SOIL EROSION RISK AND MITIGATION THROUGH CROP ROTATION ON ORGANIC AND CONVENTIONAL CROPPING SYSTEMS

BY

ALISON G. NELSON

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

Department of Plant Science
University of Manitoba
Winnipeg, Manitoba

SOIL EROSION RISK AND MITIGATION THROUGH CROP ROTATION ON ORGANIC AND CONVENTIONAL CROPPING SYSTEMS

BY

ALISON G. NELSON

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

Department of Plant Science
University of Manitoba
Winnipeg, Manitoba

0-494-08925-3

Your file Votre référence
ISBN:
Our file Notre référence
ISBN:

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

*****

COPYRIGHT PERMISSION

Soil Erosion Risk and Mitigation Through Crop Rotation on Organic and Conventional Cropping Systems

BY

Alison G. Nelson

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of

Manitoba in partial fulfillment of the requirement of the degree

Of

Master of Science

ACKNOWLEDGEMENTS

This research would not be possible without the help from a number of individuals and organizations. I would like to thank:

The farmers, whose generosity with their time and ideas made both the survey and on-farm portions of this research possible, made this project more meaningful and my time spent on the road much more enjoyable.

Dr. Jane Froese, my principal advisor, for her guidance and enthusiasm in this project.

Dr. Martin Entz and Dr. David Lobb, my committee members, for their expert advice and input.

The Natural Sciences and Engineering Research Council and The Organic Agriculture Centre of Canada, for providing funding for the project.

Dr. Stewart Brandt, Dr. Martin Entz and Dr. Robert Blackshaw, researchers at the long-term studies, for allowing me to collect soil samples.

The Manitoba Farm Mediation board and Gary Martens, for going through my survey and giving me feedback for revision.

The numerous organic certifying bodies, civil servants and farmer organizations, for distributing my survey to both organic and conventional farmers.

Dr. Ibrahim Saiyed, for his advice and technical help regarding my soil tests.

Dr. Tee Boon Goh and Greg Adrian for the use of their laboratories and equipment.

Dr. Brenda Frick and Dr. Andy Hammermeister, for their valuable insight into the organic sector, advice and interest in this project.

The summer students, Melissa, Tina and Paul, for their help in the lab with soil tests.

My parents, for their support and help throughout this entire project, which included many evenings of stuffing, stamping and sealing envelopes.

My friends, Amy, Amber, Elin, Beth and Kelly, for fun times and philosophical talks when they were most needed.

Travis, for everything. You kept me going with your sense of humour, faith in my abilities, willingness to do the dishes and ability to lift heavy things.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS ii

LIST OF TABLES vi

LIST OF FIGURES ix

ABSTRACT x

FORWARD xii

CHAPTER 1: GENERAL INTRODUCTION 1

CHAPTER 2: LITERATURE REVIEW 4

Introduction 4
Soil Erosion 4
Effects of Soil Erosion 4
History of Soil Erosion in Canada 5
Soil Conservation 6
Factors Affecting Soil Erosion Risk 9
Introduction 9
Soil Properties Involved in Erosion Risk 9
Texture 9
Soil Organic Matter 10
Soil Aggregate Stability 12
Interaction of Soil Properties on Soil Erosion Risk 13
Effect of Tillage on Soil Erosion Risk 14
Effect of Crop Rotation on Soil Erosion Risk 16
Effect of Other Cropping Practices on Soil Erosion Risk 18
Sustainable Agriculture 21
Definition 21
Organic Agriculture 22
Definition 22
Organic Agriculture Sector in Canada 23
Sustainability of Organic Agriculture 23
Comparing Organic and Conventional Farming Systems 25
Soil Erosion on Organic versus Conventional Systems 26

CHAPTER 3: EVALUATION OF PRODUCTION DIFFERENCES ON ORGANIC AND CONVENTIONAL FARMS 31

Introduction 31
Materials and Methods 32
Survey Design 32

Selection of Survey Participants 32
Survey Sections 33
Statistical Analysis 34
Results and Discussion 35
Description of Respondents 35
Response Rates 36
Farm Descriptions 38
Cropping Practices Differences 41
Tillage Practices 41
Soil Cover 44
Fertility Inputs 46
Seeding Practices 47
Crop Rotation 49
Rotation Practices from Rotations Listed in the Survey 49
Five-Year Rotation Period 51
Planned Rotation/Commitment to Rotation 53
Other Soil Conservation Practices 56
Actual Soil Cover 57
Farmer Opinions 59
Statement Responses 59
Measures of Success 62
Summary 64

CHAPTER 4: COMPARISION OF SOIL EROSION RISK ON LONG-TERM ORGANIC AND CONVENTIONAL SYSTEMS 68

Introduction 68
Materials and Methods 69
Long-Term Studies Descriptions 69
Glenlea Long-Term Crop Rotation Study 72
Scott Alternative Cropping Systems Trial 72
Lethbridge Low-Input Agriculture Trial 75
Soil Sampling 77
Soil Tests 78
Texture 79
Dry Aggregate Size Distribution 79
Wet Aggregate Size Distribution 80
Organic Carbon 80
Statistical Analysis 81
Results and Discussion 82
Texture 82
Dry Aggregate Stability 83
Glenlea Long-Term Crop Rotation Study 83
Scott Alternative Cropping Systems Trial 84
Lethbridge Low-Input Agriculture Trial 86
Wet Aggregate Stability 87

Glenlea Long-Term Crop Rotation Study 87
Scott Alternative Cropping Systems Trial 89
Lethbridge Low-Input Agriculture Trial 90
Organic Carbon 91
Glenlea Long-Term Crop Rotation Study 91
Scott Alternative Cropping Systems Trial 93
Lethbridge Low-Input Agriculture Trial 96
Summary 97

CHAPTER 5: COMPARISON OF SOIL EROSION RISK ON ORGANIC AND CONVENTIONAL FARMS 100

Introduction 100
Materials and Methods 101
Selection of Study Farms and Fields 101
Supplementary Information 102
Soil Sampling 102
Soil Tests 103
Soil Cover Analysis 104
Statistical Analysis 104
Results and Discussion 106
Overall Comparison of Soil Properties 106
Comparison of Farm Pairs with Same Texture 108
Comparison of Farm Pairs with Various Crop Rotations 109
Comparison of Farm Pairs with Different Tillage Practices 111
Comparison of Annual and Perennial Rotations 112
Soil Cover Analyses 113
Summary 115

CHAPTER 6: GENERAL DISCUSSION AND CONCLUSIONS 117

Discussion 117
Future Research 119
Conclusions 120

LITERATURE CITED 122

APPENDIX A Mail Out Survey 131

APPENDIX B Map of Sampling Sites – Long-Term Studies and Farm Pairs 144

APPENDIX C Plot Plans for Long-Term Studies 145

LIST OF TABLES

Table **Page**

Table 2-1. Water erosion risk reduction in Canadian provinces due to management practices 7

Table 3-1. Breakdown of respondents by management category and province 37

Table 3-2. Breakdown of organic farmers by province in 2002 38

Table 3-3. Average farm size (acres) 39

Table 3-4. Number of farms with animals 39

Table 3-5. Number of farmers with mixed farming operations 40

Table 3-6. Input use reduction on Conv farms over last 10 years 41

Table 3-7. Various tillage practices employed by farmers 43

Table 3-8. Practices used by farmers affecting the amount of soil cover 46

Table 3-9. Fertility practices employed by farmers 47

Table 3-10. Seeding practices used by farmers 48

Table 3-11. Crops grown in rotation 49

Table 3-12. Farms with forages in rotation versus animals on farm 50

Table 3-13. Crop rotation from 1999-2003 in one field 52

Table 3-14. Farmers with planned crop rotation 54

Table 3-15. Farmers commitment level to the planned crop rotation 55

Table 3-16. Reasons for changing a planned crop rotation 56

Table 3-17. Other soil conservation practices employed by farmers 57

Table 3-18. Land in soil cover categories in fall after all field operations 58

Table 3-19. Land in soil cover categories in spring after seeding 58

Table 3-20. Mean values from opinion statements 59

Table 3-21. Mean values for factors of success 64

Table 4-1. Summary of rotations and treatments from long-term rotation studies sampled 71

Table 4-2. Rotations from Scott Alternative Cropping Systems Trial...........................74

Table 4-3. Rotations from the Lethbridge Low-Input Agriculture Trial 76

Table 4-4. Mean particle size analysis from long-term studies 83

Table 4-5. Mean dry Mean Weight Diameter (MWD) and ANOVA from Glenlea.......84

Table 4-6. Mean dry Mean Weight Diameter (MWD) and ANOVA from Scott...........85

Table 4-7. Mean dry Mean Weight Diameter (MWD) and ANOVA from Lethbridge .87

Table 4-8. Mean wet Mean Weight Diameter (MWD) and ANOVA from Glenlea 88

Table 4-9. Mean wet Mean Weight Diameter (MWD) and ANOVA from Scott 90

Table 4-10. Mean wet Mean Weight Diameter (MWD) and ANOVA from Lethbridge 91

Table 4-11. Mean percent organic carbon and ANOVA from Glenlea..........................92

Table 4-12. Mean percent organic carbon and ANOVA from Scott 94

Table 4-13. Interaction means of dry Mean Weight Diameter (MWD) and percent organic carbon at Scott...95

Table 4-14. Mean percent organic carbon and ANOVA from Lethbridge.....................97

Table 5-1. Mean soil property and soil cover values for individual study farms 107

Table 5-2. Mean soil property values for organic and conventional farm pairs in the same textural class..109

Table 5-3. Mean soil property values for organic and conventional farm pairs with a crop rotation including row crops 110

Table 5-4. Mean soil property values for organic and conventional farm pairs with a crop rotation including perennial crops 111

Table 5-5. Mean soil property values for organic and conventional farm pairs with different tillage practices....112

Table 5-6. Mean soil property values for farms with an annual or perennial rotation ...113

Table 5-7. Mean percent soil cover for organic and conventional farm pairs 114

Table 5-8: Mean soil property values for farms with an annual or perennial rotation ...115

LIST OF FIGURES

Figure **Page**

Figure 4-1. Map of sampling sites for the long-term studies and paired organic and conventional farms....144

Figure 4-2. Plot plan for the Glenlea Long-Term Crop Rotation Study....145

Figure 4-3. Plot plan for the Scott Alternative Cropping Systems Trial....146

Figure 4-4. Plot plan for the Lethbridge Low Input Agriculture Trial....147

ABSTRACT

Nelson, Alison G. M. Sc. University of Manitoba, April 2005. Soil Erosion Risk and Mitigation through Crop Rotation on Organic and Conventional Cropping Systems. Major Professor: Dr. Jane Froese

Organic cropping systems are often accused of increasing soil erosion risk through an increased use of tillage for weed control. However, little research has been conducted in Canada regarding soil erosion risk on organic farms. It is known that crop rotations can be used to ameliorate a variety of agronomic problems encountered in cropping systems, including soil erosion. Organic systems, which do not use synthetic pesticides and fertilizers, rely more heavily on crop rotations than conventional systems to solve agronomic problems such as weeds and insects. The objective of this study was to compare cropping practices (including crop rotations and tillage regime) on organic and conventional cropping systems, and examine the effect of crop rotation (annual-, biennial-, or perennial-containing rotations) and management (organic or conventional) on soil properties relating to wind and water erosion risk.

A mail-out survey was the source of data on soil conservation, crop rotation and tillage practices from 225 organic and conventional farmers in the study provinces of AB, SK, MB, ON, PEI, NB and NS. When compared to conventional farmers, organic farmers had more perennials and green manures in rotation, but fewer organic farmers had zero tillage practices on their farm. More organic farmers had other soil conservation practices (such as shelterbelts, contour tillage, ridge tillage and the use of composts) on their farm than conventional farmers.

Soil from three long-term rotation studies in the prairies (Lethbridge, AB; Scott, SK and Glenlea, MB) and 25 paired organic and conventional farms (in AB, SK, MB,

ON, PEI and NS) was sampled. The effect of management and rotation on dry and wet aggregate stability, as well as percent organic carbon (C) was determined. At the long-term studies, the biennial-containing rotation resulted in the highest wet and dry aggregate stability. Management significantly affected organic C in both the long-term studies and the farm pairs, with the organically managed soils having lower C contents than the conventionally managed soils. Despite the lowered organic C levels in the organic systems, aggregate stability remained higher, or equivalent to the conventional systems. This result indicates that aggregate stability in the organic systems is independent of total organic C levels at the current time (however, there are limitations to lowered levels of organic C, and at some point lower C will begin to affect soil properties). The organic soils may be higher in certain C compounds (such as polysaccharides) that stabilize the soil aggregates, but do not alter the total organic C levels.

Few differences in the measured soil properties of the paired organic and conventional farms were found. However, when farms were compared based on having an annual- or perennial-containing rotation, the farms with perennials in rotation were found to have higher wet aggregate stability. Rotation (annual- versus perennial-containing rotations) had a larger effect on wet aggregate stability and percent organic C than management in the farm pairs.

Organic management does not inherently lead to a higher risk of soil erosion than conventional management. While organic systems generally have higher intensities of tillage than conventional systems, organic farms also tend to have more perennials in rotation, which has been shown in this study to lower the risk of soil erosion.

FORWARD

This thesis has been written in manuscript style. The manuscripts were prepared in accordance with the style requirements of the Canadian Journal of Plant Science.

CHAPTER 1

GENERAL INTRODUCTION

Soil erosion has been a problem in Canadian agriculture since cultivation began and native ecosystems were converted to cropland. All cultivated land in Canada has been affected by, or has the potential for, soil degradation (Science Council of Canada 1986). Soil erosion by water (Shelton et al. 2000) and wind (Padbury and Stushnoff 2000) still pose a threat to the sustainability of Canadian agriculture today. The 1980's saw a large number of research agendas focused on the problem of soil erosion. Numerous publications and workshops occurred around this time (Soil Conservation Committee of the Agricultural Institute of Canada 1980; Science Council of Canada 1986; Prairie Farm Rehabilitation Administration 1983; van Vliet 1983). At this time, a number of soil conservation initiatives gained favor with farmers, such as reduced tillage practices and decreased use of summerfallow. Wind erosion risk was estimated to have decreased by seven percent in the Prairies between 1981 and 1991 due to conservation tillage practices and cropping system changes (Wall et al. 1995). Water erosion risk in Canada decreased by 11% during the same time period, also because of conservation tillage and cropping system changes (Wall et al. 1995).

The risk of soil erosion is affected by a number of soil properties, including dry aggregate stability, wet aggregate stability and organic carbon (C). These soil properties are affected by cropping system management practices, of which tillage and crop rotations are extremely important in determining soil erosion risk. Dry and wet aggregate stability indicate the soil's resistance to wind and water erosion, respectively (Lehrsch and Jolley 1992). Organic C helps to build soil structure and stability (Watson et al.

2002). Cropping practices such as including forages in rotation, applying manures, and using green manures have been found to increase organic C and aggregate stability levels (VandenBygaart et al. 2003; Biederbeck et al. 1998; Entz et al. 2002; Aoyama et al. 1999a; Aoyama et al. 1999b). All of the practices mentioned above are believed to be more common in organic systems compared with conventional systems, and these practices will help to decrease soil erosion risk.

Organic agriculture is increasing is popularity in Canada. Market sales of organic products have increased at a 15 to 20% annual rate of growth for the decade before 2003 (Haumann 2003). Consumers are increasingly demanding organic products because of concerns about food safety (genetically modified organisms, as well as pesticide, hormone and antibiotic residues) and negative environmental effects of conventional agriculture production (Klonsky 2000). On the production side, farmers are choosing to convert their production to organic for many reasons, including: reduction of input costs and a possible increase in profits (Willick 2004), increased farmer independence (Entz et al. 2001), as well as a concern about the negative health or environmental impacts of synthetic chemical use (Henning 1994).

There are many claimed benefits and limitations to organic agriculture, yet few of these claims have been confirmed through scientific investigation. One of the alleged limitations of organic agriculture is that it increases the risk of soil erosion through an increased use of tillage for weed control; however, few studies have compared soil erosion risk in organic and conventional systems in Canada (Moulin et al. 2001; unpublished data, Alan Moulin), and none have compared soil erosion risk on organic and conventional farms.

This study examined current organic cropping systems in Canada and how they compared to non-organic systems with respect to soil erosion prevention. The research was undertaken on a large geographic scale, encompassing ecozones in Alberta, Saskatchewan, Manitoba, Ontario and Prince Edward Island. There were three major objectives to the study. The first objective was to characterize cropping practices related to soil erosion risk on organic and conventional farms in certain Canadian provinces, and identify differences (if any) between organic and conventional systems. Secondly, the soil properties affecting erosion risk were compared on organic and conventional systems for various combinations of rotations involving annual, biennial and perennial crops using long-term organic versus conventional studies located in the prairie provinces. The final objective was to compare the soil properties related to erosion risk on organic and conventional systems in the study provinces using soil samples obtained from paired comparisons of organic and conventional farms of similar crop rotations.

CHAPTER 2

LITERATURE REVIEW

Introduction

The negative environmental impacts of modern industrial agricultural practices are receiving increasing attention by both the general public and the agricultural industry itself. For this and food safety reasons, environmentally sustainable agricultural initiatives such as organic farming are becoming more popular (Klonsky 2000). Organic agriculture is one of the more commonly known alternative agricultural systems that attempts to attain environmental sustainability. Despite the increasing popularity of organic agriculture (as evidenced by an increasing number of certified organic farms and organic food sales in Canada, (Haumann 2003)), there is a lack of information regarding these systems and their environmental impact on the Canadian agricultural resource.

Soil Erosion

EFFECTS OF SOIL EROSION. Soil erosion refers to the wearing away of the earth's surface. This is a natural phenomenon that both helps to form soil and also, more commonly, cause soil loss. Particular agricultural practices, such as field enlargement, the removal of perennial crops and vegetation and lack of soil cover in the winter (Baudry and Papy 2001), can accelerate the rate of soil loss through erosion to unsustainable levels (McRae et al. 2000).

Soil is a critical resource to both plants and animals. Soil functions include serving as the biological habitat and gene reserve for numerous organisms; a filter, buffer or detoxifier of compounds between air, water and plant roots; as well as the medium for production of biomass, which provides food, fodder and energy for animal life (Blum 1998). The loss of soil through erosion is, therefore, an important issue on many levels. For agricultural systems, the loss of soil can mean the loss of productive land and the restriction of crop types grown in rotation to lower valued crops (e.g., substituting forages for cash crops in rotation). This restriction of crop types can come either through legislation (Ketcheson 1977) or through a loss of soil quality and, therefore, soil productivity (Verity and Anderson 1990).

Soil erosion degrades the quality of soil through the loss of organic matter, soil structure and nutrients (Soil Conservation Committee of the Agricultural Institute of Canada 1980). Bauer and Black (1994) found that soil erosion decreased soil productivity because the lowered soil organic matter content resulted in a decline in soil fertility. Larney et al. (2000) found that a removal of 20 cm of topsoil lead to declines between 36 to 71% of the soil organic carbon levels in the top 7.5 cm of soil at four research sites in Alberta. These effects have social, economic and ecological consequences.

HISTORY OF SOIL EROSION IN CANADA. Significant soil losses have occurred on agricultural land in Canada since cultivation began. During the 1980's, some researchers attempted to quantify the tolerable rates of soil loss, the total amount of soil lost through erosion in Canada, and the economic impact of erosion. A soil loss rate of less than 6 t ha^{-1} $year^{-1}$ has been identified as a tolerable or sustainable for most agricultural areas, meaning that this rate of soil loss is generally offset by the rate of soil formation (Shelton et al. 2000). Using the 1981 agriculture census, and a soil loss value of 10 or more t ha^{-1}

year^{-1} indicating moderate or severe rates of erosion, Dumanski et al. (1986) estimated the area of land affected by water and wind erosion. They concluded that in Canada, 5.84 million hectares of arable land had been affected by moderate or severe water erosion levels while 6.36 million hectares had been affected by wind erosion levels that were either moderate or severe. The estimates of the on-farm economic impact of these erosion figures ranged from 266-424 million dollars for water erosion and 218-283 million dollars for wind erosion.

The prairies have been greatly affected by both wind and water erosion, with moderate or severe (i.e., over 10 t ha^{-1} year^{-1} of soil loss) water and wind erosion levels occurring on 4.64 million hectares and 6.31 million hectares of land, respectively (Dumanski et al. 1986). In the grain growing areas of the prairies, 14% of improved farmland has lost significant amounts of topsoil through erosion (Science Council of Canada 1986). De Jong and Kachanoski (1988) estimated that organic carbon levels have declined by 40-50% in the Chernozemic soils over the past 80 years, and that 70% of organic carbon losses in a Black Chernozemic soil after 50 years of cultivation are due to erosion. The same study found that erosion was the major factor affecting organic carbon losses on study sites in Saskatchewan between the mid-1960's and the early 1980's.

SOIL CONSERVATION. Soil conservation refers to all practices that reduce or prevent the degradation of soil, including preventing erosion, salinization and compaction of soil.

Changes in cropping and tillage practices within the last two decades have combined to decrease the overall wind and water erosion risk in the majority of Canadian provinces. Cropping practices have shifted towards a reduction in the amount of summerfallow used and an increased use of continuous cropping with more diversified crop rotations. Reduced tillage practices, which include such systems as zero tillage, contour tillage and ridge tillage, have also helped to decrease soil erosion risk in most areas. Wall et al. (1995) estimated the percent reduction of water erosion risk due to these changes in cropping and tillage practices from 1981 to 1991 in each province (Table 2-1). All provinces experienced a reduction in erosion risk due to the adoption of conservation tillage practices. However, two maritime provinces, Prince Edward Island and Nova Scotia, actually had an increase in water erosion risk due to changes in cropping systems due to intensification of cropping and an increase in the area under potato production. The overall reduction in water erosion risk for Canada was estimated to be 11 percent for the ten year period from 1981 to 1991.

Table 2-1: Water erosion risk reduction in Canadian provinces due to management practices

	Reduction in water erosion risk due to management changes	
Province	Reduction due to cropping practices (%)	Reduction due to tillage practices (%)
British Columbia	7	10
Alberta	5	8
Saskatchewan	5	3
Manitoba	6	9
Ontario	10	11
Quebec	3	3
New Brunswick	2	4
Prince Edward Island	-9	3
Nova Scotia	-3	3

(Wall et al. 1995)

Wall et al. (1995) also estimated that there has been a seven percent reduction in wind erosion risk in the prairies between 1981 and 1991. Two-thirds of that seven percent decrease is attributed to increased use of conservation tillage, while the other third was attributed to changes in cropping system, primarily a decrease in land area under summerfallow. Padbury and Stushnoff (2000) later estimated that wind erosion risk has declined by 32% on the prairies between 1981 and 1996; the wind erosion risk declined by eight percent due to cropping system changes and 25% due to tillage changes (mostly due to an increase in the amount of acres that were zero tilled). The authors found that proportion of land in the prairies under conservation tillage increased seven percent to 32% and direct seeding increased nine percent to 16% between 1991 and 1996. As well, the total share of cultivated land under fallow decreased by 10% between 1981 and 1996 (Padbury and Stushnoff 2000). These large shifts in cropping and tillage practices are the main reasons why there was a decrease in both water and wind erosion in the prairie provinces.

While there have been reductions in soil erosion risk through the adoption of soil conservation techniques, some researchers have stated that the overall level of adoption by farmers has been inadequate. As of 1996, approximately half of cultivated land in the prairies under reduced tillage as opposed to conventional tillage (Padbury and Stushnoff 2000). In a review, Stonehouse (1995) found that the off-farm costs of soil degradation are generally much higher than the on-farm costs, so there is little economic benefit to farmers adopting soil conservation practices. He also observed that conservation practices, such as conservation tillage and cropping practices (such as including forages, cover crops or green manures in rotation), can be profitable under certain conditions, but risk-averse farmers will not be inclined to adopt new practices unless there is a demonstrated (economic, aesthetic or ethical) benefit of concern to the farmer. Most farmers adopt conservation tillage practices to slow soil degradation and reduce inputs, not to increase yields. This lack of yield increase has been identified as the major reason farmers choose not to adopt conservation tillage practices (Larney et al. 1994).

Factors Affecting Soil Erosion Risk

INTRODUCTION. A number of soil and environmental factors combine to determine the risk of soil erosion in a given area. The Universal Soil Loss Equation (USLE) identifies them as: the soil's inherent susceptibility to erosive forces, climate, topography, cropping system and conservation practices (Wischmeier 1976). Soil properties that influence the soil's resistance to erosion include texture, structural stability and organic matter content (Lal and Elliot 1994).

SOIL PROPERTIES INVOLVED IN EROSION RISK.

Texture

The particle size distribution, or texture of the soil, is an inherent property of a given soil. Texture affects the importance of other factors in determining soil erodibility (Wischmeier and Mannering 1969), such as soil structure. For instance, silty or sandy soils tend to have fewer stable aggregates than soils of other textures (Shepherd et al. 2002). While texture cannot be altered by cropping system management, it should be considered when managing the soil erosion risk of a particular farm system.

The texture of a soil will affect the soil's resistance to both wind and water erosive forces. In the case of wind erosion, coarse-textured soils do not have sufficient binding materials to form aggregates while fine-textured soils have aggregates that break into fine, highly erodible particles, making these soils more erodible by wind (Chepil 1953). Chepil (1953) found that soils with about 27% clay, the greatest proportion of silt possible, and a moisture equivalent of about 23% were the least erodible by wind.

For water erosion, soils with a silt texture are generally the most erodible, however, sand and clay soils are also susceptible to water erosion. Sandy soils are easily detached (but not as easily transported as other soils), while clay soils have greater run-off due to lower water infiltration rates (but are less easily detached than other soils) (Lal and Elliot 1994). Subsoils with more clay content can cause higher rates of run-off because soils with higher amounts of clay have a slower rate of water infiltration than other textures (Lal and Elliot 1994). For both wind and water erosion, medium-textured soils are the least erodible, with a balance of sufficient cementing agents and non-transportable particles.

Soil Organic Matter

Soil organic matter, also called humus, is the organic fraction of the soil that includes undecayed plant and animal residues (Tabatabai 1996). Soil organic matter affects a number of other soil physical, chemical and biological properties, including soil structure, cation exchange capacity, nitrogen and phosphorus availability, and activity of soil microflora and microfauna (Bolinder et al. 1999; Tabatabai 1996). Because of its ability to influence other soil properties, organic matter is deliberately managed in organic farming systems in order to increase crop production (Watson et al. 2002). Soil organic matter plays a critical role in soil fertility in organic systems as it accounts for over 95% of nitrogen found in most soils (Berry et al. 2002). Soil particles are brought together through physical forces (such as freeze/thaw cycles) and aggregates are stabilized through binding agents, of which organic matter is an important component (Dalal and Bridge 1996).

Organic matter consists of three identifiable fractions: active, well-decomposed and living organisms (Magdoff 1996). These fractions of organic matter have different roles in maintaining good soil structure and biological activity (Watson et al. 2002). The active soil fraction, which is composed of younger soil organic matter, is capable of linking soil particles together and stabilizing aggregates (Shepherd et al. 2002). The well-decomposed fraction, containing more humified substances than the active fraction, has more stable binding agents and helps with long-term aggregate stability (Shepherd et al. 2002). The living organisms are important for maintaining the biological activity of the soil, which ensures that there is constant input of organic materials to the soil.

Soil organic matter plays a role in the movement of water and air through soil, maintaining soil tilth, the retention of water and the prevention of erosion (Gregorich et al. 1994). Cropping practices that accumulate organic matter (such as forages in rotation) tend to modify soil physical properties, making the soil more resistant to erosive forces (Rachman et al. 2003). Soil organic carbon (SOC) is a commonly measured property in soil organic matter research, and makes up about 50-58% of humified substances found in the soil (Gregorich et al. 1994).

Soil Aggregate Stability

Aggregate stability is a measure of soil strength, or the ability of an aggregate to resist breakdown by some force (Lehrsch and Jolley 1992). Aggregate stability is often measured in soil erosion studies, as it indicates how susceptible the soil will be to wind and water forces. There are many methods to determine aggregate stability, all of which include imparting stress on aggregates through either wet sieving, controlled rates of wetting and waterdrop impact (Lehrsch and Jolley 1992). Wet sieving indicates the soil's resistance to flowing water (Lehrsch and Jolley 1992), and is a common method of wet aggregate stability measurement. Dry aggregate stability is most often measured through sieving and it indicates the distribution and stability of dry soil aggregates (White 1993).

