecoregion
Established 1976, deep ripping added 1978
Brown soil zone
Weakly calcareous and moderately saline till parent material

This site is mapped as 80% Hemaruka and 20% Steveville soils. The Hemaruka series is a Brown Solodized Solonetz with a well developed columnar B horizon. The A horizon is mainly a loam texture developed on moderately fine textured, weakly calcareous and moderately saline till. The Steveville series is also a Brown Solodized Solonetz with mainly a loam texture. This series has a layer 0 to 100 cm thick of medium textured weakly calcareous till material over medium textured, moderately calcareous, weakly saline modified Cretaceous or soft rock sediments. (Kjearsgaard 1976, Lickacz and Kastelic 1989).

Site B
Legal location NW 36-38-18-4
County of Stettler
Aspen parkland ecoregion
Established 1983 (ripping depth 42 cm)
Black soil zone
Lacustrine parent material

This site is mapped as a Gadsby silt loam and loam, developed on lacustrine parent material. The lacustrine material is fairly shallow and the underlying till material may be within 1 to 1.25 metres of the soil surface. The Gadsby series is classified as a Thin Black Solodized Solonetz. The Gadsby series has a very hard B horizon and a fairly high salt content in the subsoil.(Bowser et al. 1951, Lickacz and Kastelic 1989)

Site C
Legal location NW 16-34-8-4
Special Area #4 (Consort)
Mixed grass ecoregion
Established 1975, deep ripping added 1978
Dark Brown soil zone
Glacial till parent material

This site is mapped as 70% Halkirk, 20% Brownfield and 10% Dishpan soils. The Halkirk series is a Dark Brown Solodized Solonetz with mainly a loam texture. Halkirk soils have a hard, intact, round-topped columnar B horizon. The Brownfield series is classified as a Dark Brown Solod with a prominent AB horizon gradually merging into the B horizon. Both the Halkirk and Brownfield series developed on till material. The

Dishpan series is a Saline Rego Gleysol occurring in poorly drained low areas where groundwater discharge maintains a high salt concentration near the surface. The Dishpan series formed on fluvial-lacustrine parent material. (Kjearsgaard 1976, Lickacz and Kastelic 1989)

Site D
Legal location: NE 30-50-14-4
County of Minburn
Aspen parkland ecoregion
Established 1981 (ripping depth 60 cm)
Black soil zone
Residual parent material

This site is mapped by soil survey as a Kavanagh Loam. The Kavanagh Loam map unit includes Black and Dark Grey Solodized Solonetz and Solonetz developed on residual parent material. (Bowser et al. 1962, Lickacz and Kastelic 1989)

Site E
Legal location SW 3-40-16-4
County of Paintearth
Aspen parkland ecoregion
Established 1976, with ripping treatment added in 1978 (ripping depth 45 cm)
Dark Brown soil zone
Clay till veneer over residual shale parent material

This site is mapped by soil survey as a Halkirk-Torlea unit. The Halkirk-Torlea unit is a Dark Brown Solodized Solonetz with inclusions of 10 to 30% Dark Brown Solods (Brownfield) and Solonetzic Dark Brown Chernozemics (Flagstaff). Gleyed and Gleysolic soils occupy less than 15% of this map unit. Soils developed from a clay loam to clay till veneer over residual shale, slopes are 2 to 5% and eroded pits may cover 30% of the surface. (Wells and Nikiforuk 1988)

Site F
Legal location SE 33-28-7-4
Special Area #3 (Oyen)
Dry Mixed Grass ecoregion
Established 1978 (ripping depth 50 cm)
Brown soil zone
Fluvial or eolian parent material

This site is mapped as 50% Cavendish, 30% Rolling Hills and 20% Dishpan. The Cavendish series is an Orthic Brown Chernozem with a loamy sand texture in the A horizon. The soil developed from course textured fluvial or eolian parent material that is weakly calcareous. This sandy textured soil tends to have less structure and therefore color is an important component for horizon identification. The Rolling Hills series is a Brown Solodized Solonetz with a course textured fluvial or eolian layer approximately 30 to 75 cm deep over moderately fine alluvial or lacustrine material. This material is weakly calcareous and moderately saline. These soils have large variability in texture and show a strong columnar structure in the B horizon that breaks to a subangular structure that is also very hard. The Dishpan series is a Saline Rego Gleysol with a silt loam texture. They occur in low areas developed from strongly saline fluvial or lacustrine material. Groundwater discharge maintains a high salt concentration near the surface and salt crusts are often observed. (Kjearsgaard 1976, Lickacz and Kastelic 1989)

Site G
Legal location: SE 12-41-14-4
County of Flagstaff
Aspen parkland ecoregion
Established 1979 (ripping depth 45 cm)
Black soil zone
Medium textured till parent material

This site is mapped by soil survey as a Heisler 4/3 map unit. This is a Chernozemic unit developed on medium textured tills where the map unit contains significant amounts of Solonetzic soils. Dominant soils at 30 to 40% each are the Heisler series and the Elnora series. The Heisler series is a Solonetzic Black Chernozemic soil and the Elnora is an Orthic Black Chernozemic. Significant soils in this map unit at 15 to 30% each are the Killam and Daysland series. The Killam series is a Black Solodized Solonetz and the Daysland is a Black Solod. (MacMillan et al. 1988, Lickacz and Kastelic 1989)

Site H
Legal location: NW 30-50-14-4
County of Minburn
Aspen parkland ecoregion
Established 1985
Black soil zone
Residual parent material

This site is mapped by soil survey as a Kavanagh Loam. The Kavanagh Loam series includes Black and Dark Grey Solodized Solonetz and Solonetz developed on residual parent material. (Bowser et al. 1962, Lickacz and Kastelic 1989)

Site I
Legal location NW 9-31-4-4
Special Area #3 (Oyen)
Dry Mixed Grass ecoregion
Established 1975, deep ripping added 1981
Brown soil zone
Fine textured weakly saline till parent material

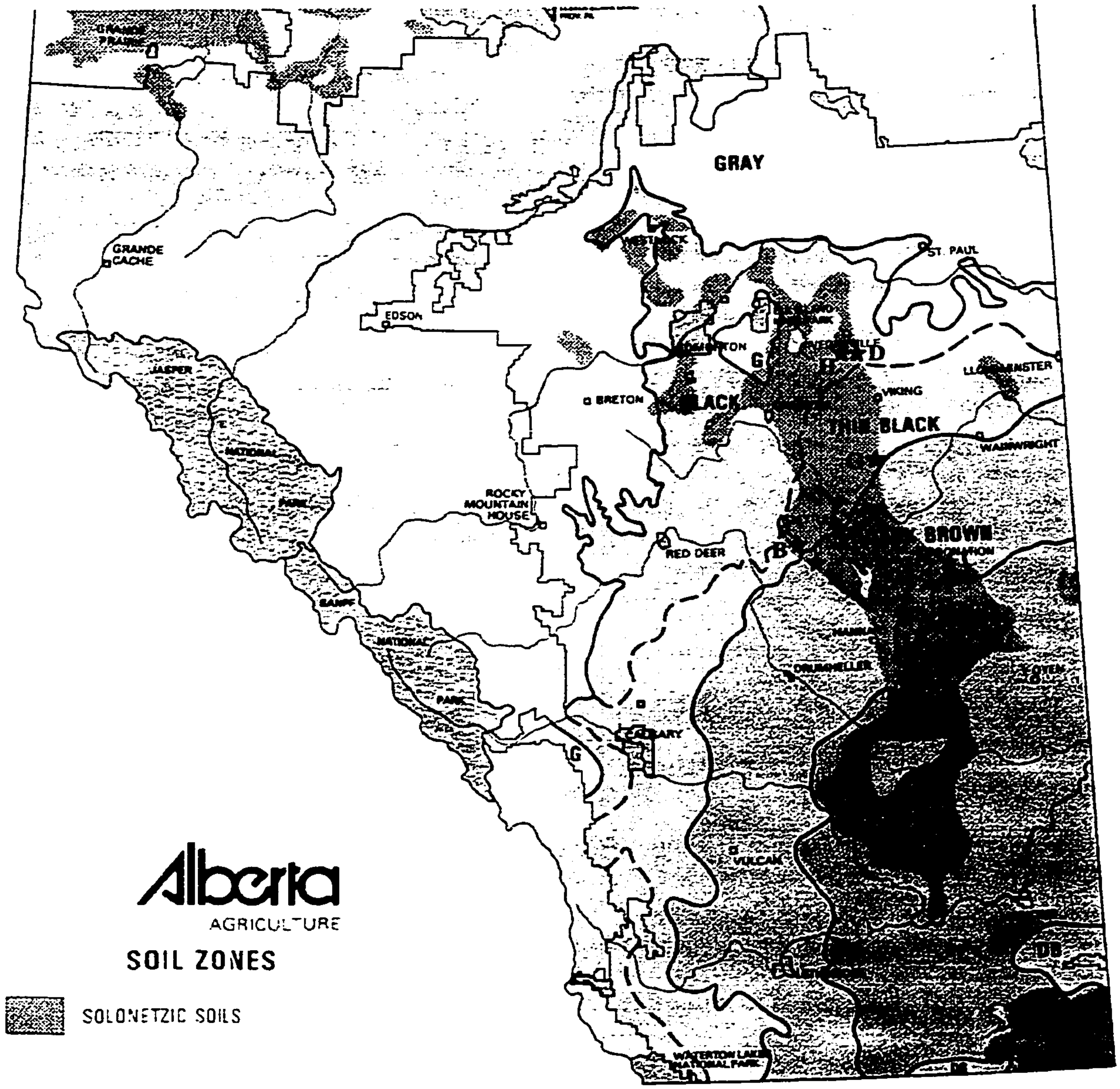
This site is mapped as 40% Halliday, 30% Maleb and 30% Hemaruka soils. Halliday is a Brown Solod series with a loam texture that developed on moderately fine textured, weakly calcareous and weakly saline till material. A transitional AB horizon is present and the transition into the columnar Bnt horizon is gradual. Maleb series is an Orthic Brown Chernozem developed on similar moderately fine textured, weakly calcareous till. These soils usually have a prismatic structure with a subangular blocky secondary structure. The Hemaruka series is a Brown Solodized Solonetz similar to the Halkirk series in the Dark Brown soil zone, but with a shallower A horizon. The B horizon has a well developed round-topped columnar structure. This series also has a mainly loam texture, developing on moderately fine textured, weakly calcareous and moderately saline till material. (Kjearsgaard 1976, Lickacz and Kastelic 1989)

Site J
Legal location NW 31-38-14-4
County of Paintearth
Aspen parkland ecoregion
Established 1983 (ripping depth 50 cm)
Dark Brown soil zone
Saline or sodic till parent material

This site is mapped as a Halkirk-Brownfield unit with gentle slopes of 2 to 5%. Halkirk soils are Dark Brown Solodized Solonetz with loam to sandy loam textures. The B horizon has intact round-topped columns that do not break down readily. The Brownfield soils are a Dark Brown Solod with round topped columnar structure breaking readily into blocky aggregates. (Wyatt et al. 1938, Lickacz and Kastelic 1989)

Site K
Legal location SE 4-37-18-4
County of Stettler
Aspen parkland ecoregion
Established 1983 (ripping depth 50 cm)
Dark Brown soil zone
Till parent material

This site is mapped as a Halkirk series, a Dark Brown Solodized Solonetz. Halkirk soils are distinguished by a hard round-topped B horizon that has a sharp contact with the horizon above. Dark Brown Chernozemic soil is also present on approximately one-third of the site. (Bowser et al. 1951, Lickacz and Kastelic 1989)



★ Field plot locations

Scale: 1 mm = approximately 45 km

Adapted from Agdex 518-8

Figure 2.1 Field plot locations.

III. LONG-TERM EFFECTS OF DEEP RIPPING ON SOIL CHEMICAL AND PHYSICAL PROPERTIES

3.1 Introduction

Select soil chemical and physical properties were evaluated to determine if significant differences exist between the deep ripped and unripped (control) treatments 15 to 20 years after ripping. A review of the scientific literature was undertaken to determine the effects on soil chemical and physical properties previously found from deep ripping Solonetzic soils. This research, conducted after a long time frame, will add to the scientific knowledge regarding the longevity of beneficial effects from deep ripping.

3.1.1 Soil Chemical Properties

Lavado and Cairns (1980) studied the effect of deep ripping on Solonetzic soils at two locations in the Brown soil zone of Alberta. A ripper with wide chisel blades designed to elevate some material from the Csk horizon into the Bnt was used. The soils were sampled 2 years after treatment and the results compared to a check strip of ordinary farm tillage. At one site the Bnt horizon was 10 to 21 cm below the surface, with a Csk horizon immediately below the Bnt. A second site had a deeper Bnt horizon at 19 to 37 cm, also with a Csk horizon below. There was no change in pH in the Ap horizon at either site, while the second site showed a significant increase in pH with ripping at the equivalent depth of the Bnt horizon. Deep ripping at that site showed a significant increase in the sodium level in the Ap horizon and a significant decrease in extractable calcium in the Bnt compared to the check strip.

Alzubaidi and Webster (1982) studied the effect of deep tillage on a Black Solonetz in east-central Alberta. The deep tillage plots were ripped in one direction to a depth of approximately 46 cm using a tractor-mounted cultivator. The cultivator had narrow teeth spaced 23 cm apart. The plots were ripped 4 times to disturb the Bnt horizon physically. An Ap horizon with medium blocky to medium granular structure was located over a Bnt horizon. The Bnt was approximately 25 cm below the surface, with a Csk horizon below the Bnt. Electrical conductivity (EC) was low in the Ap and Bnt horizons of the control plots, increasing sharply below 30 cm where accumulated soluble salts occur. Sodium sulfate was the dominant salt at all depths. Exchangeable Ca:Na ratios were very low in the Ap and Bnt horizons at 0.57 and 2.00, respectively. Exchangeable sodium percentage (ESP) values were approximately 12 in the Ap horizon, increasing to about 42 in the Bnt2 horizon. ESP expresses the extent to which the soil exchange complex is occupied by sodium (Brady and Weil 1999). High levels of exchangeable sodium, greater than approximately 15%, are undesirable. No significant changes were found in pH or EC due to deep tillage but a significant increase in ESP in the Ap horizon of approximately 12 for the control to 25 in the ripped plots was observed.

Webster and Nyborg (1986) evaluated two Solonetzic soil sites in east-central Alberta, one of the sites was analyzed previously by Alzubaidi and Webster (1982). The deep tillage trials at both sites were prepared using a tractor-mounted cultivator to a depth of approximately 46 cm. Soil samples were taken in 15-cm increments from the soil surface to a depth of 90 cm. There was no significant increase in sodium adsorption ratio (SAR) at either test site from deep tillage (compared to the normal tillage check plot) for either 0 to 15 cm or 15 to 30 cm depths, but SAR was undesirably high in the range of 16 to 22. This differed from earlier work by Alzubaidi and Webster (1982) who found higher exchangeable sodium in the deep ripped trial versus normal tillage at one site. SAR is another method used to characterize the sodium status of soils in addition to ESP (Brady and Weil 1999). SAR provides information on the comparative concentrations of sodium, calcium and magnesium ions in the soil solution. It is more easily measured than ESP, and takes into consideration that adverse effects of high sodium are moderated by the presence of calcium and magnesium ions. SAR values greater than approximately 13 are undesirable.

Bole (1986) evaluated leaching, deep ripping and acidification on an irrigated calcareous Solodized Solonetz in Alberta during four seasons. Elemental sulfur was used to create acidic conditions and dissolve the naturally occurring lime. Ripping was completed to a depth of 50 to 60 cm with 50-cm shank spacing. Deep ripping resulted in significantly lower levels of soluble sodium and SAR after the second year but the differences were not significant in the third or fourth year. Surface infiltration rate and hydraulic conductivity remained higher after 3.5 years with ripping compared to no ripping.

Wetter et al. (1987) measured differences in soil chemical parameters within the rip zone of the shank and 30.5 cm to the side of the shank three years after ripping. The soil was a Dark Brown Solodized Solonetz in Alberta with a dense Bnt horizon at a depth of 13 to 26 cm and a Cca horizon at depths greater than 32 cm. The treatments were ripped to a depth of 40 cm with 61-cm spacing. No significant differences in soil properties between the shank rip zone and the between-shank positions were found. Soil pH increased significantly in the Ap and Bnt horizons of the ripped versus control sites, SAR was reduced in the Bnt from approximately 12 to less than 7. Deep ripping elevated calcium salts from lower depths.

The lack of effect between the rip zone of the shank versus the between-shank position was attributed to a homogenous working of the soil during the ripping operation. Soil conditions were dry at the time of ripping, the Bnt columns were above the subsoiling depth and the ripping was done with a narrow shank spacing of 61-cm. There was no evidence that the two subsoiled treatments were reverting to the previous conditions.

