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Prairie Agricultural Landscapes

A Land Resource Review

Canada

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Prairie Agricultural Landscapes

A Land Resource Review

Compiled by:

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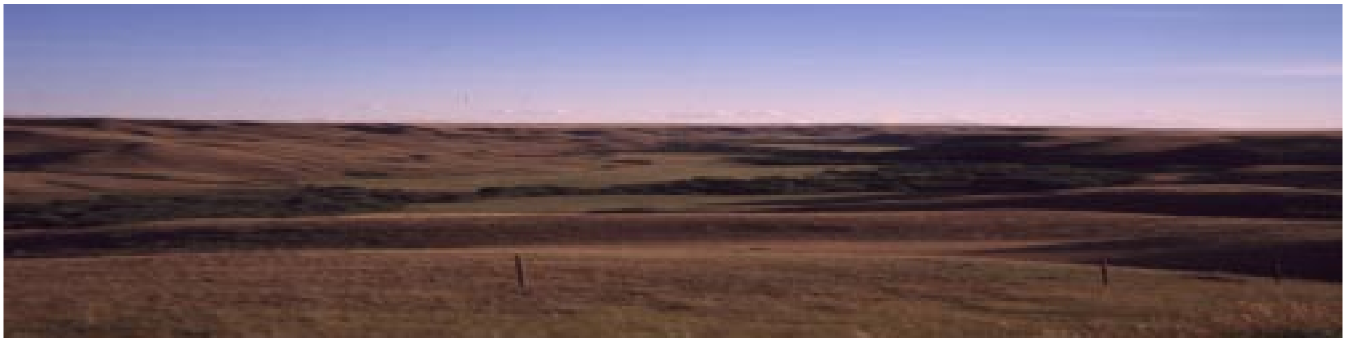

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Cal Straub, Director, Technical Service
Bernie Ward, Director, Analytical and Communications Service
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-- Dr. Bernie Sonntag,
Director General, PFRA

Photo by Dave Reede

Executive Summary

Background

The Prairie Agricultural Landscapes (PAL) study is designed to help focus and direct the Prairie Farm Rehabilitation Administration's (PFRA) future programs and activities centred on sustainable land use, specifically in the area of healthy and productive agricultural lands.

Resource conservation and economic viability are paramount to the long-term prosperity of the agriculture industry and rural areas of the Prairie provinces. Economic factors are the dominant forces driving change on the Prairie agricultural landscape and will spur the growth in demand for primary and processed goods.

The Canadian Agri-Food Marketing Council (CAMC) has set an ambitious target for the agricultural industry. CAMC has challenged primary producers, processors and governments to significantly increase Canadian agriculture and agri-food exports to 4% of the global agri-food market share by the year 2005. The target is comprised of approximately 40% primary production and 60% processed goods.

Much of the primary production growth needed to meet the CAMC trade target is expected to come from the Prairies, which comprise more than 80% of Canada's agricultural land base. The increase in production and processing of goods in the Prairie region will pose numerous challenges for the sustainable management of the resource base.

The land base required to meet these targets is forecast to come from improved crop management, increased cropping intensity, reduction of summerfallow and increased pressure to cultivate environmentally sensitive lands. The implications of these changes in the agriculture and agri-food industry must be evaluated from economical, sociological and environmental perspectives.

State of Land and Water Resources

SOIL EROSION

Soil erosion causes redistribution of soil in the landscape due to the action of wind, water and tillage. Much of the Prairies are affected by all three agents of erosion. The effects deplete the soil's capacity to grow crops, increase soil and crop yield variability within fields and cause environmental impacts such as reduced water and air quality.

The effects of erosion on crop yields and soil productivity are substantial. Erosion removes the soil fractions which contribute to nutrient availability and help maintain a good physical environment for plant growth. Severe loss of soil reduces the rooting volume available to plants, further depleting nutrient and water availability.

Better crop residue management through direct seeding has substantially reduced, but not eliminated the risk of erosion. PFRA has determined that more than 50% of annually cropped fields are exposed to erosion each year on the Prairies. The reduction of fall tillage and summerfallow and the adoption of direct seeding systems, have decreased the period during which soils are exposed to a high erosion risk. However, there remains ample opportunity for erosion to occur. Severe and widespread erosion can take place during extreme weather events (high winds and heavy rains), and particularly during years of consecutive droughts.

Universal adoption of reduced tillage and low disturbance seeding systems will not eliminate soil erosion. Soils will still be exposed to high erosion risk after low residue crops, drought, disease, fire, or excessive straw harvesting. Permanent soil conservation practices are required to supplement crop residue management systems. Further work is needed to identify areas which are unsuitable for annual crop production and those areas that should be protected with perennial forages or windbreaks.

SALINITY

Saline soils contain sufficient soluble salts in the root zone to hinder the growth of most crop plants. Soil salinity can also reduce the moisture extracting capability of plants. The net effect depends upon a number of factors, including soil texture, plant species and variety and proximity of the root zone to water sources. Other non-crop effects involve mired machinery, loss of fertilizer inputs and inefficiencies from farming fragmented fields.

Historic salinity arises from geologic and long-term climatic conditions, whereas *saline seeps* are believed to be primarily due to post-settlement factors such as the breaking of the Canadian Prairies and ongoing summerfallow practices. When the water table approaches the soil surface, evapotranspiration can concentrate soil salts at or near the surface.

Cropping for salinity control is far from a precise science. Practices that reduce the accumulation of excessive soil moisture may help to curtail or control salinity. These include cropping strategies within saline lands themselves or on upslope groundwater recharge areas. Lowering the groundwater table within the saline area itself is the ultimate objective.

Satellite imagery and aerial photography have commonly been used to visually map salinity. More precise ground survey techniques are also employed. The total extent of moderate-to-severe salinity on the Prairies (resulting in a 50% reduction in productivity) is estimated at 1.4 million hectares. An additional 10 million hectares may be slightly salinized.

Saline soils should be managed according to their salt content. To be effective, conservation practices applied and crops grown must reflect the history, current salinity status and productive potential of the land.

ORGANIC MATTER

Soil Organic Matter (SOM) is a vital component of the soil fabric, responsible for improving soil structure, tilth, fertility and health. Soils are able to store organic carbon and thus provide a sink for atmospheric carbon. SOM in Prairie soils dominates national accounts of SOM, and could play an important role offsetting greenhouse gas emissions through carbon sequestration.

The concentration and mass of organic matter in soil is extremely sensitive to soil management practices. Recent estimates suggest that 14-40% of the Soil Organic Carbon (SOC) originally in the Canadian Prairies soils has been lost since cultivation began. The time required to recover SOM concentrations to approach those of pre-cultivation lands is estimated at more than 75 years in the Brown soil zone, and more than 150 years in the Black soil zone.

Practices that maximize the addition of organic residues, or minimize the rate of organic matter decay and erosion, will be most effective in maintaining SOC. Such practices include growth of perennial crops, minimizing soil disturbance, reducing the frequency of fallowing, returning crop residues to the soil and maximizing crop productivity by including legumes in rotations and increasing fertilizer use efficiency.

WATER QUALITY

Water quality is vital to the health of all living organisms, from fish and aquatic insects, to wildlife and humans. Water quality varies greatly in the streams, lakes, rivers and groundwaters of the Prairies, reflecting the region's many landscapes and land uses.

Agricultural development on the Prairies has resulted in widespread land clearing and drainage, soil erosion, water withdrawals, livestock concentration areas, land application of manure and inorganic fertilizer and the use of pesticides. There is increasing recognition that these developments have had a similarly widespread and adverse effect on water quality. Agricultural sources of water contamination include:

- runoff from fields to which fertilizers, pesticides and manure are applied
- runoff and wastewater from livestock operations
- leaching of land-applied contaminants to groundwater.

Across the Canadian Prairies, the ecological and health-related impacts of agriculture on water quality have generally not been studied. However, in some areas of the Prairies, agricultural activities have had significant localized effects, resulting in water quality guidelines being exceeded. While the overall significance of agriculture's impact on water quality across the Prairies is not well understood, it is generally accepted that the greater the level of agricultural intensity in an area, the greater the risk to ground and surface water quality. This is significant in light of the desire for expansion and intensification of agricultural production across the Prairies.

RIPARIAN AREAS

Riparian areas are transitional ecosystems between land and water environments. These corridors are characterized by lush vegetation bordering rivers, creeks, streams and wetlands. The health of a riparian area rests on its ability to maintain its overall structure in a dynamic setting, and to perform a number of important ecological functions. Riparian areas provide fish and wildlife habitat, dissipate stream energy, filter sediments and nutrients, stabilize streambanks, store water and contribute to aquifer recharge, and provide lush vegetation amenable to livestock grazing.

Although riparian areas account for less than 5% of the Prairie landscape, they provide essential habitat for the majority of the region's wildlife species and are important sources of biological diversity. Riparian areas can be negatively affected by agricultural activities both within and adjacent to the riparian zone.

Assessment tools have been developed to measure riparian health; however, to date no Prairie-wide assessments have been conducted. Studies at selected sites in Saskatchewan and Alberta have revealed that agriculture has contributed to reduced riparian function and capability. Similar extensive studies have not been reported for Manitoba, although qualitative assessments have been carried out on several watersheds in the province.

Riparian areas provide essential habitat for Prairie wildlife species and are important sources of biological diversity.

RANGELAND AND SEEDED FORAGES

There are 23 million hectares of native rangeland and seeded forages dedicated to livestock production in the Prairie provinces. To date, few formal assessments or inventories of the condition of these lands have been done.

To obtain an estimate of rangeland condition, PFRA surveyed professionals knowledgeable in rangeland assessment. The survey found that more than half of Prairie rangeland is in less than good condition, with some areas reporting over three-quarters of the land in less than good condition.

Overall condition could be significantly improved through the implementation of planned grazing systems, combined with proven range management techniques. Such a shift in range management would increase production, reduce erosion potential, create wildlife habitat, and replenish deteriorated soil carbon levels.

Land Use and Farming Systems

To remain successful, Prairie producers adjusted to different climates and soil types, and to changing markets, technology and transportation systems. The relationship between current land use and farming practices in the many Prairie landscapes can be used to evaluate the potential of these landscapes to adapt to future economic and environmental scenarios.

The opportunities for agricultural systems to change are limited by landscape characteristics.

Photo by Dave Reede

It has long been understood that agricultural land use is related to landscape characteristics, and further, that the opportunity and ability of agricultural systems to change is limited by landscape. In the PAL study, areas with similar agricultural practices and land uses were grouped together. Then the soil and landscape types found within each group were characterized. This approach identified the range of landscapes which can support a given set of farming practices.

These Land Practices Groups were defined using a statistical analysis of the 1996 Census of Agriculture compiled by Soil Landscape of Canada (SLC) polygons. Distinctive soil landscape types from the SLC data were developed and the proportion of these landscapes in each Land Practices Group was determined. The combination of soils and land use helped relate the specific SLC polygon to the issues described in the State of Land and Water Resources section of this report.