Both wet and dry aggregate size distribution are used as measures of aggregate stability. Aggregate size distribution reflects the relative proportion of certain aggregate size classes in a given soil. Management effects (from tillage and cropping practices or the use of organic amendments) are often detected in size-specific fractions, and so determining the breakdown of soil weight into various size fractions has the potential to provide researchers with more information than a simple aggregate stability measurement taken with a single sieve (Angers and Mehuys 1988). That is, a certain soil weight distribution of aggregate size fractions will reveal information regarding the effect of certain management practices.

Interaction of Soil Properties on Soil Erosion Risk

The soil properties affecting soil erosion risk interact and affect the overall ability of the soil to resist erosive forces. It is, therefore, important to measure all of the aforementioned soil properties in order to more fully understand how a given soil will function under occurrences of erosion. Texture is the major influencing factor on soil structure, and influences how much organic matter is stored in the soil (Shepherd et al. 2002). Texture plays a role in the ability of organic matter to improve aggregate stability, with clay soils having a higher ability to bind soil particles than sandy soils (Shepherd et al. 2002). Silt soils have generally been found to have the highest risk of water erosion, because weak aggregation allows the particles to be detached and transported easily (Lal and Elliot 1994).

Organic matter influences physical properties within each soil textural group (Shepherd et al. 2002). Heavy-textured soils have the ability to sequester and store more SOC than light-textured soils when conservation practices such as reduced tillage and lowered summerfallow are adopted (Liang et al. 2002). Organic matter accumulation and aggregation are closely related to one another: the various fractions of organic matter are required for aggregation, while organic matter is protected from degradation within soil aggregates (Carter 1996). Soil organic matter influences aggregate stability, with the active, well-decomposed and living organisms fractions of soil organic matter helping to stabilize aggregates (for instance, younger, more active organic matter plays an important role in aggregate stability) (Shepherd et al. 2002). The importance of various organic matter fractions to aggregate stability means a more biologically active soil with frequent additions of fresh organic matter will be more likely to have stable soil aggregates than a soil with less biological activity (Shepherd et al. 2002). The amount of soil aggregation and the amount of organic matter are affected by management practices (Carter 1996) such as tillage and crop rotation.

EFFECT OF TILLAGE ON SOIL EROSION RISK. Tillage greatly affects how susceptible a given soil is to erosion: lower amounts of tillage help to decrease the risk of soil erosion, while higher levels of tillage can increase erosion risk in a number of ways. For example, soil tillage is known to affect aggregate size distribution and aggregate stability (Huwe 2003). Tillage itself physically breaks the soil, reducing structural stability. Tillage also lowers aggregate stability by exposing new soil to freeze-thaw and wet-dry cycles, as well as by changing soil conditions (such as temperature or moisture levels) thereby increasing residue decomposition (Six et al. 1998). In addition, tillage lowers biological activity in the soil, reducing the biotic processes of soil structure formation, and, therefore, decreasing aggregate stability (Huwe 2003). In a study looking at the effect of adding one pre-seeding tillage operation to a zero tillage system, Campbell et al. (1998) found that the erodible fraction of the soil increased, showing that even a small increase in tillage intensity can have a detrimental effect on erosion risk.

Reducing tillage intensities in cropping systems has beneficial effects on soil properties related to erosion in most agricultural areas of North America. Zero, strip, mulch and reduced tillage are the most important tillage systems in use today to lower soil erosion (Huwe 2003). Zero tillage is believed to aid in the proliferation of fungal hypae that contribute to the formation of macroaggregates (Six et al. 1998), thereby building soil structure. Decreasing the frequency of tillage, combined with cropping systems that protect the soil and accumulate organic matter has been found to increase aggregate stability and reduce the soil's susceptibility to detachment (Rachman et al. 2003). Campbell et al. (2001) found that seven years of zero tillage management increased wet aggregate stability because the change in tillage regime resulted in an increased quantity of residues and lowered level of soil disturbance. In the same study, the soil's erodibility to wind was not decreased by zero tillage management; the authors concluded that wind erosion risk is mainly a function of weather conditions (which will affect soil moisture content) (Campbell et al. 2001). VandenBygaart et al. (2003) analyzed the effects of tillage on SOC (an important soil property related to erosion risk) from 23 tillage studies across Canada and concluded that in western Canada (west of the Ontario-Manitoba border) zero tillage management was effective at storing SOC.

However, zero tillage management does not increase SOC in eastern Canada (VandenBygaart et al. 2003). The inability of zero tillage management to store organic carbon in soils of eastern Canada is due to a number of factors: little to no yield differences between zero tillage and conventional tillage, higher rates of residue decomposition as a result of higher moisture levels, more corn (*Zea mays L.*) grown (corn residues decompose more quickly than more lignified crops such as wheat), soil organisms increasing the rate of decomposition, and lower levels of residue burial (VandenBygaart et al. 2003). Zero tillage systems can decrease erosion risk by lowering the amount of SOC lost, or by increasing the residues returned to the soil (either through an increase in crop production or a decrease in residue decomposition). In western Canada, it was found that only fertilized zero tillage systems gained SOC, indicating that zero tillage systems without adequate fertilization levels and that did not result in a significant decrease in soil erosion may not increase SOC levels (Campbell et al. 2001).

Despite this inconsistent effect of zero tillage management on SOC, lowering tillage levels consistently increases the level of crop residues left in fields after harvest. Tillage incorporates residues into the ground, so zero tillage management can effectively reduce erosion by maintaining a vegetative cover (Stocking 1994). By lowering tillage intensities, soil structure, biological activity and crop residues can be maintained, and (in western Canada) SOC levels can be increased, all contributing to a lowered risk of soil erosion by wind and water.

EFFECT OF CROP ROTATION ON SOIL EROSION RISK. There are a number of ways that crop rotations can affect soil erosion risk. Crops produce varying amounts of residue (e.g., row crops produce fewer residues than solid-seeded crops) and have different rates of residue decomposition, with higher levels of nitrogen in residues resulting in a higher rate of decomposition. In this way, crop rotations can affect the amount of SOC returned to the soil in crop residues. In addition, crop rotations can affect soil structure and stability, as well as soil cover. The length of crop rotation, combined with the choice of crops grown in rotation can affect soil properties.

In general, when multiyear rotations are substituted with short (2- or 3-year) rotations, overall soil structure is degraded (through lowered aggregate stability, bulk density, water infiltration rate and an increase in soil erosion), mostly due to losses in organic matter (Karlen et al. 1994). In a study where alternative farming systems (long crop rotations, manure/municipal sludge applications, ridge-tillage) were compared to conventional systems (short rotation, synthetic inputs, reduced tillage), the alternative systems had higher levels of structural stability (Karlen et al. 1994). The higher stability levels were attributed to the use of longer crop rotations and organic amendments.

Increasing the intensity and diversity of cropping systems in the Canadian prairies has been found to increase crop production, which in turn increases the potential to store soil organic matter and improve soil structure and stability (Grant et al. 2002). The ability of a crop to contribute to SOC storage is partially dependent on the type and quantity of residues returned to the soil. Vandenbygaart et al. (2003) compiled 87 comparisons of crop rotation effects on SOC storage in Canada and found patterns in the results from the studies that illustrated the ability of different crops and rotation practices to store SOC. For example, fallow was found to reduce the potential to store SOC, because fallow reduces residue inputs and increases SOC mineralization (through increased soil moisture levels) (VandenBygaart et al. 2003). When included in rotations containing wheat (*Triticum aestivum L.*) and fallow, hay and fall rye () increased the potential to store organic carbon (C), with hay having a greater storage potential because of the higher levels of above- and below-ground residues (VandenBygaart et al. 2003). The use of legume green manures as a replacement for fallow increases organic C storage, most likely because the incorporation of legume crops in the soil increases mineralizable nitrogen, thereby allowing C levels to remain high (VandenBygaart et al. 2003). When wheat was replaced with flax, the higher lignin contents in the flax residue and higher levels of flax residue loss through blowing resulted in lower SOC storage levels (VandenBygaart et al. 2003). Perennial legumes in a corn rotation were found to greatly increase SOC over a corn monoculture (although results were highly variable)

(VandenBygaart et al. 2003). Models have estimated that crops must contribute two to three Mg C ha^{-1} in eastern Canada to maintain SOC levels at 20 g C kg^{-1}; row crops such as potatoes (*Solanum tuberosum L.*), silage corn and soybeans (*Glycine max L.*) all produce insufficient residues (less than one Mg C ha^{-1}) to maintain SOC levels (Angers and Carter 1996).

In addition to SOC, the choice of crops in rotation can affect aggregate stability. Crop rotations including legumes and/or grasses generally improve aggregate stability and soil structure (Karlen et al. 1994). Legumes in rotation (either as a green manure or hay) can increase wet aggregate stability (Campbell et al. 2001). The use of annual legumes as a green manure has been found to reduce the wind erodible fraction and increase the wet aggregate stability of a given soil when compared to a fallow-wheat system (Biederbeck et al. 1998). As well, perennial forages have a beneficial effect on aggregate stability and organic C storage (Angers and Carter 1996). Forages have been found to increase and promote soil aggregation in soils of the northern Great Plains, thereby reducing soil erosion risk (Entz et al. 2002). Conversely, soil under annual crops has been found to have lowered aggregate stability values (Rachman et al. 2003). The amount of residue produced by a crop can affect aggregation, as illustrated by the greater aggregation in monoculture corn compared to a corn-soybean rotation (due to the lower amounts of residue returned by soybean) (Karlen et al. 1994).

EFFECT OF OTHER CROPPING PRACTICES ON SOIL EROSION RISK. In addition to tillage practices and crop rotation, there are a number of cropping practices that may affect soil erosion risk. Animal manure is an important tool for recycling and distributing nutrients in a cropping system, and is the most common soil amendment in organic systems (Watson et al. 2002). The benefits of manure on soil structure and organic matter are well documented (Angers and Carter 1996; Aoyama et al. 1999b). Applying manure to agricultural land generally increases soil organic matter (Aoyama et al. 1999b) because it is a direct application of organic matter, and it increases residue production (when crop yields are increased) (Aoyama et al. 1999a). In fact, the use of manure applications in conjunction with other practices that increase soil organic matter in annually tilled systems may provide similar soil protective mechanisms as zero tillage management (Aoyama et al. 1999b). In instances where erosion has already occurred, manure applications may be an effective remedial soil amendment. In a study comparing the effects of soil amendments on artificially eroded soil, manure applications significantly increased organic C levels above the untreated plots and the plots that received fertilizer, thereby increasing soil productivity of the eroded soil (Larney et al. 2000).

In addition to enhancing soil organic matter, manure applications can improve soil structure by helping to bind soil particles and form water-stable aggregates (Aoyama et al. 1999a). Aoyama et al. (1999a) discovered that applying manure resulted in an increased quantity of macroaggregates that were resistant to slaking. This increase in the amount of macroaggregates occurred along with an increase in organic matter. The beneficial effects of manure on soil properties (including soil organic matter levels and soil structure) can help to reduce the risk of soil erosion. Bolinder et al. (1999) sampled soil from 16 replicated field sites in eastern Canada, comparing conservation management (including zero tillage, crop rotations and manure amendments) and conventional management (including fall moldboard plowing, continuous cropping and no organic amendments). In fact, the manure amendments had a greater effect on soil quality indicators (including soil C) than conservation tillage and crop rotations.

Other soil fertility inputs have been studied to ascertain their effect on soil properties. Composts are another form of organic amendment that most likely improve SOC storage and soil structure, however, there is a wide range of composts that require further study before conclusions regarding the benefits of composts are made (Angers and Carter 1996). The application of synthetic fertilizers has been found to increase soil organic matter levels when the fertilizer has increased crop yields (Bremer et al. 1994). However, the benefits of fertilization are limited, and these benefits may not be fully realized if fertilization results in higher rates of mineralization of the binding agents (Angers and Carter 1996).

The maintenance of a vegetative soil cover is the most easily managed factors affecting soil erosion (Stocking 1994). The use of vegetation to manage soil erosion risk takes many forms. For example, decreasing tillage intensity, cover crops and straw spreading are management practices that increase the amount of protective residue cover. Vegetative cover aides in preventing erosion by: binding the soil with stems and roots, improving infiltration along root biopores, slowing runoff by stalks and litter, as well as facilitating electrochemical and nutrient bonding between soil and roots (Stocking 1994). Cropping systems that accumulate residues foster soils with lowered splash detachment, greater shear strength and aggregate stability (Rachman et al. 2003). In comparing organic soil amendments, Sun et al. (1995) found that crop residues were more effective at limiting erosion on a severely eroded soil than either manures or fertilizers in the first year after incorporation. Cover crops are an important management tool for maintaining a vegetative soil cover when the main crop is no longer present. Thiessen Martens and Entz (2001) found that there are sufficient resources available in many areas of the Canadian prairies to produce a cover crop after the winter wheat has been harvested.

Seeding dates can also be an important management practice affecting erosion risk. For instance, delayed seeding exposes soil to erosive forces for longer in the spring (Stocking 1994). Finally, the use of strip cropping and shelterbelts can decrease wind erosion risk by using plants to reduce the velocity of wind over a field (Cruse and Dinnes 1995).

Sustainable Agriculture

DEFINITION. Sustainable agriculture is a term that is difficult to define precisely. Ikerd, as quoted by Rigby and Cáceres (2001), defines sustainable agriculture as "capable of maintaining its productivity and usefulness to society over the long run....it must be environmentally-sound, resource-conserving, economically viable and socially supportive, commercially competitive, and environmentally sound". Despite attempts to define sustainability, there is no consensus as to how to evaluate sustainability, what practices are sustainable in particular environments, or how long a system must function to be called sustainable (Rigby and Cáceres 2001). In a review of literature, Zinck and Farshad (1995) indicate that some authors believe a sustainable agricultural system cannot be created without a clear definition of sustainability, while those involved in production fields want sustainable principles implemented instead of working on a definition.

The reduction of soil erosion is a key concept in sustainable agriculture. Indicators of sustainability are often measured in cropping systems. Unsustainable cropping systems are generally characterized by a loss of soil organic matter and soil aggregate stability (Carter 2002). Soil quality is an integral part of sustainable agriculture (Carter 2002), and soil organic matter is considered the best indicator of soil quality (Bolinder et al. 1999).

Organic Agriculture

DEFINITION. Organic agriculture is a term that is closely related to sustainable agriculture, although there is debate as to whether the two are equal in meaning or not (Rigby and Cáceres 2001). There are many definitions of organic agriculture (Rigby and Cáceres 2001), however, a common characteristic of all organic systems is the prohibition of synthetic chemicals (Hole et al. 2005). The National Standard of Canada for Organic Agriculture (1999) defines organic agriculture as "a holistic system of production designed to optimize the productivity, and fitness of diverse communities within the agroecosystem, including soil organisms, plants, livestock, and people". This definition includes many of the principal aims of organic production and processing, as outlined by the International Federation of Organic Agriculture Movements (IFOAM 2005).

Regulation is a fundamental principle in organic agriculture (Tate 1994) since it is regulation that maintains the integrity of organic production. Standards for certified organic production often include recommendations for soil, waste and pest management, and humane handling of livestock. Canada has a national standard for organic agriculture, however, it is voluntary as of May 2005, and actual organic standards are set by the individual certifying bodies. In many other countries, including those in the E.U. and the U.S.A., organic farming is subject to national and international law, with all facets of the organic sector controlled by regulations (Hole et al. 2005).

ORGANIC AGRICULTURE SECTOR IN CANADA. Organic production is a small, yet growing sector in Canadian agriculture. The most recent Census of Agriculture (2001) found that 2,230 farms produced certified organic products in Canada. In 2003, the number of certified organic farms had increased to 3,317, representing 1.3% of all farmers (Macey 2004a). The area of land under organic production or in transition to organic production was approximately 430,000 ha in 2002 (Haumann 2003), representing about 0.6% of the total agricultural area in Canada. The share of land in organic production in Canada is higher than in the U.S., where about 0.2% of the land was in organic production (Haumann 2003), but lower than some countries in Europe, where up to 8% of the land is organic (Mäder et al. 2002).

In 1994, the organic market was considered to be a niche market in Canada (Henning 1994). Sales of organic processed and non-processed products were estimated to be between $720 and $1,030 million in 2003, with growth to $3 billion expected by 2005 (Haumann 2003).

SUSTAINABILITY OF ORGANIC AGRICULTURE. Organic agriculture is the only legally defined sustainable farming system (Watson et al. 2002). Organic standards attempt to provide recommendations for sustainable production and criteria on which to evaluate whether farm practices is sustainable. All regulations in organic systems aim to create sustainable farming systems (Watson et al. 2002). However, it is difficult to create standards that contain criteria for ecologically responsible production (Rigby and Cáceres 2001). The appropriateness of practices and technologies for sustainability varies through time and space (Rigby and Cáceres 2001), so the sustainability of the practices used by organic farmers must be evaluated in the context of where and when the system is located. As well, it is becoming increasingly difficult to hold organic farmers to sustainable practices as the organic sector expands and more farmers convert to organic production for profitability reasons, rather than sustainability principles (Rigby and Cáceres 2001). Organic standards are not the only factor affecting how much the potential benefits of organic farming are realized; the degree to which an individual organic farm is sustainable is also a function of the values of the farm manager (Hole et al. 2005).

While it is difficult to hold organic farmers to the principles of sustainability through regulation and certification, many organic farmers remain committed to creating sustainable farming systems. Organic farmers continue to pursue options to reduce the risk of soil erosion on their farm through mulch tillage, ridge tillage, killed mulch systems, living mulches or cover crops, and zone tillage (Kuepper 2001). Of these options, cover crops are one of the most viable additions to cropping systems in many areas of Canada. By providing a living vegetative cover between cash crops, cover crops have a large potential to lower soil erosion risk (Annon. 2004). As well, cover crops increase organic C storage in the soil (Annon. 2004), as all of the residues from the cover crops are returned to the soil.

COMPARING ORGANIC AND CONVENTIONAL FARMING SYSTEMS. As organic agriculture in Canada has gained popularity with consumers and the number of certified organic farms expands, the proportion of research agendas focusing on organic agriculture has also increased (Hill and MacRae 1992). Lampkin (1994) identifies two different approaches to researching organic systems: comparisons between organic and conventional systems, and direct research on organic farming systems. The former is useful in comparing environmental impacts of the systems and determining what direction future research and policy initiatives should take (Lampkin 1994), while the latter is useful in advancing knowledge of successful organic management techniques.

There are methodological difficulties in comparing organic and conventional farming systems. These difficulties can impart a degree of uncertainty to results of comparison studies because of: the biases of the researcher; the nature of the farming system; varying objectives and measures of successes among farmers, researchers and society; the study time period and temporal variability of systems; and the generalizability of the results obtained on specific systems (Lampkin 1994). As well, the reasons for alternative farms being alternative are numerous. The fact that a farm is alternative may not determine the success or failure of a farming system, but instead, there may be underlying factors that determine success of a farm (for instance, soil quality) (Vandermeer 1995).

The definition of organic and conventional systems will greatly influence the comparison of organic and conventional farming systems. These systems exist on a continuum, that is, intensive conventional farming systems lies at one end of the continuum and pure organic lies at the other, with most farming systems falling between the two extremes (Klepper et al. 1977). The term 'conventional' encompasses a wide range of agricultural systems, making it important to specify the exact meaning of a conventional system in comparative studies (Hole et al. 2005). The definition of organic and conventional systems must be sufficiently precise to answer the questions posed in the research.

To reduce the possibility of errors in conclusions, system matching procedures [e.g., farm size, type and location; and management ability (Klepper et al. 1977)] must be tailored to each study depending on what is being compared between the two systems (Lampkin 1994). The pairing of systems must be done in such a way that extraneous variation is reduced, while not excluding differences that may be responsible for observed differences in the systems being compared (Hole et al. 2005). In addition, comparisons should be made on organic farms that have completed the conversion process, and sufficient comparisons must be made to give results a broader context (Lampkin 1994). Despite the difficulties in comparing organic and conventional farm systems these studies are still of interest and can affect policy changes (Vandermeer 1995).

SOIL EROSION ON ORGANIC VERSUS CONVENTIONAL SYSTEMS. Organic cropping systems have been accused of increasing soil erosion. In his book, Saving the Planet with Pesticides and Plastic, Avery (2000) argues that organic farming increases soil erosion in two ways: first, organic agriculture, with depressed yields, will require more land in cultivation to achieve the same harvest; secondly, he states that organic systems rely solely on mechanical tillage to control weeds, leaving the soil bare, and susceptible to erosive forces. Other advocates of low- or zero-tillage systems also argue that organic farming increases erosion problems through replacing synthetic chemicals with tillage for pest control (Pates 2001).

In Europe, a number of practices that have been identified as common to organic crop production have the potential to increase erosion risk, including: frequent use of tillage, wider row spacing in cereals, slower development of crops due to lower nitrogen levels, and early breakdown of crops due to diseases (Stolze et al. 2000). However, the authors identify a number of practices used in organic farming systems that can help to control erosion, including: diverse crop rotations with high amounts of forage legumes, high levels of intercropping and underseeding, less row crops grown, and the regular use of manures leading to improved soil structure and aggregate stability (Stolze et al. 2000). Despite the fact that organic farming systems have both practices that increase as well as decrease soil erosion risk, Stolze et al. (2000) conclude that organic farming has a high potential to lower soil erosion risk.

A number of studies have been undertaken to determine how organic farming systems affect soil properties relating to soil erosion risk. Two large, long-term studies that compare organic and conventional systems have measured soil properties relating to erosion: the DOK trial (bio-Dynamic, bio-Organic, and "Konventionell") in Switzerland and the Rodale Farming Systems Trial in the U.S.. In addition to the DOK and Rodale trials, there are other smaller-scale research projects that have compared working organic and conventional farms.

At the long-term DOK trial in Switzerland, organic and conventional cropping systems with identical rotations and tillage practices are being used to compare the effect of input choice on various cropping system properties. After 21 years, all treatments at the DOK trial lost soil organic matter, however, losses in the bio-dynamic plots (an organic system) were lower than in any other system (Fließbach et al. 2000). In fact, the organic matter contents of the bio-dynamic system were 15% higher than the conventional system with manure, and 30% higher than the systems receiving no manure. Siegrist et al. (1998) found that wet aggregate stability was positively correlated to earthworm (*Lumbricus terrestris, Nicodrilus nocturnes, N. longus, Octolasion cyaneum, N. caliginosus, Allolobophora rosea, A. icterica, A. chlorotica, A. handlirschi, L. rubellus and L. castaneus*) activity at the DOK trial. With higher earthworm activity levels in the organic systems, the organic plots had higher aggregate stability and higher levels of water percolation, but the organic plots also had higher incidences of splash erosion because the soil did not seal during a rain event in the organic plots (Siegrist et al. 1998). The beneficial effects of organic farming do not protect the soil from all risk of water erosion in heavy rainfall events; organic farms require soil conservation techniques (such as diverse crop rotations and the use of cover crops) to fully protect the soil from erosion.

The Rodale Farming Systems Trial, located in the U.S.A., has also been used to compare soil properties relating to soil erosion on organic and conventional cropping systems. Wander et al. (1994) found small but significant changes in total SOC due to treatments, with C levels highest in the organic cover cropped system, followed by the organic animal-based system, and lowest in the conventional fertilized cash-grain system. The organic systems in this trial accumulated biologically active organic matter as well as more stable (but still labile) organic matter. The organic cover cropped systems accumulated organic matter that was more stable than the animal-based system because the covered cropped soil had greater physical protection (Wander et al. 1994).

Shepherd et al. (2002) reviewed the literature available comparing soil structure on organic and conventional farms, and concluded that organic farms have soil structures as good as, or better than similar conventional farms. As well, the authors found that SOM levels in organic systems were generally better than conventional systems due to the regular use of organic amendments and leguminous crops. However, Shepherd et al. (2002) caution that the connection between increased organic matter storage and improved soil structure on organic farms has not yet been made. That is, there may be other factors contributing to the difference in soil structure between organic and conventional systems, such as the increase of certain SOC compounds in organic systems that stability aggregates (such as polysaccharides), while not necessarily increasing the total organic C levels (Siegrist et al. 1998).

Despite the body of research comparing soil erosion risk on organic and conventional systems, very little of the research has been done in Canada. The only such research known to have been conducted compared the potential for wind erosion risk in organic, low-input and conventional systems at a long-term trial in Scott, SK. Increased tillage operations and lower levels of production in the organic systems led to lower residue levels compared to conventional systems; lower residue levels will increase the potential for wind erosion (Moulin et al. 2001). With the organic sector in Canada growing, it is important to understand the environmental implications of organic cropping practices, and to develop best management practices. Further research into the risk of soil erosion on organic cropping systems is needed in Canada.

CHAPTER 3

EVALUATION OF PRODUCTION DIFFERENCES ON ORGANIC AND CONVENTIONAL FARMS

Introduction

Production practices help to determine the soil's resistance to wind and water erosive forces. It is generally believed that certain practices in organic and conventional systems differ; however, only a few investigations into the production differences on organic and conventional systems have occurred in Canada. Studies have compared crop yields, farm size and economics on organic and conventional farms in Canada (Entz et al. 2001; Henning 1994; Green 1990; Molder et al. 1991). Molder et al. (1991) surveyed organic farmers in Saskatchewan to determine some farm practices and the goals of the farm. Green (1990) conducted a survey to find out what the needs of organic farmers were in terms of production, marketing and certification. The marketing and credit problems among organic farmers in Quebec were determined in the survey by Henning et al. (1994). Finally, Entz et al. (2001) analyzed the crop yields, soil nutrient status and crop rotations on organic farms located in Manitoba, North Dakota and eastern Saskatchewan. No studies in Canada have detailed crop production information relating specifically to soil erosion risk.

Tillage and crop rotations are two management practices that have a major affect soil physical properties (Katsvairo et al. 2002) and soil organic carbon storage levels (VandenBygaart et al. 2003). These two management practices are also believed to be fundamentally different in organic and conventional farming systems. The objective of this study was to determine whether production practices relating to soil erosion risk differ between organic and conventional systems and if so, how.

Materials and Methods

SURVEY DESIGN. A one-time mail-out survey (Appendix A) was sent to organic and conventional farmers in the study provinces of Alberta (AB), Saskatchewan (SK), Manitoba (MB), Ontario (ON), Nova Scotia (NS), New Brunswick (NB) and Prince Edward Island (PE). The survey was prepared following recommendations given by Jackson (1988), Babbie (1990), Rea and Parker (1997) and Woodward and Chambers (1980). The survey was pre-tested on 10 individuals with farm backgrounds from Manitoba Agriculture, Food and Rural Initiatives, and changes were made for clarification or simplification purposes based on suggestions from these individuals. The Joint Faculty Research Ethics Board of the University of Manitoba reviewed and approved the survey according to the ethical requirements of the University of Manitoba.

SELECTION OF SURVEY PARTICIPANTS. In Canada, there is no comprehensive listing of organic and conventional farmers, so it was not possible to randomly sample the organic and conventional populations. Surveys were primarily (about 85%) sent through a third party, which was able to contact farmers. To reach conventional farmers, surveys were sent to government agricultural representatives in each production area of the study provinces, and these representatives were asked to forward the surveys to typical conventional farmers in their area. Contacting farmers through this means was not possible in all geographic areas and in those cases, producer groups were used to contact conventional farmers. To reach organic farmers, surveys were forwarded by organic certifying bodies. In areas where it was not possible to use certifying bodies to contact organic farmers, public listings of organic farmers were used (about 10%). Finally, surveys were distributed to a limited number of individual organic and conventional farmers who were known to the researchers involved in the project (about 5%).

Surveys were accepted up to the fall of 2004, after which, surveys were no longer entered for analysis. The deadline for acceptance of the surveys meant that the surveys from the conventional farmers in all provinces, as well as the organic farmers from Ontario who were involved in the soil sampling portion of the study (Chapter 5) were not included in the survey analysis, as the survey information came in after the deadline.

SURVEY SECTIONS. For the majority of the survey sections, farmers were asked to identify whether they used a particular cropping practice (from a provided list) on their farm. Farmers were also asked to give a detailed description of their crop rotations from 1999-2003 on one field (found in the Five-Year Rotation Period of the Crop Rotation section, Chapter 3). Organic farmers were asked to detail the rotation on their oldest certified organic field, while conventional farmers were asked to answer the questions referring to a field that is typical for the farm. Crops were placed into categories and the number of farmers in each management group growing crops belonging to the various crop categories in the last five years was tabulated.