The effects of deep ripping on EC, SAR and pH were also measured by Riddell et al. (1988) three years after ripping at two sites in east-central Alberta. The soils at both sites were classified as Dark Brown Solodized Solonetz. Both soils had a Bnt horizon from 8.5 to 22.5 cm below the surface, a BC horizon at 22.5 to 27.5 cm and a Csk horizon from 27.5 to 40 cm. Ripping was completed in two different years, using a different shank spacing for each field. The field with the 56-cm shank spacing was ripped to depths between 35 and 45 cm when the soil was moist. The following year the other field was ripped to 30 to 40 cm with 112-cm shank spacing, with very dry soil conditions. Sampling was conducted on the ripped soils in both the centre of the disturbed area created by the shank (below-shank) and 20 cm to one side (20-cm over). Ripping effects were compared to control samples from an unripped strip in the field where the 56-cm spacing was used, and from an undisturbed zone in the middle of the shanks on the 112-cm spacing. Deep ripping with the 56-cm shank spacing under moist conditions did not significantly change pH, EC or SAR in the disturbed area (below-shank or 20-cm over) versus the non-ripped. The researchers concluded sufficient moisture was present at the time of ripping to cause plastic flow shear, preventing a large zone of shear plane to develop, which is necessary to fracture the Bnt horizon. A shear plane should develop in dry conditions from upward pressure created by the tip of the subsoiler at the bottom of the curved shank. Ripping the other site at 112-cm spacing under dry conditions did result in significant differences in soil properties. The pH increased in the below-shank disturbed area of the Ap horizon to approximately 7.2 from 6.2 in the control and 6.8 for 20-cm over. The pH increased in the Bnt horizon to 8.7 below shank from approximately 7.6 in the control and 20-cm over. This change was attributed to upward lifting of subsurface material during ripping and capillary water movement. EC decreased significantly in the Csk horizon below the ripper shank to 2.8 from 4.0 in the control, but an increased EC was found in the 20-cm over samples to 5.0. The researchers concluded this was due to salts moving upward and laterally after ripping, although the value was not significantly greater than the control.

Bateman (1992) measured the effect from deep ripping as a function of relative position to the ripper shank on soil reconstructed after coal strip mining in central Alberta. The subsoil material originated from Solonetzic soil materials with a low exchangeable Ca:Na ratio. A layer of topsoil material 20 cm thick had been applied over the subsoil material. The depth of ripping was generally 40 cm to a maximum of 50 cm. Soil properties were measured in the disturbed zone created by the ripper shank (within-rip) and the undisturbed zones between ripper shanks (between-rip). Samples were taken from 0 to 7.5, 20 to 27.5 and 40 to 47.5 cm depths. The 0 to 7.5 cm depth represents the Ap horizon, the 20 to 27.5 cm depth is representative of the subsoil within the ripping depth, and the 40 to 47.5 cm depth represents subsoil below the ripping depth. A reduction in pH, EC and SAR was evident in the in-rip zone at the 20 to 27.5 cm depth, considered to be due in part to mixing of topsoil and subsoil materials within the zone of disturbance. At 40 to 47.5 cm, significantly lower EC and soluble ion concentrations were found in the in-rip positions. This was attributed to increased percolation of water and leaching of ions.

Grevers and de Jong (1993) studied the effect of deep ripping on soil properties at seven Solonetzic soil sites in the Dark Brown and Dark Grey soil zones in Saskatchewan. The Dark Brown soils were irrigated, while the Dark Grey sites were dryland. All sites were deep ripped in the fall. Soil moisture conditions at ripping were considered dry for the dryland sites and around wilting point for irrigated sites. Subsoiling was completed to an average depth of 60 to 76 cm, with shank spacing of either 60 or 112 cm. Soil samples were collected for chemical analysis to a depth of 90 cm, in increments of 0 to 15, 15 to 30, 30 to 60 and 60 to 90 cm. EC and SAR were not reduced significantly in the dryland sites due to subsoiling, but were reduced at one irrigated site.

Under irrigation or wet conditions there may be more leaching of sodium salts and therefore the benefits of deep ripping may last longer. The researchers suggest leaching of sodium likely occurs unevenly. Water probably moves down through continuous soil macropores of lower sodium material and bypasses areas that still contain high sodium. This would indicate the benefits of deep ripping would be shorter-term and subsoiling will have to be repeated periodically.

Carter and Pearen (1985) investigated the general and spatial variability of Solonetzic soils in north central Alberta. They note that previous work by Cairns (1961) and Sandoval and Reichman (1971) indicate Solonetzic soils generally show large variability in soil properties over short distances. The soils sampled were Black and Dark Brown Solonetz and Solodized Solonetz. Spatial variability as determined by point to point variation along transects was relatively large. Soil pH was less variable than extractable sodium or EC. Extractable sodium in the Ap horizon was highly variable. EC was highly variable, possibly due to the potential for resalinization to occur.

3.1.2 Soil Physical Properties

Several researchers reported deep ripping increased clay content at the surface (Lavado and Cairns 1980, Wetter et al. 1987, Bateman 1992, Grevers and DeJong 1993). Riddell et al. (1988) found no effect on clay content in the Ap horizon, but clay increased significantly in the 8.5 to 22.5 cm zone and decreased in the 27.5 to 40 cm zone.

Grevers and DeJong (1993) found soil bulk density decreased in the rip zone for 2 to 3 years after deep ripping. Bateman (1992) found bulk density and PR at the 20 to 27.5 cm depth was significantly reduced in the rip zone, and PR was lower at 40 to 47.5 cm in the within-rip versus the adjacent between-rip position.

Lavado and Cairns (1980) reported a decrease in infiltration rate in the Ap horizon after ripping, but an increase in infiltration in the Bnt at one site. Bole (1986) found an increase in the surface infiltration rate after 3.5 years. Wetter et al. (1987) found no change in available water at the 13 to 26 cm depth but more available water in May and June at the 26 to 38 cm depth due to ripping. Riddell et al. (1988) found soil water penetrated deeper in the ripped profile than in the control. Bateman (1992) found increased water percolation in the rip zone and an increase in water content at lower depths of 40 to 47.5 cm. Grevers and DeJong (1993) reported a greater percentage of available water was coming from lower in the soil profile after deep ripping. They found an increase in the soil water recharge due to ripping for 2 to 3 years.

3.1.3 Research Objectives

The deep ripped and unripped control treatments were compared to determine if significant differences in soil properties exist after 15 to 20 years. Soil pH, EC and SAR were the chemical properties selected for evaluation. Analysis of chemical properties provided information on whether beneficial or detrimental effects are present from ripping. Sodium level was found to be elevated in the Ap horizon after ripping by Lavado and Cairns (1980) and Alzubaidi and Webster (1982). Increased sodium levels in the Ap horizon can have a detrimental effect on soil tilth. Bole (1986) found a decrease in SAR over the sample depth, and Wetter et al. (1987) and Bateman (1992) found a decrease in in SAR at the Bnt depth. If additional leaching of sodium was to occur from the B horizon it may prevent the hardpan layer from reforming. The results of previous research are inconsistent as Webster and Nyborg (1986) found no change in SAR in the Ap horizon, and Riddell et al. (1988) found no change in SAR at two sites. An increased pH in the Bnt horizon was observed by Lavado and Cairns (1980), Wetter et al. (1987) and

Riddell et al. (1988). Bateman (1992) reported a decrease in pH in the rip zone at the subsoil depth. A decrease in EC was reported below the ripper shank by Riddell et al. (1988) at one of two sites and by Bateman (1992). EC did not change significantly in research by Alzubaidi and Webster (1982) and for six of seven sites by Grevers and DeJong (1993).

Physical properties selected were soil texture, bulk density and penetration resistance. Soil texture was evaluated to determine if the ripping process elevated additional clay into the Ap horizon as reported by several previous researchers (Lavado and Cairns 1980, Wetter et al. 1987, Bateman 1992, Grevers and DeJong 1993). High clay content at the surface can be detrimental to soil tilth, especially if sodium is elevated. A decreased bulk density in the rip zone was reported by Grevers and DeJong (1993) and Bateman (1992). Soil bulk density and penetration resistance (PR) were measured to determine if the hardpan layer remains less dense from ripping. A fundamental concern of deep ripping is how long the hardpan layer remains physically disturbed.

The null hypothesis tested was that variance of selected soil chemical and physical properties will be similar on the ripped and unripped treatments. Several researchers have reviewed the effects of deep ripping on similar soil chemical and physical properties in Western Canada. Varying trends have been reported with the studies occurring within a few years of deep ripping. This study examined the effects of deep ripping on soil chemical and physical properties after a longer time frame of 15 to 20 years.

3.2 Materials And Methods

3.2.1 Research Sites

The eleven field sites for this study came from on-farm sites deep ripped 15 to 20 years ago in the late 1970s and early 1980s. The sites were established by the Soil and Crop Management Branch of Alberta Agriculture, prior to Alberta Agriculture becoming Alberta Agriculture, Food and Rural Development (AAFRD). Deep ripping practices were normal for the time period of establishment, but were not identical across sites. The farmer cooperators managed the sites as part of their normal farming operations with consistent practices across treatments, but different crops and tillage practices at various sites. AAFRD discontinued monitoring of the sites in 1993. Sites for this study had to be located where consistent practices were continued across treatments. This study examines soil parameters from the deep ripped and unripped control treatments at one point in time after ripping, therefore a minimum of ten sites was desirable covering a broad region in east-central Alberta. Sites were selected on the basis of location, the plot markers having remained visible, the required deep ripping treatment being present and the unripped check strips remaining with no alterations. A list of twenty potential sites was created in consultation with AAFRD staff. The potential sites were visited and some were rejected due to lack of plot markers, inaccessibility, or recent management practices. Eleven sites were evaluated for soil properties out of approximately 13 that were suitable. The eleven sites were considered randomly chosen due to the sites being chosen initially by AAFRD, and the remaining suitable sites being the result of farmer cooperators randomly retaining plot markers along with consistent management across treatments.

3.2.2 Soil Sampling

All sites were sampled in spring 1998 and 1999. The majority of sampling was completed in 1998 with additional penetrometer readings taken in 1999. A 160-m long section from the ripped and unripped treatments was sampled for each site.

3.2.3 Soil Chemical and Physical Analyses

In 1998 core samples were taken at 12 locations in each treatment using 15-cm depth intervals, to a depth of 30 cm. Samples were systematically taken with three random samples within each 40-m distance to ensure a good distribution of sample points. The sampling locations were altered side to side within the plots to minimize the chance of sampling only in the ripper shank positions on the deep ripped plots (Figure 3.1). The 0 to 15 cm and 15 to 30 cm core samples were used for chemical and textural analysis. SAR was determined from all 12 samples, while pH and EC were determined in a 1:2 soil:water solution from 6 alternate core samples.

AAFRD had completed chemical analysis for some of the sites before ripping was completed. This information and literature review of deep ripping on similar soils indicated high variability of SAR and lower variability for pH and EC at these locations. Using the variance of the data from previous work it was determined that 12 samples should be sufficient to provide a desired confidence limit of 95%. The EC of an aqueous soil extract gives an estimation of the concentration of total soluble salts. Sodium, calcium and magnesium amounts from atomic adsorption spectrophotometry were used to calculate SAR. Soil analysis followed procedures described by McKeague (1978). SAR is easier to obtain than ESP and provides an indicator of the sodium status. Bulk density was determined at 6 of the core sampling sites, with one or two measurements taken from each 40 m section, depending on the ease of installing aluminum access tubes into the core sample holes. A Campbell Pacific 501 combination moisture-density probe was used to take two wet density and two moisture readings at depths of 15, 25, 35 and 45 cm. Dry bulk density was calculated from the average of wet density and volumetric moisture content readings. The % sand, silt and clay were determined from 4 samples using the Bouyoucos hydrometer method (McKeague 1978). One texture sample was evaluated from each of the four 40-m sections. Each site was managed independently by the farmer cooperators as part of their normal farming operations. The 0 to 15 cm sample depth corresponds to the depth of tillage and therefore had more management influence per site since ripping than the 15 to 30 cm samples. The 15 to 30 cm samples are representative of part of the B horizon, where the effect of ripping should be most apparent.

Penetrometer readings were taken at 32 random points and along 5 line transects within each treatment using a centre-cone penetrometer manufactured by Star Quality Samplers. Transects were used to ensure readings would be obtained from both the ripper shank position and between the ripper shanks. Each transect had 20 readings taken at 15-cm intervals across the direction of ripping (Figure 3.2). Penetration resistance (PR) values recorded were the maximum values obtained to push the cone into the soil to a depth of 32 cm. PR values were recorded in MPa, which represents an index of soil strength called the cone index (CI; Morrison and Bartek 1987). The cone index is the amount of force required per base area to push the cone into the soil, with the base area being the cross-sectional area at the base of the cone (Armbruster et al. 1990, Morrison and Bartek 1987).

Results can be influenced by the rate the penetrometer is pushed into the soil or by soil adhering to the cone or rod. Removal of soil adhering to the top of the cone and part way up the rod was required on several occasions. The cone was pushed into the soil by hand at a rate that attempted to approximate the ASAE Standard of 3.1 cm s^{-1} (Morrison and Bartek 1987). Penetration resistance values give an indication of the hardness or density of the soil, with values being influenced by soil moisture content and soil type (Armbruster et al. 1990). Soil moisture was low in spring 1998 resulting in very high PR readings. Two cone sizes are common, a 320-mm^2 and a smaller 129-mm^2 base area. The smaller cone with a 30 degree cone angle was used for all readings, but several sites still had PR values beyond the scale on the penetrometer. These values were all recorded as the maximum value of 11 MPa, thus providing a numerical value that could be used for statistical comparison with areas of lower PR readings. Penetration resistance readings were taken again in spring 1999 using the same sampling method. Soil moisture conditions were closer to field capacity by visual observation and most readings were below maximum values for the penetrometer.

3.2.4 Statistical Procedures

The general linear models procedure (GLM) of the Statistical Analysis System (SAS Institute Inc. 1989) was used to conduct a two way analysis of variance (ANOVA) for the selected dependent variables. The sites were treated as blocks with a ripped and control treatment present in each. Sites were considered as blocks due to the large variability in climate and soil parent material between sites. The experimental design was considered as part of a randomized complete block. The initial plots were established with other treatments between the ripped and unripped treatments at some sites. A two-way ANOVA was performed to determine if significant differences exist between treatments. The appropriate error term was specified based on sites being random not fixed. If the probability was ≤ 0.05, then the treatment effect was considered significant.

3.3 Results And Discussion

Properties from control plot data only are provided to indicate the variability in chemical and physical properties that exist without ripping at the sites (Tables 3.1 to 3.4). The deep ripping versus control plot treatment results are presented in Tables 3.5 to 3.8. Average mean values from both the control and deep ripped treatments together are presented in Tales 3.9 to 3.12.

Topsoil material (0 to 15 cm) in the control treatments ranged from a pH of 5.2 to 7.7 (Table 3.1). This range is considered strongly acid to mildly alkaline (Agriculture Canada Expert Committee on Soil Survey 1983). A pH value of $\leq$ 5.5 is of concern for growth of cereal grains (Brady and Weil 1999). Subsoil samples (15 to 30 cm) were more alkaline, ranging from a pH of 6.3 to 8.9. Topsoil and subsoil at all sites were low in soluble salts as indicated by low EC values (Table 3.1). Values did not exceed 0.50 dS m^{-1} in the topsoil, or 1.42 dS m^{-1} in the subsoil. Values less than 2 dS m^{-1} in a 0 to 60 cm depth interval are considered non-saline (Vander Pluym 1987). Yield reductions due to soluble salt content would not be a concern at any of the sites.

SAR varied considerably among sites, from 3.0 to 15.9 in the topsoil and from 3.3 to 19.8 in the subsoil or 15 to 30 cm depth (Table 3.1). SAR values of 5 or greater correspond to an exchangeable calcium to sodium ratio of 10 or less for Brown Solonetzic soils (Bennett et al. 2000). Soils of the Solonetzic order have a solonetzic B horizon with a ratio of exchangeable calcium to sodium of 10 or less, along with columnar or prismatic structure (Agriculture Canada Expert Committee on Soil Survey 1987). Ten of the eleven sites had subsoil SAR values greater than 5 (Table 3.1).

Mean clay values from the unripped controls for 0 to 15 cm samples ranged from 13.9 to 25.6% (Table 3.2). Clay values for the 15 to 30 cm samples ranged from 20.6 to 36.4%, all below the 40% clay content required to be classified as clay texture (Agriculture Canada Expert Committee on Soil Survey 1983). High clay content would not have been a limiting factor for crop growth. Overall mean bulk density for all sites was 1.40 Mg m^{-3} at the 15-cm depth, increasing slightly to 1.45 Mg m^{-3} at 45 cm (Table 3.3). These values are not extremely high and are below the range where root growth is limited in moist soils (Brady and Weil 1999). One of the problems with Solonetzic soils is the limited movement of water down into the B horizon. PR values for both random and transect sampling are correspondingly higher in 1998 versus 1999, likely due to lower soil moisture conditions in spring 1998 (Table 3.4). PR values are very high overall and indicate limiting conditions.

Evaluations of the deep ripped and unripped treatments are presented next (Tables 3.5 to 3.8). No significant treatment differences were found ($P \leq 0.05$) for pH, EC or SAR in the 0 to 15 cm depth interval (Table 3.5). This indicates that no detrimental chemical effects of deep ripping are apparent. Some researchers previously indicated increased levels of sodium in the Ap horizon after ripping which is undesirable (Lavado and Cairns 1980; Alzubaidi and Webster 1982). The 15 to 30 cm depth was not significantly different for pH or SAR, but a significant difference was observed for EC. Deep ripping may have improved water movement through the hardpan layer allowing more leaching of the soluble salts, but the soluble salt concentrations were very low in both. The deep ripped treatments had a mean EC value of 0.48 dS m^{-1} versus the control at 0.91 dS m^{-1}. A significant reduction in SAR from ripping would be desirable, but no significant differences were found. It is expected that deep ripping is mainly a physical improvement and major chemical changes are unlikely.