LAND PRACTICES GROUP DESCRIPTIONS

Dominantly Pasture

Two Land Practices Groups (differentiated by farm size) were identified as *Dominantly Pasture* with greater than 70% of the agricultural land used for grazing and forage. These areas are located in the drier areas and along the geographical limits of agriculture and contain mostly marginal land for cultivation. These groups are very important areas of natural biological diversity. Nearly three quarters (71%) of farmland in the *Dominantly Pasture, very large farms* (average farm size greater than 540 ha) group was in native vegetation in 1996, representing one-fifth of all native vegetation in the agricultural lands of the Prairies. The *Dominantly Pasture, small to large farms* has more managed hay and pasture.

Majority Pasture

Almost 20% of Prairie agricultural land is in the two *Majority Pasture* groups that have 40-70%

of the agricultural land in pasture and hay. There is a wide range in the intensity of crop inputs between the two groups. The *Majority Pasture, low level of crop inputs* group, which is generally found in drier areas and in the cooler wetter areas along the margin of cultivation. The *Majority Pasture, high level of crop inputs* which are found associated with areas of higher productivity.

Majority Cultivated, High Summerfallow

Three Land Practices Groups were identified as *Majority Cultivated , high summerfallow*. Located in the Brown and Dark Brown soils zones, they have summerfallow areas greater than 25% of cultivated land. These three groups are distinguished by the level of crop diversity.

The *Majority Cultivated, high summerfallow with pulses* group is in the more productive areas of the Dark Brown soils between Rosetown and Saskatoon, and Brown soils such as those near Swift Current. A quarter of the farms in this group grew lentils, comprising a significant portion of the 6% pulses. Another 6% of the land was cropped to oilseeds that included canola and mustard. The *Majority Cultivated, high summerfallow with oilseeds* group is found almost exclusively in the Dark Brown soils in Alberta near Drumheller, Vulcan and Warner, and in Saskatchewan near Unity, Davidson and Estevan. Most of the non-cereal annual crop production on these farms is canola or mustard seed.

The *Majority Cultivated, high summerfallow, low crop inputs and low crop diversity* group is almost exclusively in the Brown soil zone, and has traditionally been the wheat-fallow land of southern Saskatchewan and southeastern Alberta.

Majority Cultivated, with Flax

The *Majority cultivated, with flax* groups had a significant component of flax in the crop mix. The most diverse and intensive cropping on the Prairies occurs in the *Majority cultivated, very low summerfallow, very low pasture, and high crop diversity* group, which contains some of the most productive lands on the Prairies. This group had the lowest percentage of land in forages, and lowest number of cattle per farm on the Prairies.

The *Majority cultivated, very low summerfallow, medium to low pasture and high crop diversity* group is mainly found in Manitoba, on the more variable soils that surround the previous group.

The uniform Black till plain of east central Saskatchewan around the Indian Head area, is a good example of the *Majority cultivated, medium summerfallow with flax* group. Two-thirds of the farms with cropland reported summerfallow, a higher proportion than in other groups on similar soils.

Majority Cultivated, Low Summerfallow

The three *Majority cultivated, low summerfallow* groups have summerfallow less than 25% and were distinguished by crop mix. The *Majority cultivated, low summerfallow with very high oilseeds* group is almost exclusively confined to the Peace River district, and consists mainly of level or nearly level Dark Gray and Gray soils. The amount of land in oilseeds (32%) in 1996 exceeded the recommended rotation guidelines of one in four years.

The *Majority cultivated, low summerfallow with pulses* group is one of the largest groups, and is found in the moister areas of the Prairies. Annual cropping in this group is highly diversified, with oilseeds and pulses being significant components of the cropping system.

The *Majority cultivated, low summerfallow with cereals and oilseeds* group are dominantly in the Black soil zone and represent the typical Prairie farmland. Annual cropping in this group is primarily cereals and oilseeds. This group had the highest cattle numbers per farm of all the majority cultivation groups, suggesting that diversification to livestock has been more common than diversification of cropping.

The identification of Land Practices Groups provides a basis to predict changes in cropping, grazing and hay production over the Prairies. Each of the groups will behave differently to the changing pressures due to commodity prices, market opportunities, transportation changes, technological advances and environmental concerns. The Land Practices Groups can be used to identify where changing agricultural practices may present conditions that may negatively impact the agricultural land resource.

Issues Facing Management of Land Resources

Issues likely to affect changes in land management can be divided into four main categories. These categories are governed primarily according to public, environmental, community, and on-Farm considerations. Individual issues will be affected by a specific set of drivers.

Public Level Issues include those of policy and legislation, as well as international agreements. Tremendous pressure will be applied to the soil and water resource base to meet CAMC-style export targets, while at the same time seeking to reduce greenhouse gas emissions, and conserve natural biodiversity and wildlife habitat within farming systems.


Photo by Dave Reede

CAMC's growth targets require a shift in Canada's exports away from primary bulk commodities towards more processed products.

Environmental Issues encompass the public perception of agriculture; the need for abundant safe water, air and food; and the ability to cope with natural variability in such things as weather and pest cycles. Agriculture must clarify its actions and become more accountable in the public mind, while sustaining sensitive lands and reducing its effects on the environment. All of this must be balanced against the economic necessity that farmers face to hedge against significant crop loss and market forces.

Community Level Issues relate to demographic change, competing land use, rural infrastructure, and requirements for transportation and off-farm employment. There is little incentive for aging Prairie farmers to expand their land base. An increasingly educated rural labour pool will demand higher salaries. Rural communities will continue to decrease in size and number. Land use conflicts between rural residential and farming interests will increase. Expansion and improvement of existing production and processing facilities is required. Opportunities for off-farm employment will be critical to most farmers.

On-Farm Issues include a producer's ability to take risk, management of inputs and outputs, land tenure, and technological advances. Limited personal experience with highly variable soil and weather conditions, in tandem with restricted access to capital, will tend to favour the status quo in land management. Producers will seek to reduce inputs and associated costs where they can, while placing more emphasis on health and safety factors.

Sole proprietorship continues to decline across the Prairies. Short-term cash rental agreements will tend to discourage a stewardship approach to land management. Biotechnology will cause multi-national corporations to gain greater control over on-farm inputs. Farmer up-take of biotechnology may be slowed due to public concern over transgenic products. In the short term, precision farming technology will be confined to large scale operations and custom applicators.

Prairie Agricultural Landscapes - A Land Resource Review, includes a unique regional analysis to the array of resource assessments performed on the Prairie region over the past two decades. A second document, *Prairie Agricultural Landscapes: Foundations for Growth*, identifies opportunities for growth and impacts of agricultural expansion on land resources. Approaches to ensure sustainable development in the future are identified.

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Chapter 1: Introduction

The agricultural region of Western Canada is a landscape full of opportunities. With an expanding world population and economy, global demand for agricultural products will continue to increase. Much of Canada's primary and value-added production needed to meet future demands for agriculture and agri-food products is expected to come from the Prairies. Livestock production is projected to increase significantly, while crop production will diversify and intensify. More processing of agricultural products will occur in the Prairie region as it capitalizes on emerging opportunities in an expanding global market.

Comprising more than 80% of Canada's agricultural land, the Prairies have the natural resource base needed to produce abundant food and fibre. Increasing production and processing of agricultural goods in the Prairie region provides many opportunities for farmers and ranchers, while also posing many challenges for the sustainable management of the resource base. The productive capacity of the land base required to meet future demands will come from practices such as improved crop and range management, intensified crop rotations, increased use of crop inputs, reduced summerfallow and improved management of environmentally sensitive lands. These opportunities and challenges for the agriculture and agri-food industry must be examined from economical, sociological and environmental perspectives.

In 1935, in the midst of the Dirty Thirties, the Prairie Farm Rehabilitation Administration (PFRA) was created to help Prairie people develop and promote systems of farm practice and land utilization that would provide greater economic security. Today, the Prairie Agricultural Landscapes (PAL)

Across Western Canada, crop production is diversifying and intensifying as more producers capitalize on new market opportunities.

project will assist PFRA as it prepares for a significant expansion and adjustment of the Prairie agriculture and agri-food sector. As such, the PAL project marks another stage in PFRA's ongoing commitment to help Prairie people take advantage of new opportunities to manage land resources in a productive and sustainable manner.

The importance of the Prairie Agricultural Landscapes project increased when the Canadian Agri-Food Marketing Council (CAMC) announced its target for Canadian exports of 4% of global agriculture and agri-food trade by 2005. This goal was endorsed by the federal and provincial agriculture Ministers. The expectation of significant growth implies that agricultural output must increase through intensification and improved land management practices.

The results of the Prairie Agricultural Landscapes project will provide the basis for strategic decisions within PFRA's priority activity area *Better Land Quality in the Rural Prairies* established in its Strategic Framework. Furthermore, the PAL project addresses a recommendation of the Auditor General's report (Chapter 24, December 1997) which stated: "*The Prairie Farm Rehabilitation Administration should define and prioritize current and emerging land and water management issues on the Prairies ... to develop strategic objectives with measurable outcomes*".

As PFRA examines how landscape quality and resource management contribute to a robust, growing and diversified Prairie economy, it is important to recognize that management and stewardship of private land rests in the hands of thousands of individuals. The knowledge, creativity, skill and commitment to conservation and resource management of each landowner/operator determines the vitality of our agricultural landscapes. From PFRA's perspective, it was therefore essential to involve an advisory group - a Blue Ribbon Panel - comprised of leading producers, academics and researchers, to guide the PAL study and to help PFRA define strategies that meet the needs of landowners.

The PAL project renews PFRA's commitment to work with Prairie people in the management and stewardship of agricultural land. The project began in the spring of 1998 and has been implemented in two distinct phases. Phase one, the technical information review, involved contributions from more than 20 PFRA staff as well as input from representatives of other branches of Agriculture and Agri-Food Canada, provincial governments, universities and other individuals and agencies. Their analysis is contained in this report - *Prairie Agricultural Landscapes: A Land Resource Review*. The report provides a summary of the current state of land resource management in the Prairie region of Canada. It incorporates a literature review and analysis of land management systems and adds a unique regional perspective, based on landscape units, to the array of resource assessments published over the past two decades.

> ***Comprising more than 80% of Canada's agricultural land, the Prairies have the natural resource base needed to provide opportunities for farmers and ranchers to produce abundant food and fibre.***

The individual land steward's knowledge, creativity, skill and commitment to conservation and resource management, determines the viability of Prairie agricultural landscapes.

The second phase of PAL will culminate in a companion report, *Prairie Agricultural Landscapes: Foundations for Growth*. This report will identify the potential for agricultural change and expansion, the projected spatial distribution of agricultural change and the associated challenges for responsible management of land and water resources.

These are exciting times for agriculture. It's an industry with great potential; an industry benefiting from new technology and innovation; and an industry that contributes in a very significant way to the economic health of Canada. Following in the spirit of L.B. Thomson, a pioneer of resource management in the Prairies, PFRA must work in co-operation with farmers and ranchers to be successful. PFRA must take on the challenges to help the agriculture industry capture the many opportunities and to identify the solutions for resource management. Governments and producers need to work together to make Prairie landscapes more productive today, and into the future.