In order to obtain an understanding of what the current soil erosion risk is on the survey farms, farmers were asked to identify how much residue was left on the soil after all field operations in the fall, and then again in the spring after seeding. Farmers were given two pictures depicting 15% and 30% wheat residue on the soil surface and asked to classify all land on their farm into three categories: <15%, 15-30%, and >30% of soil covered by crop or crop residue (at two dates: before winter and in the spring). The percent of land falling under each of the three ground cover categories was calculated and compared for each of the management groups.

STATISTICAL ANALYSIS. Data analysis was carried out using the Statistical Package for Social Sciences (SPSS v. 12 and 13). Farmers were separated into three management groups to compare cropping practices: farmers with certified organic production (Org), farmers with conventional production (Conv) and farmers with both systems of production (Org/Conv). The most recent draft of the Canadian General Standards Board Standard for Organic Production Systems (Canadian General Standards Board 2005) requires that organic farms transition all farm production to organic, and does not allow for parallel production (that is, simultaneous production of similar products on organic and non-organic land). With this increasing strictness of certification standards, it was assumed that the Org/Conv management group mostly represents farms in transition to organic production, as these farms cannot operate with both systems of production (organic and conventional) in perpetuity. The Org/Conv group was expected to have practices that are commonly used on both organic and conventional farms.

Contingency tables, which calculate the number of respondents in each management group that fall into a particular category, were used to analyze differences in frequencies of categorical data. Pearson's chi-square was used to test the strength of the relationship between the management groups and the category being tested. *P*-values given in tables indicate the probability that a relationship does not exist, and that any pattern in the results is due to random chance. When observed or expected counts were zero in any part of a contingency table, or if 20% of the counts had an expected frequency less than five, Fisher's exact test was used to determine the statistical significance of a relationship between variables. Fisher's exact test calculates the probability of a relationship existing between variables by calculating the exact probabilities of obtaining the observed distribution, or a more extreme distribution of values (Steel et al. 1997).

Where mean values of continuous numerical variables were obtained (farm size and percent actual soil cover), analysis of variance (ANOVA) was carried out, with management group as the source of variation in the model. Shapiro-Wilk's W was used to test for normality. In all cases, the data were not distributed normally and transformations did not produce a normal distribution. The data was analyzed using the Kruskal-Wallis test, which is a nonparametric test used to test independent samples of more than two groups (Steel et al. 1997). The conclusions of the Kruskal-Wallis and ANOVA analysis corresponded in all cases (that is, the tests results were significant or not at $P<0.05$), and so the results from the ANOVA analysis are presented. Significant differences between means were determined using least significant difference (LSD).

Results and Discussion

DESCRIPTION OF RESPONDENTS. In order to better understand and interpret the survey results, it was necessary to obtain some background information on the farmers and their operation. The distribution of responses among the study provinces and management group indicate how representative the survey is in terms of geographic location and management faction. Other production information not related to soil erosion can be useful in describing what farming operations are represented in the survey.

RESPONSE RATES. A total of 225 surveys were returned, resulting in a 25% final response rate. Most of the surveys were distributed by a third party, so follow-up contact could not be made to remind farmers to complete and return the survey. There were 81 Org respondents, 101 Conv respondents and 43 respondents with both certified organic and conventional fields (Org/Conv).

Table 3-1 shows the breakdown of respondents by province. The majority of the responses were from the Prairie provinces: about 84% of respondents were from AB, SK or MB. The results from this survey, therefore, have a bias towards the Prairie experience. In particular, the survey is skewed towards Manitoba, which represents 43% of all responses. The extremely low number of responses from ON (a total of 3 surveys were received from ON) was due to the difficulty in obtaining co-operation with any particular certifying body or producer organization to forward surveys to producers. The number of responses from ON does not reflect the number of organic (or conventional) farmers in that province. In 2002, the province of ON had the third largest body of certified organic farmers (397), exceeded only by Saskatchewan (with 1150 farmers) and Quebec (619 farmers) (Macey 2004b).

Table 3-1: Breakdown of respondents by management category and province

	Respondents from each province by group						
	AB (%)	MB (%)	NB (%)	NS (%)	ON (%)	PEI (%)	SK (%)
Org	23.5	27.2	13.6	9.9	3.7	4.9	17.3
Conv	11.9	47.5	0	5.0	0	0	35.6
Org/Conv	11.6	62.8	4.7	4.7	0	0	16.3
Total responses	36	97	13	15	3	4	57
Total %	16.0	43.1	5.8	6.7	1.3	1.8	25.3

Table 3-2 shows the total number of organic farmers in each of the study provinces according to all organic certifiers in Canada (Macey 2004a). Roughly 52% of all organic producers were from the Prairies, while 17% of organic producers came from the eastern provinces of ON, NS, NB, PEI or Newfoundland (NFL) (this compares with 16% of responses from the eastern provinces and 84% from the Prairies in the study survey). In the study survey, the proportion of responses from AB, MB, NB, NS and PEI were overrepresented (with the largest discrepancy between representation in the study survey and actual numbers of farmers occurring for MB). The proportions of respondents from SK and ON were underrepresented in the study survey. The proportion of respondents in the study survey from SK and ON were about 10% lower than the actual proportion of organic farmers in those two provinces.

Table 3-2: Breakdown of organic farmers by province in 2002

Province	Number of farmers	% of total organic farmers
BC	383	12.3
AB	254	8.1
SK	1150	36.9
MB	204	6.5
ON	397	12.7
QC	619	19.8
NB	37	1.2
NS	46	1.5
PEI	26	0.8
NFL	3	0.1
YK	1	0.0
Total	3120	100

(Macey 2004b)

Farm Descriptions

There was a significant relationship between farm size and management group (Table 3-3). The Org farms were smaller in size than both the Conv and Org/Conv. Organic farming has been most commonly associated with smaller operations that are more labour-intensive in the past (Klepper et al. 1977), however, there is a wide diversity of organic systems (e.g., organic farms include intensive market gardens of less than one hectare and extensive field cropping systems, hundreds of hectares in size). This wide range of organic cropping systems makes it difficult to come to a meaningful average farm size (i.e., does farm size include grain land, pasture and hay land?) (Duram 1999). For the purpose of this study, the total farm size was compared, which gives an indication of the total amount of land under the management of a given farmer.

Table 3-3: Average farm size (hectares)

	Mean farm size	Std. deviation	Total responses
Org	196 c	287	81
Conv	978 a	773	101
Org/Conv	455 b	425	43
Total	597	677	225
P-value	<0.001	-	-

Means followed by different letters indicate significant differences as determined by LSD (*P*=0.05).

All farmers answering the survey had land producing a crop, whether it was specialty, grain or forage crops. The type of farm operation (mixed or solely crop operations) was determined by asking the farmers to indicate if they had an animal operation, and what type of operation it was. The incorporation of animals into an organic cropping system provides a number of benefits, including creating a purpose for having soil-building forages in rotation, and the ability to recycle soil nutrients through manure. In a review of organic versus conventional studies, Hole et al. (2005) concluded that the preservation of mixed farming was a major management option in organic farming that is beneficial to farm biodiversity. There was no significant difference in the percentage of farmers with animals on their farm when management groups were compared (Table 3-4).

Table 3-4: Number of farms with animals

	Farmers with animals by group (%)	Total responses
Org	55.6	81
Conv	44.6	101
Org/Conv	53.5	43
Total	50.2	225
P-value	0.301	-

The respondents with a mixed farming operation (that is, farms with both crop and livestock operations) were broken down by type of animals present on the farm, and management group (Table 3-5). Roughly 40% of all farmer groups had cattle on their farm. However, a greater proportion of Org farmers had all other types of animals on their farm than Conv producers.

Table 3-5: Number of farmers with mixed farming operations

	Farmers with animal operation on farm by group					
	Cattle (%)	Sheep and/or goats (%)	Poultry (%)	Hogs (%)	Other animals (%)	Total responses
Org	39.5	19.8 a	25.9 a	11.1 a	14.8 a	81
Conv	38.6	3.0 b	0.0 c	3.0 b	4.0 b	101
Org/Conv	41.9	4.7 b	7.0 b	4.7 ab	14.0 a	43
Total	39.6	9.3	10.7	6.2	9.8	225
P-value	0.936	<0.001	<0.001	0.070	0.029	-

Percentages followed by different letters denote significant differences between proportions of farmer groups (within a column), determined by pairwise chi-square tests (P=0.05).

For the purposes of this study, conventional farms were defined as those that did not have certified organic production. This allows for a great deal of variation from farm to farm depending on the management, and it is, therefore, possible to have a very wide spectrum of farms represented within the definition of a conventional farm in this survey. To get an indication of what sort of conventional farms were represented in the survey, conventional farmers were asked to indicate to what degree they had lowered their input use (fertilizers, pesticides and tillage) over the past ten years. Eighty-six percent of the Conv farmers indicated that they had lowered the amount of tillage used on their farm in the past decade. The average reduction of input use by conventional farmers that indicated they had reduced their use of pesticides, fertilizers and/or tillage is reported in

Table 3-6. The average reduction in tillage over the past decade exceeded the reduction in the use of pesticides and fertilizers by 30%: tillage use was lowered by an average of 63%, while pesticide and fertilizer use were lowered by 33% and 31%, respectively. Decreasing tillage use is an important soil conservation tool, and so it was determined that the majority of the Conv farmers in this survey were concerned with soil conservation.

Table 3-6: Input use reduction on Conv farms over last 10 years

	Mean reduction in input use		
	Pesticides (%)	Fertilizers (%)	Tillage (%)
Mean	33.0	31.3	63.4
Standard Deviation	28.6	26.2	26.9
Total responses	63	44	97

CROPPING PRACTICES DIFFERENCES. Many cropping practices can affect the risk of soil erosion by altering the amount of residues returned to the soil, the level of vegetative crop cover, and the degree of soil aggregate breakdown by tillage. Farmers were asked to identify all of the cropping practices they used on their respective farms from a list of practices. The practices were broken down into a number of sub-categories. Several other questions were posed to obtain more information regarding soil conservation practices and crop rotations on the survey farms.

Tillage Practices

Tillage has a direct effect on soil structure, as well as an indirect effect on vegetative soil cover and residue levels. The percent of farmers in each management group that used the listed tillage practices are given in Table 3-7. Around 60% of farmers in each management group stated that they had reduced tillage practices on their farm, indicating that the majority of farmers surveyed practiced some form of soil conservation. Sixty-six percent of Conv farmers practiced zero tillage on their farm, as compared to 10% and 20% of Org and Org/Conv farmers, respectively. As well, a greater percentage of Conv (59%) farmers directly seeded their crops than Org (14%) and Org/Conv (33%) farmers, although there was a slightly smaller difference between the proportion of Org/Conv and Conv farmers that used direct seeding when compared to zero tillage. Zero tillage and direct seeding systems generally rely heavily on synthetic herbicides for weed control, so these systems of tillage are not available for organic farmers. However, other forms of conservation tillage were practiced by a greater number of Org farmers, indicating that many Org farmers are attempting to reduce the amount of tillage on their farm.

Table 3-7: Various tillage practices employed by farmers

	Farmers practicing 'novel' and/or conservation forms of tillage by group								
	Reduced tillage (%)	Zone tillage (%)	Ridge tillage (%)	Contour tillage (%)	Zero/No tillage (%)	Direct seeding (%)	Blind tillage (%)	In-crop tillage (%)	Total responses
Org	59.5	11.4	12.7 a	21.5 a	10.1 b	13.9 c	21.5 a	24.1 a	79
Conv	61.4	4.0	1.0 b	3.0 b	66.3 a	59.4 a	0.0 b	5.0 b	101
Org/Conv	64.4	11.1	2.2 b	8.9 ab	20.0 b	33.3 b	22.2 a	28.9 a	45
Total	61.3	8	5.3	10.7	37.3	38.2	12.0	16.4	225
P-value	0.862	0.104[z]	0.001[z]	<0.000[z]	<0.001	<0.001	<0.001	<0.001	
Ag Census (Statistics Canada 2001)				3.4					

Percentages followed by different letters denote significant differences between proportions of farmer groups (within a column), determined by pairwise chi-square tests (P=0.05).

[z]Fisher's exact test was used to determine P-values due to insufficient responses in some categories.

It must be noted that the proportion of Org farmers with other forms of conservation tillage (13% and 22% for ridge and contour tillage, respectively) is much lower than the proportion of Conv farmers with zero tillage and/or direct seeding. This indicates that fewer Org farmers than Conv farmers have conservation tillage practices.

Blind (shallow tillage, done usually with harrows, after the crop has been seeded, but prior to crop emergence) and in-crop tillage were used almost exclusively by Org and Org/Conv farmers. Twenty-two percent and 24% of Org farmers used blind and in-crop tillage, respectively, as compared to 0% and 5% of Conv farmers. These more novel forms of tillage are shallow and occur either just before crop emergence (blind) or after the crop has emerged (in-crop). The fact that more Org and Org/Conv farmers use these forms of tillage suggests that organic farmers use more tillage on their farm than conventional farmers. However, these tillage operations have lower levels of soil disturbance than some other operations, and occur at a time when there is a vegetative cover, or will soon be a vegetative cover.

Soil Cover

There are a number of farm practices that will directly affect the amount of vegetative or residue cover present on a field. More Conv farmers had practices that conserved soil cover, as well as retained a greater level of soil cover in the fall and spring when crops were not present. A greater proportion of Org farmers used summerfallow on their farm: a total of 52% of Org and 53% of Org/Conv farmers used summerfallow, compared to 34% of Conv farmers. As the use of pesticides is prohibited on organic farms, all the summerfallow practiced on the organic farms was maintained through the use of tillage, while summerfallow on Conv farms was almost entirely chemical summerfallow (6% of summerfallow on Conv farms used tillage) (Table 3-8). Tillage summerfallow (as opposed to chemical fallow) is particularly destructive due to its greater intensity of tillage that works any vegetative residue present into the soil (increasing organic matter breakdown), physically breaks up soil aggregates, and destroys some soil biota. However, some common tillage implements used by organic farmers, such as a rod-weeder and a noble blade, cause little soil disturbance and destruction. These tillage implements may result in only slightly higher levels of soil disturbance than chemical summerfallow. A greater percentage of Conv farmers spread straw throughout their fields. Straw cover can help to protect the soil from erosion by providing a vegetative cover when a crop is not present. There was no difference in the percentage of farmers in each management group having permanent grass cover (not including pasture) and practicing stubble burning. The extremely low percentage of farmers that burn stubble (one percent to six percent) is most likely attributable to increased consciousness of the need for soil conservation, stricter regulations on burning stubble, the need for cattle feed in drought years and expanded markets for crop stubble (e.g., DowBioproducts Ltd., formerly the Isoboard strawboard plant in MB). The percent of all Canadian farmers with permanent grass cover from the 2001 Agriculture Census is included in Table 3-8, showing that the proportion of farmers with particular practices from the study survey match well with the overall distribution of farmers.

Table 3-8: Practices used by farmers affecting the amount of soil cover

	Farmers with practices affecting soil cover by group					
	Chemical summerfallow (%)	Tillage summerfallow (%)	Straw spreading (%)	Stubble burning (%)	Permanent grass cover (%)	Total responses
Org	0 c	51.9 a	49.4 b	1.3	36.7	79
Conv	31.7 a	5.9 b	74.3 a	5.9	43.6	101
Org/Conv	8.9 b	48.9 a	60.0 b	2.2	51.1	45
Total	16	30.7	62.7	3.6	42.7	225
P-value	<0.001	<0.001	0.003	0.227[z]	0.288	-
Ag Census (Statistics Canada 2001)					31.6	

Percentages followed by different letters denote significant differences between proportions of farmer groups (within a column), determined by pairwise chi-square tests (P=0.05).

[z]Fisher's exact test was used to determine P-values due to insufficient responses in some categories.

Fertility Inputs

Farmers were asked what common inputs they used to restore soil fertility (Table 3-9). Almost all (96%) of Conv farmers used industrial fertilizers on their farm. The small portion of Org farmers (1.3%) who use rock phosphate identified this as an industrial fertilizer. There was no difference in the level of manure use between the management groups; however, a greater proportion of Org farmers applied composts to fields than Conv and Org/Conv farmers. Biodynamic systems are a form of organic agriculture that rely on compost as an organic soil amendment, and have been shown to build soil structural stability (Mäder et al. 2002).

Table 3-9: Fertility practices employed by farmers

	Farmers using forms of fertility by group			
	Industrial fertilizers (%)	Manure (%)	Compost (%)	Total responses
Org	1.3 c	49.4	55.7 a	79
Conv	96.0 a	42.6	8.9 c	101
Org/Conv	51.1 b	40.0	33.3 b	45
Total	53.8	44.4	30.2	225
P-value	<0.001	0.528	<0.001	-

Percentages followed by different letters denote significant differences between proportions of farmer groups (within a column), determined by pairwise chi-square tests (P=0.05).

Seeding Practices

Seeding practices help to determine how much crop biomass is present, and when in the growing season the crop is present. Common seeding practices used by farmers from the three management groups were determined in the survey (Table 3-10). Sixty-one percent of Conv farmers practiced early seeding, compared to 30% of Org and 40% of Org/Conv farmers. Delayed seeding allows the first flushes of weeds to be controlled with tillage prior to crop establishment, but also means that the soil will be bare of a crop for a longer period of time at the beginning of the growing season. It is known that spring is the time of greatest water erosion potential (Shelton et al. 2000), so any delay in crop establishment will mean an increased window of opportunity for erosion to occur.

Table 3-10: Seeding practices used by farmers

	Farmers with novel seeding practices by group						
	Underseeding (%)	Strip cropping (%)	Narrower row spacing (%)	Increased seeding rate (%)	Delayed seeding (%)	Early seeding (%)	Total responses
Org	64.6 a	12.7 a	30.4 a	64.6 a	59.5 a	30.4 b	79
Conv	19.8 b	4.0 b	12.9 b	46.5 b	11.9 b	61.4 a	101
Org/Conv	66.7 a	0.0 b	26.7 a	64.4 a	64.4 a	40.0 b	45
Total	44.9	6.2	21.8	56.4	39.1	46.2	225
P-value	<0.001	0.010[z]	0.012	0.026	<0.001	<0.001	-
Ag Census (Statistics Canada 2001)		3.4					

Percentages followed by different letters denote significant differences between proportions of farmer groups (within a column), determined by pairwise chi-square tests (P=0.05).

[z]Fisher's exact test was used to determine P-values due to insufficient responses in some categories.

All other seeding practices were used by Org farmers to a greater extent. Narrower row spacing, increased seeding rates and underseeding all have the potential to increase crop cover (of the soil surface) and crop production. Increased crop production also increases the biomass returned to the soil as residue, which has the potential to increase soil organic matter levels and improve soil structure and stability (Grant et al. 2002). A properly selected cover crop can provide a vegetative soil cover in the fall. Strip cropping can help to reduce wind erosion while increasing crop diversity (Cruse and Dinnes 1995). The proportion of Canadian farmers with strip cropping (from the Agriculture Census 2001) was included in Table 3-10. The percent of total Canadian farmers that practice strip cropping (3.4%) matches the percent of conventional farmers that reported using strip cropping in the study survey (4.0%). This indicates that the survey accurately represents how many farmers use strip cropping, and that a much greater proportion of Org farmers use this practice.

Crop Rotation

Rotation Practices from Rotations Listed in the Survey. Organic cropping systems rely more heavily on crop rotations than conventional systems to solve agronomic problems, as they cannot use synthetic pesticides and fertilizers. Farmers were asked to identify, from a provided list, what crop categories were present in their rotations (Table 3-11). A greater proportion of Org farmers had forages, row crops and green manures in rotation. The percentage of Conv farmers with animals on the farm (45%) matches well with the percentage of farmers with forages in rotation (46%); however, there is a greater proportion of Org and Org/Conv farmers growing forages (66% and 80%, respectively) than have animals (56% and 54%, respectively) (Table 3-12). This indicates that Org and Org/Conv farmers are more committed to having forages in their rotation, regardless of whether there are animals present on the farm.

Table 3-11: Crops grown in rotation

	Farmers with crop categories grown in rotation by group					
	Forage crops (%)	Solid-seeded crops (%)	Row crops (%)	Winter cover crops (%)	Green manure (for plowdown) (%)	Total responses
Org	65.8 a	38.0 b	30.4 a	48.1	83.5 a	79
Conv	45.5 b	64.4 a	13.9 b	33.7	5.9 b	101
Org/Conv	80.0 a	40.0 b	15.6 ab	44.4	73.3 a	45
Total	59.6	50.2	20.0	40.9	46.7	225
P-value	<0.001	0.001	0.016	0.128	<0.001	-
Ag Census (Statistics Canada 2001)				4.6	6.6	

Percentages followed by different letters denote significant differences between proportions of farmer groups (within a column), determined by pairwise chi-square tests (*P*=0.05).

Table 3-12: Farms with forages in rotation versus animals on farm

	Farmers with forages and animals by group	
	Forage crops (%)	Animals on farm (%)
Org	65.8 a	55.6
Conv	45.5 b	44.6
Org/Conv	80.0 a	53.5
Total	59.6	50.2
P-value	<0.001	0.301

Percentages followed by different letters denote significant differences between proportions of farmer groups (within a column), determined by pairwise chi-square tests (P=0.05).

That generally twice as many Org farmers have row crops in rotation (Table 3-11) compared to Conv and Org/Conv farmers may be indicative of the greater marketing opportunities for certified organic fresh produce and specialty crops. A greater proportion of organic farmers with row crops in rotation, and a smaller proportion of Org farmers with solid-seeded grains and oilseeds in rotation compared to Conv farmers may indicate that Org farmers are substituting row crops for solid-seeded crops. If this is correct, a reduction in the soil's potential to store organic C is expected since row crops generally have lower residue levels and require more tillage than solid-seeded crops.

Legume green manures have been shown to increase mineralizable N levels in the soil, resulting in the potential for the storage of soil organic C (VandenBygaart et al. 2003). The majority of Org (84%) and Org/Conv (73%) farmers had green manures in their crop rotations, compared to 6% of Conv farmers. The proportion of conventional farmers who identified themselves as using green manures in this survey closely mirrored the percentage of total Canadian farmers using green manures, indicating that this survey is representative of the general farmer population for this category. The large difference in dependence on green manures between organic and conventional cropping systems illustrates how heavily organic farmers rely on green manures and other crop rotation practices to solve agronomic problems. Green manures can help to build or maintain SOM (Shepherd et al. 2002; VandenBygaart et al. 2003), thereby promoting a well structured soil.

Five-Year Rotation Period. The proportion of farmers in each management group that grew certain crop categories in the last five years is given in Table 3-13. The crop categories are not mutually exclusive, so one crop may appear under a number of different categories. As expected (based on the previous results from this section), more Conv farmers had solid-seeded grains and oilseeds in rotation, as compared to Org farmers. Over twice as many Conv farmers had annual legumes in their rotation than Org farmers, however, the difference between the two management groups was less pronounced than with the grains and oilseeds. Both Org and Conv farmers had fewer forage legumes in their rotation compared to annual legumes. More Org farmers (14%) had forage legumes in their rotation than Conv producers (6%), which is the opposite relationship as was found for the annual legumes. Forage legumes help to build soil organic matter and nitrogen fertility, making these crops important for organic farmers who cannot build soil fertility levels with industrial fertilizers. Annual legumes can also help improve nitrogen levels in the soil, however, annual legumes grown for harvest are highly susceptible to crop pests (including weed pressures and diseases), making them more difficult to grow when synthetic chemicals are not permitted.

Table 3-13: Crop rotation from 1999-2003 in one field

	Farmers with crop category in rotation 1999-2003 by group								
	No crop (%)	Solid-seeded grains (%)	Solid-seeded oilseeds (%)	Annual legumes (%)	Fall-seeded grains (%)	Forage legumes (%)	Forage grass (%)	Hay mixture (%)	Other crops
Org	8.6 a	51.9 b	16.0 b	21.0 b	18.5	13.6 a	3.7	23.5 a	28.4 a
Conv	0.0 b	93.1 a	71.3 a	46.5 a	12.9	5.9 a	5.9	5.9 b	7.9 b
Org/Conv	7.0 a	60.5 b	27.9 b	11.6 b	9.3	34.9 b	4.7	23.3 a	16.3 ab
Total	4.4	72.0	43.1	30.7	14.2	14.2	4.9	15.6	16.9
P-value	0.004[z]	<0.001	<0.001	<0.001	0.332	<0.001	0.919[z]	0.001	0.001

Table 3-13: Crop rotation from 1999-2003 in one field (con't)

	Farmers with crop category in rotation 1999-2003 by group				
	Underseeding (%)	Two crops (%)	Summerfallow (%)	Summerfallow with green manure (%)	Total responses
Org	22.2 a	7.4 b	22.2	18.5 b	81
Conv	6.9 b	1.0 c	11.9	2.0 c	101
Org/Conv	25.6 a	20.9 a	20.9	39.5 a	43
Total	16.0	7.1	17.3	15.1	225
P-value	0.003	<0.001[z]	0.153	<0.001	

Percentages followed by different letters denote significant differences between proportions of farmer groups (within a column), determined by pairwise chi-square tests (P=0.05).

[z]Fisher's exact test was used to determine *P*-values due to insufficient responses in some categories.

A greater proportion of Org farmers had hay mixtures, ‘other’ crops (e.g., market garden vegetables and fruits), underseeding, two crops, summerfallow and summerfallow with a green manure in the five-year rotation period than Conv farmers. Hay mixtures, underseeding and growing two crops at once are all systems of increasing spatial crop diversity, indicating that Org farmers are searching for ways to increase and benefit from cropping system diversity.

A larger number of Org/Conv farmers had summerfallow with a green manure in the five-year period: 40%, compared to 19% of Org farmers and 2% of Conv farmers. The much greater prevalence of green manures in the Org/Conv farms may be due to the fact that some of these farms may still be in a transitional period, and attempting to control weed problems with green manures.

Planned Rotation/Commitment to Rotation. To determine how important maintaining a particular crop rotation was to the farmers, a number of questions were posed regarding their commitment to a particular cropping sequence. There was a significant relationship (P=0.032) between management group and the number of farmers with a planned crop rotation (Table 3-14). Org and Conv groups had statistically similar percentages of farmers with a planned rotation (83 and 79%, respectively). The lower percent of Org/Conv farmers with a planned rotation (62%) may be indicative of more Org/Conv farmers in a transitional phase from a conventional to organic system. Transitional farmers are generally still in the process of developing a suitable crop rotation for an organic system.

Table 3-14: Farmers with planned crop rotation	
	Farmers with a planned rotation by group (%)
Org	82.7 a
Conv	78.8 a
Org/Conv	61.9 b
Total	76.9
P-value	0.032

Percentages followed by different letters denote significant differences between proportions of farmer groups, determined by pairwise chi-square test (P=0.05).

Farmers who did have a planned rotation were asked to indicate their level of commitment to maintaining their planned rotation (Table 3-15). There was a significant relationship between management group and commitment to a rotation. Almost double the number of Org farmers were very committed to their crop rotation than Conv and Org/Conv farmers. Conventional farmers can alter a rotation due to market changes and rely on synthetic chemicals to solve any agronomic problems arising from a poorly designed rotation (such as disease and weed pressures). Transitional farmers are learning what rotation works best in their new organic cropping system, and have not necessarily developed a rotation that works to prevent agronomic problems. For these reasons, the organic farmers are more committed to a particular crop rotation. The majority of farmers in all management groups were somewhat committed to their crop rotation.

Table 3-15: Farmers commitment level to the planned crop rotation

	Farmers with level of commitment to the rotation by group			
	Very committed (%)	Somewhat committed (%)	Not committed (%)	Total responses
Org	36.5 a	54.1	9.5	74
Conv	20.4 b	65.3	14.3	98
Org/Conv	19.0 b	54.8	26.2	42
Total	25.7	59.3	15.0	214
P-value	0.035^z	0.190^z	0.055^z	-

Percentages followed by different letters denote significant differences between proportions of farmer groups (within a column), determined by pairwise chi-square test (P=0.05).

^{z}Fisher's exact test was used to determine P-values due to insufficient responses in some categories.

Farmers who indicated that they were somewhat committed or not committed to a crop rotation were asked why they had changed from a planned rotation in the past (Table 3-16). There was a significant relationship between management group and changing a crop rotation because of marketing and disease reasons. A greater proportion of Conv farmers changed their rotation due to marketing and disease. Eighty-six percent of Conv farmers changed their rotation due to markets, compared to 50% of Org farmers and 62% of Org/Conv farmers. This suggests that organic farmers are less willing to change their rotation due to non-biological factors than their conventional counterparts. However, close to four times the number of Conv farmers had changed their rotation due to disease, than the number of Org and Org/Conv farmers. This may indicate that organic farmers are less concerned with disease on their farm, or that disease is not as large a problem on organic farms (possibly due to the more diverse rotations present on many organic farms).