There were no significant treatment differences for soil texture ($P \leq 0.05$) at either 0 to 15 or 15 to 30 cm depths (Table 3.6). Previous research found deep ripping caused clay content to increase at the surface (Lavado and Cairns 1980, Wetter et al. 1987, Bateman 1992, Grevers and DeJong 1993). The effect of tillage at the 0 to 15 cm depth during the past 15 to 20 years may have caused clay elevated in the ripper shank position to be evenly distributed. Each site was managed independently by the farmer cooperator and tillage practices among sites were not consistent. The values for % clay, silt and sand were very similar for the deep ripped and unripped treatments.

Db was also not significantly different between deep ripped and control treatments for 15, 25, 35 or 45 cm depths (Table 3.7). The mean values were lower for the deep ripped versus the unripped control at all depths, and the probability of the mean values having the same variance was lower at the 25 cm depth than for the other depths at 0.1124. The 501 moisture-density probe takes a volumetric measurement and the 25-cm readings may have been influenced by tillage. Six subsamples were taken from each plot for Db and this may not have been sufficient to detect significant differences if the ripping effect was not homogeneous. PR values were significantly lower for the deep ripped versus the control treatments for 1999 (Table 3.8). Both random and transect samples were significantly different. There were no differences observed in 1988, considered due to dry conditions and recording of mostly maximum values on both the deep ripped and control treatments. The 1998 values contribute very little to the study since both treatments were almost entirely above the scale of the penetrometer. PR values for 1999 provide a good indication that the deep ripping treatment has retained beneficial effects at the time of sampling.

Mean soil pH across sites (including both the deep ripped and control treatments) was 6.4 for the 0 to 15 cm depth interval (ranging from 5.3 to 7.5), with 9 of 11 sites having pHs below 7.0 (Table 3.9). Mean soil pH for the 15 to 30 cm depth interval was 7.4, varying from 6.6 to 8.9. Mean soil EC varied little between the two depth intervals, 0.29 dS m^{-1} for the 0 to 15 cm depth interval and 0.69 dS m^{-1} for the 15 to 30 cm depth interval, both low values. Mean SAR was 6.1 for the 0 to 15 cm depth interval and 8.8 for the 15 to 30 cm depth interval. Three sites had SARs > 10 in both depth intervals. All sites had higher SARs in the lower depth interval, as expected for Solonetzic soils. Mean clay content increased from the upper interval to the lower while silt and sand content decreased (Table 3.10). Maximum clay content in the 15 to 30 cm depth interval was 37.5%. Mean soil bulk density increased slightly with depth, from 1.39 Mg m^{-3} at the 15- and 25-cm depths to 1.46 Mg m^{-3} at the 45-cm depth (Table 3.11). Mean PR values were high, ranging from 7.39 to 10.26 MPa, with higher values in 1998 than 1999, as expected for much drier soils in 1998 (Table 3.12).

3.4 Conclusions

Significantly lower penetration resistance was detected in deep ripped versus unripped control treatments. EC in the 15 to 30 cm depth was significantly lower in deep ripped treatments, but EC was low overall. Bulk density did not differ significantly between treatments. There was no significant difference in % clay or SAR, indicating no detrimental effect from ripping was apparent. Analysis of soil properties indicates beneficial effects from deep ripping are apparent 15 to 20 years after deep ripping.

3.5 References

Agriculture Canada Expert Committee on Soil Survey. 1983. The Canada soil information system (Can SIS), Manual for describing soils in the field 1982 revised. Research Branch, Agriculture Canada. Ottawa, Ontario. 164 pp.

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

Alzubaidi, A. and G.R. Webster. 1982. Effect of tillage in combination with chemical amendments on reclamation of a Solonetzic soil. Can. J. Soil Sci. 62: 641-649.

Armbruster, K., A. Hertwig and H.D. Kutzbach. 1990. An improved design of cone penetrometer. J. Agric. Eng. Res. 46: 219-222.

Bennett, D.R., F.J. Hecker, T. Entz and G.M. Greenlee. 2000. Salanity and sodicity of irrigated Solonetzic and Chernozemic soils in east-central Alberta. Can. J. Soil Sci.80: 117-125.

Bateman, J.C. 1992. The effects of deep ripping and organic matter amendments on soils reconstructed after coal strip mining. M.Sc. Thesis. University of Alberta. Edmonton, Alberta. 169 pp.

Bole, J.B. 1986. Amelioration of a calcareous Solonetzic soil by irrigation, deep ripping, and acidification with elemental sulfur. Can. J. Soil Sci. 66: 347-356.

Brady, N.C. and R.R. Weil. 1999. The nature and properties of soils. 12th ed. Prentice-Hall Inc. Upper Saddle River, New Jersey. 881 pp.

Carter, M.R. and J.R. Pearen. 1985. General and spatial variability of Solonetzic soils in north central Alberta. Can. J. Soil Sci. 65: 157-167.

Grevers, M.J.C. and E. de Jong. 1993. Soil structure and crop yield over a 5-year period following subsoiling Solonetzic and Chernozemic soils in Saskatchewan. Can. J. Soil Sci. 73: 81-91.

Lavado, R.S. and R.R. Cairns. 1980. Solonetzic soil properties and yields of wheat, oats and barley affected by deep plowing and ripping. Soil Tillage Res. 1: 69-79.

McKeague, J.A. 1978. Manual on soil sampling and methods of analysis. Can. Soc. Soil Sci. Ottawa, Ontario.

Morrison, J.E. Jr. and L.A. Bartek. 1987. Design and field evaluation of a hand-pushed digital soil penetrometer with two cone materials. Trans. ASAE. 30(3): 646-651.

Riddell, K.M., G.R. Webster and J.C. Hermans. 1988. Effects of deep ripping on chemical and physical properties of a Solonetzic soil in east-central Alberta. Soil Tillage Res. 12: 1-12.

SAS Institute Inc., 1989. SAS/STAT Users Guide, Version 6, Fourth Edition, Volume 2, Cary, NC: SAS Institute Inc. 846 pp.

Vander Pluym, H.S.A. 1987. Dryland saline seep control. Agdex 518-11, Alberta Agriculture. Print Media Branch. Edmonton, Alberta. 12 pp.

Webster, G.R. and M. Nyborg. 1986. Effects of tillage and amendments on yields and selected soil properties of two Solonetzic soils. Can. J. Soil Sci. 66: 455-470.

Wetter, L.G., G.R. Webster and J. Lickacz. 1987. Amelioration of a Solonetzic soil by subsoiling and liming. Can. J. Soil Sci. 67: 919-930.

Table 3.1 Chemical properties of non-ripped control sites.

	pH		EC (dS m^{-1})		SAR	
Sites	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
A	6.9	7.7	0.37	1.40	3.8	6.6
B	6.2	6.8	0.17	0.18	2.9	5.1
C	6.0	6.9	0.22	0.71	3.0	3.3
D	6.2	7.9	0.37	1.42	15.9	15.3
E	7.0	8.9	0.34	1.22	13.5	19.8
F	7.7	8.2	0.15	0.34	4.0	7.3
G	5.2	7.0	0.29	0.11	2.2	5.3
H	6.3	7.7	0.32	1.41	12.6	13.7
I	6.8	7.9	0.23	0.30	3.3	5.2
J	5.7	6.3	0.19	0.96	6.6	11.8
K	6.0	7.0	0.50	1.90	6.8	9.8
Mean	6.4	7.5	0.29	0.90	6.8	9.4

pH and EC are mean values from 6 subsamples of the control plot for each site
SAR are mean values from 12 subsamples of the control plot for each site

Table 3.2 Textural properties of non-ripped control sites.

	% clay		% silt		% sand	
Sites	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
A	20.5	26.6	34.4	31.8	45.1	41.5
B	25.6	27.0	39.1	40.8	35.3	32.2
C	19.3	20.6	35.7	34.3	45.0	45.0
D	24.2	34.6	42.4	38.5	33.5	26.9
E	18.0	26.9	32.0	30.1	50.1	43.8
F	19.9	22.3	30.0	30.8	50.0	47.0
G	20.5	20.7	35.9	32.4	43.6	46.9
H	24.7	36.4	44.1	34.2	31.1	29.3
I	13.9	24.9	28.7	27.0	57.4	48.1
J	20.2	28.0	45.0	34.6	34.8	37.4
K	27.8	33.9	42.4	39.3	29.9	26.8
Mean	21.3	27.5	37.3	34.0	41.4	38.6

% clay, silt and sand are mean values from 4 subsamples of the control plot for each site

Table 3.3 Bulk density of non-ripped control sites.

	(Mg m^{-3})			
Sites	15 cm	25 cm	35 cm	45 cm
A	1.53	1.52	1.52	1.57
B	1.24	1.34	1.38	1.40
C	1.43	1.46	1.54	1.57
D	1.45	1.49	1.50	1.49
E	1.56	1.48	1.52	1.51
F	1.40	1.43	1.39	1.40
G	1.35	1.46	1.46	1.43
H	1.37	1.38	1.36	1.37
I	1.49	1.43	1.39	1.44
J	1.36	1.38	1.36	1.44
K	1.21	1.27	1.29	1.31
Mean	1.40	1.42	1.43	1.45

Bulk density are mean values from 6 subsamples of the control plot for each site
Mean/depth is mean value for all sites

Table 3.4 Penetration resistance of non-ripped control sites.

	(MPa)			
Sites	Random 98	Random 99	Transects 98	Transects 99
A	11.00	3.75	11.00	4.19
B	10.55	8.23	10.87	8.21
C	9.78	7.80	10.21	8.31
D	11.00	9.75	11.00	9.62
E	10.98	9.70	10.98	10.79
F	7.41	5.53	9.12	4.24
G	6.58	9.81	8.27	9.34
H	10.44	8.03	10.70	7.71
I	10.15	5.61	10.80	4.50
J	9.48	8.89	11.00	9.11
K	10.95	9.36	10.85	9.61
Mean	9.85	7.86	10.44	7.78

Penetration resistance are mean values from 32 random subsamples and 100 transect subsamples of the control plots for each site
Mean PR/year is mean value for all sites

Table 3.5 Mean soil chemical properties for deep ripped and control treatments.

	pH		EC (dS m^{-1})		SAR	
Depth	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Control	6.4	7.5	0.29	0.91a	6.8	9.4
Ripped	6.4	7.4	0.29	0.48b	5.4	8.3
Probability	0.9544	0.6396	0.8551	0.0288	0.1240	0.4143

n = 132 for pH and EC
n = 264 for SAR
Treatment means not followed by the same letter within each column are statistically different ($P \leq 0.05$) as determined by ANOVA

Table 3.6 Mean soil particle size distribution for deep ripped and control treatments.

	% clay		% silt		% sand	
Depth	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Control	21.3	27.4	37.7	35.9	41.4	38.6
Ripped	21.1	27.0	37.2	34.0	41.3	37.1
Probability	0.8053	0.7769	0.6034	0.1247	0.8974	0.2281

n = 88 for % clay, % silt and % sand
Treatment means not followed by the same letter within each column are statistically different ($P \leq 0.05$) as determined by ANOVA

Table 3.7 Mean soil bulk density for deep ripped and control treatments.

	(Mg/m^3)			
Depth	15 cm	25 cm	35 cm	45 cm
Control	1.40	1.42	1.43	1.48
Ripped	1.38	1.37	1.41	1.45
Probability	0.6233	0.1124	0.3466	0.2027

n = 132 for Db
Treatment means not followed by the same letter within each column are statistically different ($P \leq 0.05$) as determined by ANOVA

Table 3.8 Mean soil penetration resistance for deep ripped and control treatments.

	(MPa)			
	Random 98	Random 99	Transects 98	Transects 99
Control	9.85	7.86 a	10.43	7.98 a
Ripped	9.75	6.91 b	10.09	6.84 b
Probability	0.4940	0.0180	0.2495	0.0286

n = 704 for random PR and 2200 for transect PR
Treatment means not followed by the same letter within each column are statistically different ($P \leq 0.05$) as determined by ANOVA

Table 3.9 Mean soil chemical properties across sites.

	pH		EC (dS m^{-1})		SAR	
Sites	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
A	6.8	7.7	0.39	1.06	4.5	6.8
B	6.1	6.7	0.19	0.19	2.8	4.8
C	6.0	7.0	0.24	0.60	3.6	6.4
D	6.5	8.0	0.58	1.10	13.5	14.6
E	7.5	8.9	0.29	0.90	10.5	16.4
F	7.3	8.0	0.14	0.57	5.1	7.3
G	5.3	6.8	0.28	0.12	2.0	4.6
H	6.2	7.8	0.30	1.15	12.6	16.4
I	6.8	7.5	0.21	0.23	2.3	4.2
J	5.7	6.6	0.16	0.64	4.9	8.6
K	5.9	6.9	0.40	1.08	5.1	7.0
Mean	6.4	7.4	0.29	0.69	6.1	8.8

n = 12 subsamples from each site for pH and EC
n = 24 subsamples from each site for SAR

Table 3.10 Mean soil texture across sites.

	% Clay		% Silt		% Sand	
Sites	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
A	19.0	24.6	35.5	33.8	45.6	41.7
B	26.4	26.8	41.2	41.5	32.4	31.7
C	19.1	24.6	35.9	34.1	45.1	41.3
D	26.2	35.8	42.7	36.9	31.1	27.3
E	19.2	24.4	29.5	28.9	51.4	46.7
F	16.3	20.4	29.2	31.3	54.5	48.3
G	20.3	22.6	36.6	33.3	43.1	44.1
H	25.2	37.5	43.6	35.6	32.2	27.0
I	15.1	21.1	30.2	31.4	54.7	47.5
J	18.7	25.2	45.8	38.6	35.5	36.2
K	27.8	36.1	41.9	39.1	30.3	24.8
Mean	21.2	27.2	37.5	35.0	41.4	37.9

n = 8 subsamples from each site

Table 3.11 Mean soil bulk density across sites.

	(Mg m^{-3})			
Sites	15 cm	25 cm	35 cm	45 cm
A	1.55	1.50	1.50	1.54
B	1.20	1.25	1.33	1.40
C	1.44	1.47	1.54	1.58
D	1.49	1.51	1.49	1.51
E	1.55	1.49	1.52	1.53
F	1.45	1.41	1.41	1.50
G	1.32	1.40	1.43	1.48
H	1.40	1.40	1.41	1.40
I	1.47	1.39	1.38	1.43
J	1.26	1.24	1.30	1.42
K	1.18	1.28	1.31	1.32
Mean	1.39	1.39	1.42	1.46

n = 12 subsamples from each site

Table 3.12 Mean soil penetration resistance across sites.

	(MPa)			
Sites	Random 98	Random 99	Transects 98	Transects 99
A	10.91	3.80	10.98	3.93
B	10.55	6.98	10.76	6.45
C	9.90	7.69	10.37	7.85
D	11.00	9.22	11.00	8.77
E	10.95	9.04	10.99	9.76
F	7.81	5.11	7.77	5.34
G	6.52	8.13	8.40	7.83
H	10.32	7.97	10.81	8.03
I	9.63	5.19	10.03	5.07
J	9.30	8.72	10.93	8.82
K	10.91	9.42	10.85	9.67
Mean	9.80	7.39	10.26	7.41

n = 64 random subsamples from each site
n = 200 transect subsamples from each site