Chapter 2: Background

The PFRA vision for the future goes beyond prevention of resource degradation; the vision is to improve land resources. Prairie agricultural landscapes can provide a healthy and productive land and water resource base through continued cooperation between government agencies and private landowners. The PFRA role is to work with Prairie people to support a sound rural economy, a healthy environment and a high quality of life.

The Bruntland Commission defined sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development 1987). The Government of Canada has integrated this definition into its legislation, policies and programs. The concept of sustainable development provides a framework for managing the environment while developing the agricultural resource base.

> ***The*** **Prairie Farm Rehabilitation Act** ***provides Parliamentary authority to: ... secure the rehabilitation of the drought and soil drifting areas ... and to develop and promote within those areas, systems of farm practice, tree culture, water supply, land utilization and land settlement that will afford greater economic security ...***

Agriculture in Western Canada must manage the balance between natural resource development and conservation, while providing products into a competitive world market. To assess whether Prairie agriculture is sustainable, the costs of agricultural production to current and future generations must be considered. These costs include the impact of agricultural production on the environment. This view of agriculture is consistent with the strategy for environmentally sustainable agriculture development in Canada, which states: *"Through national policies, programs, and services, we help the sector maximize its contribution to Canada's economic and environmental objectives and ensure a dependable supply of safe, nutritious food at reasonable prices to consumers, with equitable returns to producers and processors".* (AAFC 1997)

The desire of industry is for western Canadian agriculture to continue along a path of economic and sustainable development. Further increases in output must be generated by changes in farm practice and technologies that add to the profitability and the environmental performance of agricultural production. Prairie agricultural landscapes encompass the key natural resources required for agricultural production. Eighty-three percent of Canada's farmland is on the Prairies. Agricultural development in this region, along with new cropping patterns and farm management practices, will strongly influence the overall direction of change for issues of soil quality, water use and quality, biodiversity and greenhouse gas emissions. There are important links between these issues and the Prairie region's contribution to global agricultural trade.

In the long-term, farmers continually make cropping choices and adapt management practices based on changing economic conditions. While production systems employed on the Prairies have evolved with the primary objective of maximizing profits, other objectives, such as improved environmental quality, have grown in importance. Agricultural practices endure increasing public criticism for compromising public good objectives. However, the agriculture sector has little economic incentive to develop or adopt practices that produce habitat for wildlife, more scenic landscapes, or improved surface and groundwater quality, because market prices of agricultural commodities do not fully reflect societal desires for the provision of environmental amenities.

The management of Prairie agricultural landscapes must consider how management decisions can affect agricultural productivity, soil erosion, water quality, rangeland condition, riparian areas and other off-site effects. For example, soil erosion can affect surface water quality with repercussions for recreational or domestic uses. Although there is a range of opinion as to the impacts of erosion to the nation, there are significant regional variations in soil and water degradation and off-site impacts of agricultural production. The following is a review of significant studies that have evaluated the state of the resources used or impacted by farming systems.

Past Assessments of Land Resources

Over the past 20 years several assessments of agricultural sustainability have been made in terms of the environmental condition of Prairie soils, economic impact, policy debate and proposed solutions. These reports give clear direction to the need for sustainable management of the Prairie agricultural landscape and the demands that society places on the management of privately owned lands. Also highlighted are the economic and public good benefits that go to society at large, rather than to producers. Progress in issue identification, management alternatives and the attainment of sustainability in land use can be tracked through the following assessments.

The report *Soil Conservation Policy: A Backgrounder* concluded that vast areas of cultivated land in the Prairie provinces are affected by some form of land degradation, and that technical advances to improve crop yields have masked the inherent decline in the fertility of cultivated soils (Canadian Federation of Agriculture 1982). PFRA (1982), in the report *Land Degradation and Soil Conservation Issues on the Canadian Prairies, an Overview*, identified salinity, erosion and declining organic matter as major soil degradation issues. Salinity was estimated to affect approximately two million hectares of land. Resulting farm income losses were estimated at $257 million annually and were expected to increase at a rate of 10% per year. Losses due to wind and water erosion were estimated at $368 million annually. Excessive


Photo by Dave Reede

Prairie agriculture is currently undergoing a major transition from bulk production of cereal crops for export toward a more diverse and integrated industry.

Healthy rangelands provide abundant quality feed for livestock while making a significant contribution to the Prairie economy.

tillage and cultivation of marginal lands were identified as major contributors to soil erosion. Losses of plant-available nitrogen due to organic matter decline were assessed at $121 million annually.

The Standing Committee on Agriculture, Fisheries and Forestry to the Senate of Canada (1984) reported that soil degradation was a problem for all of Canada. The conclusions and recommendations contained in the report were instrumental in bringing the issues of soil degradation and conservation before the Canadian public. In the same year, the book *Will the Bounty End?* was written for the Agriculture Institute of Canada, and reiterated similar conclusions to the earlier studies in terms of soil degradation requiring a national policy, research support, and effective awareness activities (Fairbairn 1984).

Agriculture Canada (1985) assessed resource conditions and provided an outlook for the future in terms of soil, water and climate change issues. It concluded that the best lands were already in use, conversion to non-agricultural uses were significant in some areas of the country, overall land quality was expected to continue to deteriorate, and there would be continued pressure to convert unimproved lands to crop production. The Science Council of Canada (1986) provided a scientific evaluation of the issues and recommended actions for policy directions, research and public education and awareness. They stated that *"losses from soil degradation on the Prairies now exceed $1.0 billion annually, and could increase to $2.7 billion within 20 years. The cumulative cost to western farmers in terms of lost revenues and increased expenditures could be devastating if restorative action is not taken"*.

Agriculture and Agri-Food Canada identified links between the health of the soil resources and the longer term health and economic competitiveness of the agriculture industry (Acton and Gregorich 1995). For the Prairie region, this report concluded farmers have adopted soil conservation practices which are reducing the risks of erosion and salinization, and providing an improvement in the health of the soil. However, the *Health of Our Soils* report did not make specific statements on the economic state of the soil resources. In terms of economic conclusions, the report's findings indicated that fertilizer use must increase, farmers must continue to adopt soil conserving technologies, permanent cover systems must be implemented on lands where erosion potential is most severe, and a range of conservation practices and technologies must be adopted where there is risk of soil erosion or degradation. The report concluded that *"New government policy for soil conservation is needed, aimed at achieving sustainable agriculture and* *built on the understanding that agro-ecosystems are part of the broader environment"* and *"soil management programs are best designed at the farm level, integrating management practices to suit specific, local soil needs"* (Acton and Gregorich 1995).

The report *Agriculture and Sustainable Development: Policy Analysis on the Great Plains* discusses agricultural issues, policies and programs related to land use, water quality, use of common property, social problems, trade impacts, climate change and biodiversity. The initiatives of PFRA and the North American Waterfowl Management Plan were found to be consistent with the principles of sustainable agriculture (Tyrchniewicz and Wilson 1994).

Significant initiatives have been undertaken by the federal and provincial governments, wildlife agencies and producer organizations, specifically to address landscape management issues (Wettlaufer and Brand 1992). In addition, the policy focus shift away from income support, mainly in the grains sector, and changes in adoption of tillage technology has resulted in land use change which is generally viewed as positive to the environment.

From the numerous conclusions of these reports, it remains clear that the need for coordinated soil and water conservation programs across the Prairies, continuing education and awareness programs, improved extension and technical advisory services to producers, on-site demonstrations by local conservation associations, and continuing research in support of soil conservation initiatives are required. However, to ensure long term sustainability, the challenge is to improve the performance of the agricultural industry by responding to new environmental, soil degradation and land use issues. It is essential to continue public investment in Prairie land management programs to ensure continuation of the private benefits and to meet public good desires.

Adoption of Conservation Practices

In addition to profitability, a number of factors affect adoption of practices such as conservation tillage, nutrient management and grazing management. Structural barriers, such as farm size and ownership may discourage adoption. For example, farmers with off-farm employment may view fewer field operations as an advantage of conservation tillage. It should be recognized that the diversity of natural resources influences the adoption of practices and technologies. Also, the financial risk of adopting new technologies may inhibit the rate of adoption because the technologies may be dependent on site-specific conditions. Identifying constraints and barriers can reduce adoption costs and targeting public policy can improve sustainability.

In the past, government programs have encouraged private landowners to conserve soil and water resources. More recently, investment in environmental management technology has received attention because of the potential to increase farm profits and improve environmental performance of agricultural production. However, the simple availability of a technology does not necessarily mean it will be adopted by farmers. Until agricultural markets recognize the environmental benefits and costs associated with conservation practices, farmers will tend to under-utilize these farming systems.

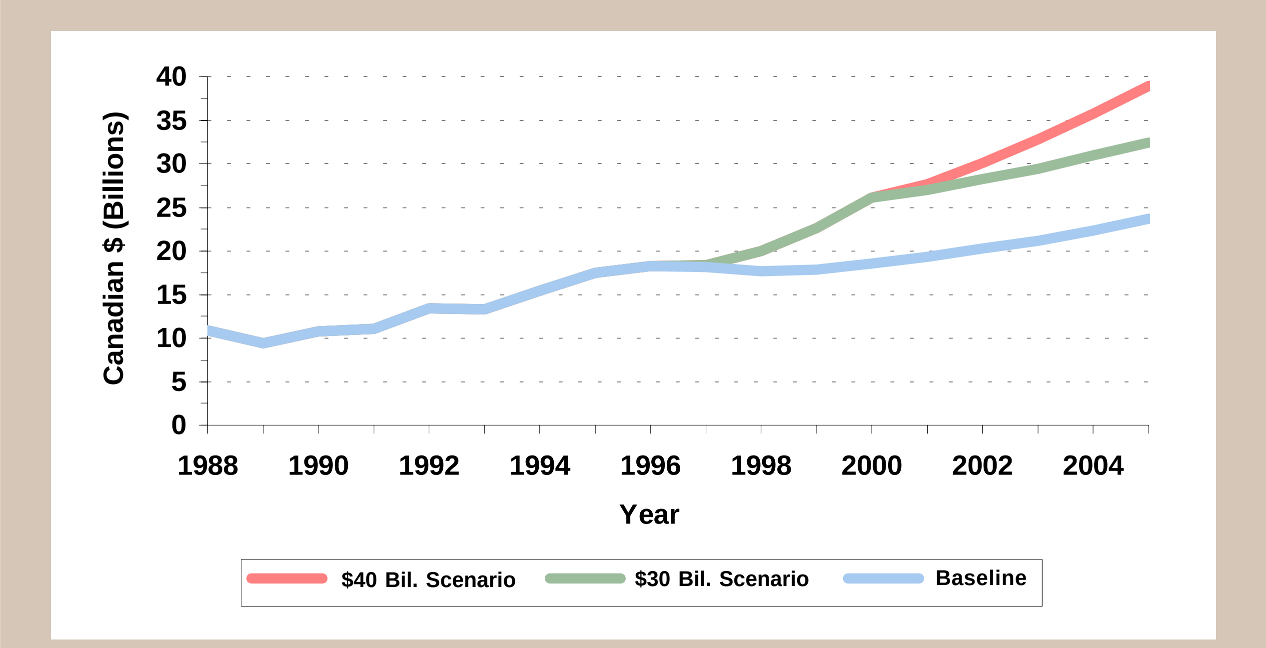
Prairie agriculture is currently undergoing a major transition from bulk production of cereal crops for export to a more diverse and vertically integrated industry. Changes in grain transportation, and globalization of trade, and the advent of new technologies are the major factors driving this change. Current commodity and input prices and low profit margins are forcing many producers to farm more land more intensively simply to make a profit. Fewer and larger farms, larger equipment, larger fields and a trend toward more rented land point to a continuing need for the adoption of conservation practices to offset the potential for increased soil degradation on the Prairies.