Table 3-16: Reasons for changing a planned crop rotation

	Farmers who have changed rotation for a reason by group					
	Market (%)	Weeds (%)	Equipment Change (%)	Weather (%)	Disease (%)	Total responses
Org	50.0 b	79.2	6.3	77.1	10.4 b	48
Conv	86.1 a	67.1	2.5	62.0	44.3 a	79
Org/Conv	61.8 b	82.4	5.9	61.8	14.7 b	34
Total	70.2	73.9	4.3	66.5	28.0	161
P-value	<.001	0.146	0.539[z]	0.177	<.001	

Percentages followed by different letters denote significant differences between proportions of farmer groups (within a column), determined by pairwise chi-square tests (P=0.05).

[z]Fisher's exact test was used to determine *P*-values due to insufficient responses in some categories.

Other Soil Conservation Practices

There are a number of other practices used on farms that can help to conserve the soil. Farmers were asked to indicate whether they used shelterbelts/windbreaks, grassed waterways, and/or water diversion terracing on their farms (Table 3-17). A greater number of Org farmers said they had shelterbelts/windbreaks on their farm compared to Conv and Org/Conv farmers. However, the proportion of farmers with shelterbelts in this survey is much higher than the national average of 14% of farmers with shelterbelts (Statistics Canada 2001). When the percent of farmers with grassed waterways from this survey (ranging from 44-49%) was compared with the number of farmers with grassed waterways nation-wide (10%), again, a large difference in numbers is noted. These differences in percent of farmers with conservation practices between the current survey and the Agriculture Census may indicate that there was some self-selection of survey respondents. That is, mostly farmers who already had soil conservation practices on their farm answered this survey.

Table 3-17: Other soil conservation practices employed by farmers

	Farmers using other soil conservation practices by group		
	Shelterbelts/Windbreaks (%)	Grassed waterways (%)	Water diversion terracing (%)
Org	74.7 a	48.1	11.4
Conv	54.5 b	43.6	6.9
Org/Conv	57.8 ab	48.9	6.7
Total responses	140	104	19
Total	62.2	46.2	8.4
P-value	0.017	0.768	0.519^z
Ag Census (Statistics Canada 2001)	13.5	10.3	

Percentages followed by different letters denote significant differences between proportions of farmer groups (within a column), determined by pairwise chi-square tests (P=0.05).

^{z}Fisher's exact test was used to determine P-values due to insufficient responses in some categories.

Actual Soil Cover

The average percentages of land falling into each of the three ground cover categories (<15%, 15-30% and >30% ground cover) by management group for fall are given in Table 3-18 and spring values are given in Table 3-19. The standard deviations of the means are extremely large, illustrating the large variations among management groups. There were significant differences in the two extreme levels of soil cover (<15% and >30%) between management groups in both the fall and spring. A greater proportion of Org farmers had <15% soil cover in the fall and spring and a greater proportion of Conv farmers had >30% soil coverage at both times. This is most likely a consequence of the much higher proportion of Conv farmers with zero tillage. With higher tillage intensities, Org farmers will have less residue cover in the fall and spring. While the seasonal distribution of soil erosion is highly dependent on individual site properties

(Kirby and Mehuys 1987), generally spring is the time of the year when soil is most susceptible to water erosion (Shelton et al. 2000; Dumanski et al. 1986).

Table 3-18: Land in soil cover categories in fall after all field operations

	Percent of total cropland with level of crop and crop residue on soil[z]						
	<15%		15-30%		>30%		
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Total responses
Org	11.8 a	24.2	15.4	24.3	54.5 b	41.0	70
Conv	3.2 b	12.3	10.8	24.8	76.3 a	35.4	99
Org/Conv	6.0 ab	11.5	8.5	17.7	63.4 ab	35.5	37
Total	6.6	17.6	11.9	23.6	66.6	38.5	206
P-value	0.006		0.278		0.001		

Means followed by different letters indicate significant differences as determined by LSD (P=0.05).
[z]Not 100% of all cropland from the surveys is represented in the three categories due to non-responses, and farmers not identifying 100% of their acres in the three categories.

Table 3-19: Land in soil cover categories in spring after seeding

	Percent of total cropland with level of crop and crop residue on soil[z]						
	<15%		15-30%		>30%		
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Total responses
Org	24.7 a	30.9	19.4	28.5	36.4 b	38.7	70
Conv	9.6 b	23.2	17.1	30.9	62.6 a	42.5	99
Org/Conv	19.2 ab	30.0	20.3	28.8	36.1 b	37.1	37
Total	16.5	28.0	18.5	29.6	49.0	42.2	206
P-value	0.002		0.814		<0.001		

Means followed by different letters indicate significant differences as determined by LSD (P=0.05).
[z]Not 100% of all cropland from the surveys is represented in the three categories due to non-responses, and farmers not identifying 100% of their acres in the three categories.

FARMER OPINIONS.

Statement Responses

To better understand farmer opinions and attitudes regarding organic farming and soil conservation survey respondents were asked to react to a number of statements. Respondents were asked to select a number from a 7-point scale, from one (strongly disagree) to seven (strongly agree) that identified the degree to which they agreed or disagreed with the statement. Table 3-20 reports the exact statements as they appeared in the mail-out survey, and the mean responses from each management group.

Table 3-20: Mean values from opinion statements

	Management group	Mean response values^z	Std. dev.	*P*-value
I believe soil erosion is a major problem in Canadian agriculture.	Org	5.1	1.6	
	Conv	5.2	1.4	
	Org/Conv	5.0	1.6	
	Total	5.1	1.5	0.998
Water erosion is a problem on my farm.	Org	2.4	1.5	
	Conv	2.6	1.5	
	Org/Conv	3.1	1.9	
	Total	2.6	1.6	0.195
Wind erosion is a problem on my farm.	Org	2.4 b	1.6	
	Conv	2.4 b	1.4	
	Org/Conv	3.2 a	1.8	
	Total	2.5	1.6	0.043
I believe that individual farmers should be responsible for soil conservation on their farm.	Org	6.2	1.3	
	Conv	6.1	1.2	
	Org/Conv	6.2	1.2	
	Total	6.2	1.2	0.627
It is possible to lower the amount of tillage used on my farm.	Org	3.3 b	1.9	
	Conv	3.8 ab	2.2	
	Org/Conv	4.3 a	1.7	
	Total	3.7	2.0	0.038

Table 3-20 (con't): Mean values from opinion statements

	Management group	Mean response values[z]	Std. dev.	*P*-value
I would be willing to spend money on soil conservation technologies.	Org	3.9 b	1.9	
	Conv	5.0 a	1.6	
	Org/Conv	4.8 a	1.8	
	Total	4.6	1.8	0.001
I would be willing to spend time learning/implementing soil conservation technologies.	Org	5.6	1.5	
	Conv	5.6	1.2	
	Org/Conv	5.7	1.5	
	Total	5.6	1.4	0.935
Organic farmers rely more heavily on tillage than conventional farmers.	Org	4.5 b	2.3	
	Conv	5.9 a	1.3	
	Org/Conv	5.9 a	1.6	
	Total	5.4	1.9	<0.001
Conventional farmers rely more heavily on tillage than organic farmers.	Org	3.1 a	2.2	
	Conv	2.4 b	1.6	
	Org/Conv	2.4 b	1.7	
	Total	2.7	1.8	0.004
I believe that organic farming is more environmentally friendly than conventional farming overall.	Org	6.6 a	1.1	
	Conv	3.4 b	1.9	
	Org/Conv	6.2 a	1.4	
	Total	5.1	2.2	<0.001
I believe that conventional farming is more environmentally friendly than organic farming overall.	Org	1.4 b	1.1	
	Conv	4.0 a	1.6	
	Org/Conv	1.9 b	1.2	
	Total	2.7	1.8	<0.001
I choose crop rotations to reduce/prevent pest problems.	Org	5.9 a	1.5	
	Conv	5.3 b	1.5	
	Org/Conv	5.8 ab	1.1	
	Total	5.6	1.4	0.013

Means followed by different letters indicate significant differences as determined by LSD (P=0.05).

[z]Mean response value, based on a 7-point scale, from 1 (strongly disagree) to 7 (strongly agree).

There were a number of opinion statements where the mean responses differed between management groups. The Org/Conv group believed they have a larger wind erosion problem than Org or Conv farmers, returning a mean response of 3.2 compared to

2.4 for the Org and Conv farmer groups. However, based on the total mean values (around 2.5), farmers in all groups believe that wind or water erosion is not a problem on their farm. Org/Conv farmers may sense a link between soil erosion and tillage, since they also reported the highest agreement with the statement: "It is possible to lower the amount of tillage used on my farm" to a greater extent than Org farmers.

Conv and Org/Conv farmers were more willing to spend money on soil conservation technologies (response of 5.0 and 4.8, respectively) than Org farmers (3.9). This lower result may be a result of farmers believing that the question refers only to zero tillage technologies. In that case, since zero tillage systems generally rely on pesticides for weed control, organic farmers would not be able or willing to adopt these technologies.

The statements regarding the use of tillage on organic and conventional systems received the expected responses from each management group. The Org farmers agreed more with the statement that conventional farmers rely more heavily on tillage, and the Conv farmers agreed more with the statement that organic farmers rely more heavily on tillage. The Org/Conv farmers' responses agreed with the Conv farmers for these two statements. In general, farmers from all groups tended to agree more (mean response of 5.4) with the statement "Organic farmers rely more heavily on tillage than conventional farmers" than the opposite statement (mean response of 2.7).

The farmer responses to the statements regarding the environmental friendliness of organic and conventional systems were quite similar to the statements regarding tillage use in the two systems. Org farmers agreed more (6.6) with the statement "Organic farming is more environmentally friendly than conventional farming overall" than Conv farmers (3.4). For the opposite statement (conventional farming is more environmentally friendly), Conv farmers agreed (4.0) more than Org farmers (1.4). Responses from the Org/Conv management group matched the responses from the Org group. The overall means indicate that all farmers tended to believe that organic farming is more environmentally friendly than conventional farming.

Finally, Org and Conv farmers had significantly (P=0.013) different responses to the statement: "I choose crop rotations to reduce/prevent pest problems". Org farmers (5.9) agreed more with this statement than Conv farmers (5.3). It is generally believed that Org farmers rely more heavily on crop rotations to solve agronomic problems, because they do no use synthetic chemicals to control pests.

Measures of Success

The definition of a successful farming system will differ depending on the manager, since each individual uses different measures of success. In order to identify the goals of farm managers, survey respondents were asked to rank the importance of various factors for determining success. Factors were rated on a seven-point scale, ranging from one (not important for determining success) to seven (extremely important for determining success). Results are shown in Table 3-21. There were four factors of success in which the responses between Org and Conv farmers differed significantly. Minimizing "ecological damage" was a more important success factor for Org farmers (6.4) than for Conv farmers (5.6). This follows from the opinion statements, where all farmers tended to agree more with the idea that organic farming is more environmentally friendly. If organic farming is believed to be more environmentally friendly than conventional farming, it follows that organic farmers are more concerned with reducing ecological damage due to farming practices. Conv farmers (6.2) rated profitability as a more important factor for success than Org farmers (5.6), possibly indicating how the decision-making process differs between Org and Conv farmers. If profitability is more important to Conv farmers, they will tend to make decisions on the basis of economic, rather than ecological reasons. Maximizing yields was rated more important for determining success by Conv farmers than Org farmers (6.1 and 5.3, respectively). Yields on organic farms are generally found to be slightly depressed compared to conventional farms in Canada (Entz et al. 2001; Henning 1994). The lower emphasis on yields as a determination of success on organic farms may be indicative of the slightly lower yield outlook for this system. Finally, the ability to have a farm/rural lifestyle was rated as a higher factor for success for the Org farmers than the Conv farmers (6.6 and 5.8, respectively).

Table 3-21: Mean values for factors of success

	Management group	Mean response value[z]	Std. dev.	*P*-value
Minimize ecological damage	Org	6.4 a	1.0	
	Conv	5.6 c	1.0	
	Org/Conv	5.9 b	1.2	
	Total	5.9	1.1	<0.001
Maximize profitability	Org	5.6 b	1.2	
	Conv	6.2 a	0.9	
	Org/Conv	6.0 a	1.1	
	Total	6.0	1.1	<0.001
Minimize input costs	Org	6.0	1.3	
	Conv	5.6	1.5	
	Org/Conv	5.8	1.4	
	Total	5.8	1.4	0.150
Maximize yields	Org	5.3 b	1.5	
	Conv	6.1 a	0.9	
	Org/Conv	5.2 b	1.5	
	Total	5.6	1.3	<0.001
Maximize crop quality	Org	6.6	0.6	
	Conv	6.2	0.7	
	Org/Conv	6.3	0.8	
	Total	6.4	0.7	0.075
Farm/Rural lifestyle	Org	6.6 a	0.9	
	Conv	5.8 b	1.2	
	Org/Conv	6.3 a	1.0	
	Total	6.2	1.1	<0.001

Means followed by different letters indicate significant differences as determined by LSD (P=0.05).

[z] Mean response value, based on a 7-point scale, from 1 (not important for determining success) to 7 (very important for determining success).

Summary

Due to a skewed survey response rate (the survey is more indicative of agriculture in the Prairie provinces) results are not applicable to ON, and should be used very cautiously with regards to the Maritimes. Three management groups responded to the survey, Org, Conv and Org/Conv. For the purposes of this study, the Org and Conv groups were of most interest. The Org/Conv farmers were generally believed to be farmers transitioning to certified organic production and results for this group were predicted to have (and generally did have) statistically intermediate values.

Org farmers more commonly used a number of practices (that are known to conserve the soil) on their farm than Conv farmers. A greater proportion of Org farmers had certain conservation tillage practices in use, including contour and ridge tillage. More Org farmers applied compost to the soil, which can increase the organic C storage potential of a soil. As well, strip cropping and shelterbelts/windbreaks (practices known to decrease wind erosion risk) were present on a greater percent of Org farms. In terms of crop rotations, a greater proportion of Org farmers had forages in rotation. In fact, more Org farmers had forages in rotation than had animals on the farm, indicating a commitment by some Org farmers to have soil-building crops in rotation. A large majority of Org farmers had green manures in their crop rotations (which are an effective C storage practice (VandenBygaart et al. 2003)). More Org farmers were committed to their planned rotation and were less likely to change their rotation due to marketing or disease reasons.

Org farmers also had a number of practices that have the potential to increase soil erosion risk. More Org farmers had summerfallow in rotation, and all of the organic summerfallow was maintained through tillage, which is detrimental to soil structure and organic C storage. As well, more Org farmers had row crops in rotation. Row crops tend to reduce the soil's potential to store organic C as compared to solid-seeded crops. A greater proportion of Org farmers practiced delayed seeding, which leaves the soil surface bare in the spring when soil is most susceptible to water erosion. Finally, a much greater proportion of Conv farmers practiced zero tillage and/or direct seeding on their farms. Zero tillage is one of the most important tillage systems used today to reduce soil erosion potential by improving aggregate stability (Huwe 2003), maintaining a large proportion of the residues on the soil surface (Campbell et al. 2001), and increasing soil organic C storage (in western Canada) (VandenBygaart et al. 2003).

In general, farmers from all management groups tended to agree that organic farmers rely more heavily on tillage than conventional farmers. However, farmers from all management groups also tended to agree with the statement that organic farming is more environmentally friendly than conventional farming overall. While organic farmers are believed to rely more heavily on tillage, Org farmers in this survey also rely more heavily on crop rotations to solve pest problems, such as weeds (which can help lower the dependence on tillage for weed control). Org farmers indicated that ecological and social factors more important for determining success on their farm than economic factors. Org farmers rated minimizing ecological damage and the ability to have a farm/rural lifestyle more important for determining success of the farm than Conv farmers did. Conversely, Conv farmers rated maximizing yields and profitability as more important for determining success of the farm than Org farmers did.

It was concluded that, in general, Org farmers use more tillage than Conv farmers. However, Org farmers do have soil conservation practices on their farm (e.g., crop rotations that include perennials). As well, Org farmers seemed to be more intent upon minimizing the negative environmental impacts of their farming practices. However, the soil conservation practices used on Org farms, taken separately, are most likely not as powerful as zero tillage and/or direct seeding (which are available almost exclusively to Conv farmers due to the reliance of these systems on synthetic herbicides) are at protecting against soil erosion risk. Org farms that employ a number of different soil conserving practices may achieve the level of soil protection found on Conv zero tillage farms. The impact of the production differences between organic and conventional farms is unknown in Canada (but will be tested in Chapters 4 and 5). However, it is known that vegetative soil cover is maintained through lowered tillage intensities, and higher levels of soil cover are important in reducing soil erosion risk. Therefore, Org farms must continue to find ways to lower the number and intensity of tillage passes in order to maintain a protective vegetative soil cover.

CHAPTER 4

COMPARISON OF SOIL EROSION RISK ON LONG-TERM ORGANIC AND CONVENTIONAL SYSTEMS

Introduction

Soil erosion risk is, in large part, determined by the soil's erodibility (the inherent susceptibility of the soil to erosive forces) (Wischmeier 1976), and certain soil properties, such as texture, structural stability and organic matter content, have a significant effect on soil erodibility (Lal and Elliot 1994). In turn, soil structural stability and organic matter content are modified by cropping systems management, including choice of crop rotation, tillage regime and the use of conservation practices. The evaluation of production differences between organic and conventional farms (Chapter 2) has shown that there are some inherent production differences between organic and conventional systems. Organic cropping systems have been accused of increasing soil erosion risk by using tillage instead of synthetic herbicides for weed control (Avery 2000; Pates 2001). Very little research in Canada has compared soil erosion risk on organic and conventional cropping systems (e.g. Moulin et al. 2000; Moulin et al. 2001).

There are methodological problems with comparing organic and conventional farming systems, which can lead to uncertainty in research results (Lampkin 1994). Many of these difficulties lie in the large variability between individual farming systems, both in terms of biological properties and systems management. Using research trials to compare organic and conventional systems is an effective way to control what variables differ between the systems. As well, replication of plots in research trials can help to isolate what factors influence the variable under study and strengthen the degree of certainty of research conclusions. Changes in ecosystems generally occur gradually, so long-term studies can be valuable in the measurement of changes due to management in cropping systems (which are simply managed ecosystems) over time (Janzen 1995). For instance, the DOK (bio-Dynamic, bio-Organic and "Konventionell") trial in Switzerland has looked at changes in system measures (such as yield and soil nutrient status) since 1978 (Fließbach et al. 2000). In this comparison of soil erosion risk on long-term organic and conventional systems, three long-term rotation studies located in the Canadian prairies were sampled. All studies included both organic and conventional cropping systems. The objective of this study was to determine the difference in soil properties relating to erosion risk (i.e., aggregate stability and organic carbon content) due to organic or conventional management, under various crop rotations.

Materials and Methods

LONG-TERM STUDIES DESCRIPTIONS. Soil samples were taken in the fall of 2003 and spring of 2004 from the three long-term rotation studies in Alberta, Saskatchewan and Manitoba. The rotation studies included the Scott Alternative Cropping Systems Trial and the Lethbridge Low Input Agriculture (LIA) Trial, both located in the Prairies ecozone, as well as the Glenlea Crop Rotation Study in the Boreal Plains ecozone. Ecozones are geographic areas of Canada that have a distinctive set of physical and biological characteristics, selected based on characteristics such as climate, physiography and drainage, soils, vegetation and wildlife (Smith et al. 1998). In Appendix B, a map showing the location of the three trials is provided. Treatments sampled were selected to represent conventional and organic cropping systems. Table 4-1 contains an outline of the crop rotations sampled from the long-term studies. See Appendix C for plot maps of the rotation studies.

Table 4-1: Summary of rotations and treatments from long-term rotation studies sampled

Long-term study	Study design	Rotations	Management type: Organic	Management type: Conventional	Crops grown in rotation: Cereal	Crops grown in rotation: Oilseeds	Legume (annual)	Legume (biennial)	Legume (perennial)	Fallow
Scott Alternative Cropping Systems Study	Randomized Complete Block	LOW[y]	X		X	X	X[z]			
		DAG[x]	X		X	X	X	X[z]		
		DAP[w]	X		X	X			X	
		LOW		X	X	X				X
		DAG		X	X	X	X			
		DAP		X	X	X			X	
Lethbridge LIA Study	Randomized Complete Block	Rotation 1 [v]	X		X			X		
		Rotation 3 [u]	X		X	X	X	X		
		Rotation 5 [t]	X		X	X			X[z]	
		Rotation 7 [s]		X	X					
Glenlea Crop Rotation Study	Randomized Complete Block	Annual	X	X	X	X	X			
		Biennial	X	X	X	X		X[z]		
		Perennial	X	X	X	X			X	

[z] Legumes grown as a green manure.
[y] LOW diversity rotation
[x] Diverse Annual Grains rotation
[w] Diverse Annual Perennials rotation
[v] Simple Perennial rotation
[u] Diverse Perennial rotation
[t] Diverse Biennial rotation
s Simple Annual rotation

Glenlea Long-Term Crop Rotation Study

The Glenlea Crop Rotation Study was established in 1992, and is located south of Winnipeg, MB at the University of Manitoba Glenlea Research Station. This study is Canada's oldest organic versus conventional cropping system comparison. The study has a split-split-plot arrangement within a randomized complete block design. Three four-year rotations (perennial-containing rotation, biennial-containing rotation, and an all annual rotation) comprise the main plots, while the subplots contain various combinations of fertilizer and pesticide inputs, representing different management groups. The three rotations are as follows: perennial rotation (wheat-alfalfa-alfalfa-flax), biennial rotation (wheat-red clover green manure-wheat-flax) and the annual rotation (wheat-pea-wheat-flax). Two subplots in each of the main plots were sampled: the subplots with no inputs used (organic management) and those with all inputs applied as needed (conventional management). Within the last rotation cycle, each of the subplots was further subdivided into four strips to introduce new crops into the rotations (the original rotation is maintained in other strips). The sub-subplot strips that were part of the originally planned rotation were sampled. Tillage systems for each rotation in the study were common to 'conventional' tillage practices in the area. In general, organic systems received one additional tillage pass than the conventional systems for each tillage operation.

Scott Alternative Cropping Systems Trial

The Scott Alternative Cropping Systems Trial was established in 1994 at the Agriculture and Agri-Food Canada Scott Research Station. The trial has a split-plot study arrangement within a randomized complete block design. The main plots have three management treatments (consisting of three varying levels of inputs), while the sub-plots have three rotation treatments (consisting of three varying levels of rotation diversity). Two management treatments were sampled to represent organic and conventional systems management: no inputs (organic) and high inputs (conventional). All three rotation treatments were sampled, that is: Low diversity (LOW), Diverse Annual Grains (DAG) and Diverse Annuals and Perennials (DAP). The rotations are slightly different in the organic and conventional plots to approximate what is grown on working organic and conventional farms, while maintaining functionally similar rotations. The actual rotations for the trial are shown in Table 4-2. Tillage systems for each of the rotations in the study were common to 'conventional' tillage practices in the area. In general, organic systems received one additional tillage pass than the conventional systems for each tillage operation.

Table 4-2: Rotations from Scott Alternative Cropping Systems Trial

Rotation	Management	Rotation phase 1	2	3	4	5	6	7
LOW[z]	organic	GM [W] fallow	wheat	wheat	GM fallow	mustard	wheat	
	conventional	fallow	wheat	wheat	fallow	canola	wheat	
DAG[y]	organic	GM [W] fallow	wheat	field peas	barley	barley	GM fallow	mustard
	conventional	canola	fall rye	field peas	barley	flax	wheat	
DAP[x]	organic	mustard	wheat or barley	wheat or barley	alfalfa	alfalfa	alfalfa	
	conventional	canola	wheat or barley	wheat or barley	alfalfa	alfalfa	alfalfa	

[z] LOW diversity rotation

[y] Diverse Annual Grains rotation

[x] Diverse Annual Perennials rotation

[W] Green manure

Lethbridge Low-Input Agriculture Trial

The Lethbridge LIA Trial was started in 1997 at the Agriculture and Agri-Food Canada Lethbridge Research Station. The trial has a randomized complete block design. Treatments consist of different rotations, which are managed either organically, with low levels of inputs, or conventionally. The purpose of this trial was not to compare organic and conventional cropping systems, however, it did contain organic and conventional systems in the study design and so it was used in this study. Four treatments were sampled from this study: three diverse organic rotations and one conventionally managed, zero tillage continuous wheat rotation. The rotations are shown in Table 4-3. Because this study was not designed to compare organic and conventional systems, it is more difficult to detect significant differences (if significant differences exist) between the two systems. The study was actually designed to evaluate different diverse rotations under organic and low-input agricultural systems. Therefore, each of the sampled rotations was tested under either organic or conventional conditions, but not both. The one conventional rotation exists in the study as a standard to which the organic rotations are compared. Therefore, whether rotation, management, or some combination of the two resulted in the changes in soil properties cannot be determined.

Table 4-3: Rotations from the Lethbridge Low-Input Agriculture Trial

		Rotation Phase			
Rotation	Management	1	2	3	4
1[x]	organic	wheat/sweet clover[z]	sweet clover	wheat/sweet clover[z]	sweet clover
3[w]	organic	wheat	field pea	linola/sweet clover[z]	sweet clover
5[v]	organic	wheat with compost	barley/red clover GM[zy]	winter triticale	linola
7[u]	conventional (zero tillage)	wheat	wheat	wheat	wheat

[z] Two crops in a rotation phase separated by a backslash indicates the first crop was underseeded to the second crop.

[y] Green manure

[x] Simple Perennial rotation

[w] Diverse Perennial rotation

[v] Diverse Biennial rotation

[u] Simple Annual rotation

SOIL SAMPLING. Soil samples were taken in the fall of 2003 to determine soil texture, dry and wet aggregate size distribution. Scott and Lethbridge were sampled in September 2003, after harvest, but prior to any fall tillage operations. Due to a sampling error, Glenlea was sampled in October 2003, after all fall tillage operations had been completed. The soil from the long-term studies was sampled again in June of 2004 to determine dry and wet aggregate size distribution, as well as to determine total organic carbon. Each selected plot from the long-term studies was soil sampled eight times: four shallow samples for determination of dry aggregate stability and total organic carbon (for spring samples), taken at the soil surface to a depth of 0 to 2-2.5 cm depth; and four deep samples taken to a 10 cm depth for measuring wet aggregate stability and texture. Aggregate stability has been found to vary throughout the growing season, and soil water content at the time of sampling is the primary factor influencing aggregate stability (Coote et al. 1988; Perfect et al. 1990). All soil samples from a study were taken in one day (with the exception of Glenlea in the spring sampling) to prevent the introduction of variation due to different water contents. The Glenlea sampling was done over two days, but no rain occurred between the sampling times so no differences in water content and aggregate stability were expected. Samples were transported in paper bags, with disturbance kept to a minimum. Samples were air-dried after their transport to the University of Manitoba (i.e., within one to eight days after their extraction). All samples were transported and stored in the same manner.

The Scott and Lethbridge studies have all phases of the rotations present each year. Since there was a wheat crop present in all of the rotations under study, this phase was sampled. At both studies, the wheat crop is the test crop used by the principal researchers. Glenlea was not fully phased, so the fall soil samples were taken just after the flax crop and the spring samples were taken just before the wheat phase.

Although soil erosion can occur at any time, the potential for water erosion is highest during the spring when the surface soil is thawed and the underlying soil is still frozen and impermeable (Shelton et al. 2000; Dumanski et al. 1986). Snowmelt runoff can account for up to 85% of annual runoff from agricultural fields in western Canada (De Jong et al. 1983). Wind erosion is also greatest in the spring, and soil erodibility is best measured at that time (Chepil 1953). Aggregate stability has been found to vary greatly throughout the growing season, and no patterns were present between the aggregate stability from the fall and spring sampling times. Because of the extreme variability of aggregate stability throughout the growing season, only the spring sampling results were analyzed. The spring sampling time was chosen to analyze since it is the most severe measure of soil erosion risk. That is, spring is the time when soil is most susceptible to erosive forces. As well, the growing season of 2003 was extremely dry and would not be indicative of the soil's condition after an average growing season.