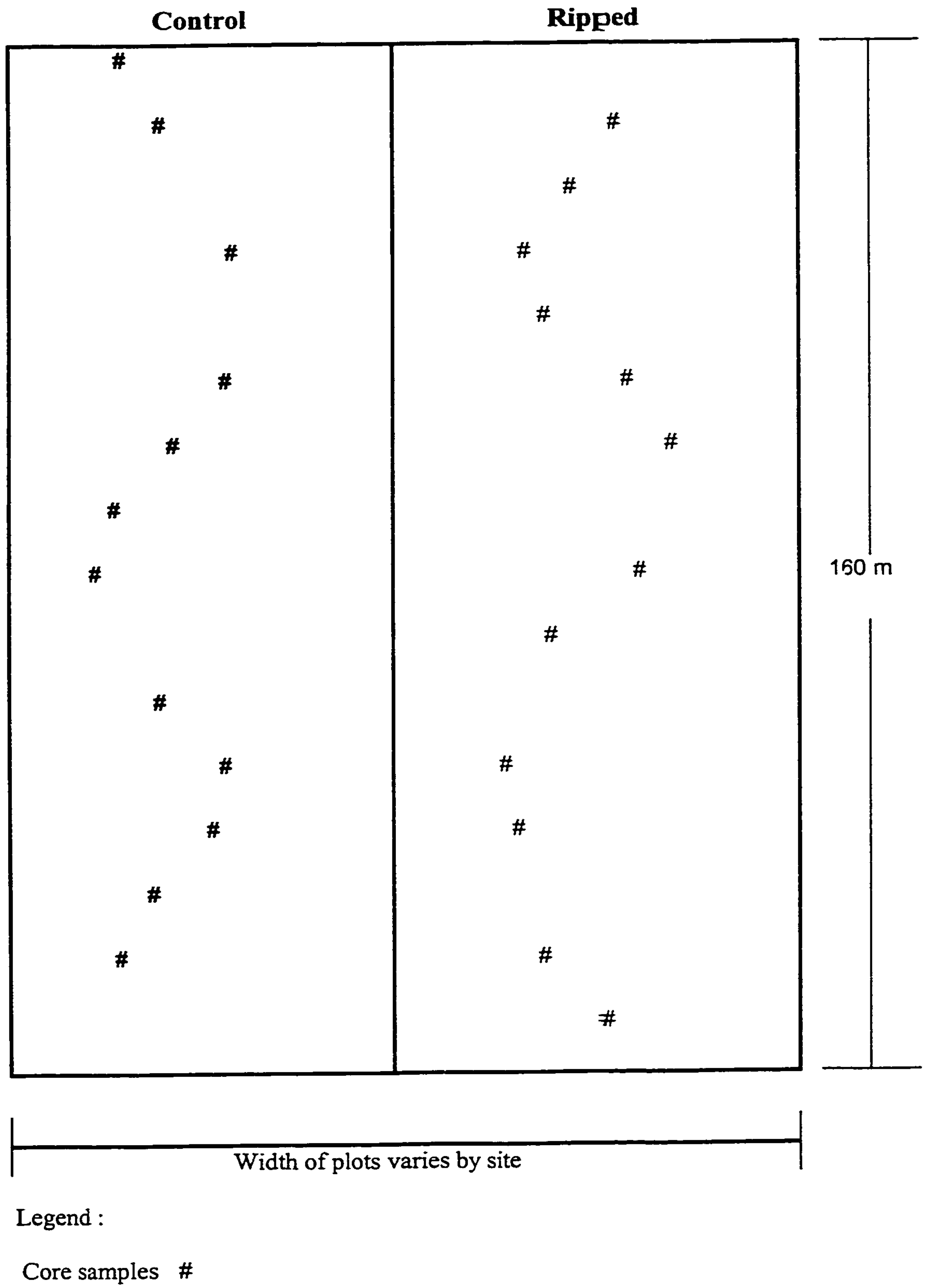
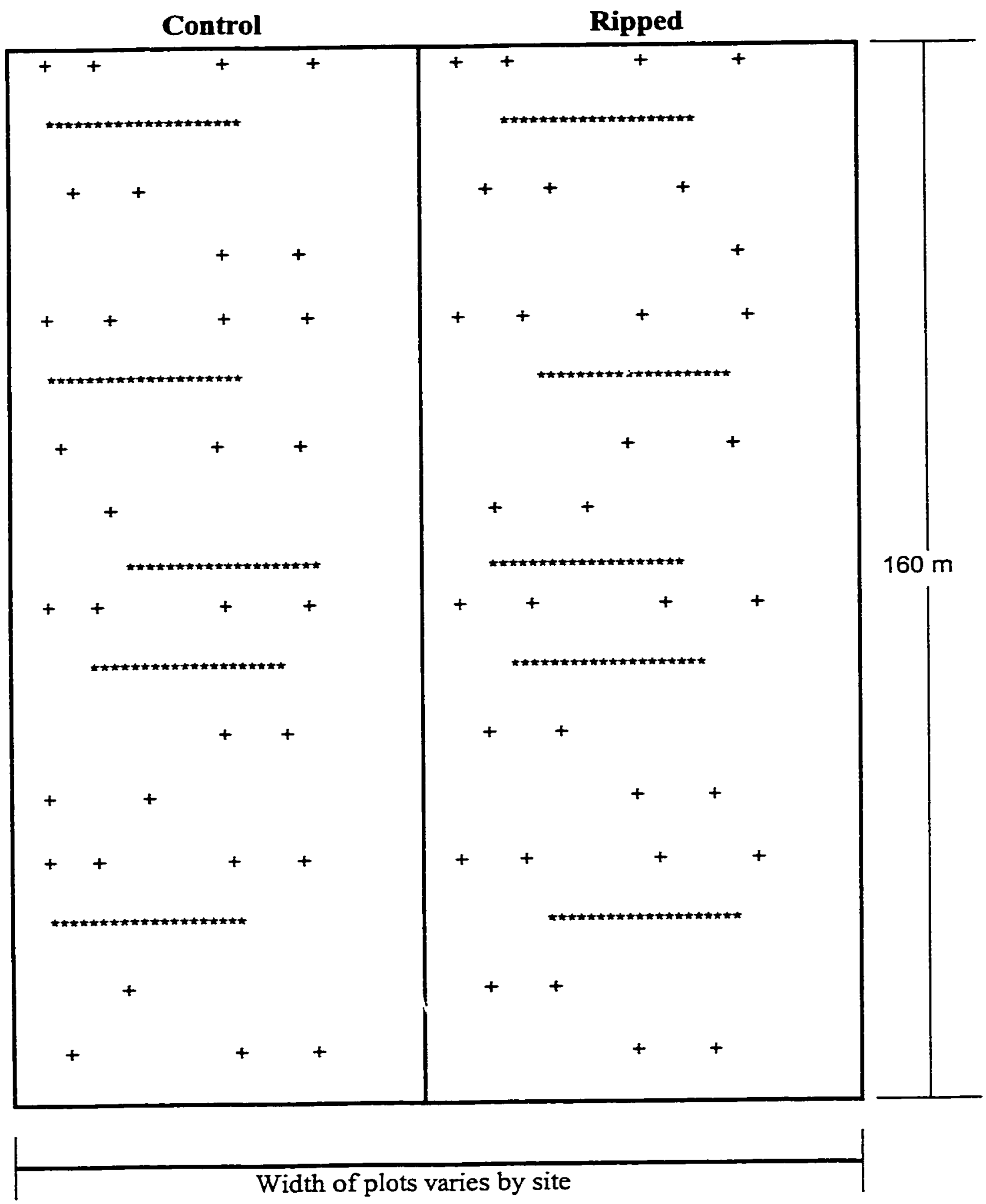


Figure 3.1 Schematic diagram of typical core sampling locations.



Legend:

PR Transects ******** (20 sample points at 15 cm intervals)

PR Random + +

Figure 3.2 Schematic diagram of typical penetration resistance evaluations.

IV. EFFECT OF DEEP RIPPING ON CROP YIELD

4.1 Introduction

The hardpan layer found in Solonetzic soil is very hard when dry and restricts water movement in the profile when wet (Grevers and Boehm 1994). This restricts moisture storage and root development to the surface soil, often resulting in moisture stress to crops and reduced yields. Solonetzic soils often occur in a complex and very close association with non-hardpan soils (Hardy 1984). This discontinuous occurrence of Solonetzic soils in association with other soils for the region often results in distinct Solonetzic patches in a given field. The wavy crop pattern typical of Solonetzic soils indicates differences in root development and topsoil depth that occur over short distances in the field (Lickacz 1993).

Management of Solonetzic soils for seedbed preparation requires timely operations in regard to soil moisture conditions. If Solonetzic soils are worked when they are too wet or too dry, they tend to form large clods. The occurrence of Solonetzic soils as patches in a field, often in close association with non-Solonetzic soils, makes optimum timing of field operations difficult for the entire area. After a rain the A horizon on the Solonetzic patches may remain wet compared to an adjacent Chernozemic area, due to the shallower topsoil and the restricted movement of water into the B horizon. If the Solonetzic patches occur over a small portion of the entire field, then tillage or seeding operations may be timed for the larger non–Solonetzic area. Large clods and poor soil tilth on the Solonetzic areas then result in poor or uneven seed germination and crop establishment.

The benefit to the agricultural producer of deep ripping Solonetzic soils will mainly be an increase in revenue as determined by increased productivity, although secondary benefits such as more uniform ripening of crops or a reduction in the need to summerfallow may be realized. Revenue increase is related to the magnitude of the productivity increase as well as the duration of the benefit.

Several researchers have evaluated the benefits of deep tillage on non-Solonetzic soils. Sene et al. (1985) reviewed some of the literature related to deep tillage on hardpan soils.

They reported that Naderman and Randall (1984) found deep tillage increased corn yields by 80% on some soils in the eastern United States while there was no yield increase, or even yield reductions, for others. Carter and Tavernetti (1968) found cotton yields in California decreased when soil bulk density increased from 1.5 to 1.6 Mg m^{-3}. Gerard et al. (1982) determined that root elongation ceases at critical soil strength values, which are texture related. The critical strength value ranged from a low of 2.5 MPa in clay soils to a range of 6.0 to 7.0 MPa for coarse textured soils, measured at field capacity. If the measured soil strength is above the critical value, then yield will be reduced.

Vepraskas and Miner (1986) found the number of roots below the Ap horizon in ripped treatments significantly greater than in non-ripped treatments. They also found the inverse relationship between penetration resistance and root concentration was significant and linear. Oussible and Crookston (1987) investigated the effect of yield and plant growth with deep ripping on compacted clay loam soil in Morocco. They found the ability of wheat roots to grow throughout the soil profile was not markedly different after deep ripping, but the roots were finer and more profuse. The plants in the ripped plots grew taller, had more reproductive shoots and more kernels of grain. This resulted in significant grain yield increases.

Stypa et al. (1987) investigated a silt loam Gleyed Melanic Brunisolic soil in Ontario and found bulk densities of 1.5 Mg m^{-3} at 15 to 45 cm depth did not restrict root development more than in an artificial medium of low bulk density. They suggested that due to natural structural cracks of the Bm horizon and biopores, rooting was not restricted as much as suggested by the bulk density. Roots were not able to develop into unstructured soil with a bulk density of 1.8 Mg m^{-3}.

Vepraskas (1988) investigated a method to estimate the probability that deep ripping will increase crop yields where dense tillage pans exist. Crop yield responses to deep ripping are related to both soil physical properties and the amount and distribution of rainfall. He noted that during years with adequate rainfall there may be little effect on crop yield from deep tillage. Deep tillage increased yields where a dense layer with a bulk density greater than 1.63 Mg m^{-3} existed within or just below the Ap horizon, and a sand content greater than or equal to 73% was present in the Ap horizon. The sand content was used to indicate water holding capacity of the soil. Through regression analysis he found tobacco yields increased through deep ripping in approximately 7 out of 10 years.

Lavado and Cairns (1980) studied the effect of subsoiling on crop yields at two Solonetzic locations in the Brown soil zone of Alberta. The soils were sampled two years after treatments had been applied, and the results compared to ordinary farm tillage. Deep ripping at one site resulted in improved yields in both field and greenhouse experiments over the control. At another site yield was only determined by greenhouse experiment, with yield lower for ripped than unripped treatments. Increased Na+ in the Ap horizon had a detrimental effect on soil physical properties. They concluded that a narrower Ca:Na ratio, a greater depth to the Bnt horizon and a higher clay content might be important factors contributing to the detrimental effect of deep ripping on crop growth at this site.

Webster and Nyborg (1986) evaluated two Solonetzic soil sites in east-central Alberta. The six-year average yield for two crops, at both sites, was not significantly different for deep ripped and normal tillage treatments. Bole (1986) found yields of spring barley in Alberta were not affected by leaching, deep ripping and acidification on an irrigated calcareous Solodized Solonetz over four seasons. Elemental sulfur was used to create acidic conditions and dissolve the naturally occurring lime. There was no significant yield increase from the deep ripping or sulfur treatments.

Grevers and de Jong (1993) studied the effect of deep ripping on soil physical properties and crop yield at seven Solonetzic soil sites in the Dark Brown and Dark Gray soil zones in Saskatchewan. The Dark Brown soil sites were irrigated, while the Dark Gray sites were dryland. Crop production was increased due to subsoiling for up to five years at one site, and up to four years at the other Solonetzic sites. One site had reduced crop emergence in the first year due to poor seedbed conditions. They concluded the increases in crop production were due to increased soil water extraction at greater depths, and greater water use efficiency. Approximately 67% of the soil water removed came from below 30 cm with deep ripping, versus 55% for the non-ripped treatments.

The crop yield advantage from deep ripping Solonetzic soils without chemical amendments or irrigation appears to decrease with time and speculation remains that the hardpan reforms (Grevers and Boehm 1994). Grevers and de Jong (1993) reported that yield increases from subsoiling persist for up to 5 years, and therefore subsoiling may need to be repeated on that time frame. Lickacz (1993) reported that yields from one deep ripped field were significantly greater than the unripped treatment after 14 years, and subsoiling may have long-term benefits if soil characteristics are suitable for deep ripping and the hardpan is thoroughly shattered.

4.1.1 Research Objectives

Yield data collected from the deep ripped and unripped control plots were compared to determine if significant differences exist. Substantial increases in yield or yield increases over a longer time period must be achieved for deep ripping to be cost effective for the farmer. The scientific literature reports mixed results for whether increased yield is achieved or how long the benefit is maintained. Further information is required in this regard for producers to make informed management decisions. This study examines sites where at least 5 years of yield data was available to determine if significant differences are present. The null hypothesis tested was that the variance in mean grain yield will be similar in the deep ripped and control treatments.

4.2 Materials And Methods

4.2.1 Research Sites

The study sites are located in the east-central region of Alberta on deep ripping plots established in the 1970s and early 1980s by the Soil and Crop Management Branch of Alberta Agriculture, prior to Alberta Agriculture becoming Alberta Agriculture, Food and Rural Development (AAFRD). Ten field sites were evaluated where at least five years of yield data were available from AAFRD for both the deep ripped and control treatments (Table 4.1). These ten sites are the same sites used for analyses of soil properties in Chapter III (one additional site was analyzed for soil properties). The Soil and Crop Management Branch collected yield data from the sites for varying numbers of years after establishment until monitoring was discontinued in 1993 (Soil and Crop Management Branch 1994). The sites were managed by the farmer cooperators as part of the normal field operations and crop rotations for the remainder of the field. The crops typically grown were wheat (*Triticum aestivum*), oats (*Avena sativa*), barley (*Hordeum vulgare*) and canola (*Brassica napus*). Wheat was the dominant crop grown, especially in the drier regions. Summerfallow was included as part of the crop rotation; therefore, yield data were not available in these years. Harvesting schedules of the farm cooperators and schedules of AAFRD staff also resulted in not all of the sites being evaluated every year. No distinction was available as to whether the site was summerfallowed or not sampled for other reasons.

4.2.2 Yield Sampling

Sampling by AAFRD consisted of clipping 10 to 20 square yard samples from each treatment, drying, threshing and recording grain and straw weights. Grain weights were evaluated for this study (Table 4.2), after conversion to a square metre basis. The number of site years of data collection ranged from 5 to 15.

4.2.3 Statistical Procedures

The sites were treated as blocks with a ripped and control treatment present in each. Sites were considered as blocks due to the large variability in climate. The experimental design was considered as part of a randomized complete block. The initial plots were established with other treatments between the ripped and unripped treatments at some sites. Yield data were analyzed statistically to determine if significant differences were present between the deep ripped and unripped control treatments. Yield data for the sites were not comparable in years of collection due to different plot establishment dates, differing number of years of data collection, different crops being grown at various sites and the absence of yield data for summerfallow years. Sites were not compared due to the differences in crop types grown. Each site was evaluated independently using a t-Test to determine if mean values from all the years crops were grown were significantly different

(P< 0.05 and P< 0.10) between the control and the deep ripped treatments using the statistical function of Microsoft Excel (Microsoft Corporation 1997).

4.3 Results And Discussion

A significant increase in grain yield due to deep ripping occurred at four sites ($P<0.05$), and at six sites $P<0.10$ (Table 4.3). The % yield increase ranged from 4 to 41%, and the mean grain yield was higher with deep ripping at all sites. Sites A, F, I and C are located in the lowest precipitation areas of the Dry Mixed Grass and Mixed Grass ecoregions (Strong and Leggat 1992) and had yield increases of 4, 12, 8 and 4% respectively. Sites H and D are located adjacent, and farthest north in the Aspen Parkland ecoregion. These sites had very different yield increases, 41% for site H and 7% for site D. Poor soil tilth due to surface cloddiness was visually apparent at site D and may have been a contributing factor. Overall, sites in the Aspen Parkland ecoregion (sites H, D, G, B, E and J) had greater yield increases than sites in the drier ecoregions.

There was considerable variability of yield data within treatments at all sites. This is a common occurrence with Solonetzic soils, due to the close association of Solonetzic and Chernozemic soils in these areas and the nature of Solonetzic soil (in Chapter III pH and SAR were found to be highly variable within and among sites). The coefficient of variation (CV) was high for all sites, including both control and deep ripped treatments, ranging from approximately 35 to 70% (Table 4.4). The average grain yield CV for the ripped treatment (48.0%) was marginally lower than that for the control (50.3%), and was lower than the control at seven of ten sites. For sites where the same crop was sampled for at least three years the standard error (SE) for the ripped treatment was lower than the control for four of nine sites (Table 4.5).

The change in yield for the ripped treatment compared to the control was determined for each year (Table 4.6). The majority of sites in any given year or the majority of sites over all years sampled; both showed a positive yield increase from deep ripping. There were 80 site years of data with 63 years showing a positive yield increase, 2 years with no change and 15 years with lower yields.

Precipitation data is provided from the Forestburg coal mine plant site for all years that correspond to the yield data (Table 4.7). Forestburg is located in the Aspen Parkland ecoregion, approximately in the centre of the area where the plots are located. The long-term average annual precipitation at this location is 401 mm, with the May to August long-term average at 254 mm. Precipitation for the May to August period inclusive was compared to the long-term average for the same period (Table 4.6). Seven of the years were higher than the long-term average, six years were below normal and three years were near average.

The inconsistency in the benefit of deep ripping is of concern to agricultural producers. There are many reasons that the yield increases may either not result or may not persist. In drier regions the moisture deficit may be so substantial that ripping to increase moisture storage and access of plant roots to the stored moisture may be of little economic value. Lickacz (1993) found crop responses to deep ripping were greater in higher precipitation areas. Another concern is how well the hardpan layer is shattered during the initial ripping operation. If the soil is too wet when ripped, very little shattering of the hardpan layer may occur. Information on how well the hardpan layer was initially shattered during ripping was not available for the sites. Ripping can result in adverse seedbed conditions the first year. Sites C and D both show a decline in yield on the deep ripped treatment for the first crop after ripping, which may be an indicator of this problem (Table 4.2).