Growth Objectives

The foremost challenge facing agriculture today is to find the balance between economic viability and managing the land to ensure long-term resource conservation. The interrelationships of economic, environmental and social concerns are complex. In the future, these forces will have a dramatic influence on how farmers decide the best use of their land base. Since business viability is critical to any operation, farmers' land use decisions may not always be optimal for the long term, from a societal and environmental standpoint.

In the end, economics will drive change for both primary and processed goods. The Canadian Agri-food Marketing Council (CAMC), a group of leaders from the agriculture, food industry and market sectors, has set an aggressive target for the agricultural industry. CAMC has challenged primary producers, processors and governments to significantly increase Canadian agriculture and agri-food exports to about 4% of the world market, up from the current 3%. This aggressive growth target may be slowed by current low prices for many commodities, but it is expected that the drive for growth will continue.

CAMC's target would also require a shift in Canada's agricultural exports away from primary bulk commodities in favour of a significantly greater proportion of processed products. This target would see 40% of Canadian agricultural exports in primary commodities and 60% in processed goods. Figure 2.1 illustrates the growth targets for Canadian Agriculture and Agri-food exports set by CAMC, as compared to the baseline Agriculture and Agri-Food Canada (AAFC) projections.



Source: Statistics Canada Merchandise Trade Database Calculations by AAFC.

Figure 2.1 **Projected Canadian agriculture and agri-food exports.**

Much of the growth needed to meet the trade target will come from the Prairie land base. The increase in production and processing of goods in the Prairie region means greater pressure on the sustainability of land and water resources. An increase in annual cropland and improved forage to meet these targets is forecast to come from new breaking and reduced areas of summerfallow, and may result in increased pressure to cultivate environmentally sensitive lands (AAFC, Policy Branch, Economic and Policy Analysis Directorate 1998).

One of the environmental pressures on the agricultural landscape will come from an expanding agriculture sector which expects to increase the area seeded to a more diverse mix of annual crops. It is estimated that one million hectares of new land in Canada will have to be broken and brought into production to meet identified agriculture and agri-food export targets (AAFC, Policy Branch, Economic and Policy Analysis Directorate 1998). In comparison, the Canadian Wheat Board (CWB) forecasts that 400 000 hectares of land will have to be brought into production in Western Canada to meet world grain market demands by 2007 (Brewin 1998). Increasing the area seeded to annual crops by cultivating marginal soils currently in grassland has the potential for significant environmental costs, which include reduced soil quality, loss of wildlife habitat and reduced biodiversity. The CWB and AAFC both estimate that the summerfallow area in Western Canada will have to be reduced by approximately two million hectares.

There are also plans to significantly expand the livestock sector in the Prairie region. The Environmental Policy and Analysis Directorate projects that the number of hogs could increase by 5.5 million head (30%) and cattle could increase by 700,000 head (15%) to meet the export target identified by CAMC (AAFC, Policy Branch, Economic and Policy Analysis Directorate 1998). These aggressive growth targets for the livestock sector are echoed by provincial governments, processors and producer associations. For example, the growth of hog production and processing in Manitoba is expected to exceed the national projections with additions to the breeding herd and marketings growing more than 5% per year (Manitoba Agriculture and Food 1999). The magnitude of the growth and benefits of the development depend, in large part, on whether such trends are sustained over time, soil and water conservation practices are used and inherent soil and landscape capabilities and limitations are respected. The Canadian Cattlemen’s Association also indicates that the current areas in forage and pasture, while adequate today, will not support the base cow herd necessary for significant livestock expansion (Strankman 1998).

Significant land resource pressures may also arise in other areas. These include ongoing urbanization, production of feed grains for livestock versus crops for processing and export and marginal and better quality lands vying for pasture or annual crop production. Irrigated lands support intensive crop and livestock production and resultant value-added industries. However, expansion of irrigated lands requires significant capital output and will have perceived environmental consequences.

The development of irrigation has had a long and diverse history, beginning with some of the first land settlements in the driest areas of the Canadian Prairies. Irrigation works were primarily developed in southern Alberta and southwestern Saskatchewan with significant additional developments over the past thirty years in central Saskatchewan and southern Manitoba (PFRA 1982; Shady 1989). Currently more than 630 000 hectares are developed for irrigation across the Prairies, using a range of intensive and non-intensive technologies, and a range of private and organized project schemes (Statistics Canada 1997). There is significant interest within the three Prairie provinces for the continuation of irrigation developments and water efficiency improvements to meet expected market demands for the grain exports and domestic livestock feed requirements (Sask Water Corporation 1995; Gaia Consulting and Werner Research 1999; Alberta Agriculture Food and Rural Development 1999).

Social Influences

Global Influences

The issues facing agriculture are both national and international. As an export-dependent industry, the sector needs to remain competitive on an international scale.

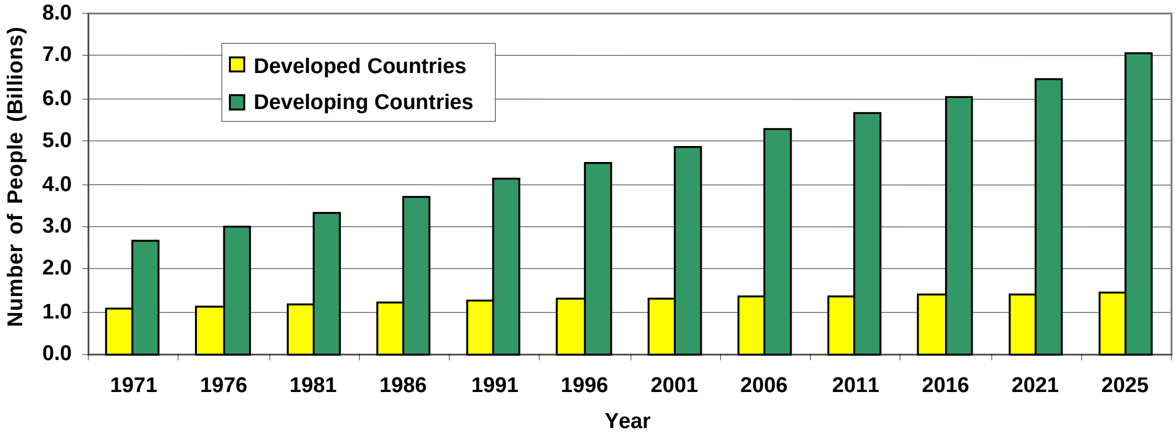
Population trends, (Figure 2.2) will have a significant impact on Prairie agriculture. The global issues of poverty, health, shelter, malnutrition, education and food security will place ever-increasing pressure on both prime and marginal agricultural lands. In addition, population growth continues to add pressure to cultivate more marginal lands in all areas of the world for food production. Housing and infrastructure tend to use the better agricultural land adding additional pressure to cultivate marginal lands.

While environmental sustainability is desired around the globe, mounting pressures for food production, increased housing and infrastructure encroachment on agriculture soils and overgrazing by livestock in many areas of the world combine to pose significant negative influences on land use. While the impact of these trends is generally greater in developing countries than on the Canadian Prairies, there is none-the-less increased pressure to use our own land base more intensively.

Prairie Population

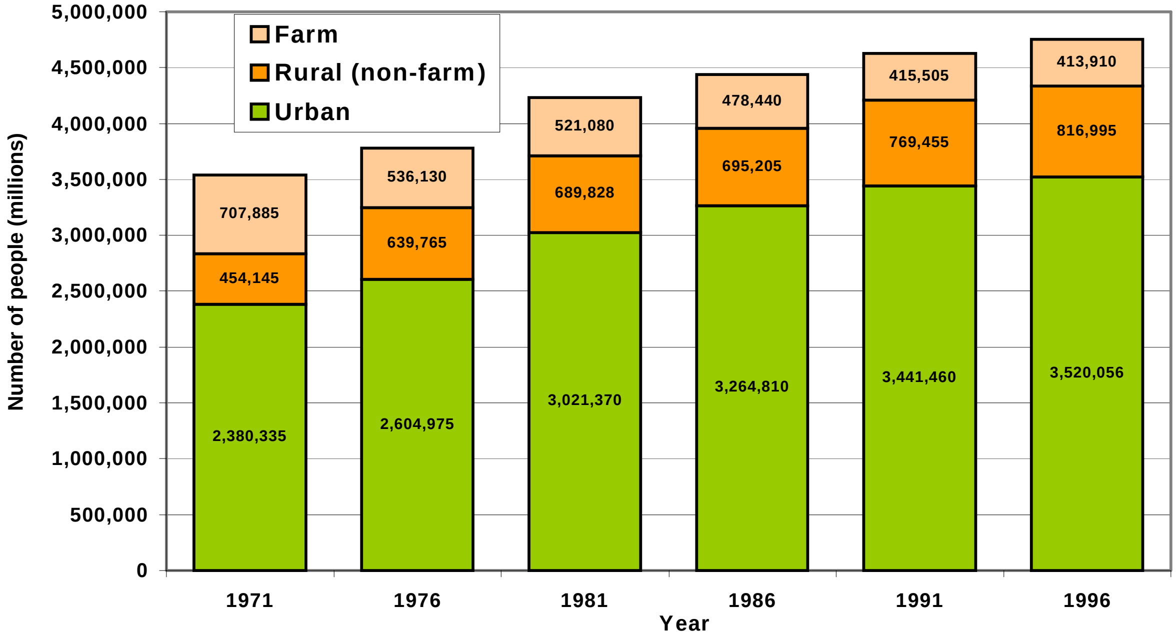
Rural, urban and on-farm population trends are shown in Figure 2.3 for the period 1971 to 1996. These trends are the result of economic and technological changes, and have resulted in several issues of concern for the Prairie region. The number of farms and the on-farm population have been in decline for many decades. This trend is expected to continue, dictated by increasing economies of scale in input supply and farm production, and associated restructuring of the grain handling and transportation system.

It is increasingly difficult to define an average farm. The gross trends show that average farm size is consistently increasing, but Figure 2.4 shows that medium size farms are in rapid decline. This, in turn, has an impact on the restructuring taking place in rural communities that have direct economic and social ties to agriculture. The reduction in farm numbers has affected critical population levels required to maintain desired services in many rural communities on the Prairies.