SOIL TESTS. The soil was tested in the laboratory for a number of properties that affect erosion risk, including texture, dry and wet aggregate size distribution and organic carbon content.

Texture

Texture is an inherent soil property, however, texture will affect the soil's aggregate stability and influence organic matter storage potential. The soil texture was determined on the plots that were sampled in the fall of 2003 to ensure that all plots in a study had similar baseline soil physical properties. Texture analysis was done on the fall 2003 samples using the hydrometer method outlined by Sheldrick and Wang (1993) with slight modifications by Ellis (1996). Because texture is a relatively static soil property, it was not measured again on the spring 2004 samples.

Dry Aggregate Size Distribution

Dry aggregate size distribution was used as a measure of dry aggregate stability, and will henceforth be referred to as dry aggregate stability. It is a measure of the soil's resistance to forces similar to the erosive forces of wind. A Ro-Tap sieving machine was used to determine dry aggregate stability on the shallow samples. Campbell et al. (2001) found dry aggregate stability to be a less reliable measure of aggregate stability than wet aggregate stability. To reduce the amount of variation in results, the spring 2004 samples were sieved four times. The sieve opening sizes selected for the analysis were 4.75, 2.00, 0.85 and 0.25 cm. Methods followed those outlined by (White 1993). The sieving results are presented as Mean Weight Diameter (MWD), which is a summation equation given by:

$$MWD = \sum_{i=1}^{n}(\text{mean diameter of size fraction}_i)(\text{proportion of total sample retained on sieve}_i)$$

(White 1993).

Wet Aggregate Size Distribution

Wet aggregate size distribution was used to measure wet aggregate stability. Angers and Mehuys (1988) found the size distribution of aggregates a more sensitive measure of differences in aggregates due to cropping treatments than wet aggregate stability measured on a single sieve. The size distribution of wet aggregates determined by wet sieving indicates the soil's resistance to the erosive forces of flowing water. Wet aggregate size distribution was determined using the deep (10 cm) soil samples taken in spring 2004. Because wet aggregate size distribution is a measure of wet aggregate stability, it will simply be referred to as wet aggregate stability. Again, two sievings were carried out for each soil sample. The sieve opening sizes used were 4.00, 2.00, 0.50 and 0.25 cm. The larger sieve opening sizes (4.00 and 2.00 cm) were chosen because macroaggregate stability in the field depends upon management practices (Tisdall 1996). The sieving methods outlined by Angers and Mehuys were followed (1993). The proportion of water stable aggregates (WSA_i) is calculated using the total soil weight and aggregate weights obtained at each sieving step, and the gravimetric water content of the soil sample. Sieving results are presented as MWD, given by the equation:

$$MWD = \sum_{i=1}^{n}(\text{mean diameter of size fraction}_i)(WSA_i)$$

Organic Carbon

Total organic matter is essential for optimum soil structure (Malhi et al. 2003), and so the level of total organic matter in the soil has a large influence on the soil's erodibility. Organic C is the primary component of soil organic matter. The loss of soil organic matter, and therefore soil organic C, causes a loss of soil structure and greater susceptibility of a soil to erosion (Smith et al. 2000). With high levels of C in soil and the natural variability of soils, it is sometimes difficult to detect small changes in total organic matter over a short time period (Bolinder et al. 1999). For that reason, organic C was determined on the shallow soil samples, as it is believed that the effect of management on soil properties will be more apparent in the surface layer where biological activity is highest (Bolinder et al. 1999). Malhi et al. (2003) found that the effect of cultivation on soil C and N was greatest in the surface five cm depth. The tube digestion method finds the percent of total organic C using rapid dichromate oxidation. The tube digestion method outlined by Nelson and Sommers (1996), modified by Saiyed (2004) was used.

STATISTICAL ANALYSIS. Data analysis on the results from the soil analysis was carried out using SAS (SAS Institute, North Carolina, USA). Outliers were removed and PROC UNIVARIATE was used to determine normality with Shapiro-Wilk's W. Homogeneity of variances among treatments was tested using Bartlett's test with PROC GLM. When distributions were not normal, data was transformed to confer normality. The data sets for dry and wet aggregate stability at Scott and organic C at Lethbridge required a log transformation to meet the analysis of variance (ANOVA) requirements of normality.

PROC GLM was used to carry out ANOVA on each of the long-term studies separately. For the Glenlea and Scott studies, rotation and management (organic or conventional) were sources of variation in the model statements. At Lethbridge, only rotation was a source of variation in the model statement. When the ANOVA analysis indicated that treatments were a significant source of variation, least significant difference (LSD) was used to determine significant differences between treatment means.

Results and Discussion

For dry and wet aggregate size distribution and organic C content, means were determined for rotation and management. Mean differences between treatments were generally small, but statistically significant differences are discussed. Although these differences are small, they represent significant biological differences due to the treatments (Paul Voroney, University of Guelph and Alan Moulin, Agriculture and Agri-Food Canada, pers. comm.).

TEXTURE. Texture was measured on the fall 2003 soil samples (Table 4-4). Soil texture was found to be identical in all plots at a given study. The Scott and Lethbridge soils have a loam texture, while the Glenlea soils have a clay texture. Glenlea has a high percentage of clay (55%), indicating that there will be a high amount of aggregation, however, portions of this fine-textured soil that are not aggregated will be highly susceptible to transport by wind and water erosive forces. The percent clay at both Scott and Lethbridge (12% and 19%, respectively) is below Chepil's (1953) stated ideal (27%) for low erodibility by wind. The high sand content at Scott and Lethbridge (42% and 41%, respectively) in these soils will hinder the formation of soil aggregates, which is necessary to protect against wind erosion. The higher clay content at Glenlea should allow the soils at Glenlea to store more organic C. It is expected that the soils from Scott and Lethbridge will have a higher inherent risk of soil erosion than the soils from Glenlea.

Table 4-4: Mean particle size analysis from long-term studies

Location	Clay (%)	Sand (%)	Silt (%)	Textural class
Scott	12.3 (2.16)	41.7 (6.60)	46.1 (5.75)	Loam
Lethbridge	19.4 (3.62)	41.4 (2.68)	39.1 (4.27)	Loam
Glenlea	55.3 (4.19)	12.3 (2.31)	32.4 (2.79)	Clay

Values in brackets are standard deviations of the mean.

DRY AGGREGATE STABILITY. Dry aggregate size distribution was used to measure dry aggregate stability, which is an indicator of the soil's resistance to wind erosive forces. Dry aggregate stability is reported as a dry MWD, with higher MWDs indicating higher resistance to wind erosion.

Glenlea Long-Term Crop Rotation Study

Mean dry mean weight diameter (MWD) values were determined for the three rotations (annual, biennial and perennial) and the two management groups (organic and conventional). Table 4-5 shows the MWDs for the treatments and the *P*-values from the ANOVA analysis. Rotation was found to have a significant effect ($P = 0.0079$) on dry aggregate stability. The perennial-containing rotation (50% alfalfa) had a significantly lower mean dry MWD (2.37) than the other two rotations, indicating that soil under the perennial rotation was more susceptible to wind erosion. The perennial rotation requires more tillage (because the alfalfa stand is terminated using tillage) than the other rotations. It is possible that the higher levels of tillage intensity in the perennial rotation caused a lowering of dry aggregate stability. The biennial and annual rotations had roughly the same dry MWD values (2.91 for the annual rotation, 2.98 for the biennial rotation).

Table 4-5: Mean dry Mean Weight Diameter (MWD) and ANOVA from Glenlea

	Mean Dry MWD
Rotation	
Annual	2.91 a
Biennial	2.98 a
Perennial	2.37 b
Management	
Organic	2.83
Conventional	2.65
ANOVA	
Rep	0.1470
Rotation	0.0079***
Rep(Rotation)	0.5329
Management	0.1707
Rotation x Management	0.3239

*** Significant to 0.01
Means followed by different letters indicate significant differences between means determined by LSD (*P*=0.05).

Scott Alternative Cropping Systems Trial

The MWD values from Scott (Table 4-6) were much lower than those found at Glenlea, indicating that the soil at Scott is more susceptible to erosion by wind than the soil at Glenlea. As at Glenlea, rotation had a significant effect on dry aggregate stability at Scott. The DAG rotation had the highest MWD (0.64), followed by the DAP rotation (0.56) and the LOW rotation (0.40). The LOW diversity rotation relied more heavily on fallow than the other rotations. Fallow was present two years in a six year LOW rotation cycle for both the organic and conventional systems (fallow in the organic systems had a green manure, while in the conventional systems bare soil fallow was used). The only other rotation to use fallow was the organic DAG rotation, which used a green manure fallow two years out of a seven year rotation cycle. Bare soil fallow has been shown to lower the soil's potential to store organic C (VandenBygaart et al. 2003), and therefore lower the ability of the soil to form stable aggregates. Adding a green manure into a bare soil fallow increases the soil's storage potential for organic C above that of a bare soil fallow (VandenBygaart et al. 2003). Rotations with only annual crops have been found to lower aggregate stability as compared to rotations with a diversity of lifecycles (i.e., biennials and perennials) (Rachman et al. 2003). The DAG rotation includes fall rye in the conventional systems. The inclusion of fall rye in this rotation has been found to significantly decrease the potential for wind erosion, most likely due to the increased cover during the fall and spring (Moulin et al. 2001).

Table 4-6: Mean dry Mean Weight Diameter (MWD) and ANOVA from Scott

	Mean Dry MWD
Rotation	
LOW[z]	0.40 c
DAG[y]	0.64 a
DAP[x]	0.56 b
Management	
Organic	0.54
Conventional	0.52
ANOVA	
Rep	0.3804
Management	0.3725
Rep x Management	0.1209
Rotation	<0.0001***
Rotation x Management	0.5810

*** Significant to 0.01
Means followed by different letters indicate significant differences between means determined by LSD (*P*=0.05).
[z] LOW diversity rotation
[y] Diverse Annual Grains rotation
[x] Diverse Annual Perennials rotation

Lethbridge Low-Input Agriculture Trial

The dry MWDs from Lethbridge (Table 4-7) were slightly lower than those found at Glenlea, indicating that the soils at Lethbridge may be more susceptible to wind erosion than soil from Glenlea. However, the dry MWD values at Lethbridge were higher than the MWDs at Scott, suggesting that the Lethbridge soil is less prone to wind erosion than soil at Scott. Rotation was not a significant source of variation of dry MWD values. The trial at Lethbridge was established at a later date than the other studies (it was established in 1997, five years after Glenlea, and three years after Scott). The duration of the study may not be sufficient at this time for significant differences in soil properties to appear. As well, the study at Lethbridge was not designed to identify differences between organic and conventional cropping systems, but to evaluate various diverse rotations managed organically and under a low-input system. Lethbridge has three diverse organic rotations and one conventional continuous wheat rotation. The conventional rotation is used in part as a check or baseline comparison cropping system. The three organic rotations may be too similar (i.e., lacking a broad range of crop rotations using different crop categories) to cause large differences in soil properties. For instance, none of the organic rotations had annual crops exclusively, all the organic rotations had at least one grain crop underseeded to a legume, and no rotation in the study had an extended period (more than one year) with a sole perennial crop.

Table 4-7: Mean dry Mean Weight Diameter (MWD) and ANOVA from Lethbridge

	Mean Dry MWD
Rotation	
Rotation 1 (organic)[x]	2.13
Rotation 3 (organic)[w]	2.29
Rotation 5 (organic)[v]	1.93
Rotation 7 (conventional)[u]	1.88
ANOVA	
Rep	0.3148
Rotation	0.2112
Rep x Rotation	0.0584*

* Significant to 0.1

[x] Simple Perennial rotation

[w] Diverse Perennial rotation

[v] Diverse Biennial rotation

[u] Simple Annual rotation

WET AGGREGATE STABILITY. Wet aggregate size distribution was used to measure wet aggregate stability, which is an indicator of the soil's resistance to water forces. Wet aggregate stability is reported as a wet MWD, with higher MWDs indicating higher resistance to water erosion.

Glenlea Long-Term Crop Rotation Study

The mean MWD values for the three rotations present at Glenlea, as well as for the organically and conventionally managed plots are given in Table 4-8. Both rotation and management were found to significantly affect wet aggregate stability at Glenlea (P = 0.001 and 0.037 for rotation and management, respectively). The biennial rotation had the highest MWD (1.39), while the annual (1.01) and perennial (1.07) rotations had similar MWDs to one another. The biennial rotation lends stability to the soil through adding a crop to the rotation that is not an annual, while at the same time, does not require the same level of tillage intensity that is needed to terminate a perennial crop (such as alfalfa in the perennial rotation – which requires a number of passes with a discer in the fall to terminate the stand). In addition, the biennial is plowed under as a green manure crop. The high amount of fresh residues with a high nitrogen content (because it is a leguminous crop) added as a green manure will help to increase biological activity and the amount of fresh organic matter, thereby increasing aggregate stability (Shepherd et al. 2002).

Table 4-8: Mean wet Mean Weight Diameter (MWD) and ANOVA from Glenlea

		Mean Wet MWD
Rotation		
	Annuals	1.01 b
	Biennials	1.39 a
	Perennials	1.07 b
Management		
	Organic	1.20 a
	Conventional	1.10 b
ANOVA		
	Rep	0.9266
	Rotation	0.0010***
	Rep(Rotation)	0.7694
	Management	0.0370**
	Rotation x Management	0.3403

** Significant to 0.05, *** Significant to 0.01
Means followed by different letters indicate significant differences between means determined by LSD (P=0.05).

Management was also found to significantly affect wet MWD values. Plots under organic management had higher MWDs (1.20) than plots under conventional management (1.10). This indicates that plots under organic management (i.e., receiving no pesticides or fertilizers) are more resistant to soil erosion by water than plots under conventional management. The DOK trial (bio-Dynamic, bio-Organic, and "Konventionell") in Switzerland revealed that earthworm activity and aggregate stability are positively correlated, and that organically managed plots, having higher levels of earthworm activity than the conventional plots, had higher wet aggregate stability values (Siegrist et al. 1998). Drinkwater et al. (1995) reported better soil C cycling in the absence of pesticides. Shepherd et al. (2002) concluded from the literature that when similar organic and conventional farms are compared, organic farms generally have as good or better soil structure than conventional farms.

Scott Alternative Cropping Systems Trial

Scott had similar MWD values (Table 4-9) to those found at Glenlea, indicating that the soils at the two studies were roughly similar in their resistance to water erosion. Management was found to significantly affect the wet aggregate stability (P = 0.034). However, LSD detected no significant difference between the mean MWDs for organic and conventional management.

Table 4-9: Mean wet Mean Weight Diameter and ANOVA from Scott

	Mean Wet MWD
Rotation	
LOW[z]	1.22
DAG[y]	1.08
DAP[x]	1.17
Management	
Organic	1.11
Conventional	1.22
ANOVA	
Rep	0.0050***
Management	0.0324**
Rep x Management	0.9551
Rotation	0.8994
Rotation x Management	0.0607*

* Significant to 0.1, ** Significant to 0.05, *** Significant to 0.01
[z] LOW diversity rotation
[y] Diverse Annual Grains rotation
[x] Diverse Annual Perennials rotation

Lethbridge Low-Input Agriculture Trial

Wet MWD values are given for Lethbridge in Table 4-10. The MWD values were slightly higher at Lethbridge than those found at Glenlea or Scott, indicating that the soil was more resistant to water erosion at Lethbridge than at the other two studies. As with dry aggregate stability, rotation did not significantly affect wet MWDs at Lethbridge. Again, the lack of response of soil properties to treatments (rotation) may be due to the younger age of this study, or to the fact that the organic rotations are too similar to one another to cause large enough differences to be detected.

Table 4-10: Mean wet Mean Weight Diameter (MWD) and ANOVA from Lethbridge

	Mean Wet MWD
Rotation	
Rotation 1 (organic) [x]	1.95
Rotation 3 (organic) [w]	1.46
Rotation 5 (organic) [v]	1.19
Rotation 7 (conventional) [u]	1.98
ANOVA	
Rep	0.2230
Rotation	0.1621
Rep x Rotation	0.0051***

*** Significant to 0.01

[x] Simple Perennial rotation

[w] Diverse Perennial rotation

[v] Diverse Biennial rotation

[u] Simple Annual rotation

ORGANIC CARBON. Organic C is an important soil property related to erosion risk. Carbon is an indicator of soil organic matter levels, and is integral to building and maintaining soil structural stability. Organic C content was measured as a percent of total soil.

Glenlea Long-Term Crop Rotation Study

Organic C concentrations at Glenlea were found to be around 5 percent (Table 4-11). Management significantly affected the percentage of organic C (P = 0.0134); the conventional plots had higher organic C levels (5.1%) than the organic plots (4.8%). At Glenlea, management also significantly affected wet aggregate stability, but it was found that the organic plots had higher levels of stability than the conventional plots. Therefore, Glenlea represents a situation where lower organic C levels due to organic management coincided with higher wet aggregate stability. It is possible that the organic systems are stabilizing the soil aggregates through some mechanism (e.g., polysaccharides or VAM) other than total organic C. These higher levels of stability may be due to a more diverse weed population in the organic systems, which has been found at Glenlea (Humble 1991).

Table 4-11: Mean percent organic carbon (C) and ANOVA from Glenlea

	Mean Organic C (%)
Rotation	
Annuals	4.8
Biennials	5.0
Perennials	5.0
Management	
Organic	4.8 b
Conventional	5.1 a
ANOVA	
Rep	0.7400
Rotation	0.8776
Rep(Rotation)	0.0096***
Management	0.0134**
Rotation x Management	0.5325

** Significant to 0.05, *** Significant to 0.01
Means followed by different letters indicate significant differences between means determined by LSD (P=0.05).

Bulk density was not measured in this study. When bulk density is added to SOC calculations, conclusions about treatment effects on carbon levels may change. Deen and Kataki (2003) found mean SOC concentrations to be higher under a spring moldboard plowing treatment when compared to other tillage treatments, which included a zero tillage system. However, when the authors calculated SOC on an equivalent mass basis, there was no significant difference between the five tillage treatments. The most recent measure of bulk density at the Glenlea site was by Moulin et al. (2000) in 1999, and at that time there were no significant differences between any of the treatments at Glenlea. This indicates that any observed differences in organic C percent would translate to a difference in SOC content on a mass basis.

Scott Alternative Cropping Systems Trial

The organic C levels at Scott (Table 4-12) were found to be lower than those at Glenlea (about three percent at Scott and five percent at Glenlea). At Scott, rotation significantly affected organic C levels ($P < 0.0001$). The highest organic C levels were found in the DAP (i.e., perennial) rotation (3.2%), followed by the LOW diversity rotation (3.0%), and then the DAG (diverse annual) rotation (2.7%). It was expected that rotations containing perennials would have higher organic C levels, as perennials have more biomass in their roots, and therefore, return more organic matter to the soil. At Scott, the researchers had trouble establishing an alfalfa stand, and in some site years an oat/pea mixture replaced the alfalfa. Therefore, the DAP rotation does not necessarily accurately represent a rotation including a perennial forage. It was also expected that the DAG rotation would have a higher level of organic C than the LOW rotation, which consists solely of annual crops and fallow. The DAG rotation had the highest dry aggregate stability and the lowest levels of organic C. This is similar to what was seen with the organic plots at Glenlea, where organic plots had the highest wet aggregate stability and lowest organic C.

Table 4-12: Mean percent organic carbon (C) and ANOVA from Scott

	Mean Organic C (%)
Rotation	
LOW[z]	3.0 b
DAG[y]	2.7 c
DAP[x]	3.2 a
Management	
Organic	2.9
Conventional	3.0
ANOVA	
Rep	0.3637
Management	0.4883
Rep x Management	0.0011***
Rotation	<0.0001***
Rotation x Management	<0.0001***

*** Significant to 0.01
Means followed by different letters indicate significant differences between means determined by LSD (P=0.05).
[z] LOW diversity rotation
[y] Diverse Annual Grains rotation
[x] Diverse Annual Perennials rotation

When the interaction effect is considered, the reason the DAG rotation does poorly compared with the other rotations becomes clearer. There was a significant interaction effect between rotation and management at Scott (P = <0.0001) (Table 4-13). Managed organically, the DAG rotation suffers a decreased level of organic C when compared to all other rotations. The organic DAG plots are drawing down the mean organic C level for the overall rotation, leading to the conclusion that the DAG rotation has the lowest organic C concentration. However, the DAG rotation only has significantly lower organic C levels when managed organically. The interaction means from the dry aggregate stability analysis show that the organic DAG plots did not suffer a decline in aggregate stability due to the lowered organic C levels (Table 4-13). This pattern, having appeared at both Glenlea and Scott, points towards the conclusion that the organic systems are stabilizing the soil aggregates through some mechanism that is independent of total organic C percent.

Table 4-13: Interaction means of dry Mean Weight Diameter (MWD) and percent organic carbon (C) at Scott

Rotation	Management	Dry MWD	Organic C (%)
LOW[z]	conventional	0.38	2.9 b
DAG[y]	conventional	0.65	3.1 ab
DAP[x]	conventional	0.53	3.1 ab
LOW	organic	0.43	3.0 ab
DAG	organic	0.63	2.2 c
DAP	organic	0.59	3.4 a
P-value		0.5810	<0.0001

Means followed by different letters indicate significant differences between means determined by LSD (P=0.05).

[z] LOW diversity rotation

[y] Diverse Annual Grains rotation

[x] Diverse Annual Perennials rotation

It has been found that organic agriculture can increase the amount of certain organic C compounds that are known to stabilize soil aggregates, while not increasing the total amount of organic C in the soil (Siegrist et al. 1998). Polysaccharide content may be one such compound. Pierson and Mulla (1990) conducted a side by side comparison and found that an organic farm, while having lower organic C and polysaccharide content, had higher wet aggregate stability than a neighboring conventional farm. The authors hypothesized that this occurred because the organically managed soil was wetter and in an earlier stage of cohesion recovery than the drier, conventionally managed soil. As well, it has been found that colonization of plant roots by vesicular-arbuscular mycorrhizal (VAM) fungi improves aggregate stability (Siegrist et al. 1998). Studies have found colonization by VAM fungi to be improved under organic management because phosphorus levels are lower than conventional, fertilized systems. High levels of phosphorus in the soil have been found to depress the amount of VAM present (Mäder et al. 2002; Entz et al. 2004). VAM fungi have been found to produce glomalin, which is a glycoprotein that is correlated to aggregate stability (Wright 2005). Higher levels of the presence and activity of VAM fungi (which are properties found in organic systems) would produce more glomalin, promoting greater aggregate stability. Drinkwater et al. (1995) found that organic systems (in the absence of pesticides) positively affected C and nitrogen cycling in the soil, which had cascading effects to other properties, including improved soil aggregate stability. It is possible that the direct effect of pesticides on target and non-target organisms has negative implications for aggregate stability.

Lethbridge Low-Input Agriculture Trial

Organic C percentages ranged from 2.1% to 2.9% at Lethbridge, representing the lowest average organic C levels of the three studies. The rotation treatments did not have a significant effect on organic C percentages (Table 4-14). Again, the lack of significant results at the Lethbridge site may be due to the age of the trial and the relatively small differences in rotation treatments (when compared to the Glenlea and Scott trials).

Table 4-14: Mean percent organic carbon (C) and ANOVA from Lethbridge

	Mean Organic C (%)
Rotation	
Rotation 1 (organic) [x]	2.1
Rotation 3 (organic) [w]	2.2
Rotation 5 (organic) [v]	2.9
Rotation 7 (conventional) [u]	2.4
ANOVA	
Rep	0.1607
Rotation	0.1508
Rep x Rotation	<0.0001***

*** Significant to 0.01

[x] Simple Perennial rotation

[w] Diverse Perennial rotation

[v] Diverse Biennial rotation

[u] Simple Annual rotation

Summary

Significant differences were found at both the Glenlea and Scott studies, but not at Lethbridge. Dry aggregate stability was significantly affected by rotation at both Glenlea and Scott. At Glenlea, the biennial and annual rotations had the highest MWDs; at Scott, the DAG rotation had the highest MWDs. The DAG rotation at Scott and the biennial rotation at Glenlea are functionally similar: both rotations have legume green manures or an annual legume (the DAG rotation in the conventional system does not have a green manure, but a diverse selection of annual grains including a legume). The rotations with a legume green manure or an annual legume had the highest dry aggregate stability values at Glenlea and Scott.

Wet aggregate stability was influenced by both management and rotation at Glenlea, and management at Scott. The specific relationship between management and wet aggregate stability was not detected at Scott using LSD. At Glenlea, organically managed plots had higher resistance to water erosion. The biennial rotation at Glenlea had the highest wet aggregate stability values. The results from both Glenlea and Scott for wet and dry aggregate stability indicate that an annual grain rotation containing a legume green manure or a fall-seeded grain crop (as in the conventional DAG plots) will help build structural stability, thereby protecting the soil from wind and water erosion.

Organic C levels were found to be influenced by management at Glenlea and rotation at Scott. At Glenlea, the conventional systems had higher organic C levels than the organic systems, which is the opposite relationship as that found for wet aggregate stability (where the organic plots had higher wet aggregate stability). At Scott, this pattern was repeated: the organically managed DAG rotation had significantly lower organic C levels when compared to the other rotation by management treatments. This same rotation had the highest dry aggregate stability values. This pattern suggests that these organic systems were stabilizing soil aggregates through some mechanism that is either independent of organic C entirely, or that is independent of total organic C levels. Organic systems have been found to increase certain organic C compounds (such as polysaccharides) that help to build structural stability while not necessarily increasing the total organic C levels in the soil (Siegrist et al. 1998).

Soil aggregate stability was found to be influenced mainly by rotation. Rotations that included a biennial legume green manure had the highest soil structural stability. Organic systems had lower organic C levels than the conventional systems, but did not have lower aggregate stability. The organic systems are most likely stabilizing aggregates through some mechanism that is independent of total organic C levels. Polysaccharides or VAM fungi are possible mechanisms serving to stabilize soil aggregate stability.

CHAPTER 5

COMPARISON OF SOIL EROSION RISK ON ORGANIC AND CONVENTIONAL FARMS

Introduction

Research trials often allow agricultural scientists to reach more conclusive research results when comparing cropping systems than on-farm trials. However, there are limitations on the inference of results obtained from research trials comparing organic and conventional cropping systems. For instance, in research trials, many variables, such as crop rotations and tillage practices are held constant, which may not reflect actual organic and conventional systems (Lampkin 1994). By pairing organic and conventional farms according to a number of criteria, a number of variables are held constant between the two systems, while at the same time representing true system management differences (Lampkin 1994).

The current study is part of a larger one that also compared soil properties on long-term organic versus conventional research trials (Chapter 4). The research trials used in this study defined the organic systems as those plots that did not receive synthetic pesticides or fertilizers. In reality, most organic systems are a whole system, one that combines a number of long-term solutions to solve agronomic problems at the systems level (Watson et al. 2002). When comparing organic and conventional farming systems, researchers must compromise between holding a great number of factors constant between systems to obtain stronger results and allowing certain differences due to differences in the management system to obtain more relevant results (Lampkin 1994). In order to better understand what is happening on working organic and conventional farms in Canada, soil samples from paired organic and conventional farms were taken to complement the data collected from the long-term studies. The objective of this study was to compare wet and dry aggregate stability as well as percent organic C content on organic and conventional farms that had similar crop rotations.

Materials and Methods

SELECTION OF STUDY FARMS AND FIELDS. Organic farms were selected for the soil analysis portion of the study using the respondents from the survey (Chapter 3). Only organic farms that had been certified organic for at least five years were considered for participation in the second portion of the study. The effects of cropping system changes on soil properties occur over time. The five year certification requirement was used to allow sufficient time in which differences due to system changes could appear. Five organic farms from each of the provinces of Alberta, Saskatchewan, Manitoba and Ontario were selected; five organic farms from the Maritime provinces were also selected (two from Prince Edward Island and three from Nova Scotia). The survey asked farmers for information on the field on their farm which had been certified for the longest time. For the organic farmers participating in the soil testing, the field described in the survey was sampled. Soil was sampled to determine wet and dry aggregate stability and percent organic matter.

To reduce natural spatial variability in background soil properties (such as texture) and topography, the selected organic farmers were asked to provide the name of nearby conventional farmers that had similar crops in their rotations. Conventional fields were selected at the time of sampling, with the help of the farmers. Fields were selected to minimize the distance between paired organic and conventional fields, as well as the difference between crop rotations and background soil properties.

In two cases, the organic farmers had both certified organic and conventional land. For these farms, both a certified organic and a conventional field were sampled, and these two fields represented a paired comparison.