The concern for agricultural producers will be the amount of yield increase from ripping and the time frame the benefits are received. Current and projected commodity prices will have to be considered. This study only examined whether there is potential for longer term yield increases or not. The magnitude of the yield benefits may not be sufficient to provide an economic return.

4.4 Conclusions

Significant increases in grain yield due to deep ripping occurred at six of ten sites ($P \leq 0.10$). All sites had a mean overall yield increase from deep ripping. Two sites had a beneficial effect over a period of more than 10 years, and all sites showed yield increases for the majority of years sampled. No visual trend was apparent towards a decline in yield benefits; therefore re-ripping may not be required on a regular basis.

4.5 References

Bole, J.B. 1986. Amelioration of a calcareous Solonetzic soil by irrigation, deep ripping, and acidification with elemental sulfur. Can. J. Soil Sci. 66: 347-356.

Grevers, M.J.C. and M.M. Boehm. (1994-Updated). Deep tillage of Saskatchewan soils. [Homepage of Saskatchewan Agriculture and Food], [Online]. Available: http://www.agr.gov.sk.ca/land_wat_clim/soil/Scd0294.asp [17 June 1999].

Grevers, M.J.C. and E. de Jong. 1993. Soil structure and crop yield over a 5-year period following subsoiling Solonetzic and Chernozemic soils in Saskatchewan. Can. J. Soil Sci. 73: 81-91.

Hardy, J.R. 1984. Solonetzic soils in Alberta-a review. Regional Development Branch (Alberta), Agriculture Canada. Edmonton, Alberta. 12 pp.

Lavado, R.S. and R.R. Cairns. 1980. Solonetzic soil properties and yields of wheat, oats and barley affected by deep plowing and ripping. Soil Tillage Res. 1: 69-79.

Lickacz, J. (1993-Revised). Management of Solonetzic soils. Adapted from Agdex 518-8 [Homepage of Alberta Agriculture, Food and Rural Development], [Online]. Available: http://www.agric.gov.ab.ca/agdex/500/1800008.html [14 Feb 2000].

Microsoft Corporation. 1997. Excel 97 SR-2. One Microsoft Way, Redmond, Washington.

Oussible, M. and R. K. Crookston. 1987. Effect of subsoiling a compacted clay loam soil on growth, yield, and yield components of wheat. Agron. J. 79: 882-886.

Sene, M., M.J. Vepraskas, G.C. Naderman and H.P. Denton. 1985. Relationships of soil texture and structure to corn yield response to subsoiling. Soil Sci. Soc. Am. J. 49: 422-427.

Soil and Crop Management Branch. 1994. Solonetzic soils deep tillage feasibility study-cumulative yield data. Unpublished. Alberta Agriculture. Edmonton, Alberta. 20 pp.

Strong, W.L. and K.R. Leggat. 1992. Ecoregions of Alberta. Alberta Forestry, Lands and Wildlife. Land Information Services Division, Resource Information Branch. Edmonton, Alberta. 59 pp.

Stypa, M., A. Nunez-Barrios, D.A. Barry, M.H. Miller and W.A. Mitchell. 1987. Effects of subsoil bulk density, nutrient availability and soil moisture on corn root growth in the field. Can. J. Soil Sci. 67: 293-308.

Vepraskas, M.J. 1988. A method to estimate the probability that subsoiling will increase crop yields. Soil Sci. Am. J. 52: 229-232.

Vepraskas, M.J. and G.S. Miner. 1986. Effects of subsoiling and mechanical impedance on tobacco root growth. Soil Sci. Soc. Am. J. 50: 423-427.

Webster, G.R. and M. Nyborg. 1986. Effects of tillage and amendments on yields and selected soil properties of two Solonetzic soils. Can. J. Soil Sci. 66: 455-470.

Table 4.1 Crops grown after deep ripping by site.

	Sites									
Year	A	B	C	D	E	F	G	H	I	J
1978	*		*		O*	*				
1979	--		--		O	--	*			
1980	W		W		W	W	W			
1981	--		--	*	W	--	--		*	
1982	W		W	B	W	W	W		--	
1983	W	*	W	--	W	--	B		W	*
1984	W	--	--	W	W	W	C		--	W
1985	W	--	W	O	W	--	W	*	W	O
1986	W	B	W	O	W	--	W	W	--	C
1987	W	W	--	--	W	--	B	B	W	W
1988	W	C	--	--	W	W	--	W	--	--
1989	W	B	--	B	B	--	C	C	W	C
1990	W	W	B	W	--	W	W	--	--	--
1991	W	--	--	--	W	--	B	B	W	--
1992	W	--	W	O	W	--	B	C	--	C
1993	W	--	--	--	W	--	--	--	--	--

* = year deep ripping occurred
W = wheat
B = barley
O = oats
C = canola
-- = no data available (summerfallow or not sampled)

Table 4.2 Mean value of grain yield (g m^{-2}) by site.

	Site A			Site B		
Year	Crop	C	R	Crop	C	R
1978	*					
1979	--					
1980	wheat	270	264			
1981	--					
1982	wheat	196	208			
1983	wheat	118	118	*		
1984	wheat	126	145	--		
1985	wheat	129	145	--		
1986	wheat	221	232	barley	245	286
1987	wheat	255	270	wheat	115	147
1988	wheat	209	185	canola	87	127
1989	wheat	136	152	barley	176	215
1990	wheat	148	127	wheat	246	287
1991	wheat	180	234	--		
1992	wheat	222	208	--		
1993	wheat	228	264	--		

	Site C			Site D		
Year	Crop	C	R	Crop	C	R
1978	*					
1979	--					
1980	wheat	155	116			
1981	--			*		
1982	wheat	180	226	barley	354	310
1983	wheat	95	106	--		
1984	--			wheat	151	208
1985	wheat	158	181	oats	88	146
1986	wheat	155	155	oats	229	227
1987	--			--		
1988	--			--		
1989	--			barley	112	95
1990	barley	134	124	wheat	105	235
1991	--			--		
1992	wheat	158	194	oats	152	217
1993	--			--		

Values are means of grain yield calculated from paired samples taken from the check (C) and deep ripped (R) treatments
* = year deep ripping occurred
-- = no data available (summerfallow or not sampled)

Table 4.2 continued. Mean value of grain yield (g m^{-2}) by site.

	Site E			Site F		
Year	Crop	C	R	Crop	C	R
1978	oats *	84	104	*		
1979	oats	81	120	--		
1980	wheat	200	278	wheat	283	313
1981	wheat	65	119	--		
1982	wheat	140	80	wheat	155	177
1983	wheat	93	108	--		
1984	wheat	73	125	wheat	135	128
1985	wheat	163	250	--		
1986	wheat	175	193	--		
1987	wheat	68	139	--		
1988	wheat	95	174	wheat	90	110
1989	barley	148	235	--		
1990	--			wheat	70	86
1991	wheat	174	192	--		
1992	wheat	97	136	--		
1993	wheat	150	185	--		

	Site G			Site H		
Year	Crop	C	R	Crop	C	R
1978						
1979	*					
1980	wheat	244	266			
1981	--					
1982	wheat	44	65			
1983	barley	508	477			
1984	canola	162	169			
1985	wheat	185	239	*		
1986	wheat	250	327	wheat	154	207
1987	barley	349	387	barley	171	223
1988	--			wheat	133	232
1989	canola	68	97	canola	106	108
1990	wheat	338	356	--		
1991	barley	255	359	barley	201	372
1992	barley	191	230	canola	82	49
1993	--			--		

Values are means of grain yield calculated from paired samples taken from the check (C) and deep ripped (R) treatments
* = year deep ripping occurred
-- = no data available (summerfallow or not sampled)

Table 4.2 continued. Mean value of grain yield (g m^{-2}) by site.

Year	Site I Crop	Site I C	Site I R	Site J Crop	Site J C	Site J R
1978						
1979						
1980						
1981	*					
1982	--					
1983	wheat	202	220	*		
1984	--			wheat	233	209
1985	wheat	136	149	oats	217	284
1986	--			canola	103	119
1987	wheat	177	221	wheat	159	158
1988	--			--		
1989	wheat	109	121	canola	116	130
1990	--			--		
1991	wheat	124	101	--		
1992	--			canola	57	62
1993	--			--		

Values are means of grain yield calculated from paired samples taken from the check (C) and deep ripped (R) treatments
* = year deep ripping occurred
-- = no data available (summerfallow or not sampled)

Table 4.3 Statistical comparison of grain yield (g m^{-2}) by site.

Site	# Years	Grain yield (g m^{-2}) Check	Grain yield (g m^{-2}) Ripped	Probability	% Increase
A	13	192.5	200.8	0.1480	4
B	5	173.8a	212.5b	0.0001	22
C	7	149.6	155.6	0.3266	4
D	7	177.9	191.1	0.4114	7
E	15	120.5a	165.5b	0.0001	37
F	5	139.1A	155.4B	0.0517	12
G	11	226.2a	259.4b	0.0001	15
H	6	143.0a	201.0b	0.0001	41
I	5	145.3	156.3	0.2395	8
J	6	157.7A	173.0B	0.0602	10

Treatment means not followed by the same lower case letter within each row are statistically different ($P \leq 0.05$) as determined by T-test

Treatment means not followed by the same upper case letter within each row are statistically different ($P \leq 0.10$) as determined by T-test

% Increase = % yield change of ripped minus check divided by check

Table 4.4 Coefficients of temporal variation of grain yield.

	Coefficient of Variation (%)	
Site	Control	Ripped
A	36.9	34.7
B	43.9	35.5
C	38.9	40.3
D	59.9	57.5
E	52.1	48.8
F	70.2	59.8
G	54.8	48.9
H	45.9	60.6
I	49.6	41.0
J	51.0	53.3

Table 4.5 Mean and standard error (SE) for one crop type at a site.

		Control		Ripped	
Site	Crop	Mean ($g\ m^{-2}$)	SE	Mean ($g\ m^{-2}$)	SE
A	Wheat	192.5	6.0	200.5	5.9
C	Wheat	151.6	5.5	159.8	6.1
D	Oats	159.0	11.4	182.6	12.8
E	Wheat	122.1	4.4	164.2	5.6
F	Wheat	139.1	11.9	155.4	11.3
G	Wheat	199.9	10.7	235.9	12.0
G	Barley	330.6	16.8	367.9	13.9
I	Wheat	145.3	8.4	156.3	7.5
J	Canola	95.4	5.0	108.3	7.6

Values are for 3 or more years of data for one crop type at a site

Table 4.6 Percent change in yield for ripped treatment over control by site across years.

		Sites									
Year	Ppt	A	B	C	D	E	F	G	H	I	J
1978	0.90					+24.4					
1979	0.94					+48.3					
1980	1.45	-2.0		+25.4		+39.4	+10.5	+8.9			
1981	0.78					+83.2					
1982	1.31	+6.4		+25.6	-12.3	-42.9	+14.0	+47.5			
1983	1.16	0.0		+11.2		+15.7		-6.2		+8.9	
1984	0.64	+15.4			+37.9	+70.6	-0.05	+4.1			-10.3
1985	1.04	+12.7		+14.7	+65.6	+52.8		+29.2		+9.1	+30.7
1986	0.96	+5.0	+16.8	0.0	-0.8	+10.7		+30.9	+34.7		+15.8
1987	0.87	+5.9	+27.6			+103.8		+10.9	+29.8	+24.8	-0.9
1988	0.88	-11.7	+45.1			+81.9	+21.9		+74.5		
1989	1.17	+12.4	+22.1		-15.9	+58.0		+43.2	+1.1	+11.5	+12.4
1990	1.20	-14.4	+17.1	-7.3	+123.2		+23.9	+5.5			
1991	1.27	+29.9				+10.3		+40.5	+85.0	-18.3	
1992	0.84	-6.3		+22.9	+43.1	+39.5		+20.5	-40.4		+8.8
1993	1.04	+15.9				+23.2					

Percent increase = (Average yield of ripped treatment – Average yield of control)/(Average yield of the control)

Ppt = (sum of monthly precipitation May to August inclusive in a given year)/(sum of long-term monthly precipitation May to August inclusive from Forestburg plant site)

Table 4.7 Precipitation data for the evaluation period of the yield data from the Forestburg plant site (mm).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	M-A	Ann
1978	26.5	11.9	2.8	19.0	80.1	59.9	30.4	56.9	73.2	20.1	17.9	5.1	227.3	403.8
1979	7.8	27.8	3.8	16.8	47.2	89.1	61.7	40.8	29.8	19.1	6.6	10.8	238.8	361.3
1980	16.3	13.0	17.7	5.7	43.3	142.6	60.2	122.1	36.9	6.0	0.2	45.9	368.2	509.9
1981	10.5	7.8	19.5	11.9	66.1	26.1	74.3	30.4	44.6	17.7	7.7	6.0	196.9	322.6
1982	44.8	8.9	20.3	6.9	56.8	46.6	135.9	93.9	44.8	24.5	11.3	5.2	333.2	499.9
1983	8.6	8.7	12.8	7.5	55.2	147.3	70.7	20.6	24.2	7.3	20.1	18.3	293.8	401.3
1984	24.3	0.5	10.7	17.3	22.2	80.1	23.0	36.6	117.8	11.2	14.9	20.6	161.9	379.2
1985	6.8	16.6	1.2	42.8	65.0	39.1	60.7	99.9	21.4	19.8	8.5	18.3	264.7	400.1
1986	12.1	13.7	28.9	23.1	23.4	46.6	149.8	24.6	65.3	15.4	18.9	1.8	244.4	423.6
1987	3.6	13.3	27.4	26.8	14.3	31.1	83.5	93.1	50.8	4.3	5.5	10.8	222.0	364.5
1988	6.3	14.9	30.0	1.4	10.0	86.3	38.3	88.8	62.7	7.3	6.9	19.1	223.4	372.0
1989	20.3	7.7	3.2	13.5	34.3	96.6	107.6	58.1	21.2	30.1	14.1	13.3	296.6	420.0
1990	15.7	7.1	16.0	16.0	20.4	103.2	140.3	42.1	4.8	12.3	16.0	11.9	306.0	405.8
1991	6.1	13.7	2.4	43.0	84.7	121.2	65.0	51.5	4.3	41.2	1.1	9.6	322.4	443.8
1992	8.0	18.6	5.7	19.9	64.7	21.7	96.2	31.1	38.0	22.6	10.2	22.7	213.7	359.4
1993	5.0	6.6	45.5	40.0	44.7	95.6	89.1	35.6	21.8	20.0	21.6	9.2	265.0	434.7
LTN	15.7	12.9	15.6	18.2	43.6	76.9	78.5	55.1	39.6	16.5	11.7	16.6	254.1	401.1

M-A = May to August
Ann = Annual precipitation
LTN = Long tem normal precipitation

V. SUSTAINABILITY OF DEEP RIPPING

5.1 Introduction

The longevity of deep ripping effects on Solonetzic soils is very important to agricultural producers. Mixed results have been reported on whether beneficial effects last. Wetter et al. (1987) reviewed deep ripping results, indicating generally favorable results in eastern Europe with mixed results in North America on Solonetzic soils. Grevers and de Jong (1993) reported that yield increases from deep ripping last up to 5 years, and therefore may need to be repeated on that time frame. Lickacz (1993) reported that yield increases were significantly improved by deep ripping after 14 years at one site, and deep ripping may have long-term benefits if the hardpan layer is thoroughly shattered at the time of ripping and soil characteristics are suitable. Mixed results have also been reported regarding whether substantial amounts of subsoil material is elevated to the surface during ripping, as well as the movement of water and ions in the profile after ripping. It would be beneficial if soil characteristics associated with a longer yield benefit from deep ripping could be identified.

Disturbed soils have less strength than undisturbed soils, and soils will show an increase in strength again over time. This may be referred to as age-hardening of soils, curing, strength regain or thixotropy (Dexter et al. 1988). Several processes are involved but the principal ones are particle rearrangement and particle-particle cementation. During soil disturbance clay particles in particular are displaced from low free energy equilibrium positions to higher energy positions. Over time these particles will rearrange back to the lower free energy positions and soil strength will increase. Therefore clay content may be one of the contributing factors to sustainability of deep ripping. Soil water content and the chemistry of the colloid/solute system are important in the rearrangement process, and many ions, molecules, colloids and amorphous gels are important in strengthening or cementing the particle-particle bonds.

Bennett et al. (2000) indicated SAR values greater than approximately 4.5 or ESP values greater than 5 result in greater potential for clay dispersion, structural breakdown and surface crust formation, which reduce crop yield. The threshold level for SAR to prevent structural deterioration may be lower than 10 for soils that disperse readily, and spring moisture leaches electrolytes from the surface. SAR may be another important factor in the sustainability of deep ripping.

Perumpral (1987) conducted a review of cone penetrometer applications. He concluded penetration resistance data are influenced by many factors including soil type, soil strength, soil moisture, penetrometer penetration rate, penetrometer cone size, shape and surface roughness; and therefore must be interpreted carefully. Elbanna and Witney (1987) found that soil PR is a function of soil moisture, soil specific weight and soil type. They found that soil strength measured with a cone penetrometer increased as soil water content decreased. At high clay ratios and low moisture contents very high cone penetration resistance values result. They indicated that Gerard et al. (1962) found a slow rate of drying caused closer packing of soil particles and harder soil conditions than a fast drying rate.