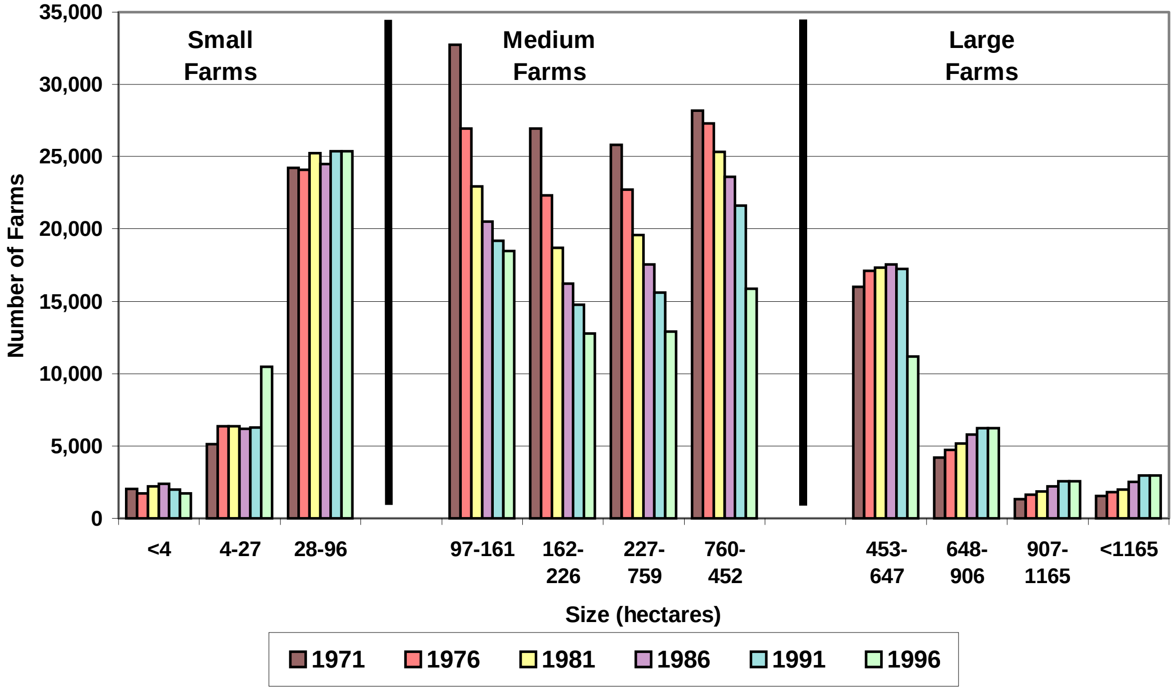
Source: FAO Database, UN Population Division

Figure 2.2 World population.



Source: Statistics Canada, 1996 Census of Agriculture

Figure 2.3 Prairie population.



Source: Statistics Canada, Census of Agriculture

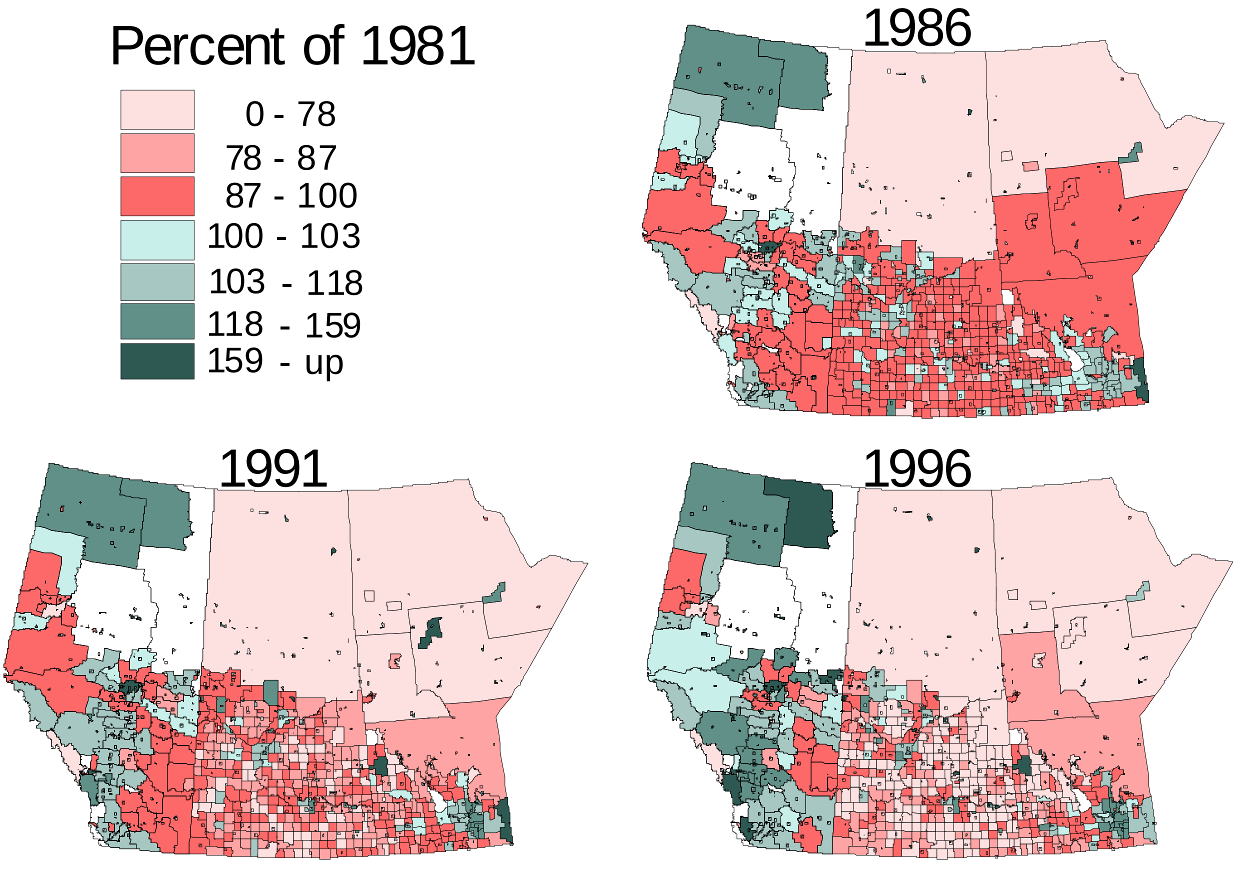
Figure 2.4 Prairie farm size.

The three maps in Figure 2.5 vividly illustrate the population shifts that have occurred in the Prairie region from 1981 to 1996. There has been a rapid exodus from rural areas of Saskatchewan to urban areas in Alberta. This impacts the tax base needed to support existing infrastructure. Community consolidation with associated reductions in schools, health care and government services make it more difficult to maintain the critical mass necessary for viable communities. Rural trading centres are serving larger geographic areas, and with an aging rural population, the forecast for the short term remains for further declines in rural communities. In fact, dramatic declines are forecast in some areas. Rural areas near larger urban centres are an exception, as urbanites increasingly seek a rural lifestyle within commuting distance of the cities.

The relative stability in the small farm category may be due to increases in intensive operations, retiring farmers retaining some ownership and residency, and acreage operations in proximity to urban employment centres.

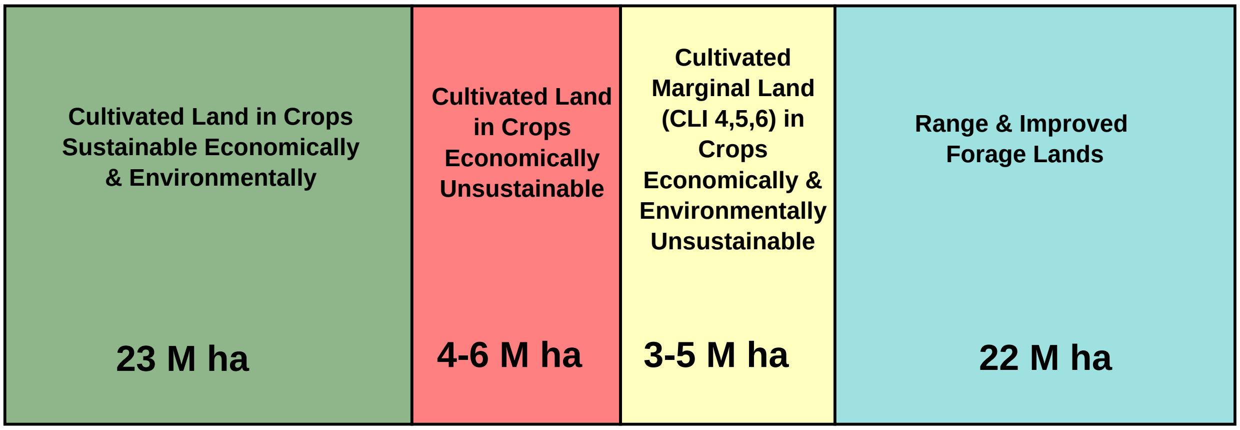
Economic/Policy Influences

Society expects Prairie farmers to meet the competitive demands of the world market while providing a safe, secure and nutritious food supply for both Canadians and the world. At the same time, farmers are expected to manage their land base, livestock and production inputs, and outputs of manure and other residues in a manner that serves society's interests in



Source: Statistics Canada

Figure 2.5 Percent change in population 1986-1996 (1981 base year).



Source: Adapted from Saskatchewan Agriculture and Food and PFRA 1995.

Figure 2.6 **Prairie agricultural land base total 52 M ha.**

respecting the environment. For the most part, private landowners bear the costs of these *public good* aspects of Prairie land use.

Figure 2.6 illustrates the sustainability of the Prairie land base in terms of its inherent quality, current use and the economic influences on its use. Figure 2.6 is based on the assessment of the Prairie grains and livestock sectors of the early 1990s. The left and right bars represent sustainable land use, as defined by land use for particular soil qualities. This includes 23 million hectares of cropland on the better classes of soil and over 22 million hectares of range and forage lands generally on the poorer land classes (Saskatchewan Agriculture and Food and PFRA 1995).

The centre sections are the marginal lands which are defined by economic and environmental parameters. Economically marginal lands include about 4-6 million hectares which do not produce a long-term net income. The area included in this definition can change dramatically from year to year, depending on prevailing commodity prices and input costs. Many would argue that for 1998 and 1999, the area of economically unsustainable annual crops is much larger. The current farm income situation will likely affect land use decisions over the next several years.

Most significant for this study, and from the perspective of sustainability, are the 3-5 million hectares of marginal land currently in annual cultivation, which are neither environmentally sustainable nor economically profitable under current uses. These lands are comprised mainly of the Canada Land Inventory (CLI) classes 4, 5 and 6. A more detailed estimate of the 3-5 million hectares considered to be environmentally sensitive in annual cultivation was done in 1997 and is contained in Table 2.1.

Although the estimated extent of the problem varies, it is the environmentally marginal land classes which have been targeted for conversion from annual crop production to more appropriate land use such as forages and pasture. This movement is evident in the Permanent Cover Programs (PCP) of the late 1980s to early 1990s. Benefits of the PCP include reduced soil degradation, improved water quality, enhanced wildlife habitat, increased carbon sequestration, reduced off-site costs of soil erosion and reduced government payments from acreage-based programs.