Due to the extremely low survey response rate in Ontario, organic and conventional farm pairs from a previous University of Guelph study were used. These farm pairs had been selected to minimize the difference between background soil properties, and the organic farms had been certified for at least five years.

SUPPLEMENTARY INFORMATION. Conventional producers that participated in the study were asked to fill in the mail-out survey that was used to evaluate production differences on organic and conventional farms. This survey provided information on the crop rotation and tillage practices on the sampled field. The surveys from the conventional producers (and the organic and conventional producers from ON) were returned during the winter of 2004-2005. The surveys from these farmers were received after the cut off date for the survey analysis, and were, therefore, not included in the results for the evaluation of production differences on organic and conventional farms (Chapter 2).

SOIL SAMPLING. Soil was sampled once on the study farms, in the spring of 2004. Figure 4-1 in Appendix B shows the location of the farm pairs on a map. Purposive selection of sampling sites in the study fields was used to reduce variability in soil properties due to topography. In the majority of the study fields, slopes were present. When fields had a relatively large area of level land that was not an obvious site of soil deposition or loss, this area was sampled. Where slopes were present throughout the field, an area was chosen that would be a site of both soil deposition and loss, to give roughly an average value of the soil properties on land that has/had experienced erosion. In most cases, this area was a mid-slope position. Verity and Anderson (1990) found that grain yields were lowest in upper slope positions, especially on the shoulder positions, and yields increased moving down the slope, where yields were highest at the lower slope positions, especially at the depositional footslope positions. This indicates that soil quality in a mid-slope position will be an intermediate value between the upper and lower slopes.

SOIL TESTS. Soil was tested for texture, total organic carbon and dry and wet aggregate size distribution. The methods used for the long-term studies (Chapter 4) were also used for the paired farm samples. Texture was used to determine how closely the soil from the paired organic and conventional fields matched.

As with the long-term studies, the shallow samples (0 to 2-2.5 cm) were used to determine organic C, as surface soil is more responsive to management practices than subsoil. However, differences in SOC due to tillage relocation would also be highest in the surface layer of soil (Bolinder et al. 1999). While tillage erosion was not measured in this study, many of the sampled fields were on rolling land and evidence of erosion was present. In many cases, tillage erosion was most likely a major source of soil redistribution; in a few cases, the farmers indicated that tillage erosion was a problem on the field either at present or in the past. Slopes that showed evidence of severe tillage erosion (i.e., lighter slope tops indicating that tillage had pulled all of the topsoil from the top of a slope) were not sampled to ensure that the sampled soil was not mixed with subsoil that had been pulled down from the apex of the slope.

SOIL COVER ANALYSIS. Vegetative cover was also studied on the paired organic and conventional farms. Pictures of the ground were taken in the spring at the time of sampling. These pictures indicate the amount of vegetative soil cover in the spring when soil is most susceptible to erosion. The amount of soil cover in the spring is also indicative of the soil cover through the fall, for instance, bare soil in the spring, even after a few tillage operations, would point to a low level of soil cover in the fall and winter months. The pictures were scanned into the computer, and the percentage of soil covered by residue and plants was determined using the image analysis software ASSESS (L. Lamari, University of Manitoba, Winnipeg, MB).

STATISTICAL ANALYSIS. Statistical analysis was done using SAS (SAS Institute, North Carolina, USA). The organic and conventional data sets for each soil property were tested for normality using Shapiro-Wilks W (P = 0.05) and homogeneity of variances using Bartlett's test.

For the soil cover analysis, the data sets did not conform to a normal distribution, even with transformations. However, the assumptions of the t-test are that the residual errors are normally distributed with homogenous variances. For the soil cover analysis comparing farm pairs with perennials in rotation, row crops in rotation and overall soil cover analysis it was not possible to transform the data in such a way that the residual errors were normally distributed to P=0.05 level. The data for the soil cover analysis was transformed so that the residual errors were as close to normally distributed as possible, and the variances were as homogenous as possible (as determined by Levene's test). The analysis was done on the transformed data (that was closest to a normal distribution) regardless, but no significant results were found. No attempt was made to conduct non-parametric analyses, as these are more sensitive than regular analyses of variances, so it was determined that these tests would not alter the conclusions of non-significant differences.

All results from the soil property and cover tests were combined and paired t-tests were used to compare the measured soil properties on the paired organic and conventional farms. Further analysis was done on the measured soil properties and soil cover percentages by performing paired t-tests on sub-groups of the farm pairs that had been grouped according to a number of management practices, including: rotation, tillage and soil cover. Sub-groups compared farm pairs that had rotations including perennials, rotations with row crops. Also, sub-groups that compared farm pairs with different tillage practices were analyzed.

To determine whether crop rotation had an effect on the soil properties measured farms were separated into two groups: farms with perennials in rotation and farms without perennials in rotation. A t-test was carried out comparing the two rotation groups for each of the measured soil properties.

Results and Discussion

OVERALL COMPARISON OF SOIL PROPERTIES. All 25 farm pairs were analyzed together to determine if there was an overall difference in soil properties or soil cover levels between the paired organic and conventional farms. For all three soil properties, dry and wet aggregate stability and organic C concentration, there were no overall significant differences between the organic and conventional farms. Table 5-1 shows the mean soil property and soil cover values for each study farm, and the *P*-values from the t-tests. Even with attempts to reduce variability between farms, it is impossible in a study such as this to remove all external sources of variation. The inherent spatial variability of soil properties provided one of the most difficult barriers to successful pairing of farms. The spatial variability of the measured properties was most likely larger than differences in soil properties due to management practices, therefore masking any effects of organic and conventional management.

Table 5-1: Mean soil property and soil cover values for individual study farms

			Mean Field Values						
Site	Management	Texture	Sand (%)	Silt (%)	Clay (%)	Dry MWD^z	Wet MWD^z	Organic C (%)	Soil cover (%)
NS	Organic	SiL	22	13	65	5.24	5.59	4.1	100.0
NS	Conventional	SiL	14	29	57	4.08	5.11	5.3	100.0
NS	Organic	LS	2	83	15	0.92	3.39	2.8	65.8
NS	Conventional	SL	12	63	25	1.93	4.15	2.8	36.4
NS	Organic	SL	9	55	36	2.08	3.04	3.3	1.5
NS	Conventional	SiL	11	28	61	2.82	2.24	1.9	45.7
PEI	Organic	SL	9	63	28	1.29	1.10	2.0	0.2
PEI	Conventional	SL	4	71	25	0.71	2.57	2.1	1.1
PEI	Organic	SCL	28	55	17	2.51	2.79	2.0	11.9
PEI	Conventional	SL	10	57	33	2.23	3.50	1.9	1.3
ON	Organic	L	25	27	48	3.49	1.99	2.9	1.3
ON	Conventional	SiL	15	25	60	2.60	1.80	2.9	3.9
ON	Organic	S / LS	1	85	14	0.35	3.62	2.5	68.6
ON	Conventional	SL	8	75	17	1.11	2.06	1.6	16.7
ON	Organic	SiL	23	21	56	3.02	1.23	4.2	1.9
ON	Conventional	SiL	22	25	53	2.96	1.92	5.5	16.5
ON	Organic	SiL	0	27	73	4.45	4.54	4.1	100.0
ON	Conventional	SiL	25	23	52	2.13	1.25	2.6	12.4
ON	Organic	SL	4	67	29	0.56	1.48	1.0	71.2
ON	Conventional	SL	4	53	43	2.63	1.49	4.4	91.8
AB	Organic	L	20	43	37	1.10	0.51	2.5	52.9
AB	Conventional	L	23	39	38	1.41	0.46	1.9	-
AB	Organic	L	19	37	44	1.95	2.22	4.4	21.9
AB	Conventional	SiL	13	35	52	1.74	1.64	4.8	-
AB	Organic	CL	12	35	53	1.55	1.13	5.0	-
AB	Conventional	L	36	23	41	1.76	2.54	3.3	-
AB	Organic	SiL	21	33	46	0.91	2.55	8.5	100.0
AB	Conventional	SiL	13	27	60	1.12	1.42	7.2	100.0
AB	Organic	L	9	33	58	2.06	0.61	3.7	-
AB	Conventional	L	22	43	35	2.24	2.72	5.7	-
MB	Organic	L	22	43	35	2.74	1.20	1.7	8.9
MB	Conventional	LS	19	42	39	0.23	3.21	1.3	39.5
MB	Organic	LS	12	47	41	0.63	3.40	2.9	33.1
MB	Conventional	L	7	85	8	2.26	0.94	4.5	25.8

Table 5-1 (con't): Mean soil property and soil cover values for individual study farms

			Mean Field Values						
Site	Management	Texture	Sand (%)	Silt (%)	Clay (%)	Dry MWD	Wet MWD	Organic C (%)	Soil cover (%)
MB	Organic	L	7	82	11	2.06	0.75	4.2	6.9
MB	Conventional	L	3	76	21	2.03	0.66	4.0	27.5
MB	Organic	SL	17	36	47	0.42	2.58	4.5	55.3
MB	Conventional	L	17	37	46	0.71	1.51	4.3	75.6
MB	Organic	C	22	38	40	2.70	0.69	4.2	11.9
MB	Conventional	C	6	61	33	2.28	0.92	3.9	21.8
SK	Organic	SCL	6	59	35	1.89	1.12	3.9	17.6
SK	Conventional	CL	14	45	41	2.09	1.45	2.5	22.8
SK	Organic	L	47	21	32	1.69	0.59	2.8	32.8
SK	Conventional	L	48	19	33	2.07	0.87	4.6	-
SK	Organic	SiL	33	19	48	1.70	0.72	3.2	1.0
SK	Conventional	SiL / L	29	32	39	1.86	0.59	2.0	22.3
SK	Organic	SL	22	31	47	4.07	2.65	7.1	100.0
SK	Conventional	SCL	23	35	42	1.72	2.01	5.6	100.0
SK	Organic	SiL	17	23	60	1.35	1.32	3.6	39.2
SK	Conventional	SL	13	37	50	1.22	1.43	3.8	-
		Overall Organic Mean				**2.03**	**2.03**	**3.64**	**27.06**
		Overall Conventional Mean				**1.92**	**1.94**	**3.62**	**31.06**
					P-value	0.3194	0.4089	0.8103	0.1824

SiL = Silt Loam, LS = Loamy Sand, SL = Sandy Loam, SCL = Sandy Clay Loam, L = Loam, S = Sand

[z] Mean Weight Diameter

COMPARISON OF FARM PAIRS WITH SAME TEXTURE. Eleven of the 25 farm pairs had soil texture classes that matched (among the pair), as determined from the soil textural triangle using the percent sand, silt and clay. By only comparing farm pairs with the same textural class, the analysis only contains farm pairs with similar background soil properties. When the soil properties of only the farm pairs with the same soil texture were compared, significant differences between organic and conventional farm pairs was found for organic C levels (Table 5-2). The concentration of organic C in the conventional farms was higher than in the organic farms. Despite lower organic C levels in the organic farms, there was no significant difference between the farm pairs in terms of aggregate stability. This follows from the results found at the long-term studies (Chapter 3), where aggregate stability levels in the organic systems were not affected by the level of organic C in the soil. Again, this supports the hypothesis that some mechanism, which is independent of total organic C levels, in organic systems stabilizing soil aggregates in organic farming systems.

Table 5-2: Mean soil property values for organic and conventional farm pairs in the same textural class

	Mean values for soil properties		
	Dry MWD [z]	Wet MWD [z]	Organic C (%)
Organic	2.28	1.79	3.7
Conventional	2.15	1.76	4.3
P-value	0.6172	0.8675	0.0381

[z] Mean Weight Diameter

COMPARISON OF FARM PAIRS WITH VARIOUS CROP ROTATIONS. Farm pairs were separated into subgroups according to the type of crops grown in rotation. This was done to identify whether there are significant soil property differences between organic and conventional systems when the farms have certain crop rotation categories (rotations with row crops and rotations with perennials). Ten farm pairs were identified in which both the organic and conventional farms had rotations that included row crops. The mean soil property values for the organic and conventional farms are shown in Table 5-3. There were no significant differences between the organic and conventional farms for any of the measured soil properties. Row crops generally require higher intensities of tillage than solid-seeded annual or perennial crops. The lack of significant differences between the organic and conventional farms indicates that the cropping practices in two systems do not differ to such an extent that the risk of soil erosion is altered by management.

Table 5-3: Mean soil property values for organic and conventional farm pairs with a crop rotation including row crops

	Mean values for soil properties		
	Dry MWD[z]	Wet MWD[z]	Organic C (%)
Organic	2.39	2.89	2.9
Conventional	2.32	2.61	3.1
P-value	0.5619	0.1364	0.5739

[z] Mean Weight Diameter

Farm pairs that both had perennial crops in rotation were also placed into a sub-group and soil properties between organic and conventional systems were compared. Eight farm pairs had crop rotations that included perennials, the results from the analysis are shown in Table 5-4. As was found in the analysis for the row crops, no significant differences between the organic and conventional farms were found when comparing farms with perennial-containing rotations. Again, this indicates that organic and conventional cropping systems are similar enough that there is no difference in soil properties that affect erosion risk.

Table 5-4: Mean soil property values for organic and conventional farm pairs with a crop rotation including perennial crops

	Mean values for soil properties		
	Dry MWD^z	Wet MWD^z	Organic C (%)
Organic	2.26	2.67	5.1
Conventional	2.00	2.54	4.9
P-value	0.6457	0.7430	0.3149

^{z} Mean Weight Diameter

COMPARISON OF FARM PAIRS WITH DIFFERENT TILLAGE PRACTICES. Some studies have found that the tillage regime used on a farm can alter soil properties such as organic C levels and aggregate stability. To discover whether differences in tillage systems on the paired organic and conventional systems had an affect on soil erosion risk, the farm pairs in which only the conventional farmer used zero tillage were analyzed. Means and *P*-values from the statistical analysis can be found on Table 5-5. The conventional farms that practiced zero tillage had significantly higher dry aggregate stability values when compared to the organic farm pairs (without zero tillage). Aggregate stability can be increased with zero tillage management, because there are fewer tillage operations, which physically break up soil aggregates (Rachman et al. 2003; Campbell et al. 2001). As well, aggregate stability is very dependent on soil moisture status at the time of sampling, the higher the moisture status of the soil, the greater the stability (Coote et al. 1988; Perfect et al. 1990). Zero tillage is effective at conserving soil moisture, and in the drier areas of the prairies, zero tillage is often adopted specifically for moisture conservation reasons. For that reason, it is possible that the zero tilled soils had higher moisture levels at the time of sampling and therefore higher aggregate stabilities. However, wet aggregate stability and organic C levels were not affected by the difference in tillage practices amongst farm pairs.

Table 5-5: Mean soil property values for organic and conventional farm pairs with different tillage practices

	Mean values for soil properties		
	Dry MWD[z]	Wet MWD[z]	Organic C (%)
Organic	2.17	2.36	3.6
Conventional (Zero tillage)	3.72	2.86	3.4
P-value	0.0015	0.4389	0.8378

[z] Mean Weight Diameter

COMPARISON OF ANNUAL AND PERENNIAL ROTATIONS. To determine the relative importance of crop rotation compared with management practices in the farm pairs, the organic and conventional farm pairs were dropped and soil properties from farms were compared based on the crop rotation type (rotations only including annuals and rotations with perennials) (Table 5-6). At the outset of the project, it was believed that crop rotation would greatly affect soil erosion risk. Forty-two farms were included in this analysis. The type of crop rotation significantly affected wet aggregate stability (P=0.0022) and organic C (P<0.0001). The soils under perennial rotations have greater resistance to water erosion and higher levels of organic C. The benefits of perennials in rotation have been shown by other researchers. Cropping system management (organic or conventional) was found to have a significant effect on organic C levels when farm pairs of similar texture were compared, however, the significance of the management effect was lower (P=0.0381) than the significance of the effect of rotation (P<0.0001). These results show that the choice of crops grown in rotation has a larger effect on soil properties affecting erosion risk than cropping system management (organic or conventional). Crop rotations that include perennials reduce the risk of soil erosion in both organic and conventional systems.

Table 5-6: Mean soil property values for farms with an annual or perennial rotation

	Mean values for soil properties		
	Dry MWD[z]	Wet MWD[z]	Organic C (%)
Annual	2.04	1.62	3.0
Perennial	2.10	2.55	4.4
P-value	0.6849	0.0022	<0.0001

[z] Mean Weight Diameter

SOIL COVER ANALYSES. A number of the farm pair sub-groups that were analyzed for the measured soil properties were also analyzed for percent soil cover (Table 5-7). This included the comparisons of farm pairs with rotations including row crops, rotations including perennials and farm pairs with different tillage regimes. Again, these sub-groups were picked to determine whether farm pairs with similar crop rotations or dissimilar tillage practices differed significantly in terms of percent soil cover in the spring. If the organic and conventional farm pairs had different tillage practices, even with a similar crop rotation, it would be expected that the farms with higher tillage intensities would have less soil cover. For the analysis of farm pairs with different tillage practices, it was expected that the conventional farms, with zero tillage practices, would have higher levels of soil cover in the spring, due to the lower levels of tillage used. There were no significant differences in percent soil cover between the organic and conventional farms in the spring at sampling time. The level of soil cover in the farm pairs stayed the same regardless of the crop rotation category or tillage practices used. In the spring, when soil erosion risk is the highest, the organic and conventional farms had comparable soil cover. The mean percent soil cover for the farm pairs with perennial crops in rotation (about 50%) was much higher than the farm pairs with row crops (about 30%).

Table 5-7: Mean percent soil cover for organic and conventional farm pairs

	Mean percent soil cover for farm pairs		
	With a rotation including row crops (%)	With a rotation including perennial crops (%)	With different tillage practices (%)
Organic	34.9	51.3	29.7
Conventional	30.5	54.3	29.4
P-value	0.5950	0.6485	0.5465

For the final analysis, the organic and conventional farm pairs were dropped, and farms with annual versus perennial rotations were compared analyzed for percent soil cover (Table 5-8). The fields with perennial crops in rotation had 10% higher levels of soil cover than the fields with only annuals in rotation; however, this did not represent a significant difference between rotations. Soil cover is highly dependent on rotation phase, so the results of the soil cover analysis was very dependent on the previous and current crop in each field. Even rotations that include perennials may not have higher levels of soil cover (compared to annual-only rotations) when sampled in the annual phase of a rotation.

Table 5-8: Mean soil property values for farms with an annual or perennial rotation	
	Mean soil cover (%)
Annual	27.2
Perennial	37.0
P-value	0.2548

Summary

Very few significant differences between the organic and conventional farm pairs were detected, indicating that farm management did not affect soil properties relating to soil erosion risk. When farm pairs with identical textures were analyzed, the level of organic C in the organic farms was significantly lower than the conventional farms. Despite the lowered organic C levels in the organic farms, aggregate stability values were not affected, following the pattern found at the long-term studies (Chapter 4). As was hypothesized in Chapter 4, this indicates that the organic systems are stabilizing soil aggregates through some mechanism other than total organic C. It is possible that the organically managed soil has increased levels of certain organic C compounds that are stabilizing the soil aggregates, but not increasing the total organic C level in the soil.

No significant differences were found either when the farm pairs were analyzed as a whole (where crop rotation and proximity are the only selection criteria), or when the farm pairs were analyzed by crop rotation categories. However, when the farm pairs were dropped and farms were simply compared according to having an annual rotation or a perennial-containing rotation, significant differences appeared between the two rotation categories. The farms that had crop rotations containing perennials had significantly higher wet aggregate stability and organic C concentrations. The effect of rotation (in the annual versus perennial analysis) was more significant than any of the analyses that looked at the effect of management. This indicates that rotation has a much stronger, overriding effect on soil properties relating to soil erosion risk than systems management (organic or conventional). Crop rotation is the most effective way to manage soil erosion risk, with rotations that include perennial crops imparting the highest levels of resistance to erosion.

Tillage differences were only found to affect dry aggregate stability. Conventional farms that practiced zero tillage or direct seeding had significantly higher dry aggregate stability values than the paired organic farms that did not use direct seeding or zero tillage on the farm. Tillage physically breaks soil structure and exposes soil below the surface, subjecting this newly exposed soil to more rapid drying and C mineralization.

No significant differences were found between the farm pairs for percent soil cover. Soil cover is quite variable and dependent on rotation phase. The results from the soil cover analysis were influenced by the sampling year's rotation phase, possibly masking any trends in the data.

It was concluded that rotation was more important than management in determining soil erosion risk. A rotation that includes perennial crops can decrease soil erosion risk. Organic systems can lower organic C levels below those found in conventional systems, however, this does not affect aggregate stability levels. Organic systems are most likely stabilizing soil aggregates through some mechanism (such as polysaccharides or VAM fungi) that is independent of total organic C levels.

CHAPTER 6

GENERAL DISCUSSION AND CONCLUSIONS

Discussion

Differences between organic or conventional crop rotations and tillage practices were expected to lead to differences in soil erosion risk between the two cropping systems. Some key differences in cropping practices between the surveyed organic and conventional farmers were found. More organic farmers had forages and green manures in rotation, which tend to build soil structural stability and improve organic C storage. However, significantly fewer organic farmers used zero tillage or direct seeding practices compared to conventional farmers. Both zero tillage and direct seeding lower soil erosion risk by maintaining vegetative and residue cover on the soil, as well as through reducing the number of tillage passes used on a field in a growing season. Most of the surveyed farmers agreed that organic farmers rely more heavily on tillage than conventional farmers. While tillage has been found to influence soil erosion risk in other studies, the soil analyses from this found that crop rotation has an overriding effect on soil properties.

Management significantly affected organic C levels in some situations on the long-term studies and farm pairs (with the organically managed soil having lower levels of SOC); however, in all cases, differences in organic C levels did not translate into differences in structural stability. At the Glenlea long-term study and on farm pairs with identical textures, organic management significantly lowered organic C levels compared to the conventional systems. However, these lowered C levels did not affect aggregate stability, and at Glenlea, the organic plots actually had higher wet aggregate stability than the conventional plots. At Scott, the organically managed diverse annual rotation had the lowest organic C levels, but the highest dry aggregate stability values, repeating the pattern of lowered C levels that do not affect soil structure. Bulk density was measured at the Glenlea study previously, and has been found not to vary between the organic and conventional plots, suggesting that the differences in organic C percentages indicate actual differences in organic C content by weight. This supports the hypothesis put forth by Siegrist et al. (1998), which states that organic systems stabilize soil structure by increasing certain SOC compounds that build structure, while not raising the total organic C levels of the soil.

The studies comparing soil properties from the long-term studies and the farm pairs showed that crop rotation has a significant effect on soil erosion risk. The effect of crop rotation is most likely larger than the effect of organic or conventional management. Rotation significantly affected structural stability at both Glenlea and Scott (the green manure rotations had higher stability levels), and the perennial rotation resulted in higher organic C levels at Scott. When the farm pairs were analyzed according to annual versus perennial rotations rather than organic versus conventional management, significant differences appeared. The farms with perennial crops in rotation had higher organic C and wet aggregate stability values when compared to the farms with only annuals in rotation.

Future Research

This study took a broad view of organic and conventional cropping systems in Canada. As such, the soil erosion risk in the two systems was compared. However, the purpose of this study was not to determine the mechanisms behind any differences in soil properties relating to erosion risk. It would be useful to study these systems in more depth (both on the long-term studies and on farm pairs) in order to identify the cropping practices in both systems that resulted in significant differences in the measured soil properties. Studies that look at specific management practices would allow for more exact agronomic recommendations for managing soil erosion.

The results of the soil analyses from both the long-term studies and the paired farm comparisons suggested that there are mechanisms in the organically-managed soils that are stabilizing aggregates but not altering the total organic C levels. Further investigation regarding the organic C fractions and substances (such as polysaccharides and glomalin) present in the organic and conventional systems is needed to prove or disprove this hypothesis. Glomalin is a carbon-containing compound produced by VAM fungi, which helps to build and stabilize soil aggregates (Wright 2005). Analysis of glomalin content of the soil samples would help to identify the relative presence and activity of VAM fungi, as well as possibly explain differences in aggregation between organic and conventional systems.

This study determined that organic systems, on average, do rely more on tillage than conventional systems. Agronomic research of reduced tillage techniques in organic systems would help to reduce soil erosion risk. As well, periodic studies that measure soil properties of long-term studies will yield useful data regarding the temporal changes of soil erosion risk in the systems. There is a need to maintain long-term system comparison trials (such as the three that were sampled in this study) in order to study changes in system performance indicators over time. Studies of soil property dynamics will help to identify trends in the data and isolate the factors that are affecting changes in the measured properties. Finally, long-term studies can be used to determine at what point lowered SOC levels will begin to affect other soil properties such as aggregate stability.

Conclusions

Organic or conventional management affected organic C levels, but did not affect the other measures of soil erosion risk (wet and dry aggregate stability). By itself, management does not seem to affect the risk of soil erosion. However, crop rotation did alter the risk of soil erosion. Rotations that include perennials or green manures can help build organic C levels and structural stability, reducing the risk of soil erosion. As more organic systems include perennials and green manures in rotation, it cannot be said that organic farms increase soil erosion risk through an increased reliance on tillage for weed control. While the majority of the surveyed organic farmers did not have direct seeding or zero tillage practices on the farm, it was found that organic farms utilized other soil conservation techniques to a greater degree than conventional systems, including contour and ridge tillage, shelterbelts and strip cropping. While organic systems generally have higher intensities of tillage than conventional systems, organic farms also tend to have more perennials in rotation, which has been shown in this study to lower the risk of soil erosion. Organic management does not inherently lead to a higher risk of soil erosion than conventional management. Farmers can manage soil erosion risk most effectively by choosing crop rotations that include green manures or perennials.

LITERATURE CITED

Angers, D. A. and M. R. Carter. 1996. Aggregation and organic matter storage in cool, humid agricultural soils. In M. R. Carter and B. A. Stewart, eds. Structure and Organic Matter Storage in Agricultural Soils. CRC Press, Boca Raton, FL. 193-211.

Angers, D. A. and G. R. Mehuys. 1988. Effects of cropping on macro-aggregation of a marine clay soil. Can. J. Soil Sci. 68: 723-732.

Angers, D. A. and G. R. Mehuys. 1993. Aggregate stability to water. In M. R. Carter, ed. Soil Sampling and Methods of Analysis. Lewis Publishers, Boca Raton, FL. 651-657.

Anonymous. 2004. Diversifying cropping systems. Sustainable Agriculture Network, Burlington, VT.

Aoyama, M., D. A. Angers, and A. N'Dayegamiye. 1999a. Particulate and mineral-associated organic matter in water-stable aggregates as affected by mineral fertilizer and manure applications. Can. J. Soil Sci. 79: 295-302.

Aoyama, M., D. A. Angers, A. N'Dayegamiye, and N. Bissonnette. 1999b. Protected organic matter in water-stable aggregates as affected by mineral fertilizer and manure applications. Can. J. Soil Sci. 79: 419-425.

Avery, D. T. 2000. Saving the Planet with Pesticides and Plastic. 2nd Edition. Hudson Institute, Indianapolis, IN. 476 pp.

Babbie, E. 1990. Survey Research Methods. Second Edition. Wadsworth Publishing Co., Belmont, CA. 395 pp.

Baudry, J. and F. Papy. 2001. The role of landscape heterogeneity in the sustainability of cropping systems. In J. Nosberger, H. H. Geiger, and P. C. Struik, eds. Crop Science. CAB International, Wallingford, Oxon. 243-259.

Bauer, A. and A. L. Black. 1994. Quatification of the effect of soil organic matter content on soil productivity. Soil Sci. Soc. Am. J. 58: 185-193.

Berry, P. M., R. Sylvester-Bradley, L. Philipps, D. J. Hatch, S. P. Cuttle, F. W. Rayns, and P. Gosling. 2002. Is the productivity of organic farms restricted by the supply of available nitrogen? Soil Use and Management 18: 248-255.

Biederbeck, V. O., C. A. Campbell, V. Rasiah, R. P. Zentner, and Guang Wen. 1998. Soil quality attributes as influenced by annual legumes used as green manure. Soil Biol. and Biochem. 30: 1177-1185.

Blum, W. H. 1998. Basic concepts: degradation, resilience and rehabilitation. In R. Lal, W. H. Blum, C. Valentine, and B. A. Stewart, eds. Methods for Assessment of Soil Degradation. CRC Press, New York, New York. 1-16.