Mapfumo and Chanasyk (1998) found that a functional relationship exists between penetration resistance, bulk density and moisture content that varied significantly with soil texture. They stated that a penetration resistance (PR) of 2 MPa is the threshold value where plant growth is restricted, from earlier work by Taylor et al. (1996) and Naeth et al. (1991). Mapfumo and Chanasyk (1998) investigated a sandy loam, loam and clay loam soil. They found a PR of 2 MPa is achieved at a bulk density of 1.67 Mg m^{-3} for a sandy loam soil and 1.63 Mg m^{-3} for the loam soil, at any moisture content. For the clay loam soil, the bulk density that corresponds to a PR of 2 MPa varied with moisture content. At volumetric moisture contents of 10, 20 and 30%, the bulk densities were 1.54, 1.80 and 2.07 Mg m^{-3}, respectively. They concluded bulk density is the dominant independent variable that determines PR in coarser textured to medium textured soils, while moisture content is the dominant independent variable in finer textured soils that accounts for most variation in PR. The plastic limit of the coarser textured soils is lower than that of finer textured soils. The higher plasticity index of the higher clay soil means that it is subject to compaction over a wider range of moisture contents. They found that for the clay loam soil, field capacity lies within the danger zone for workability.

Therefore cultivation at field capacity could result in severe compaction. Tillage operations may therefore be another factor affecting sustainability of the benefit that occurs after initial ripping. Conventional tillage practices were common in the study area for the years examined.

5.1.1 Research Objectives

The objective of this study was to determine if soil factors contributing to yield increase from deep ripping could be identified using multiple linear regression. If a significant long-term yield increase from deep ripping occurs at some locations and not others, then it would be beneficial to identify the contributing factors. This information would help agricultural producers determine locations where benefits of deep ripping may be most sustainable.

5.2 Materials and Methods

Grain yield and precipitation data from Chapter IV were compared with chemical and physical data from Chapter III. The yield increase occurred on the deep ripping treatments; therefore relevant deep ripping data are evaluated. The percent yield increase obtained (deep ripping versus control treatments) is presented with relevant chemical and physical data from the deep ripping treatments for each site (Table 5.1). Precipitation data from the Forestburg plant site for the May to August period is presented in Table 5.2. The yield data were evaluated in relation to the physical and chemical data using multiple linear regression analysis. This method determines possible relationships of factors that influenced crop yield. Percent yield increase was used as the dependent variable and various soil physical and chemical factors as independent variables. The independent variables were analyzed first using the topsoil parameters (0 to 15 cm) and the PR values for 1999. PR values for 1998 were excluded as the majority of sites had many maximum values. The independent variables for subsoil parameters (15 to 30 cm) were then analyzed, and finally analyses of both topsoil and subsoil variables combined (Table 5.3).

Percent yield increase data are also presented with chemical and physical data from the control treatments (Table 5.4). Presumably this provides a representation of conditions similar to when deep ripping occurred. It would be beneficial if conditions prior to deep ripping could be used as an indicator of future yield increases. The independent variables for topsoil and subsoil were again analyzed using multiple linear regression, both separately and together (Table 5.5).

The yields for each crop type were plotted versus years after ripping to determine any trends (Figures 5.1 to 5.4). The majority of data were for wheat. The years of missing data may be summerfallow years, or simply years where not all sites had data collection. Individual sites with at least five years of data for a particular crop type were plotted to determine trends by site (Figure 5.5, 5.7, 5.9, 5.11, 5.13 and 5.15). The remaining four sites were not plotted as they did not have at least five years of data for a single crop type. A second graph was plotted with the addition of annual precipitation data from the Forestburg coal mine plant site for the May to August period (Table 5.2). These graphs provide a general indicator of precipitation for the region on a yearly basis. The data must be used with caution for any site as local moisture conditions may have varied significantly. The graphs are included to indicate yield fluctuations that may be mostly precipitation related (Figures 5.6, 5.8, 5.10, 5.12, 5.14 and 5.16). Site E and G are located closest to the Forestburg plant site, site C and A a little farther (approximately 90-100 km) and sites A, F and I farthest away (approximately 140 km).

5.2.1 Statistical Procedures

Multiple linear regression analysis was used to determine the significance of soil chemical and physical properties on crop yield. The regression procedure (Reg) of the Statistical Analysis System (SAS Institute Inc. 1989) was used to conduct multiple linear regression analysis using stepwise selection.

5.3 Results And Discussion

The topsoil parameters (0 to 15 cm) of importance for yield increase determined by stepwise multiple linear regression are EC, SAR and clay content (Table 5.3). The parameter of importance for the subsoil (15 to 30 cm) was clay content. The parameters of importance when all of the independent variables were used from Table 5.1 (excluding PR for 1998) were clay content for both the 0 to 15 and 15 to 30 cm depths, pH at 0 to 15 cm and SAR for 15 to 30 cm.

The comparison of grain yield for the deep ripped and control plots compared with years after ripping for all sites together are shown for each crop type (Figures 5.1 to 5.4). The yield advantage for the deep ripped plots does not appear to be decreasing with time. Site E has twelve years of data for wheat, with the last sampling fifteen years after deep ripping. The yield advantage of ripping is apparent throughout (Figure 5.9). This site had one of the highest yield increases with ripping, and has a higher pH and SAR at the 15 to 30 cm depth than most other sites, as well as a high PR (Table 5.1). Site H has the highest yield increase at 40.6%, and also has a high SAR and pH at the 15 to 30 cm depth, and high PR values. Site D is located near site H and has similar properties except it did not exhibit the higher yield increases. Personal observation of site D when sampling in 1998 and 1999 indicated poor soil tilth with many large and very hard aggregates at the surface. This may be a factor in the lower response to ripping. Sites with high sodium and clay at 15 to 30 cm would likely have a very hard layer that was restricting water and root penetration down into the soil profile. Ripping of these soils should provide access to more water and nutrients for the crops, likely accounting for the larger yield increases. In Chapter IV it was noted that sites in higher precipitation regions had larger yield increases.

Sites with a high SAR at the 15 to 30 cm depth have a higher PR reading, such as sites C, D, E and H (Table 5.1). Site A does not follow the trend but caution must be used since PR is very dependent on soil moisture conditions at the time of sampling. Visual observation indicated very good soil moisture conditions during sampling at site A in spring 1999.

It would be beneficial to agricultural producers if a prediction of the sustainability of deep ripping could be determined from the soil parameters prior to ripping. These models did not have as good a correlation as with the deep ripped data (Table 5.5). The only significant parameter for topsoil (0 to 15 cm) and subsoil (15 to 30 cm) depths was SAR. The R-square for the models and the significance of SAR was lower than for the deep ripped data (Table 5.5). The parameter of importance using stepwise multiple linear regression when all the independent variables were used from Table 5.4 (excluding PR for 1998) again was SAR for the 15 to 30 cm depth (Table 5.5).

A significant yield advantage occurred at many of the sites evaluated and all sites showed some increased yield for deep ripped versus unripped treatments (Chapter IV). The trend lines do not indicate that a major decline in this benefit has occurred. Evaluation of soil chemical and physical properties in Chapter III found a significant difference in EC at the 15 to 30 cm depth and PR (for 1999). The lower EC value for the ripped versus unripped treatments may indicate some leaching has occurred post-ripping but EC values were low overall. There were no significant differences for soil texture or SAR, indicating there were no long-term detrimental changes in soil physical or chemical properties from deep ripping. None of the study sites had any visual indication that resalinization was occurring.

Clay content, pH and SAR contributed significantly to yield increases. Additional information may be provided by further examination of the subsoil characteristics associated with the hardpan layer. A high SAR, pH and clay content at the 15 to 30 cm depth, along with high Db or PR readings would all be indicators of a very hard and impermeable B horizon. Evaluation of the control treatments indicates SAR at the 15 to 30 cm depth may be the best parameter to evaluate prior to ripping. Evaluation of soil physical and chemical parameters prior to deep ripping may provide useful indicators, but the regression models did not have good correlation. Success will still depend on achieving adequate shattering of the hardpan layer and development of adequate seedbed conditions.

5.4 Conclusions

The trend lines do not visually indicate that a decline in the beneficial effects from deep ripping is occurring after a period of up to 15 years. Multiple linear regression determined that clay content, pH and SAR contributed significantly to yield increases on the deep ripped treatments. Field evaluation prior to deep ripping of SAR at 15 to 30 cm, possibly with inclusion of clay content and pH, may provide a useful indicator for the long-term success of deep ripping at a particular location.

5.5 References

Bennett, D.R., F.J. Hecker, T. Entz and G.M. Greenlee. 2000. Salinity and sodicity of irrigated Solonetzic and Chernozemic soils in east-central Alberta. Can J. Soil Sci. 80: 117-125.

Dexter, A.R., R. Horn and W.D. Kemper. 1988. Two mechanisms for age-hardening of soil. J. Soil Sci. 39: 163-175.

Elbanna E.B. and B.D. Witney. 1987. Cone penetration resistance equation as a function of the clay ratio, soil moisture content and specific weight. J. Terramechanics 24:41-56.

Grevers, M.J.C. and E. de Jong. 1993. Soil structure and crop yield over a 5-year period following subsoiling Solonetzic and Chernozemic soils in Saskatchewan. Can. J. Soil Sci. 73: 81-91.

Lickacz, J. (1993-Revised). Management of Solonetzic soils. Adapted from Agdex 518-8 [Homepage of Alberta Agriculture, Food and Rural Development], [Online]. Available: http://www.agric.gov.ab.ca/agdex/500/1800008.html [14 Feb 2000].

Mapfumo, E. and D.S. Chanasyk. 1998. Guidelines for safe trafficking and cultivation, and resistance-density-moisture relations of three disturbed soils from Alberta. Soil Tillage Res. 46: 193-202.

Perumpral, J.V. 1987. Cone penetrometer applications- a review. Trans. ASAE 30(4):939-944.

SAS Institute Inc., 1989. SAS/STAT Users Guide, Version 6, Fourth Edition, Volume 2, Cary, NC: SAS Institute Inc. 846 pp.

Wetter, L.G., G.R. Webster and J. Lickacz. 1987. Amelioration of a Solonetzic soil by subsoiling and liming. Can. J. Soil Sci. 67: 919-930.

Table 5.1 Summary of deep ripping data with % yield increase.

Site	A	B	C	D	E	F	G	H	I	J
yield % Inc	4.3	22.3	4.0	7.4	37.3	11.7	14.7	40.6	7.6	9.7
clay 0-15	17.4	27.1	18.9	28.3	20.4	12.7	20.2	25.7	16.4	17.2
clay 15-30	22.5	26.6	28.5	37.0	22.6	18.6	24.4	38.5	17.3	22.4
pH 0-15	6.6	6.0	5.9	6.8	7.9	7.0	5.3	6.2	6.8	5.7
pH 15-30	7.8	6.6	7.1	8.1	8.8	7.7	6.6	7.9	7.0	6.9
EC 0-15	0.4	0.2	0.3	0.8	0.2	0.1	0.3	0.3	0.2	0.1
EC 15-30	0.7	0.2	0.5	0.8	0.6	0.8	0.1	0.9	0.2	0.3
SAR 0-15	5.2	2.8	4.3	11.0	7.6	6.2	1.7	12.6	1.4	3.2
SAR 15-30	7.0	4.6	9.4	14.0	13.0	7.3	3.9	19.2	3.2	5.3
Db 15	1.6	1.2	1.5	1.5	1.5	1.5	1.3	1.4	1.4	1.2
Db 25	1.5	1.2	1.5	1.5	1.5	1.4	1.3	1.4	1.4	1.1
Db 35	1.5	1.3	1.5	1.5	1.5	1.4	1.4	1.5	1.4	1.2
Db 45	1.5	1.4	1.6	1.5	1.5	1.6	1.5	1.4	1.4	1.4
PR-R (98)	10.8	10.5	10.0	11.0	10.9	8.2	6.5	10.2	9.1	9.1
PR-R (99)	3.9	5.7	7.6	8.7	8.4	4.7	6.4	7.9	4.8	8.5
PR-T (98)	11.0	10.7	10.5	11.0	11.0	6.4	8.5	10.9	9.3	10.9
PR-T (99)	3.7	4.7	7.4	7.9	8.7	4.2	6.3	8.4	5.6	8.5

Yield % Inc. = the average % yield increase of the deep ripped versus the control plot across years

Clay 0-15 = mean value of % clay from 4 subsamples of the deep ripped plot at 0-15 cm depth

Clay 15-30 = mean value of % clay from 4 subsamples of the deep ripped plot at 15-30 cm depth

pH 0-15 = mean value of pH from 6 subsamples of the deep ripped plot at 0-15 cm depth

pH 15-30 = mean value of pH from 6 subsamples of the deep ripped plot at 15-30 cm depth

EC 0-15 = mean value of EC (dS/m) from 6 subsamples of the deep ripped plot at 0-15 cm depth

EC 15-30 = mean value of EC (dS/m) from 6 subsamples of the deep ripped plot at 15-30 cm depth

SAR 0-15 = mean value of SAR from 12 subsamples of the deep ripped plot at 0-15 cm depth

SAR 15-30 = mean value of SAR from 12 subsamples of the deep ripped plot at 15-30 cm depth

Db = mean value of Db (Mg/m^3) from 6 subsamples of the deep ripped plot at the indicated depth in cm

PR-R = mean value of PR (MPa) from 32 subsamples of the deep ripped plot for the year 1998 or 1999, taken in a random pattern

PR-T = mean value of PR (MPa) from the 100 subsamples of the deep ripped plot for the year 1998 or 1999, taken as 5 transects (transect is 20 samples at 15 cm intervals across the direction of initial ripping)

Table 5.2 Precipitation for Forestburg plant site (May to August).

Year	Precipitation (mm)	Year	Precipitation (mm)
1978	227.3	1986	244.4
1979	238.8	1987	222.0
1980	368.2	1988	223.4
1981	196.9	1989	296.6
1982	333.2	1990	306.0
1983	293.8	1991	322.4
1984	161.9	1992	213.7
1985	264.7	1993	265.0

The long-term normal for the May to August period at this site is 254.1 mm

Table 5.3 Multiple linear regression analysis for deep ripped data.

Parameters	Selection	Variables	Probability	R^2 for model
Topsoil	Stepwise	Clay (0 to 15 cm)	0.0367	0.79
		SAR (0 to 15 cm)	0.0280	
		EC (0 to 15 cm)	0.0089	
Subsoil	Stepwise	Clay (15 to 30 cm)	0.0695	0.35
All Parameters*	Stepwise	Clay (0 to 15 cm)	0.0011	0.94
		Clay (15 to 30 cm)	0.0010	
		pH (0 to 15 cm)	0.0033	
		SAR (15 to 30 cm)	0.0006	

* excludes 1998 PR data

Table 5.4 Summmary of control plot data with % yield increase.

Site	A	B	C	D	E	F	G	H	I	J
yield % Inc	4.3	22.3	4.0	7.4	37.3	11.7	14.7	40.6	7.6	9.7
clay 0-15	20.5	25.6	19.3	24.2	18.0	20.0	20.4	24.7	13.9	20.2
clay 15-30	26.6	27.0	20.6	34.6	26.2	22.3	20.7	36.4	24.9	28.0
pH 0-15	6.9	6.2	6.0	6.2	7.0	7.7	5.2	6.3	6.8	5.7
pH 15-30	7.6	6.8	6.8	7.9	8.9	7.0	7.0	7.7	7.9	6.3
EC 0-15	0.4	0.2	0.2	0.4	0.3	0.1	0.3	0.3	0.2	0.2
EC 15-30	1.4	0.2	0.7	1.4	1.2	0.3	0.1	1.4	0.3	1.0
SAR 0-15	3.8	2.9	3.0	15.9	13.5	4.0	2.2	12.6	3.3	6.6
SAR 15-30	6.6	5.1	3.3	15.3	19.8	7.3	5.3	13.7	5.2	11.8
Db 15	1.5	1.2	1.4	1.4	1.6	1.4	1.4	1.4	1.5	1.4
Db 25	1.5	1.3	1.5	1.5	1.5	1.4	1.5	1.4	1.4	1.4
Db 35	1.5	1.4	1.5	1.5	1.5	1.4	1.5	1.4	1.4	1.4
Db 45	1.6	1.4	1.6	1.5	1.5	1.4	1.4	1.4	1.4	1.4
PR-R (98)	11.0	10.5	9.8	11.0	11.0	7.4	6.6	10.4	10.1	9.5
PR-R (99)	3.8	8.2	7.8	9.8	9.7	5.5	9.8	8.0	5.6	8.9
PR-T (98)	11.0	10.9	10.2	11.0	11.0	9.1	8.3	10.7	10.8	11.0
PR-T (99)	4.2	8.2	8.3	9.6	10.8	6.4	9.3	7.7	4.5	9.1

Yield % Inc. = the average % yield increase of the deep ripped versus the control plot across years

Clay 0-15 = mean value of % clay from 4 subsamples of the control plot at 0-15 cm depth

Clay 15-30 = mean value of % clay from 4 subsamples of the control plot at 15-30 cm depth

pH 0-15 = mean value of pH from 6 subsamples of the control plot at 0-15 cm depth

pH 15-30 = mean value of pH from 6 subsamples of the deep control at 15-30 cm depth

EC 0-15 = mean value of EC (dS/m) from 6 subsamples of the control plot at 0-15 cm depth
EC 15-30 = mean value of EC (dS/m) from 6 subsamples of the control plot at 15-30 cm depth
SAR 0-15 = mean value of SAR from 12 subsamples of the control plot at 0-15 cm depth
SAR 15-30 = mean value of SAR from 12 subsamples of the control plot at 15-30 cm depth
Db = mean value of Db (Mg/m^3) from 6 subsamples of the control plot at the indicated depth in cm
PR-R = mean value of PR (MPa) from 32 subsamples of the control plot for the year 1998 or 1999, taken in a random pattern
PR-T = mean value of PR (MPa) from the 100 subsamples of the control plot for the year 1998 or 1999, taken as 5 transects (transect is 20 samples at 15 cm intervals)

Table 5.5 Multiple linear regression analysis for control plot data.