Through the PCP, about 500 000 hectares were converted to more appropriate land use under various contract options. About 80% of the PCP lands are now in hay production, and in most cases there is a strong link to local cattle operations. A 1994 survey of participants indicated that 80% of the PCP lands would remain in permanent cover after the term of the contract expired (Vaisey et al. 1996). However, with these contracts now maturing, it will be interesting, given generally poor commodity prices, to see what land use changes occur.

Prairie producers contend with a range of domestic and global policies that influence markets, commodity prices, trade and environmental issues. In terms of world trade, it is generally accepted that Prairie agriculture has enjoyed a net benefit from international agreements, such as the General Agreement on Tariffs and Trade (GATT) and the North American Free Trade Agreement (NAFTA), which have dismantled many restrictive trade policies. These policies had primarily been in the form of income supports that often masked market signals, and hindered the ability of producers to react and take advantage of market opportunities.

In addition to trade agreements, environmental conventions have been signed in recent years which oblige Canada, and other signatory nations, to implement environmental strategies and action plans. Two examples are the Convention on Biodiversity and the Protocol on Ozone Depletion. This environmental thrust is also reflected in the world trade responses – environmentally targeted interventions are rated as more acceptable than programs which are commodity targeted. It is becoming more likely that the next round of world trade negotiations will find environmental issues at the forefront.

Until recently, agriculture policy in most industrialized nations, and to some extent in Canada, had evolved into a complex mix of support and stability mechanisms for the industry. Income support programs are declining in response to requirements under the GATT and due to fiscal constraints. Federal government support now emphasizes income stabilization through programs such as Crop Insurance and the Net Income Stabilization Account. As a result of this shift, federal government expenditures on agriculture have declined significantly. This shift in policy focus ensures market signals are not distorted by support programs.

Transportation policy changes of the mid 1990s are expected to create significant production shifts as well as new opportunities for value-added production. The elimination of the Western Grain Transportation Act (WGTA) in 1995 has reduced Prairie farm receipts by approximately $577 million per year. Efficiency gains in the transportation and grain handling systems are expected to partially offset these losses in the longer term. An added pressure for eastern Sask-atchewan and Manitoba is the change in the Canadian Wheat Board pooling. Over time, this policy change may shift the production emphasis from export grains to grains for livestock feeding and forage for grazing.

Table 2.1 Environmentally marginal land in annual cultivation by soil zone (1996 ha).

Province	Black	Brown	Dark Brown	Dark Gray	Gray	Total
Manitoba	218 000	0	0	41 000	20 000	279 000
Saskatchewan	319 000	897 000	615 000	105 000	79 000	2 016 000
Alberta	185 000	293 000	234 000	93 000	135 000	939 000
Total	722 000	1 190 000	849 000	238 000	234 000	3 234 000

Source: PFRA 1998 (Unpublished analysis)

Recent changes to trade and transportation policies are expected to foster growth in the livestock sector.

Trade and transportation policy changes are expected to have an environmentally positive impact in the long term, while the removal of export grain-based policy is expected to benefit the livestock sector. This should, in turn, result in a more sustainable use of environmentally sensitive lands for forage or livestock grazing. The long-term shift from grains to forage, pasture and livestock production is dependant on relative profitability and on-farm infrastructure.

The international trade of beef and pork is very important to the Prairie provinces. The beef and pork sectors rely heavily on the export of live and slaughtered animals, since the domestic market is small relative to the output of the sector. In the longer term, it is expected that there will be increased feeding of animals on the Prairies due to the comparative price advantage of feed grains and elimination of the WGTA. In particular, the pork industry is currently in a rapid expansion phase, with significant increases projected in each of the Prairie provinces over the next five years.

ENVIRONMENTAL INFLUENCES

An issue that is creating significant interest in the Prairie provinces is climate change, specifically the recent discussion leading to the Kyoto Protocol. There is potential for the agriculture industry to be affected by changes to climate, and at the same time there is an opportunity to form part of the mitigative solution (Environment Canada 1997; International Institute for Sustainable Development 1998; and AAFC, Research Branch 1998).

The balance of evidence suggests that the climate is changing due to the burning of fossil fuels, deforestation and industrial and agricultural processes. The result is increased concentrations of greenhouse gases (GHG), mainly carbon dioxide, methane and nitrous oxide. Overall there is a gradual warming of the atmosphere, and an expected rise in the average global temperature of one to four degrees Celsius over the next century.

Agriculture is responsible for 9.5% of the GHGs produced in Canada, including less than 1% of the carbon dioxide, 38% of the methane and 61% of the nitrous oxide. Nitrous oxide has 310 times the impact that carbon dioxide has as a greenhouse gas, while methane has 21 times greater impact than carbon dioxide (AAFC 2000). The Kyoto Protocol states that Canada must reduce its GHG emissions to 6% below 1990 levels by 2010 (AAFC 2000).

Agriculture is a source for several GHGs, and is a potential sink for CO_2. The Kyoto Protocol does not currently recognize soils as a GHG sink but, Canada is negotiating to have soils formally recognized.

Carbon is an area where the sink potential is likely greatest and an area where scientists feel that significant progress can be made. Carbon is still being lost from agricultural soils, but changes in soil management practices have progressively reduced these losses. Management practices to reduce carbon loss include reduced tillage systems, reduced summerfallow, marginal cropland conversion to permanent cover and riparian grazing management. It is predicted that in the near future, Prairie soils will no longer be a source of carbon loss, but a net sink (Bruce et al. 1998).

The livestock industry is the primary agricultural source of methane. Methods of mitigating methane production include increased feed efficiency in ruminant animals and improved manure management.

Nitrous oxide is potentially agriculture's greatest contributor to the GHG problem. Reduced emissions could be accomplished through optimal application, timing and placement of fertilizer and through improved handling and storage of manure.

Climate change and its possible effects on Canadian Prairie agriculture are of increasing concern. Forecasts indicate that as a result of climate change, the southern Prairies may experience more warming than the global average, with longer, warmer and drier summers. While increases in temperature will lengthen the growing season, the lack of moisture and more severe insect infestations may reduce potential yields by 10-30%. There will be a commensurate increase in demand for irrigation and water management. Depending on the quality of soils, agriculture may be able to expand to the north. However, the soils on the northern agriculture fringe are inherently more fragile.

While society, governments and international forces can influence the decisions of individual landowners, they do not have the final say. Those decisions are generally made by private landowners who, while influenced by the larger picture, will ultimately act in the best interests of their own farm and on the basis of shorter term considerations. Again, the basic dilemma of the landowner is balancing the pragmatism needed to stay in business with the altruistic expectations of society at large.

The strong forces driving change and PFRA's ongoing commitment to sustainable development clearly emphasizes the need for appropriate action by farmers, ranchers, industry and government to ensure that land resources are cared for. Public and private interests must work together to ensure that environmental considerations are integrated into all aspects of public and private decision making within the agriculture and agri-food sector. A suite of policy, program and technical options needs to be available so farm operators can make selections that match their resource and economic situations.

Conversion of marginal cropland to perennial cover improves soil fertility, reduces the potential for erosion and reduces organic matter losses from the soil.

Chapter 3: Current State of Land & Water Resources

Introduction

In 1983, PFRA published "Land Degradation and Soil Conservation Issues on the Canadian Prairies". This assessment of Prairie soil resources was the cornerstone of a great deal of subsequent soils programming in the region.

The 1983 report concluded that wind erosion, water erosion, salinity and organic matter decline posed serious threats to Prairie agriculture. For example, the report stated that Prairie farmers would lose $100 million in 1984 as a result of soil degradation. This was equivalent to as much as a 10% drop in net farm income from cash crops.

Since the 1983 report, agricultural production systems have evolved, as has the understanding of their impact on natural resources and processes. It is now generally accepted that the agricultural industry operates within various ecosystems and that agricultural production is highly dependent on the natural resources of these ecosystems. In turn, land clearing, drainage, annual cropping and grazing have dramatically altered the nature of ecosystems within which agriculture is conducted. The changes are such that natural ecosystems which have been impacted by agriculture are now referred to as agro-ecosystems.

The philosophy of sustainability of agro-ecosystems has also emerged into mainstream thinking since the 1983 report. This approach provides a conceptual framework upon which to integrate the environmental, economic, and social impacts of man's activities. Consequently, it is no longer sufficient to consider the effects of agricultural production on the soil resource in isolation from environmental, economic and social impacts.

This chapter provides a review of the state of some of the most critical natural resources that have been affected by agriculture: soil, water, riparian areas and rangelands. It will examine the processes that affect the quality of these resources, review recent research results and provide an indication of what factors pose the greatest risk to these resources.

Soil Quality

Soil quality is a key component of the sustainability of agricultural production systems and of the ecosystems within which agriculture is practiced (Doran et al. 1996). Consequently, soil quality is a concern for both the production of food and the mitigation of agriculture's environmental impacts.

Concepts of *soil quality* and *soil health* have been used interchangeably and have evolved from simple expressions of the suitability of a soil for agricultural production to expansive definitions which include components of environmental quality, biodiversity and socio-economic values. Leopold (1949) defined soil health as *"the capacity for self renewal"*. Acton and Gregorich (1995) defined soil quality to be *"the soil's fitness to support crop growth without becoming degraded or otherwise harming the environment"*. Karlen et al. (1997) stated that soil quality is *"the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation"*. Lal (1998) suggested an even more expansive definition which includes the following four principal soil functions:

- sustainable biomass production and biodiversity
- regulation of water and air quality by filtering, buffering, detoxification and regulating geochemical cycles
- preservation of archeological, geological and astronomical records
- support of the socioeconomic structure, culture and aesthetic values and to provide engineering foundation.

Janzen et al. (1992) provided a very pragmatic and elegant discussion on this topic, arguing that any statement of soil quality must be made with reference to its desired function. In addition to food production, soils also have important roles in purification and detoxification of ecosystems through decomposition of wastes. They noted that a highly productive agricultural soil may be less well-suited to environmental preservation.

Evaluation of soil quality requires the integration of measurable soil physical, chemical and biological properties that are definitive indicators of soil quality or changes in soil quality (Coen 1996). Changes in soil quality can be quite slow as in the case of natural weathering processes, or they can be more rapid as in the case of human activity where land use and farming practices can degrade, maintain or improve soil quality. Generally, it is easier to quantify a change in soil quality over time rather than to evaluate changes in soil quality over space.

Sojka and Upchurch (1999) argue that soils perform a multitude of functions simultaneously and that soil functions are a spatially complex integration of static and dynamic physical, chemical and biological factors. They contend that soil quality would need to be defined for each soil and for an infinite number of environment and management scenarios. They conclude that the development of a universally applicable soil quality index is unattainable due to the complexity of soil functions.

It is obvious from this discussion that a consensus on the definition of soil quality and how to measure it has not yet been reached. In fact, the assessment of soil quality in itself may not be sufficient to evaluate the effects of different stresses on the output of agricultural production systems. Janzen et al. (1992) argue that soil quality is only one of the factors which influence soil productivity, and that landscape and soil management factors are also important. Landscape parameters influencing soil productivity include climatic, topographic and hydrological factors. Management factors such as rotations, tillage, fertilizer and irrigation also impact soil productivity.