Bolinder, M. A., D. A. Angers, E. G. Gregorich, and M. R. Carter. 1999. The response of soil quality indicators to conservation management. Can. J. Soil Sci. 79: 37-45.

Bremer, E., H. H. Janzen, and A. M. Johnston. 1994. Sensitivity to total, light fraction and mineralizable organic matter to management practices in a Lethbridge soil. Can. J. Soil Sci. 74: 131-138.

Campbell, C. A., F. Selles, G. P. Lafond, V. O. Biederbeck, and R. P. Zentner. 2001. Tillage-fertilizer changes: Effect on soil soil quality attributes under long-term crop rotations in a thin Black Chernozem. Can. J. Soil Sci. 81: 157-165.

Campbell, C. A., A. G. Thomas, V. O. Biederbeck, B. G. McConkey, F. Selles, D. Spurr, and R. P. Zentner. 1998. Converting from no-tillage to pre-seeding tillage: Influence on weeds, spring wheat grain yields and N, and soil quality. Soil and Tillage Research 46: 175-185.

Canadian General Standards Board. 2005. Third Committee Ballot Draft: Organic Production Systems Part 1: General Principles. CAN/CGSB-32.310-xxxx Part 1. URL: http://www.organicagcentre.ca/DOCs/OrgStds_Jan05_Principles.pdf (20 April 2005)

Carter, M. R. 1996. Analysis of soil organic matter storage in agroecosystems. In M. R. Carter and B. A. Stewart, eds. Structure and Organic Matter Storage in Agricultural Soils. Lewis Publishers, Boca Raton, FL. 3-11.

Carter, M. R. 2002. Soil quality for sustainable land management: organic matter and aggregation interactions that maintain soil functions. Agron. J. 94: 38-47.

Chepil, W. S. 1953. Factors that influence clod structure and erodibility of soil by wind: I. Soil Texture. Soil Science 75: 473-483.

Coote, D. R., C. A. Malcolm-McGovern, G. J. Wall, W. T. Dickinson, and R. P. Rudra. 1988. Seasonal variation of erodibility indices based on shear strength and aggregate stability in some Ontario soils. Can. J. Soil Sci. 68: 405-416.

Cruse, R. M. and D. L. Dinnes. 1995. Spatial and temporal diversity in production fields. In R. K. Olson, C. A. Francis, and S. Kaffka, eds. Exploring the Role of Diversity in Sustainable Agriculture. American Society of Agronomy, Madison, WI. 73-94.

Dalal, R. C. and B. J. Bridge. 1996. Aggregation and organic matter storage in sub-humid and semi-arid soils. In M. R. Carter and B. A. Stewart, eds. Structure and Organic Matter Storage in Agricultural Soils. CRC Press, Boca Raton, FL. 263-307.

De Jong, E., C. B. M. Begg, and R. G. Kachanoski. 1983. Estimates of soil erosion and deposition for some Saskatchewan soils. Can. J. Soil Sci. 63: 607-617.

De Jong, E. and R. G. Kachanoski. 1988. The importance of erosion in the carbon balance of prairie soils. Can. J. Soil Sci. 68: 111-119.

Deen, W. and P. K. Kataki. 2003. Carbon sequestration in a long-term conventional versus conservation tillage experiment. Soil and Tillage Research 74: 143-150.

Drinkwater, L.E., D.K. Letourneau, F. Workneh, A.H.C. Van Bruggen, and C. Shennan. 1995. Fundamental differences between conventional and organic tomato agroecosystems in California. Ecological Applications. 54: 1098-1112.

Dumanski, J., D. R. Coote, G. Luciuk, and C. Lok. 1986. Soil conservation in Canada. J. Soil and Water Cons. 204-210.

Duram, L. A. 1999. Factors in organic farmers' decisionmaking: diversity, challenge, and obstacles. Am. J. Altern. Agric. 14: 2-10.

Ellis, R. 1996. Standard Operating Procedures: Particle size analysis (hydrometer method). University of Manitoba, Winnipeg, MB.

Entz, M. H., V. S. Baron, P. M. Carr, D. W. Meyer, S. R. Smith, Jr., and W. P. McCaughey. 2002. Potential of forages to diversify cropping systems in the northern Great Plains. Agron. J. 94: 240-250.

Entz, M. H., R. Guilford, and R. Gulden. 2001. Crop yield and soil nutrient status on 14 organic farms in the eastern portion of the northern Great Plains. Can. J. Plant Sci. 81: 351-354.

Entz, M. H., K. R. Penner, J. K. Vessey, C. D. Zelmer, and J. R. Thiessen Martens. 2004. Mycorrhizal colonization of flax under long-term organic and conventional management. Can. J. Plant Sci. 84: 1097-1099.

Fließbach, A., Mäder, P., Dubois, D., and Gunst, L. 2000. Organic farming enhances soil fertility and biodiversity. Research Institute of Organic Agriculture (FiBL). Report 1, 1-16.

Grant, C. A., G. A. Peterson, and C. A. Campbell. 2002. Nutrient considerations for diversified cropping systems in the northern Great Plains. Agron. J. 94: 186-198.

Green, C. O. A needs assessment study of the non-chemical crop production industry. 1990. Saskatchewan Department of Agriculture and Food, Regina, SK.

Gregorich, E. G., M. R. Carter, D. A. Angers, C. M. Monreal, and B. H. Ellert. 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils. Can. J. Soil Sci. 74: 367-385.

Haumann, B. 2001 The World of Organic Agriculture 2003 - Statistics and Future Prospects. H. International Federation of Orgnaic Agriculture Movements. URL: http://www.ifoam.org (29 October 2001).

Henning, J. 1994. Economics of organic farming in Canada. In N. H. Lampkin and S. Padel, eds. The Economics of Organic Farming: An International Perspective. CAB International, Wallingford, Oxon. 143-160.

Hill, S. B. and R. J. MacRae. 1992. Organic farming in Canada. Agriculture, Ecosystems and Environment 39: 71-84.

Hole, D. G., A. J. Perkins, J. D. Wilson, I. H. Alexander, P. V. Grice, and A. D. Evans. 2005. Does organic farming benefit biodiversity? Biological Conservation 122: 113-130.

Humble, S. M. 1991. M.Sc. Thesis. University of Manitoba.

Huwe, B. 2003. The role of soil tillage for soil structure. In A. E. Titi, ed. Soil Tillage in Agroecosystems. CRC Press, Washington, D.C. 27-50.

IFOAM. 2005. The Principal Aims of Organic Production and Processing. URL: http://www.ifoam.org/organic_facts/principles/pdfs/Principal_Aims_of_Organic_Prodution_and_Processing.pdf (19 June 2005).

Jackson, W. 1988. Research Methods: Rules for Survey Design and Analysis. Prentice-Hall Canada Inc., Scarborough, ON. 290 pp.

Janzen, H. H. 1995. The role of long-term sites in agroecological research: A case study. Can. J. Soil Sci. 75: 123-133.

Karlen, D. L., Varvel, G. E., Bullock, D. G., and Cruse, R. M. 1994. Crop rotations for the 21st century. Advances in Agronomy 53: 1-45.

Katsvairo, T., W. J. Cox, and H. van Es. 2002. Tillage and rotation effects on soil physical characteristics. Agron. J. 94: 299-304.

Ketcheson, J. 1977. Conservation tillage in eastern Canada. J. Soil and Water Cons. 31: 57-60.

Kirby, P. C. and G. R. Mehuys. 1987. The seasonal variation of soil erosion by water in southwestern Quebec. Can. J. Soil Sci. 67: 55-63.

Klepper, R., W. Lockeretz, B. Commoner, M. Gertler, S. Fast, D. O'Leary, and R. Blobaum. 1977. Economic performance and energy intensiveness on organic and conventional farms in the corn belt: a preliminary comparison. Amer. J. Agr. Econ. (February): 1-9.

Klonsky, K. 2000. Forces impacting the production of organic foods. Agriculture and Human Values 17: 233-243.

Kuepper, G. 2001. Pursuing conservation tillage systems for organic crop production. Appropriate Technology Transfer for Rural Areas. Organic Matters Series. URL: http://www.attra.ncat.org/attra-pub/PDF/omconservtill.pdf. (10 April 2003).

Lal, R. and W. Elliot. 1994. Erodibility and erosivity. In R. Lal, ed. Soil Erosion Research Methods. St. Lucie Press, Delray Beach, FL. 181-208.

Lampkin, N. H. 1994. Researching organic farming systems. In N. H. Lampkin and S. Padel, eds. The Economics of Organic Farming: An International Perspective. CAB International, Wallingford, Oxon. 27-43.

Larney, F. J., H. H. Janzen, B. M. Olson, and C. W. Lindwall. 2000. Soil quality and productivity responses to simulated erosion and restorative amendments. Can. J. Soil Sci. 80: 515-522.

Larney, F. J., C. W. Lindwall, R. C. Izaurralde, and A. P. Moulin. 1994. Tillage systems for soil and water conservation on the Canadian Prairie. In M. R. Carter, ed. Conservation Tillage in Temperate Agroecosystems. CRC Press, Boca Raton, FL. 305-328.

Lehrsch, G. A. and P. M. Jolley. 1992. Temporal changes in wet aggregate stability. Transactions of the ASAE. 35: 493-498.

Liang, B. C., B. G. McConkey, C. A. Campbell, A. M. Johnston, and A. P. Moulin. 2002. Short-term crop rotation and tillage effects on soil organic carbon on the Canadian prairies. In Kimble, R. Lal, and Follett, eds. Agriculture Practices and Policies for Carbon Sequestration in Soil. Lewis Publishers, Boca Raton, FL. 287-293.

Macey, A. 2004a. "Certified Organic" The Status of the Canadian Organic Market in 2003. Agriculture and Agri-Food Canada.

Macey, A. 2004b. The state of organic farming in Canada in 2002. EcoFarm & Garden Winter 2004, 44-47.

Mäder, P., A. Fließbach, D. Dubois, L. Gunst, P. Fried, and U. Niggli. 2002. Soil fertility and biodiversity in organic farming. Science 296: 1694-1697.

Magdoff, F. R. 1996. Soil organic matter fractions and implications for interpreting organic matter tests. In F. R. Magdoff, M. A. Tabatabai, and E. A. Jr. Hanlon, eds. Soil Organic Matter: Analysis and Interpretation. Soil Science Society of America, Inc, Madison, WI. 11-19.

Malhi, S. S., S. A. Brandt, and K. S. Gill. 2003. Cultivation and grassland type effects on light fraction and total organic C and N in a Dark Brown Chernozemic soil. Can. J. Soil Sci. 83: 145-153.

Martens, J.R., and M.H. Entz. 2001. Availability of late-season heat and water resources for relay and double cropping with winter wheat in prairie Canada. Can. J. Plant Sci. 81: 273-276.

McRae, T., C. A. S. Smith, and L. J. Gregorich. 2000. Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project. Agriculture and Agri-Food Canada. Ottawa, ON. 224 pp.

Molder, P. J., Negrave, P. D., and Schoney, R. A. 1991. A descriptive analysis of Saskatchewan organic producers. Paper presented at the Agriculture Institute of Canada National Conference, July, Fredericton, NB.

Moulin, A., S. S. Malhi, and S. A. Brandt. 2001. Potential for wind erosion in alternative cropping systems. In A. G. Thomas and S. A. Brandt, eds. Scott alternative cropping systems project review: The first six years. Volume 9 - Workshop Proceedings. [CD ROM]. Agriculture and Agri-Food Canada, Saskatoon, SK. 5-1 - 5-7.

Moulin, A., McCaughey, W. P., Burton, D., Entz, M. H., and Chen, W. 2000. Carbon storage in fertilized pastures: Glenlea. Agriculture and Agri-Food Canada, Brandon, MB.

Nelson, D. W. and L. E. Sommers. 1996. Total carbon, organic carbon, and organic matter. Methods of Soil Analysis. Part 3. Chemical Methods - SSSA. Soil Science Society of America and American Society of Agronomy, Madison, WI. 961-1010.

Padbury, G. and C. T. Stushnoff. 2000. Risk of wind erosion. In T. McRae, C. A. S. Smith, and L. J. Gregorich, eds. Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project. Agriculture and Agri-Food Canada, Ottawa, ON. 69-76.

Pates, Mikkel. 2001. 'Beckies' follow Beck's research. Agweek . 10 December 2001.

Perfect, E., B. D. Kay, W. K. P. van Loon, R. W. Sheard, and T. Pojasok. 1990. Factors influencing soil structural stability within a growing season. Soil Sci. Soc. Am. J. 54: 173-179.

Pierson, F. B. and D. J. Mulla. 1990. Aggregate stability in the Palouse region of Washington: Effect of landscape position. Soil Sci. Soc. Am. J. 54: 1407-1412.

Prairie Farm Rehabilitation Administration. 1983. Land degradation and soil conservation issues on the Canadian prairies. Agriculture Canada, Regina, SK.

Rachman, A., S. H. Anderson, C. J. Gantzer, and A. L. Thoompson. 2003. Influence of long-term cropping systems on soil physical properties related to soil erodibility. Soil Sci. Soc. Am. J. 67: 637-644.

Rea, L. M. and R. A. Parker. 1997. Desiging and conducting survey research: a comprehensive guide. 2nd Edition. Jossey-Bass Inc., San Francisco, CA. 254 pp.

Rigby, D. and D. Cáceres. 2001. Organic farming and the sustainability of agricultural systems. Agricultural Systems 68: 21-40.

Saiyed, I. 2004. Organic Carbon Determination: Rapid Dichromate Oxidation Technique. University of Manitoba, Winnipeg, MB.

Science Council of Canada. 1986. A growing concern: soil degradation in Canada. Science Council of Canada, Ottawa, ON.

Sheldrick, B. H. and C. Wang. 1993. Particle size distribution. In M. R. Carter, ed. Soil Sampling and Methods of Analysis. Lewis Publishers, Boca Raton, FL. 499-511.

Shelton, I. J., G. J. Wall, J. M. Cosette, R. Eliers, B. Grant, D. King, G. Padbury, H. Rees, J. Tajek, and L. van Vilet. 2000. Risk of water erosion. In T. McRae, C. A. S. Smith, and L. J. Gregorish, eds. Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project. Agriculture and Agri-Food Canada, Ottawa, ON. 59-67.

Shepherd, M. A., R. Harrison, and J. Webb. 2002. Managing soil organic matter - implications for soil structure on organic farms. Soil Use and Management 18: 284-292.

Siegrist, S., D. Schaub, L. Pfiffner, and P. Mäder. 1998. Does organic agriculture reduce soil erodibility? The results of a long-term field study on loess in Switzerland. Agriculture, Ecosystems and Environment 69: 253-264.

Six, J., E. T. Elliott, K. Paustian, and J. W. Doran. 1998. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Sci. Soc. Am. J. 62: 1367-1377.

Smith, R. E., Veldhuis, H., Mills, G. F., Eliers, R. G., Fraser, W. R., and Lelyk, G. W. 1998. An ecological stratification of Manitoba's natural landscapes. Technical Bulletin 98-9E. Agriculture and Agri-Food Canada, Winnipeg, MB.

Smith, W. N., G. Wall, R. Desjardins, and B. Grant. 2000. Soil organic carbon. In T. McRae, C. A. S. Smith, and L. J. Gregorich, eds. Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project. Agriculture and Agri-Food Canada, Ottawa, ON. 85-92.

Soil Conservation Committee of the Agricultural Institute of Canada. Soil erosion on agriclutural land in Canada. The Agrologist Fall 1980, 23-28. 1980.

Statistics Canada. 2001. 2001 Census of Agriculture. [CD-ROM]. Statistics Canada.

Steel, R. G. D., J. H. Torrie, and D. A. Dickey. 1997. Principles and procedures of statistics: a biometrical approach. 3rd Edition. WCB McGraw-Hill, Madison, WI. 1-666 p.

Stocking, M. A. 1994. Assessing vegetative cover and management effects. In R. Lal, ed. Soil Erosion Research Methods. Soil and Water Conservation Society, Ankeny, Iowa.

Stolze, M., A. Piorr, A. Häring, and S. Dabbert. 2000. The environmental impacts of organic farming in Europe. Stuttgart-Hohenheim, Germany.

Stonehouse, D. P. 1995. Profitability of soil and water conservation in Canada: A review. J. Soil and Water Cons. 50: 215-219.

Sun, H., F. J. Larney, and M. S. Bullock. 1995. Soil amendments and water-stable aggregation of a desurfaced Dark Brown Chenozem. Can. J. Soil Sci. 75: 319-325.

Tabatabai, M. A. 1996. Soil organic matter testing: An overview. In F. R. Magdoff, M. A. Tabatabai, and E. A. Jr. Hanlon, eds. Soil Organic Matter: Analysis and Interpretation. Soil Science Society of America, Inc., Madison, WI. 1-9.

Tate, W. B. 1994. The Development of the Organic Industry and Market: An International Perpective. In N. H. Lampkin and S. Padel, eds. The Economics of Organic Farming: An International Perspective. CAB International, Wallingford, Oxon. 11-25.

Tisdall, J. M. 1996. Formation of soil aggregates and accumulation of soil organic matter. In M. R. Carter and B. A. Stewart, eds. Structure and organic matter storage in agricultural soils. Lewis Publishers, Boca Raton, FL. 57-96.

van Vliet, L. J. P. 1983. Soil degradation in British Columbia. B.C. Ministry of Agriculture and Food. Victoria, B.C.

VandenBygaart, A. J., E. G. Gregorich, and D. A. Angers. 2003. Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. Can. J. Soil Sci. 83: 363-380.

Vandermeer, J. 1995. The ecological basis of alternative agriculture. Annual Review of Ecology and Systematics 26: 201-224.

Verity, G. E. and D. W. Anderson. 1990. Soil erosion effects on soil quality and yield. Can. J. Soil Sci. 70: 471-484.

Wall, G. J., E. A. Pringle, G. A. Padbury, H. W. Rees, J. Tajek, L. J. P. van Vliet, C. T. Stushnoff, R. G. Eilers, and J. M. Cosette. 1995. Erosion. In D. F. Acton and L. J. Gregorish, eds. The Health of Our Soils: Toward Sustainable Agriculture in Canada. Ottawa: Supply and Services Canada. 61-76.

Wander, M. M., S. J. Traina, B. R. Stinner, and S. E. Peters. 1994. Organic and conventional management effects on biologically active soil organic matter pools. Soil Sci. Soc. Am. J. 58: 1130-1139.

Watson, C. A., D. Atkinson, P. Gosling, L. R. Jackson, and F. W. Rayns. 2002. Managing soil fertility in organic farming systems. Soil Use and Management 18: 239-247.

White, W. M. 1993. Dry aggregate distribution. In M. R. Carter, ed. Soil Sampling and Methods of Analysis. Lewis Publishers, Boca Raton, FL. 659-662.

Willick, B. 2004. Why I became an organic farmer. The Canadian Organic Grower. Fall 2004. 40-42.

Wischmeier, W. H. 1976. Use and misuse of the universal soil loss equation. J. Soil and Water Cons. 31: 5-9.

Wischmeier, W. H. and J. V. Mannering. 1969. Relation of soil properties to its erodibility. Soil Sci. Soc. Amer. Proc. 33: 131-137.

Woodward, C. A. and L.W. Chambers. 1980. Guide to questionnaire construction and question writing. Canadian Public Health Association. Ottawa, ON.

Wright, S. 2005. Glomalin: A manageable soil glue. USDA-ARS-Sustainable Agricultural Systems Lab. Beltsville, MD.

Zinck, J. A. and A. Farshad. 1995. Issues of sustainability and sustainable land management. Can. J. Soil Sci. 75: 407-412.

APPENDIX A

MAIL-OUT SURVEY

UNIVERSITY OF MANITOBA | Faculty of Agricultural and Food Sciences

Department of Plant Science
Winnipeg, Manitoba
Canada R3T 2N2
Telephone (204) 474-8221
Fax (204) 474-7528

Dear Farm Manager,

You have been selected to participate in a research project being carried out by the Faculty of Agricultural and Food Sciences, University of Manitoba. This questionnaire was written by Alison Nelson, a Master of Science candidate, under the guidance of Dr. Jane Froese, Assistant Professor of Farming Systems. The purpose of the project is to examine the risk of soil erosion on organic and conventional farms in various regions across Canada. The questionnaire will take approximately 45 minutes to complete. We understand that your time is valuable and appreciate your willingness to assist us in this research effort. A stamped envelope has been included for returning the questionnaire. Your participation is critical to the success of this project, and we have every hope that you will join us in this research effort. As partial compensation for your time, all questionnaire respondents will be entered into a draw for two $200 prizes (with an estimated 200 respondents, your chance would be 1 in 100 of winning).

The questionnaire is designed to be answered by the primary farm manager or someone with a thorough knowledge regarding the regular practices used on the farm. Your participation will help us understand current attitudes and practices pertaining to soil erosion in farming systems. Be assured that all responses will be kept confidential, and all identifying information will be removed prior to publication of results. Alison Nelson (as the principal researcher) will be the only individual with access to the information that is originally collected, and to identifying information. Once all the data has been analyzed, a report of the results will be mailed to all questionnaire respondents.

Funding for this research was generously provided by the Natural Sciences and Engineering Research Council (NSERC), and the Organic Agriculture Centre of Canada (OACC).

Attached to this letter is a consent form (in duplicate) to fulfill the requirements of the Joint-Faculty Research Ethics Board at the University of Manitoba. Please read and sign one copy to send back with the completed questionnaire.

Thank you for your time.

Sincerely,

Alison Nelson

Any questions or concerns can be directed to:

Alison Nelson
University of Manitoba
Winnipeg, MB R3T 2N2

Phone: (204) 474-6073
Fax: (204) 474-7528

.ca

www.umanitoba.ca/faculties/afs/plant_science/

UNIVERSITY OF MANITOBA | Faculty of Agricultural and Food Sciences

Department of Plant Science
Winnipeg, Manitoba
Canada R3T 2N2
Telephone (204) 474-8221
Fax (204) 474-7528

CONSENT FORM

Soil Erosion Risk and Mitigation through Crop Rotation in Organic and Conventional Cropping Systems

Researcher(s): Alison Nelson & Dr. Jane Froese

Sponsor: Natural Sciences and Engineering Research Council
Organic Agriculture Centre of Canada

This consent form, a copy of which is for your records, is only part of the process of informed consent. The brief description of the project (on the previous page) indicates what the research is about and what your participation will involve. If you would like more detail about anything pertaining to the research, please feel free to ask.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate. This does not waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to refrain from answering any questions without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

This research has been approved by the Joint-Faculty Research Ethics Board. If you have any concerns or complaints about this project you may contact Alison Nelson at 474-6073, or e-mail umnels06@cc.umanitoba.ca; Jane Froese at 474-6504, or e-mail jane_froese@umanitoba.ca; or the Human Ethics Secretariat at 474-7122, or e-mail margaret_bowman@umanitoba.ca.

Participant's Signature ______________________ Date____________

Researcher's Signature ______________________ Date Oct 7

(Sign and send one copy back with the survey, and keep the other copy for your records.)

A. Demographic Information

The following questions are intended to provide some information regarding your farm operation. For a field to be considered **organic,** it must be certified organic. If a field is not certified organic, it is considered **conventional.** The results from this section will identify the extent to which farm operations are organic or conventional. All information will be kept confidential.

1. Name: ____

2. Mailing Address (For mailing of questionnaire results. All answers are confidential.):

   ____

   ____

3. Farm location (RM, County, District, etc.):____________________________

4. How many acres do you farm? ____________ (pasture and cultivated acres.)
   a. How many acres are farmed **conventionally** (see above definition)?________
   b. How many acres are certified **organic** (see above definition)?________
   c. How many acres are in transition to organic?__________
   d. How many acres are managed organically, but are not certified (do not include fields that are in transition to organic)?__________

      Why is this acreage not certified organic? ____________________

      ____

      ____

5. Do you try to reduce your inputs on any part of the farm which is **NOT** managed organically? (Do not include certified organic fields, organically-managed fields and transitional fields.)

   ☐ Yes ☐ No

   a. What inputs are reduced?

      Pesticides -- [ ]
      Fertilizers -- [ ]
      Tillage-- [ ]

   b. By approximately how much have you reduced these inputs as compared to 10 years ago? (Assuming average weather conditions in a growing season.)

      Pesticides: ____________%
      Fertilizers: ____________%
      Tillage: ____________%

6. Do you have livestock on the farm?

   ☐ Yes ☐ No

   a. If YES, what kind(s) of animal operation(s) do you have, and how many animals?

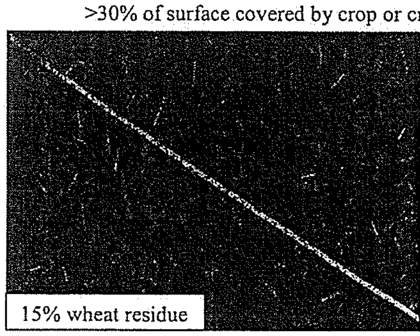
Animal Operation	Number of animals
____________________	__________
____________________	__________
____________________	__________
____________________	__________
____________________	__________

B. Soil Erosion Risk

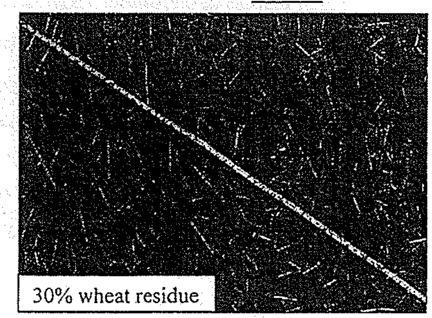
This section is intended to provide information regarding the soil erosion risk on organic and conventional farms. The following questions are about any practices you use on your farm to reduce soil erosion.

7. Tillage practices can be classified according to how much residue is left on the surface before winter and after spring seeding. Based on the amount of crop residue left on the surface at these 2 times of the year, what type of tillage practices are generally used on your farm? (Use the pictures below as a guide for choosing your tillage practice categories. Base your answers on the average weather you've experienced in the past 5 years.)
   a. **Before Winter** (after all tillage, seeding and harvest operations)
   <15% of surface covered by crop or crop residue ------ Area of Farm _______acres
   15-30% of surface covered by crop or crop residue----Area of Farm _______acres
   >30% of surface covered by crop or crop residue ------Area of Farm _______acres

   b. **Spring** (after seeding)
   <15% of surface covered by crop or crop residue ------Area of Farm _______acres
   15-30% of surface covered by crop or crop residue---- Area of Farm _______acres
   >30% of surface covered by crop or crop residue ------ Area of Farm _______acres



15% wheat residue



30% wheat residue

8. Do you belong to any organizations involved with soil conservation?
   ☐ Yes ☐ No
   a. If YES, please list the organization(s).________________________________

____

____

9. Do you currently have soil conservation practices on your farm?
   ☐ Yes ☐ No
   a. If NO, Do you have plans to implement soil conservation practices on your farm in the future?
      ☐ Yes ☐ No
      i. If YES, what do you plan to do? ______________________________

      ____

      ____

      ____

10. What practices and/or inputs are you currently using on your farm (in any field) that affect the risk of soil erosion? (Please check all that apply.)

Tillage

Reduced tillage --------------------------[ ]
Zone tillage ------------------------------[ ]
Ridge tillage -----------------------------[ ]
Contour tillage---------------------------[ ]
Zero/No tillage (direct seeding using low-disturbance seeding equipment) -[ ]

Direct seeding into stubble ------------[ ]
Blind tillage (post-seeding, pre-emergent tillage) -------------------[ ]
In-crop tillage (post-emergent tillage) -----------------[ ]

Soil Cover

Chemical summerfallow ---[ ]
Tillage summerfallow ---[ ]

Straw spreading ------------------------[ ]
Stubble burning ------------------------[ ]
Permanent grass cover (do not include pasture) ----------------------------------[ ]

Fertility

Apply industrial fertilizers-------------[ ]
Apply manure ---------------------------[ ]

Apply compost -------------------------[ ]

Seeding

Underseeding----------------------------[ ]
Strip cropping --------------------------[ ]
Narrower row spacing* ----------------[ ]

Increased seeding rate* ----------------[ ]
Delayed seeding* -----------------------[ ]
Early seeding*---------------------------[ ]

*Relative to the average practice in your area.