Parameters	Selection	Variable	Probability	R^2 for model
Topsoil	Stepwise	SAR (0 to 15 cm)	0.1369	0.25
Subsoil	Stepwise	SAR (15 to 30 cm)	0.0686	0.36
All Parameters*	Stepwise	SAR (15 to 30 cm)	0.0686	0.36

*excludes 1998 PR data

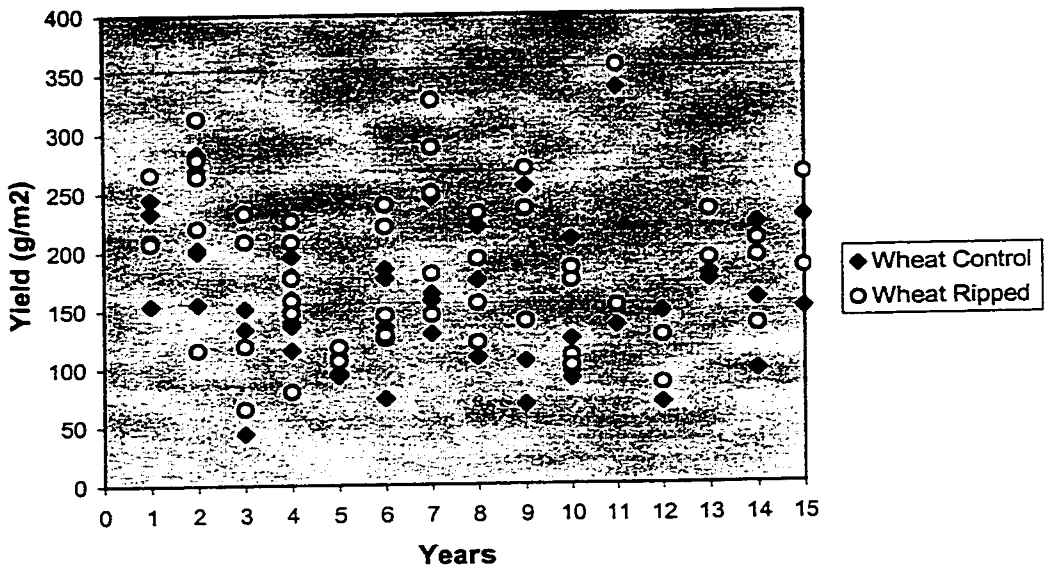


Figure 5.1 Wheat yields at all sites versus number of years after ripping for control and deep ripped plots.

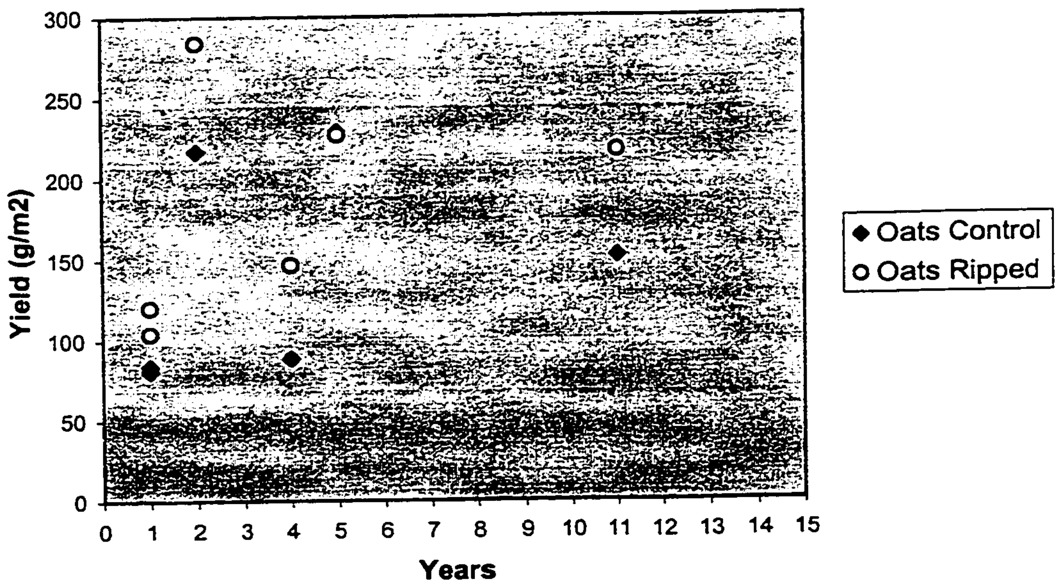


Figure 5.2 Oat yields at all sites versus number of years after ripping for control and deep ripped plots.

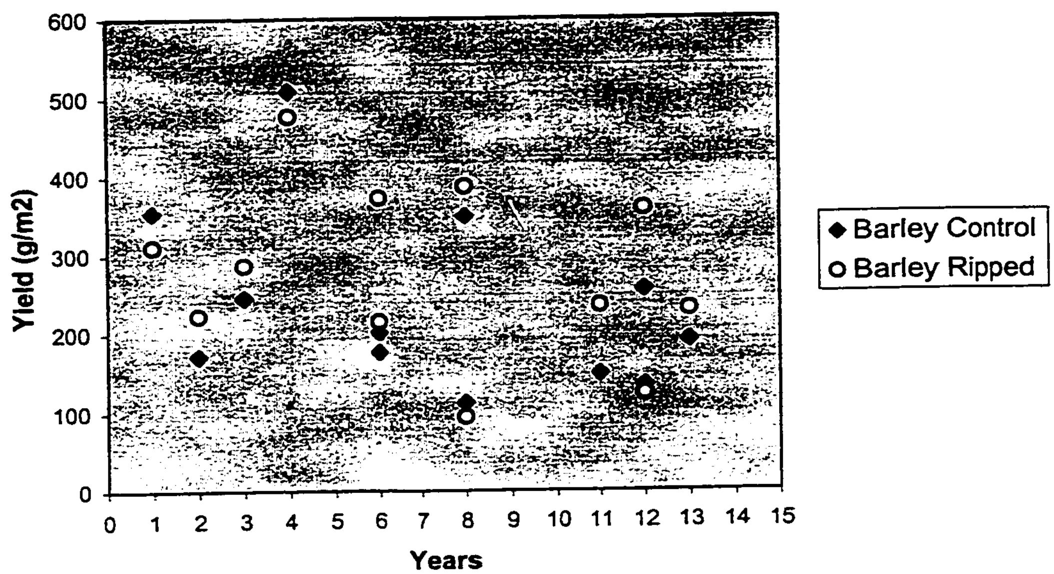


Figure 5.3 Barley yields at all sites versus number of years after ripping for control and deep ripped plots.

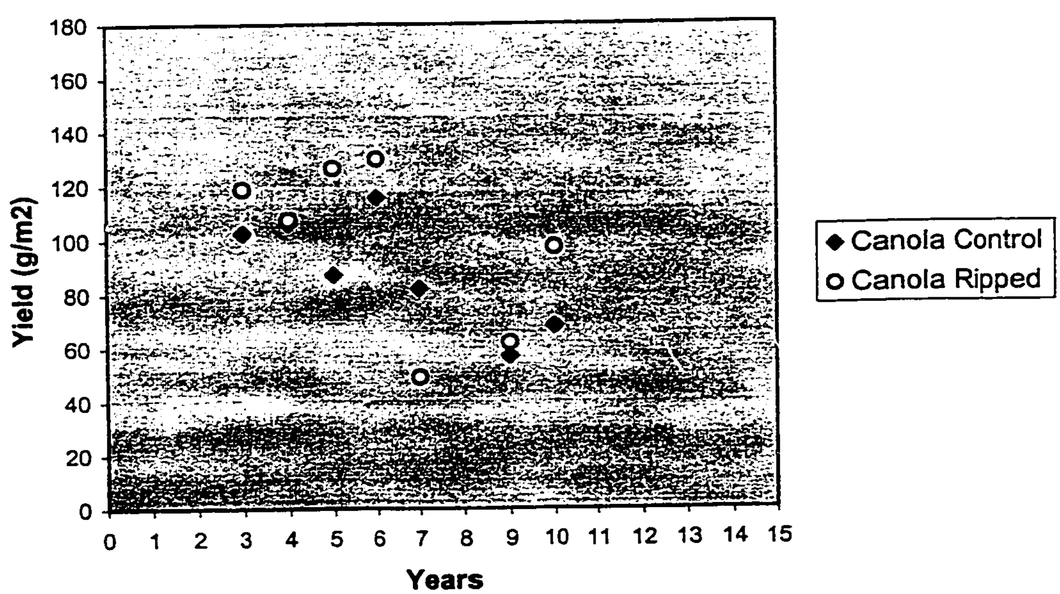


Figure 5.4 Canola yields at all sites versus number of years after ripping for control and deep ripped plots.

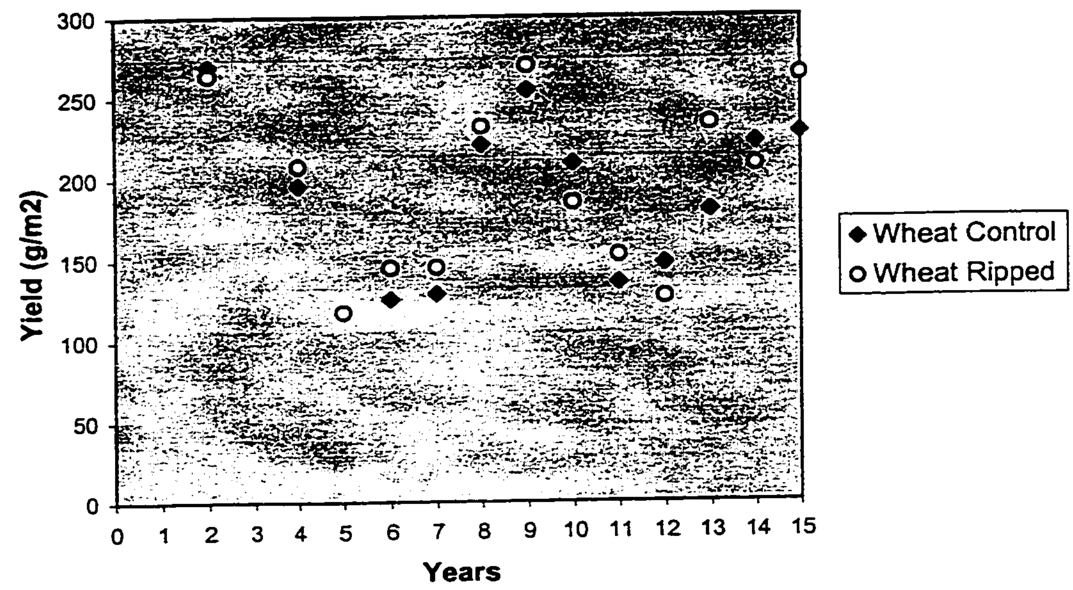


Figure 5.5 Wheat yield at site A versus number of years after ripping for control and deep ripped plots.

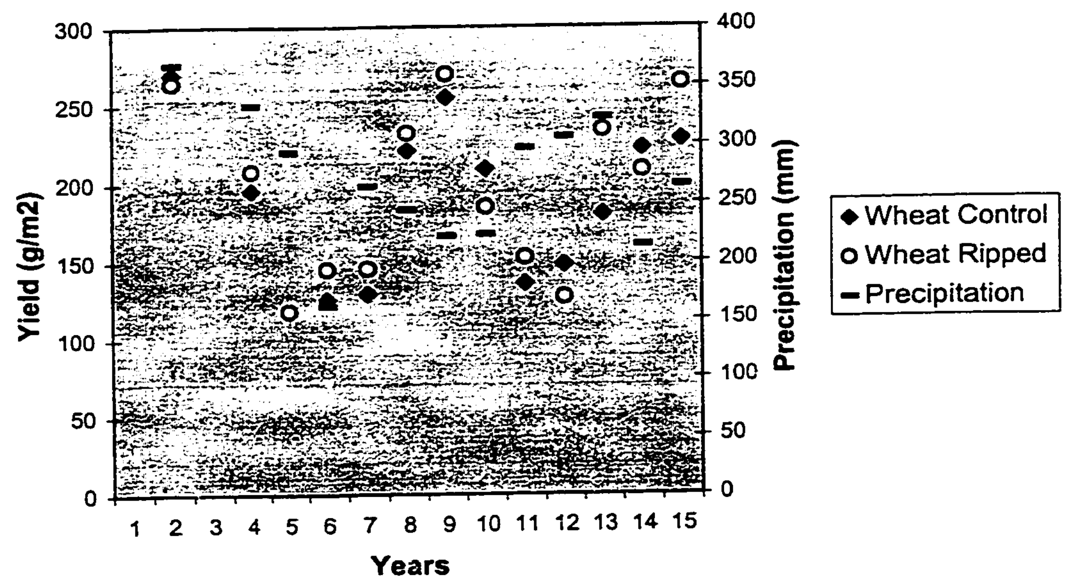


Figure 5.6 Wheat yield at site A versus years after ripping and general precipitation.

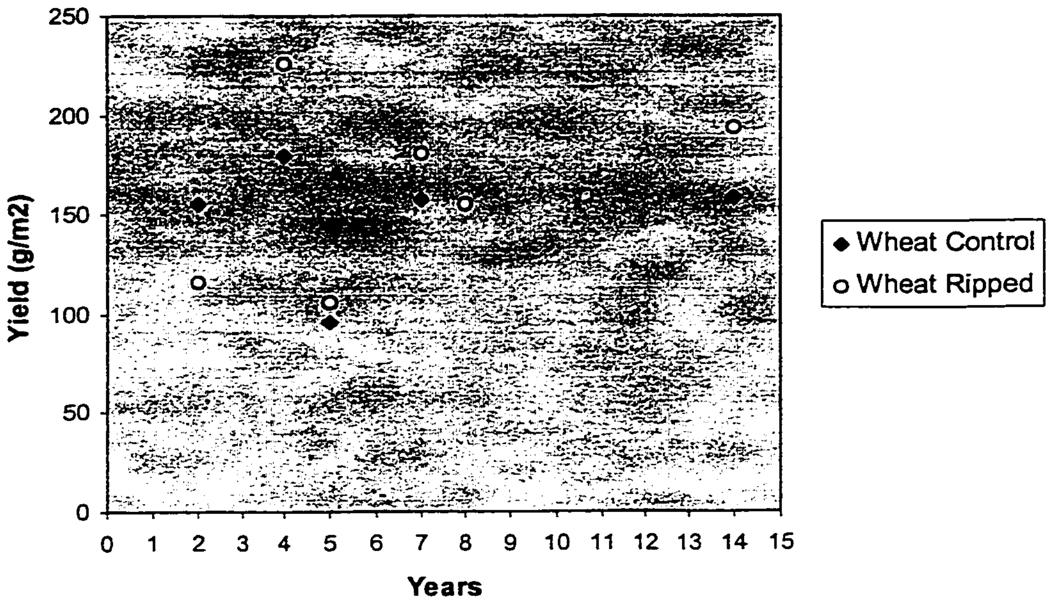


Figure 5.7 Wheat yield at site C versus number of years after ripping for control and deep ripped plots.

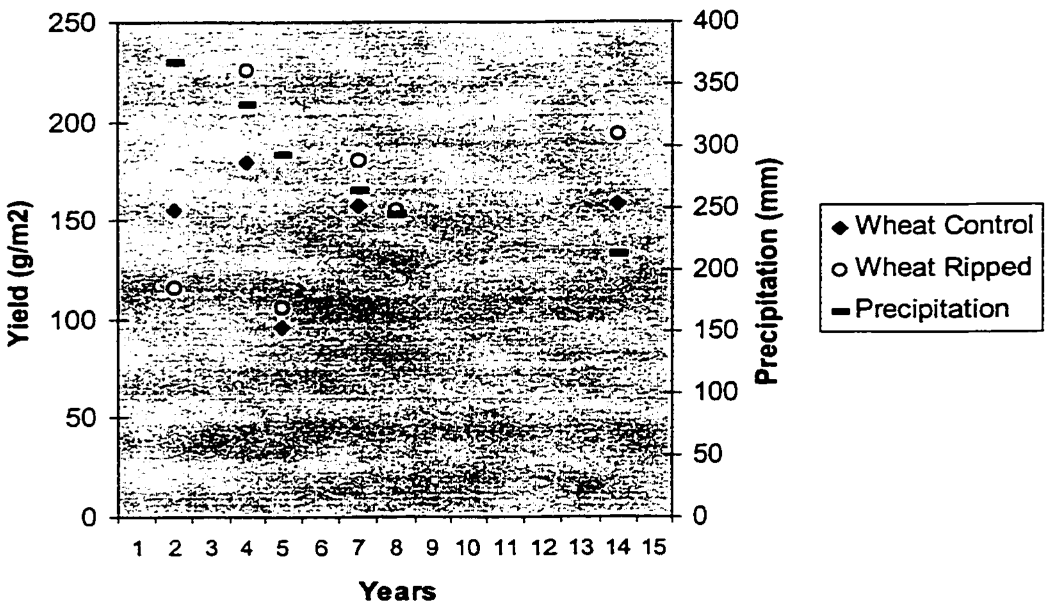


Figure 5.8 Wheat yield at site C versus years after ripping and general precipitation.