Crop yields will be highly variable in fields with severely eroded knolls and accumulations of topsoil in lower slope positions.

To evaluate the effects of agricultural management practices on annual cropland, it seems most appropriate to focus on: soil productivity under defined management systems as expressed by yields of Prairie crops, and soil organic matter levels and dynamics. These interrelated parameters integrate the effects of soil degradation processes and also provide some indication of the ability of soils to mitigate the environmental impacts of agriculture. Results will also be discussed in relation to the landscape factors discussed by Janzen et al. (1992), and will take advantage of the very significant body of soils and agronomic research conducted on the Canadian Prairies and elsewhere.

Soil Erosion

Soil erosion causes redistribution of soil in the landscape due to the action of wind, water and tillage. Many Prairie fields in annual crop rotations are affected by all three agents of erosion, with eroded fields occasionally affected by other forms of soil degradation. Wind and water erosion are caused by the action of wind or water on inadequately protected soils. Tillage erosion is the redistribution of soil due to gravity or dragging when loosened by tillage.

Erosion may injure growing plants through sandblasting or bury them through deposition. Areas of soil loss are depleted in their capacity to grow crops, and soil and crop yield variability within fields is increased. Erosion may also have environmental impacts such as reduced air and water quality.

Areas of concentrated water flow may be eroded down to the subsoil, causing gullies which cannot be easily crossed by farm machinery.

Strong winds are common on the Prairies, particularly in the spring. Fields which have a dry, loose soil surface and little vegetation are susceptible to wind erosion. Exposed knolls and sandy soils are most affected, although clay soils which have been exposed to freeze-drying may also be severely impacted. The majority of wind-eroded soil is deposited behind soil clods, weeds or grass, or in depressions, ditches or coulees. Dust from eroding fields can be carried thousands of kilometres and may cause environmental problems.

Water erosion due to snowmelt or heavy rainstorms is most frequent on hilly fields, but large volumes of water flowing across nearly level fields can also cause significant damage. Water erosion tends to be most severe on steep slopes and increases with slope length. Areas of concentrated water flow may be eroded down to the subsoil, causing gullies which cannot be easily crossed by farm machinery.

Tillage erosion has recently been recognized as a significant factor in soil redistribution within the landscape. The significance and severity of the problem on the Prairies is currently being estimated (King et al. 1999). Impacts include soil profile destruction, decreased soil productivity, reduced crop yields, and increased susceptibility to wind and water erosion.

Factors affecting the severity of tillage erosion include tillage frequency, landscape position, slope gradient and curvature, soil physical properties, soil moisture, tillage tool shape and design, tillage tool cutting depth, configuration of tillage implement, ability of tillage equipment to conform to field surfaces and tillage ground speed (Busacca et al. 1984; Lobb et al. 1995).

EFFECT ON CROP YIELDS AND SOIL PRODUCTIVITY

The effects of erosion on crop yields and soil productivity are substantial. Erosion removes the finer soil fractions which contribute to nutrient availability and help maintain a good physical environment for plant growth. Severe loss of soil reduces the rooting volume available to plants, further affecting nutrient and water availability. Eroded soil is usually deposited in areas which already have productive soils, these added increments of topsoil do little to enhance crop yields. Occasionally, poor quality subsoil or sand is deposited onto productive topsoil and, after mixing by tillage, net soil productivity may decline.

Sandblasting of young seedlings during wind erosion, rill erosion during early vegetative growth (Rasmusson and Douglas, 1991), or burial by deposited soil can reduce plant survival and potential crop yield which in some cases may require reseeding. The extent and significance of this loss has not been well quantified.

Most experiments which evaluate the effects of erosion on crop yields use mechanical scalping of various increments of soil and relate depth of soil removed to crop yields. The results of scalping experiments do not account for the selective removal of the most fertile fractions of soils by wind and water erosion.

Dormaar et al. (1986) reported on a soil scalping experiment at Lethbridge. After 22 years, and 14 wheat crops, soil productivity had not been restored to its original level. Plots with 8-10, 10-20 and greater than 46 cm soil removed, yielded 88%, 63% and 41% respectively of the unfertilized and uneroded check. Additions of 45 kg/ha N and 22 kg/ha P_2O_5 only restored yields on plots which had 8-10 cm of soil removed. The plot with greater than 46 cm soil removed yielded only 57% of the check, despite the use of fertilizer. Productivity was restored by 30 t/ha manure (Dormaar et al. 1988) and high rates of fertilizer (Dormaar et al. 1997a).

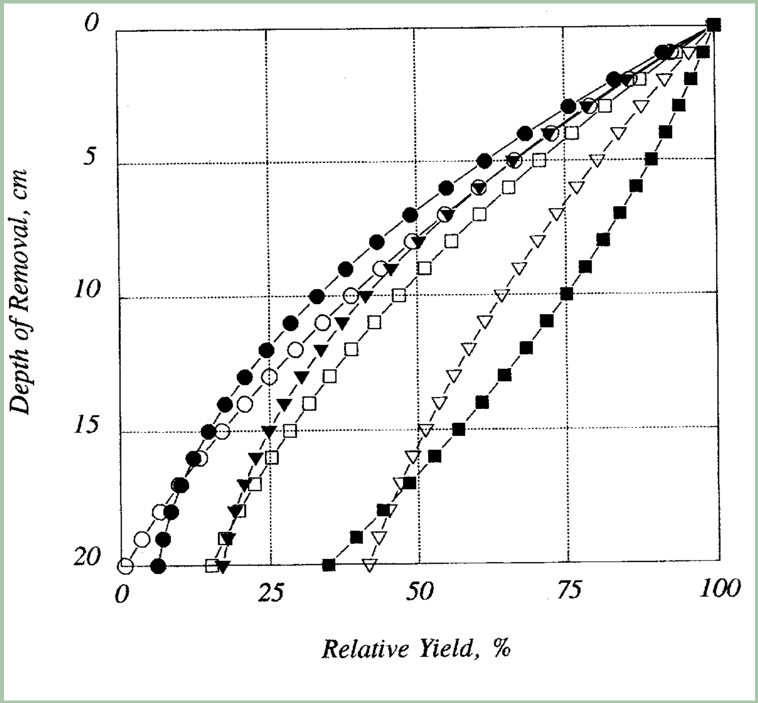
The effect of soil removal on wheat yields at six sites in Alberta is shown in Figure 3.1. For four of the six soils, removal of about 7 cm of soil reduced yields by 50%. Losses of topsoil from the surface reduced yields more than loss of soil from deeper layers. The average yield reduction was 110 kg/ha/cm soil lost (Larney et al. 1995a). Yield losses due to erosion may not be the only concern. Experiments show that the milling properties of wheat grown on an artificially eroded soil may be degraded (Dormaar et al. 1997b).

Soil erosion results in serious loss of soil productivity and likely a decrease of crop quality. In some cases productivity can be restored by fertilizer, but at considerable cost.

Soil Redistribution in the Landscape

The interest in precision farming has drawn attention to yield differences within fields which are largely due to variability in soil quality and water availability. Soil erosion and deposition further increase soil variability and in-field yield differences (Verity and Anderson 1990).

Soil redistribution in the landscape due to erosion is not uniform. Overworked field edges, pockets of sandier soils, or ridges in otherwise flat fields are more susceptible to wind erosion. Slight depressions can channel runoff, resulting in gullies if runoff volumes are large.



○ = Dark Brown, Silty Clay Loam (non-irrigated)
● = Dark Brown, Silty Clay Loam (irrigated)
▽ = Brown Clay, Loam (non-irrigated)
▼ = Thin Black, Clay Loam (non-irrigated)
□ = Gray Luvisol, Clay Loam (non-irrigated)
■ = Thick Black, Loam (non-irrigated)

Source: From Larney et al. 1995a

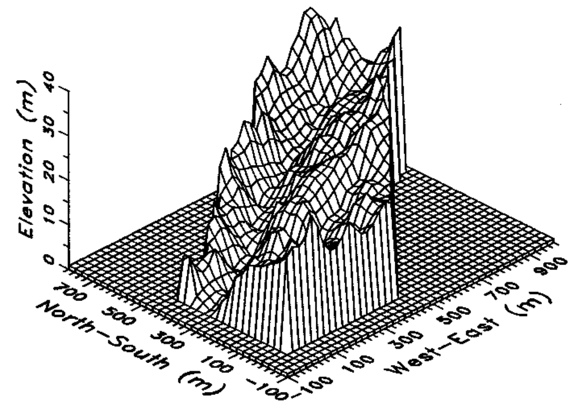
Figure 3.1 Spring wheat yield (relative to non-eroded soil) with the removal of successive 1 cm increments of topsoil at six study sites in Alberta.

Crests of knolls in hilly topography may be eroded by wind and scalped by tillage implements. Mid-slope positions can be eroded by tillage, wind and water erosion. Lower slopes may be subject to water erosion, or may gain soil from upper slopes (Moulin et al. 1994). Convergent footslopes are particularly susceptible to gully erosion, but may in turn trap wind eroded soil. Depressions usually gain soil through deposition of wind or water eroded materials, or they may be filled in by tillage.

Figures 3.2, 3.3, and 3.4 illustrate the complex relationships between topography and soil redistribution for a test watershed in Idaho. Erosion rates tended to be higher from topographic highs with deposition dominating in lower slope positions, but not in all cases. The result is significant differences in soil fertility, moisture holding capacity and soil structure. Uniform application rates of farm inputs will be inefficient in fields which have been badly eroded, leading to additional production costs, sub-optimum yields and negative environmental impacts.

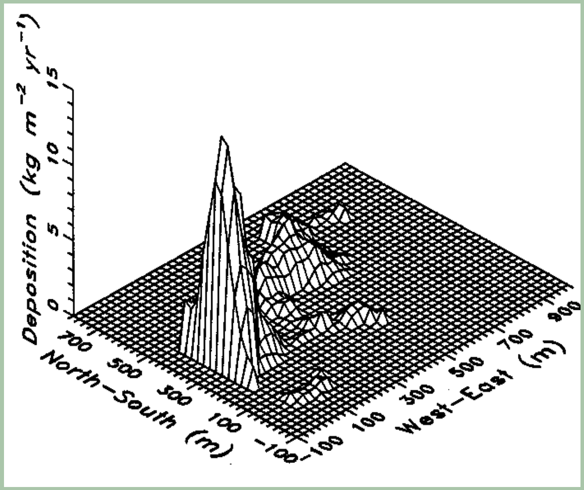
EFFECT ON WATER QUALITY

Sediments are removed by wind and water erosion and deposited when the energy of wind or water flow is reduced. Much eroded soil never leaves field boundaries and is instead redeposited in depressions or behind clumps of vegetation. Novotny and Chesters (1989) noted that up to 80% of water-eroded soil remains in the field. It is likely, though not yet



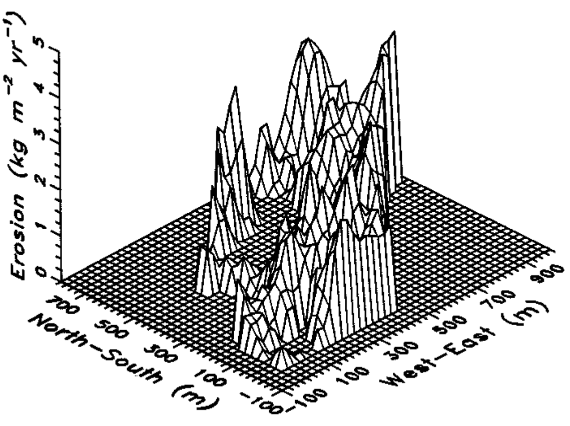
Source: Busacca et al. 1993
Note: Vertical exaggeration 15x.