Weed Control

Mechanical or hand-weeding ---------[ ]

Herbicides-------------------------------[ ]

Crop Rotation

Crop rotation that includes forage crops------------------------------[ ]
Crop rotation that includes solid-seeded crops ----------------------[ ]

Crop rotation that includes row crops -------------------------------------[ ]
Winter cover crops---------------------[ ]
Green manure for plough-down --[ ]

Other Pracitces

Shelterbelts/Windbreaks ---------------[ ]
Grassed waterways --------------------[ ]
Water diversion terracing --------------[ ]
Other practices
____________________ -----------[ ]

____________________ -----------[ ]
____________________ -----------[ ]
____________________ -----------[ ]
____________________ -----------[ ]
____________________ -----------[ ]

11. Evidence of soil erosion can often be seen in the field. This question is intended to obtain information about soil erosion potential in all farmed areas on the farm. For the purpose of this questionnaire, soil erosion is divided into 3 categories: Rill & Gully, Sheet, and Wind erosion. Each erosion category is further divided into degrees of severity (from no erosion to severe). For each of the 3 categories, please consider all areas on your farm (whether they are managed organically or conventionally) and mark the acreage that matches the various degrees of erosion severity. (Fields may have areas with different degrees of erosion severity.) **When you are finished, all farmed acres of your farm should be represented in <u>each</u> of the 3 categories.**

*For Category 1 and Category 3, the evidence of erosion will vary depending on the weather conditions. Please base your answers on the average of what you've experienced in the past 5 years.[1]

Category 1	***Rill erosion**** *(small channels that equipment can pass over)* ***& Gully erosion**** *(large channels equipment cannot pass over)*	# of Acres Managed Organically (Certified, Transitional or Non-Certified)	# of Acres Managed Conventionally
a	No rill/gully erosion visible **OR** structures to prevent rills/gullies		
b	Rill erosion visible & no structures to control erosion		
c	Rill & some gully erosion visible & no structures to control erosion		
d	Gully erosion visible & no structures to control erosion		

Category 2	***Sheet erosion*** *(soil is removed in a uniform layer by wind and water)*		
a	Slope & knoll soil is similar colour as rest of field & crop growth & yield uniform through field		
b	Slope & knoll soil is similar colour as rest of field & crop growth or yield is slightly different in areas		
c	Slope & knoll soil is lighter colour than rest of field & crop height, stand & yield is reduced in areas of field		
d	Slope & knoll soil is lighter colour than rest of field & crop height, stand & yield is very reduced on large areas of field		

Category 3	***Wind erosion****		
a	No visible evidence of wind erosion		
b	Light soil drifting is visible in windy conditions		
c	Heavy clouds of soil are visible in windy conditions		

[1] This question was adapted from questions 3 & 4, Worksheet #15 of the Ontario Environmental Farm Plan Workbook, First Edition (1993), © Ontario Farm Environmental Coalition.

C. Field History

The following section is intended to obtain information about crop rotations and tillage practices for a specific field on your farm. Please answer the questions for only **one field**. If your farm has fields that are certified organic, please refer to the field that has been certified organic for the longest period of time. If your entire farm has conventionally cropped fields, please refer to a typical field on your farm (a field that most accurately represents the practices used on your farm). Your selected field will be called **Field 1** throughout the rest of the questionnaire.

Field 1:

The next five pages have questions regarding your selected field (**Field 1**). Please answer all questions for that field.

12. What is the legal land description of the field?________________________

    a. Number of acres:______________

    b. Is this field:

    Conventionally managed-------------------------- [ ]

    Certified organic ----------------------------------- [ ]

    How many years has the field been certified organic? ____________

    In transition to organic ---------------------------- [ ]

    Managed organically, but not certified ---------- [ ]

Crop rotation on Field 1:

13. Please fill in all the information you can about the crop rotation used on **Field 1** starting with the field season of 1999. Please include in the table any underseeded crops, cover crops, summerfallow, green manure, etc.

			Time of Planting	
Year	**Crop**	**Variety**	**Fall** (of previous year)	**Spring**
1999				
2000				
2001				
2002				
2003				

14. Do you have a planned/base rotation?

☐ Yes ☐ No

a. If YES, is your planned/base rotation represented in the above table?

☐ Yes ☐ No

If NO, what is your rotation? ______________________

15. How committed are you to maintaining the current rotation?

☐ **Very committed** ☐ **Somewhat committed** ☐ **Not committed**

a. If "Somewhat committed" or "Not committed", what has made you change a planned rotation in the past? (Please check all that apply)

Marketing reasons/crop prices---------------[ ]
Weed populations/pressure-------------------[ ]
Change of equipment ------------------------[ ]
Weather conditions---------------------------[ ]
Disease pressure -----------------------------[ ]
Other
______________________ ---------------[ ]
______________________ ---------------[ ]
______________________ ---------------[ ]

Tillage History on Field 1:

16. Please fill in all the information you can on the table below regarding tillage on **Field 1**, starting January 1, 1999. Multiple passes of the same implement in a year may be grouped together in the table. However, **tillage operations carried out with different equipment or for different purposes should be recorded in separate rows.** (Table is continued on next page if additional space is required.)

		Timing of Tillage Operation Place an X in the column matching the timing of tillage operation. (if multiple passes, please indicate # of passes)							
Year	**Crop**	Prior to Seeding	Seeding	Pre-Emergent	In-Crop	Post-Harvest	**Tillage Equipment** (use number codes at bottom)	**Depth of tillage** (in inches)	**Purpose of Tillage Operation** (use letter codes at bottom)
e.g., 1999	*Barley (spring)*	X *(2 passes)*					*4*	*5"*	*A & D*
1999	*Barley*		X				*16*	*2½"*	*C*
"	"			X			*19*	*1"*	*D*
"	"					X	*11*	*6"*	*F*
									Cont'd on next page

Tillage Equipment Codes

1....Wide blade cultivator (36" blades)
2....Rod weeder
3....Field cultivator (9-12" sweeps)
4....Field cultivator with harrows
5....Heavy duty cultivator/Chisel plow (16-18" sweeps)
6....Heavy duty cultivator/Chisel plow with rodweeder
7....Heavy duty cultivator/Chisel plow with harrows
8....Soil saver
9....Tandem disc-offset disc
10..Discer seeder
11..Moldboard plow
12.......Disc drill
13.......Hoe drill
14.......Planter
15.......Air seeder, shovel openers
16.......Air seeder, knife openers
17.......Air seeder, harrows/packers
18.......Fertilizer injector
19.......Harrows
20.......Coil packer
21.......Tine harrows and packer
22.......Rotary hoe
23.......Other (please specify in chart)

Purpose of Tillage Operation Codes

A ....Soil loosening
B.....Seedbed preparation
C.....Seeding
D ....Weed control
E.....Incorporation of product (e.g. fertilizer, pesticides, etc.)
F.....Stubble cultivation/Residue management
G ....Other (please specify in chart)

Tillage History on Field 1 (cont'd):

		Timing of Tillage Operation Place an X in the column matching the timing of tillage operation. (if multiple passes, please indicate # of passes)							
Year	Crop	Prior to Seeding	Seeding	Pre-Emergent	In-Crop	Post-Harvest	Tillage Equipment (use number codes at bottom)	Depth of tillage (in inches)	Purpose of Tillage Operation (use letter codes at bottom)

Tillage Equipment Codes

1....Wide blade cultivator (36" blades)
2....Rod weeder
3....Field cultivator (9-12" sweeps)
4....Field cultivator with harrows
5....Heavy duty cultivator/Chisel plow (16-18" sweeps)
6....Heavy duty cultivator/Chisel plow with rodweeder
7....Heavy duty cultivator/Chisel plow with harrows
8....Soil saver
9....Tandem disc-offset disc
10..Discer seeder
11..Moldboard plow
12.......Disc drill
13.......Hoe drill
14.......Planter
15.......Air seeder, shovel openers
16.......Air seeder, knife openers
17.......Air seeder, harrows/packers
18.......Fertilizer injector
19.......Harrows
20.......Coil packer
21.......Tine harrows and packer
22.......Rotary hoe
23.......Other (please specify in chart)

Purpose of Tillage Operation Codes

A ....Soil loosening
B.....Seedbed preparation
C.....Seeding
D ....Weed control
E.....Incorporation of product (e.g. fertilizer, pesticides, etc.)
F .....Stubble cultivation/Residue management
G.....Other (please specify in chart)

D. Opinions/Attitudes:

This final section is designed to gain knowledge of the opinions and attitudes Canadian farmers have regarding soil conservation and organic farming. For the following sentences, circle the number that best represents the extent to which you agree or disagree with the sentence.

17. I believe soil erosion is a major problem in Canadian agriculture.

Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

18. Water erosion is a problem on my farm.

Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

19. Wind erosion is a problem on my farm.

Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

20. I believe that individual farmers should be responsible for soil conservation on their farm.

Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

21. It is possible to lower the amount of tillage used on my farm.

Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

22. I would be willing to spend money on soil conservation technologies.

Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

23. I would be willing to spend time learning/implementing soil conservation technologies.

Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

24. Organic farmers rely more heavily on tillage than conventional farmers.

Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

25. Conventional farmers rely more heavily on tillage than organic farmers.

Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

26. I believe that organic farming is more environmentally-friendly than conventional farming overall.

Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

27. I believe that conventional farming is more environmentally-friendly than organic farming overall.

Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

28. I choose crop rotations to reduce/prevent pest problems.

Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

29. Please rank the importance of the following factors for determining success of your farm. Circle the number that best represents the extent to which you feel these factors are important:

a. Minimize ecological damage
   Not important 1 2 3 4 5 6 7 Extremely important

b. Maximize profitability of the farm
   Not important 1 2 3 4 5 6 7 Extremely important

c. Minimize input costs
   Not important 1 2 3 4 5 6 7 Extremely important

d. Maximize yields
   Not important 1 2 3 4 5 6 7 Extremely important

e. Maximize crop quality
   Not important 1 2 3 4 5 6 7 Extremely important

f. Ability to have farm/rural lifestyle
   Not important 1 2 3 4 5 6 7 Extremely important

30. Please answer this question only if you have **certified organic fields.** Rank the importance of the following factors for deciding to **farm organically**. Circle the number that best represents the extent to which you feel these factors are important:

a. Personal/Family safety & health
   Not important 1 2 3 4 5 6 7 Extremely important

b. Environmental concerns
   Not important 1 2 3 4 5 6 7 Extremely important

c. Organic price premiums
   Not important 1 2 3 4 5 6 7 Extremely important

d. Independence from input companies
   Not important 1 2 3 4 5 6 7 Extremely important

e. Desire to produce healthy food
   Not important 1 2 3 4 5 6 7 Extremely important

f. Organic philosophy (lifestyle)
   Not important 1 2 3 4 5 6 7 Extremely important

31. When making decisions regarding farm practices profitability and environmental impact are important concerns. To indicate how each of these concerns factor into decisions you make, please circle the number that best represents the extent to which you consider both elements on average. (0 would be 100% concerned with profitability, 10 would be 100% concerned with environmental impact, 5 would be equally concerned with profitability and environmental impact.)

Profitability 0 1 2 3 4 5 6 7 8 9 10 Environmental Impact

32. The space below is provided for your comments, if any, on this questionnaire.

____

____

____

____

That is the end of the questionnaire. Thank you for taking the time to complete it.

In addition to the mail-out questionnaire, this research project involves an on-farm experimental component. This on-farm component is necessary because we cannot replicate the wide variety of conditions and practices in Canadian agriculture on our field station or laboratories. The experimental component involves Alison Nelson (the graduate student) taking soil samples from participating fields to determine soil erosion risk. Participating farmers would receive a free soil analysis report detailing organic matter levels, texture and aggregate stability. This portion of the research project would involve a one-hour, in-person interview with Alison Nelson in the spring of 2004. As well, farmers participating in the experimental component of the research would be given a disposable camera to take ground cover pictures of portions of the field at 4 times during the growing season. If you would consider participating in the second portion of this research project, please check the box below.

☐ YES, I would consider participating in the second portion of the research project.

Name: ____

Address: ____

____

Phone #: ____

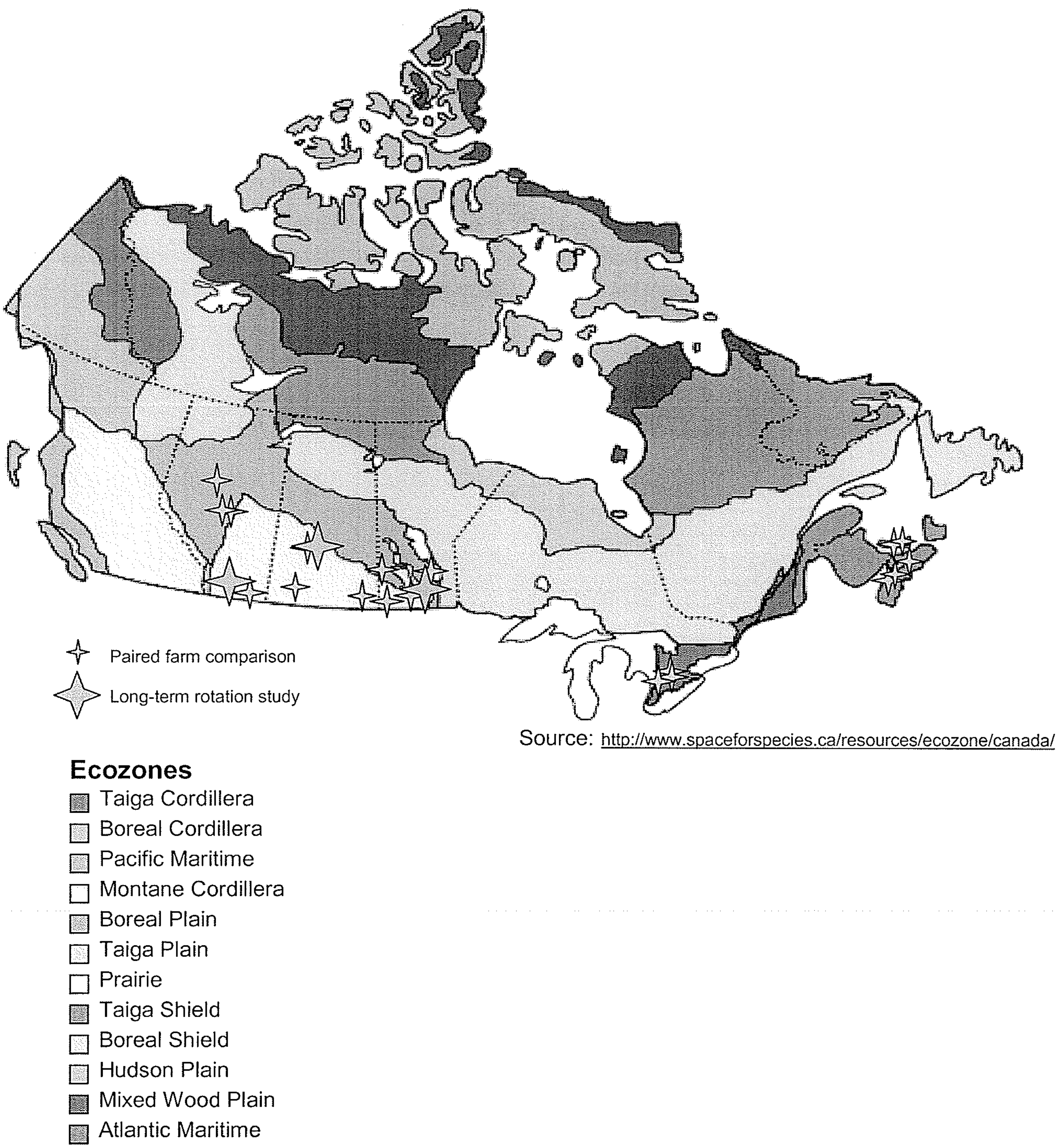
Thank you for completing the questionnaire. We ask that you return it to the address below at your earliest convenience:

Alison Nelson
Department of Plant Science
University of Manitoba
Winnipeg, MB R3T 2N2

APPENDIX B

MAP OF SAMPLING SITES – LONG-TERM STUDIES AND FARM PAIRS

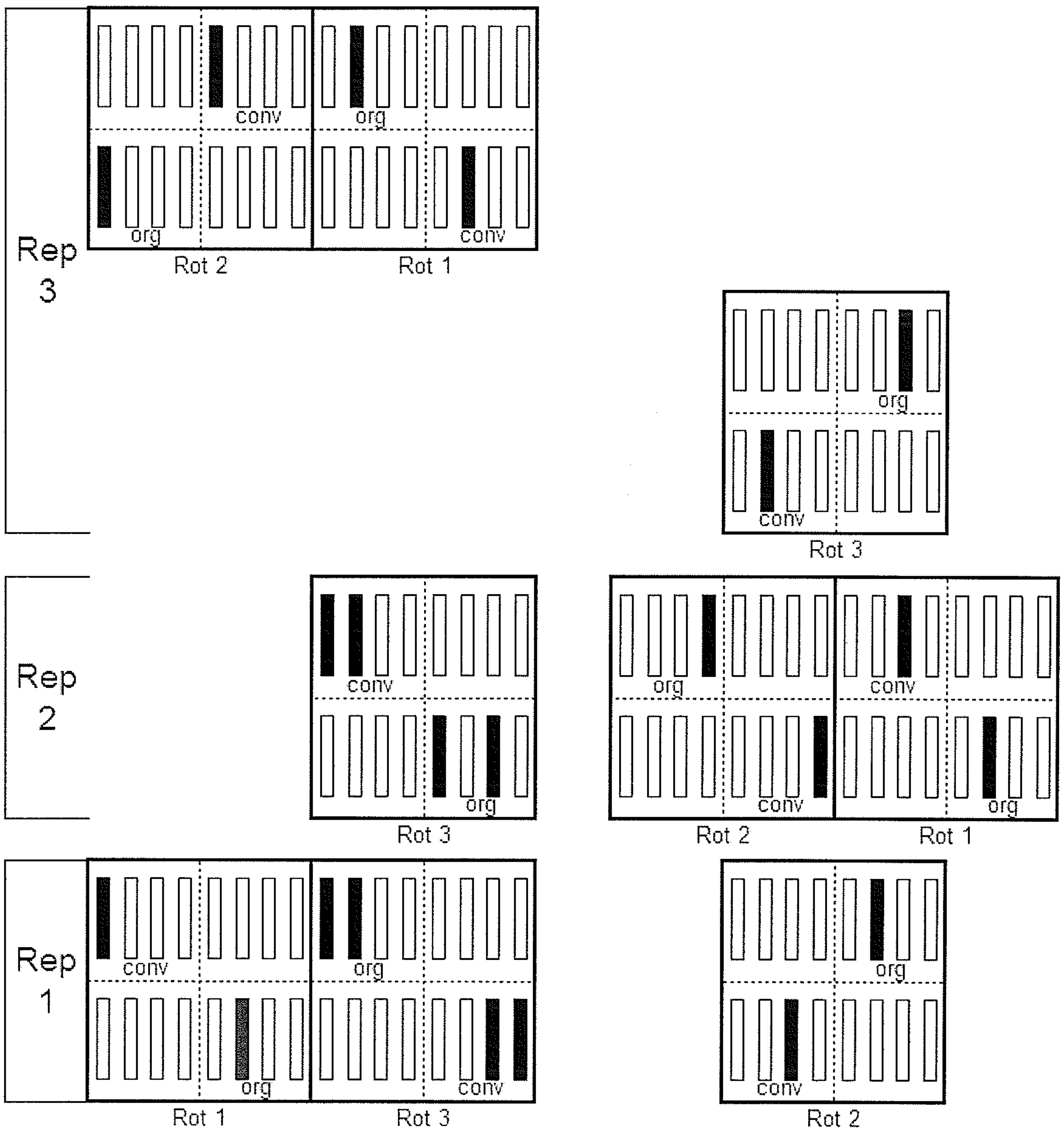
Figure 4-1: Map of sampling sites for the long-term studies and paired organic and conventional farms



APPENDIX C

PLOT PLANS FOR LONG-TERM STUDIES

Figure 4-2: Plot plan for the Glenlea Long-Term Crop Rotation Study

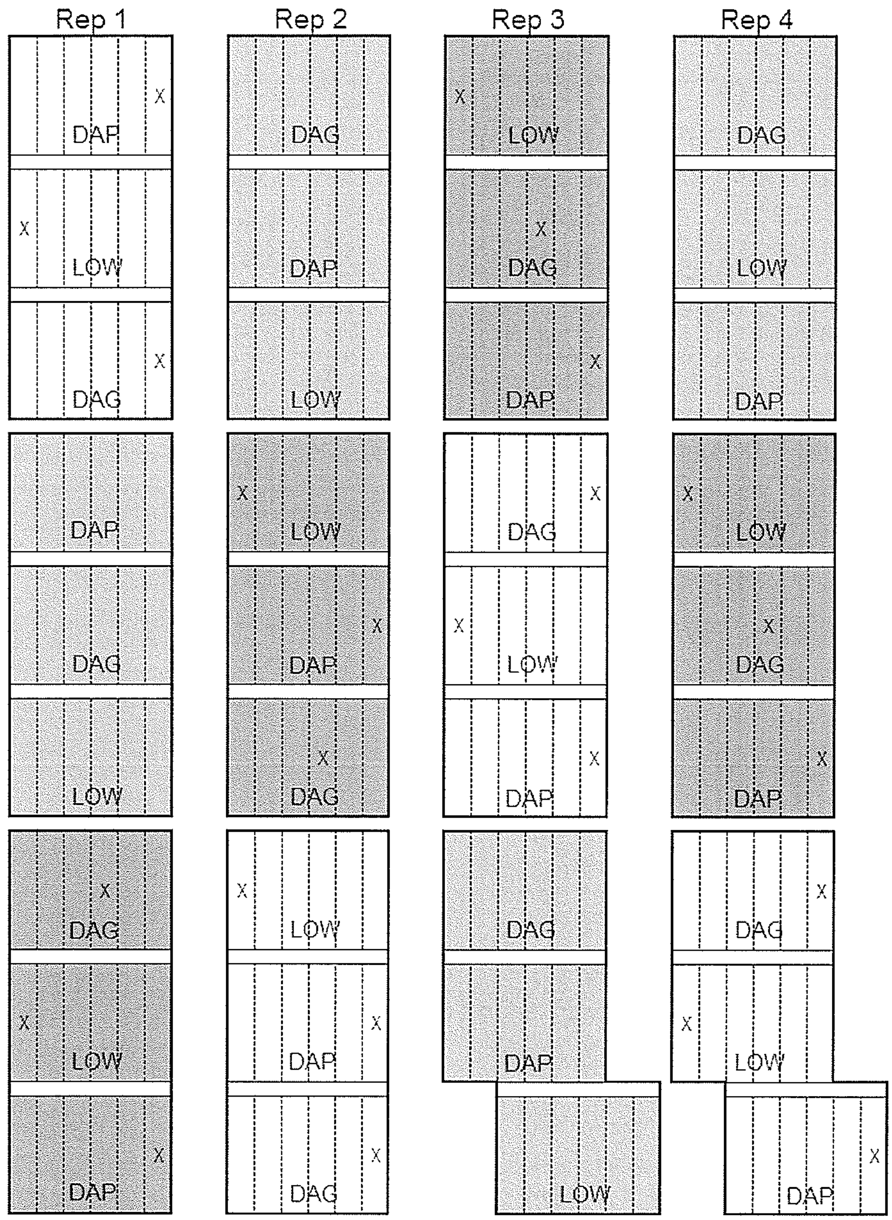


There are three, four-year rotations in the study. Each square outlined in bold outlines the main plots, the dotted lines show the division of the subplots, and the rectangles within are the sub-subplots. The sub-subplots that are filled were sampled from.

The three rotations are as follows:	Rotation 1	wheat-pea-wheat (oats, rye)-flax (oats)
	Rotation 2	wheat-red clover-wheat (oats, rye)-flax (oats)
	Rotation 3	wheat-alfalfa-alfalfa-flax (oats)

(Crops in brackets are new crops within the last rotation cycle in the sub-subplots.)

Figure 4-3: Plot plan for the Scott Alternative Cropping Systems Trial



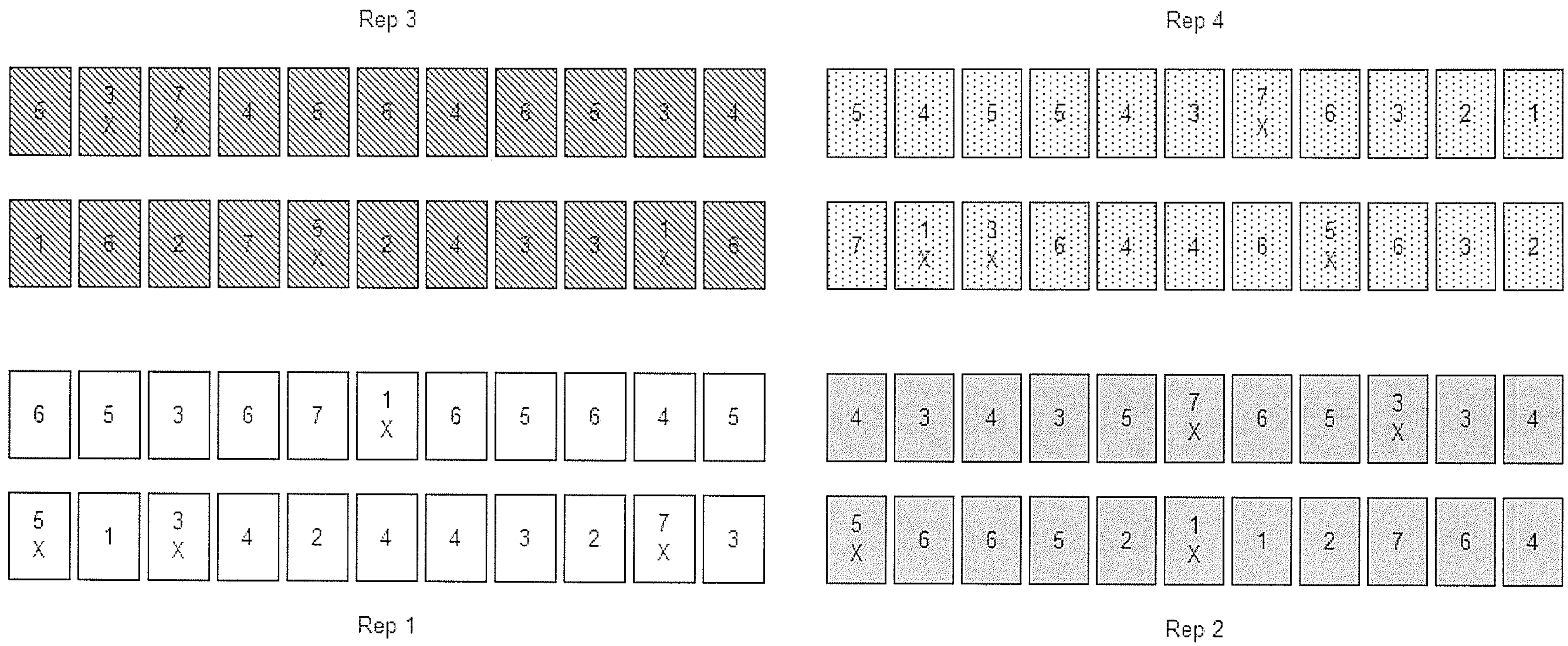
Organic
Reduced
High

The LOW and DAG rotations were slightly different for the organic and high input management systems. The subplots sampled from are marked with an X. The main plots are outlined in bold, the subplots with rotation are identified, and the rotation phases are separated by dotted lines

The rotations sampled from are:		
	Org. LOW	green manure (GM)-wheat-wheat-GM-mustard-wheat
	Conv. LOW	fallow-wheat-wheat-fallow-canola-wheat
	Org. DAG	GM-wheat-pea-barley-GM-mustard
	Conv. DAG	canola-winter cereal-pea-barley-flax-wheat
	Org. DAP	oilseed-cereal-cereal-forage-forage-forage
	Conv. DAP	oilseed-cereal-cereal-forage-forage-forage

LOW = low diversity rotation
DAG = Diverse annual grains
DAP = Diversified annual and perennial

Figure 4-4: Plot plan for the Lethbridge Low Input Agriculture Trial



There are 7 rotations, the plots are fully phased. Three of the rotations are two year rotations, the others are four year rotations, so 22 plots appear in each rep. Each square on the above map represents a plot, the numbers indicate the rotation treatment of each plot. The plots marked with an X are plots sampled from last year.

The 4 rotations sampled from are as follows:

Organic	Rotation 1	wheat/sweet clover-sweet clover plowdown (PD)
Organic	Rotation 3	sweet clover PD-wheat-field peas-linola/sweet clover
Organic	Rotation 5	winter triticale/red clover-linola-wheat (manure)-barley/red clover
	Rotation 7	continuous wheat