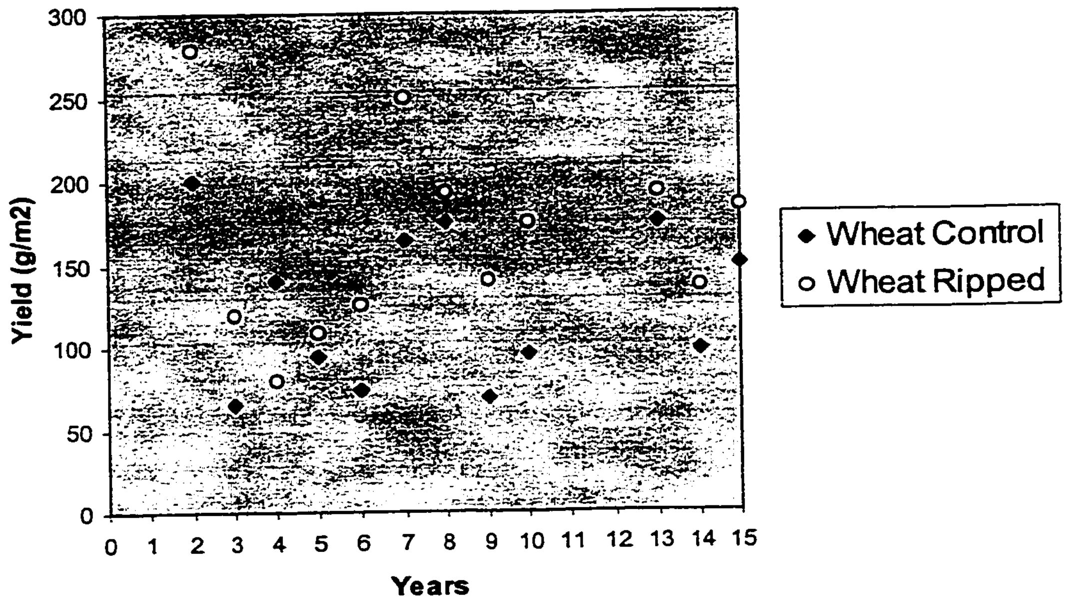


Figure 5.9 Wheat yield at site E versus number of years after ripping for control and deep ripped plots.

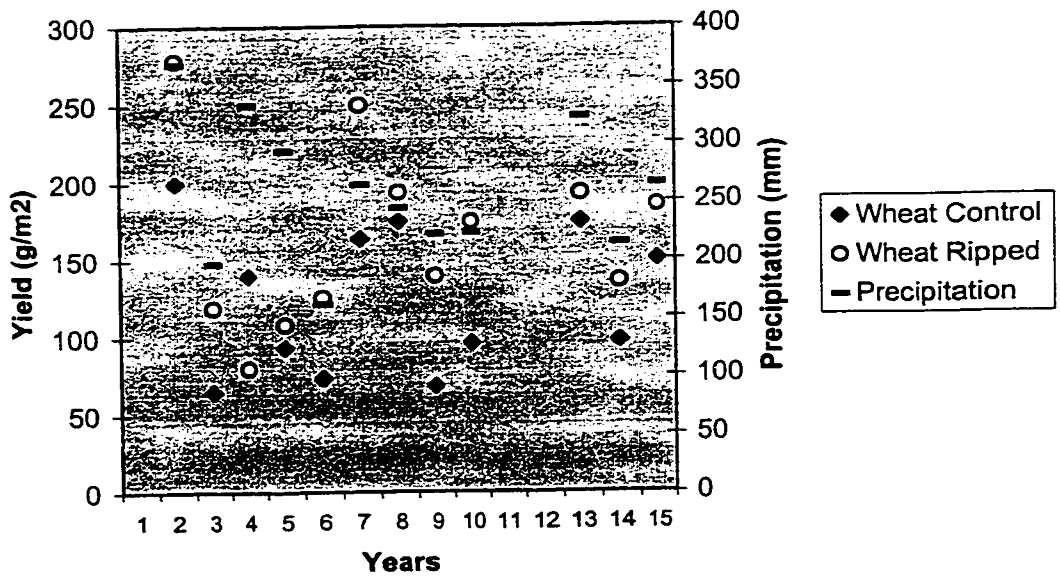


Figure 5.10 Wheat yield at site E versus years after ripping and general precipitation.

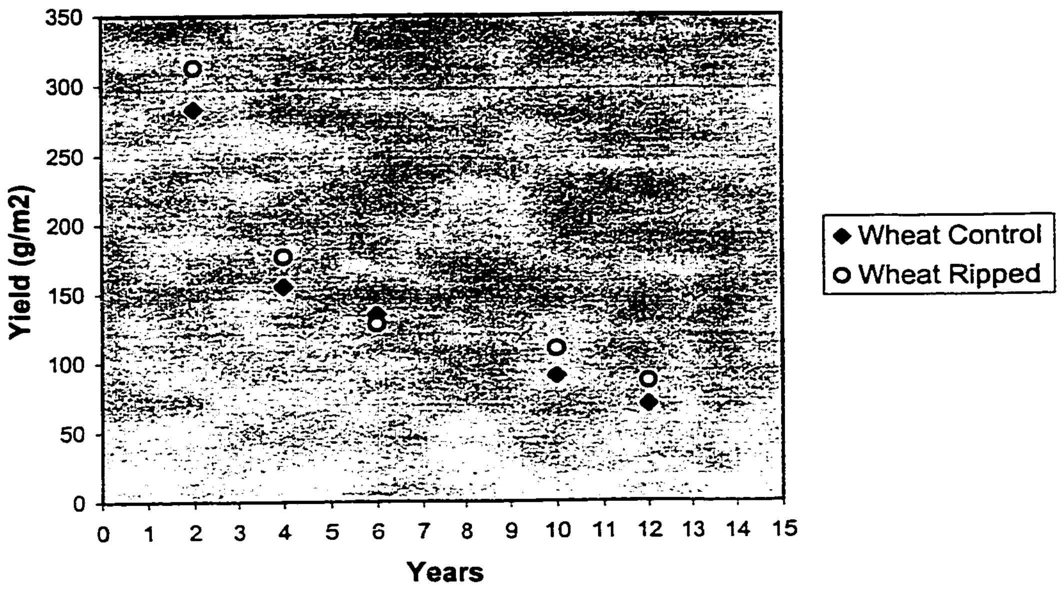


Figure 5.11 Wheat yield at site F versus number of years after ripping for control and deep ripped plots.

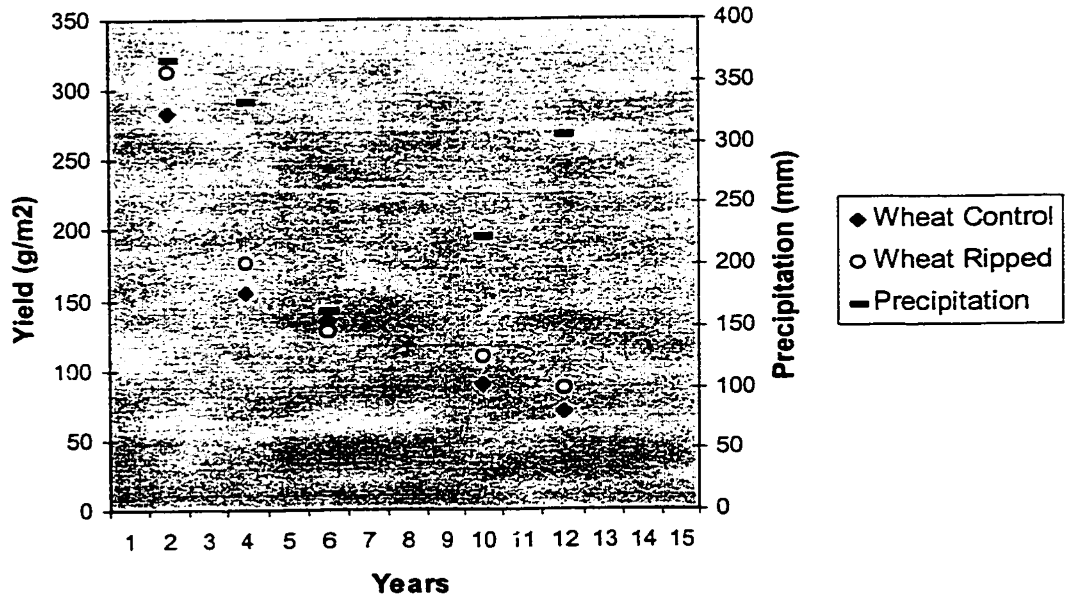


Figure 5.12 Wheat yield at site F versus years after ripping and general precipitation.

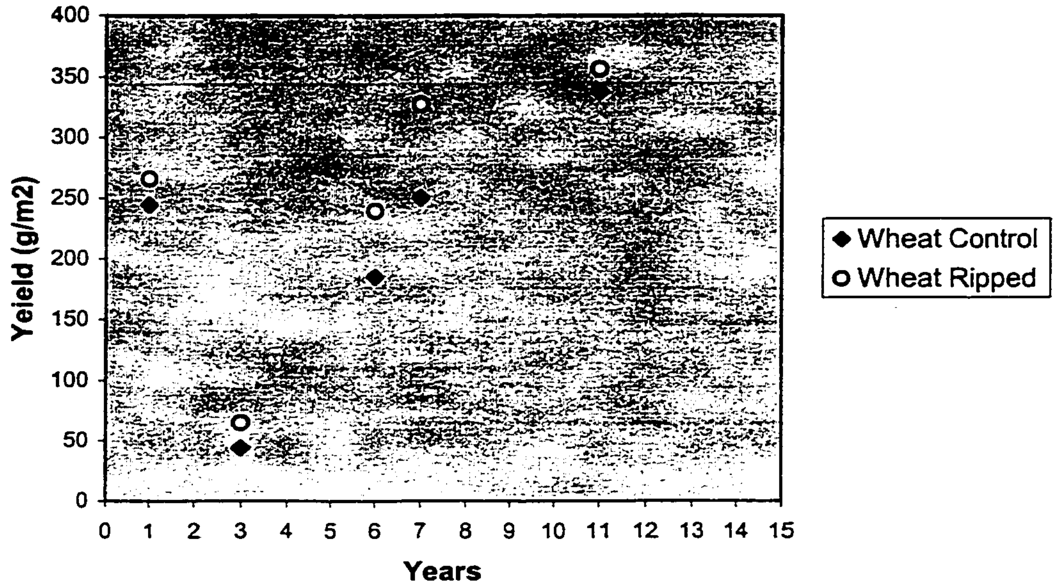


Figure 5.13 Wheat yield at site G versus number of years after ripping for control and deep ripped plots.

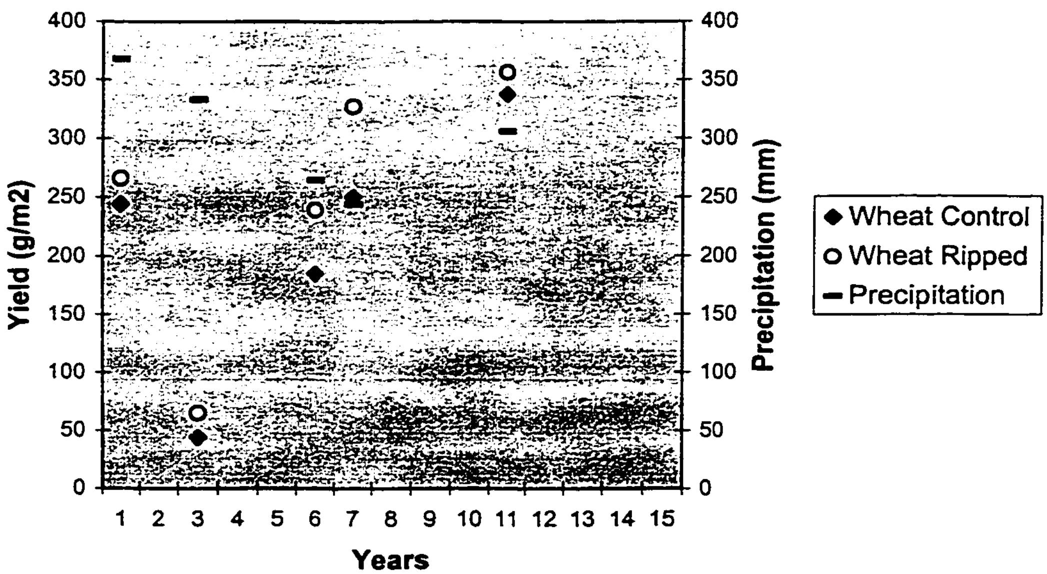


Figure 5.14 Wheat yield at site G versus years after ripping and general precipitation.

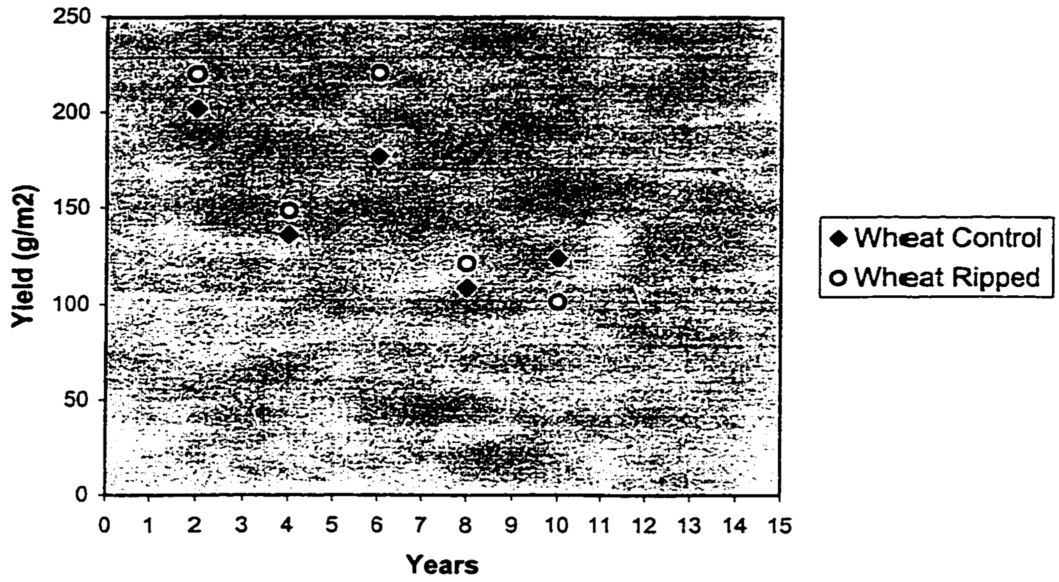


Figure 5.15 Wheat yield at site I versus number of years after ripping for control and deep ripped plots.

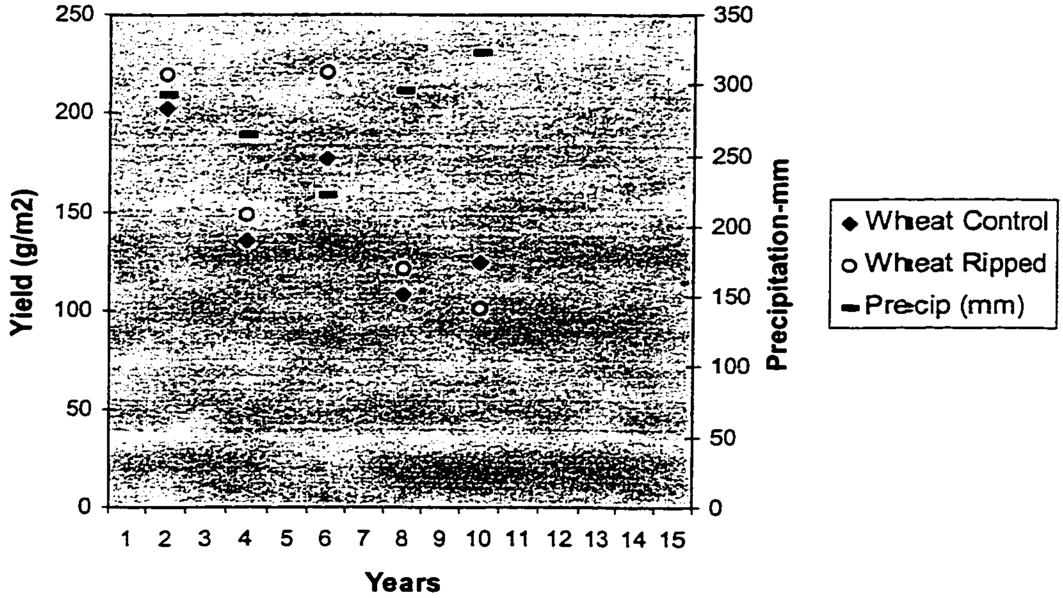


Figure 5.16 Wheat yield at site I versus years after ripping and general precipitation.