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

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

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

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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	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 phase						
Rotation	Management	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