Figure 3.2 Relative elevation of a test watershed in Idaho.



Source: Busacca et al. 1993
Note: Erosion rate in t ha^{-1} yr^{-1} is 10x the rate in kg m^{-2} yr^{-1}

Figure 3.3 Soil deposition rates in a test watershed in Idaho.



Source: Busacca et al. 1993
Note: Erosion rate in t ha^{-1} yr^{-1} is 10x the rate in kg m^{-2} yr^{-1}

Figure 3.4 Soil erosion rates in a test watershed in Idaho.

proven, that a high proportion of wind-eroded material, perhaps 75%, never leaves the immediate vicinity of the field from which it was lost. However, runoff and eroded sediment from farmland is seldom inert. It may contain organic matter, absorbed plant nutrients, heavy metals and agricultural pesticides, all of which have potential to cause pollution. Erosion sediments may cause significant surface water quality problems. The most environmentally significant plant nutrients lost by runoff and erosion are nitrogen and phosphorus, although other plant nutrients are lost to some extent.

Nicholaichuk and Read (1978) reported average concentrations of dissolved nutrients in runoff from fields on 4-5 ha experimental watersheds in southern Saskatchewan. Concentrations of phosphorus in runoff in runoff from summerfallow and stubble land were 0.3 and 0.2 mg/1itre, respectively, which exceeded desirable levels recommended in the Saskatchewan Water Quality Criteria. Average nitrate-N concentration in runoff from summerfallow and stubble fields were 1.0 and 0.2 mg/1itre, respectively.

Wind-eroded sediments are not commonly regarded as being a threat to water quality. However, 25% of wind eroded material may end up in roadside ditches and thereby in direct contact with runoff water. Substantial volumes of soil can be trapped in roadside ditches. In 1988, the municipality of Morris in south central Manitoba spent approximately $250,000 removing about 250 000 tonnes of wind-eroded topsoil from roadside ditches (Thiessen 1990).

In Alberta, Larney et al. (1999) reported that wind-borne sediments were enriched with surface-applied herbicides when compared to the concentration in soils remaining in the top 2.5 cm of the field. This demonstrates that the sorting action of erosion has the potential to increase any adverse environmental effects of chemicals adsorbed to silt and clay-sized particles.

FUGITIVE DUST

Fugitive dust is particulate matter which is transported by wind and redeposited elsewhere. It has the potential to impact human health. Visibility problems leading to traffic accidents have been blamed on fugitive dust. Examples of common sources of fugitive dust include paved and unpaved roads, construction and demolition activities, industrial activities and soil erosion (Matsumura et al. 1992; Utah Dept. Env. Quality n.d).

Concerns have been raised that fugitive dust from agricultural operations may contribute to *inhalable* particulate matter (PM). The inhalable size range of PM_{10} consists of particles less than 10μm in aerodynamic diameter. Soil particles can also contribute to the *respiratory fraction* or $PM_{2.5}$, but to a much more limited extent. Health studies have shown that both PM_{10} and $PM_{2.5}$ negatively affect respiratory health. The exacer-

A serious wind erosion event near Fillmore, Saskatchewan, resulting in a large emission of fugitive dust.

Photo by H. DeGooijer

bation of asthma and bronchitis, as well as increased hospital visits, admissions and rates of mortality have been linked to PM_{10} and $PM_{2.5}$ exposures.

Soil particles can serve as vehicles for the transport of materials such as fungi, agricultural fertilizers, herbicides, fungicides and pesticides (Grover 1991; Wheaton 1995). Pesticides adsorbed to dust particles have been found to travel thousands of kilometres, adding to potential health concerns. Strong winds associated with Prairie dust storms provide a significant opportunity for the transport of airborne soil particles.

Large amounts of soil may be held in suspension during major dust storms. Anderson (1984) reported visibilities reduced to less than one kilometre over 155 400 km^2 of the Canadian Prairies on May 14 and 15, 1984. This represents at least 6 million tonnes of soil in suspension.

Monitoring of PM_{10} and $PM_{2.5}$ is infrequent on the Canadian Prairies and the network of monitoring stations is sparse. Measured PM is not traced to the source, thus the proportion of PM attributable to agriculture cannot be determined. This lack of Canadian data has resulted in little more than speculation as to the actual amount of PM_{10} derived from agricultural lands. Many unknowns remain, including the human health effects of agricultural chemicals, the amount of soil currently moved by Prairie dust storms and the amount of inhalable dust produced by wind erosion and tillage.

FIELD-SCALE ASSESSMENTS OF EROSION

There have been several assessments of the extent and severity of erosion on the Prairies using various models. This section will focus only on field-scale research results.

Direct measurement of wind and water erosion is difficult. Erosion is extremely variable and must be measured for many years to obtain a representative sample of events. Unfortunately, there is only one site on the Canadian Prairies where erosion has been monitored for longer than 10 years and results from this and other sites to date, may not well represent the amount of erosion which takes place.

Van Vliet and Hall (1991) determined that water erosion on fallow-canola-barley plots in the Peace River area averaged 4.9 t/ha over six years. A similar rotation, but including fescue, lost an average of only 1 t/ha over the same period.

Shaykewich et al. (1991) measured water erosion at various locations in Manitoba from 1986 to 1990. Results are detailed in Table 3.1. Under conventional tillage systems, more erosion was measured from corn than from wheat. Clay areas lost the most soil, followed by sandy loams, with loam soils being less susceptible to erosion. Minimum tillage reduced erosion on two of the three sites studied. Results were extremely variable due to the timing of heavy rainfall events in relation to soil moisture, crop cover and tillage.

Most measurements of water erosion including Van Vliet and Hall (1991) and Shaykewich et al. (1991) are made on small plots and do not evaluate gully erosion. This form of erosion is common on the Prairies, particularly in the Peace River region and on the slopes of the Missouri Coteau in Saskatchewan. The extent and severity of gully erosion has not been estimated or systematically measured on the Canadian Prairies.

Larney et al. (1995b) reported on wind erosion from an intensively tilled site in a Dark Brown clay loam soil near Lethbridge. The site was monitored for three separate periods between April 1991 and May 1992. There were 16 erosion events ranging up to 11.7 hours in duration. Soil loss per storm varied from 0.5 t/ha to 30.4 t/ha. Total erosion was 144.4 t/ha.

An isotope of cesium (^{137}Cs) was released into the atmosphere by nuclear tests in the 1950s and 1960s. It was deposited through precipitation and was strongly adsorbed to soil particles (de Jong et al. 1982). When compared to an uneroded site, ^{137}Cs concentrations in eroded soils can be used as a tracer of soil movement. Sutherland and de Jong (1990) detailed several assumptions of the ^{137}Cs method, the main being that ^{137}Cs was deposited uniformly within the local area and that runoff and redistribution by snow were minor. Results were an integration of wind, water and tillage erosion between the period of ^{137}Cs deposition and eventual sampling.

Strip farming to combat erosion in north-eastern Manitoba.

The ^{137}Cs data on the Prairies indicates significant soil redistribution within the landscape. Kiss et al. (1986) assessed 43 hill slopes in the Dark Brown soil zone of Saskatchewan and reported high erosion rates over two-thirds of the landscapes. Pennock and de Jong (1987) sampled three 7 to 10 ha areas in the Black soil zone near Saskatoon. They reported that 83% of the sample points in a till soil had suffered a net soil loss. Net soil loss for glacio-fluvial and glaciolacustrine soils were recorded at 89% and 87% of sites respectively. Average erosion was 27, 16 and 21 t/ha/yr for the three sites. Deposition only occurred on 11-17% of the area. Verity and Anderson (1990) reported that severe erosion near Saskatoon had affected 25-30% of the landscape, resulting in potential yield losses of 25-49%.

Pennock and de Jong (1990) measured soil redistribution on a 25 m grid using ^{137}Cs at 21 sites at 7 locations in Saskatchewan (Table 3.2). Slopes were all less than 6% with the majority less than 4%, suggesting that water erosion from the areas sampled would be less severe than on some landscapes in Saskatchewan. Despite the low slopes, 68% of the sample points suffered erosion. Mean soil loss at 19 of the 21 sites exceeded 10 t/ha/yr with an overall average exceeding 19 t/ha/yr. Mean soil loss was two to five times larger than net soil export from the sampling sites, confirming that most soil is deposited close to the eroded area.

The ^{137}Cs data provides a fairly comprehensive picture of the

Table 3.1 Average water erosion (t/ha/yr) measured at 5 sites in Manitoba.

Soil Series	# Years	Wheat CT[1]	Wheat MT[2]	Corn CT
Leary Sandy Loam	5	17.6	N/D[3]	9.7
Gretna Clay	5	33.5	N/D	49.8
Ryerson Sandy Clay Loam	5	3.1	2.8	11.2
Carrol Clay Loam	3	3.5	1.1	14.6
Newdale Clay Loam	2	0.7	0.8	1.3

Source: Shaykewich et al. 1991
Note: [1] CT = conventional tillage
[2] MT = minimum tillage
[3] N/D = no data

extent and severity of erosion in Saskatchewan since the 1960s. There is no reason to expect that Alberta, Manitoba and the Peace River area of British Columbia would be substantially different. All of the ^{137}Cs experiments (including several not discussed here) have, without exception, demonstrated erosion over major portions of the landscape which far exceeds any optimistic estimate of soil formation. Despite the inherent inaccuracies of field-scale assessments of erosion and the sparsity of data, we can conclude that soils on the Canadian Prairies were severely degraded by erosion between the 1960s and the late 1980s.

It is likely that erosion was attenuated in the 1990s by changes to management, including the reduction of summerfallow and the adoption of direct seeding practices. Comprehensive re-evaluation of erosion rates using ^{137}Cs at many of the sites which had previously been investigated is needed to further calibrate existing data and to assess the effects of improved land management practices within the landscape.

The significance of these measured and implied rates of erosion on long-term soil productivity are not fully understood since soil formation rates for the Canadian Prairies are unknown. Erosion tolerances (T) of between 11.2 and 2.2 t/ha have been set for all soil series in the United States based on soil properties and the on-farm economic impacts of erosion (Johnson 1987). Since Prairie soils are frozen for approximately half the year, it is likely that appropriate T values would be about 50% of those suggested for the United States. If this is correct, tolerable erosion rates have been exceeded on most erosion monitoring sites on the Canadian Prairies, and even under minimum tillage systems on occasion. Zero tillage and low disturbance direct seeding are currently employed on less than 50% of annually seeded cropland on the Prairies, leading to the conclusion that current farming practices may not be sustainable over large areas of the landscape.

MANAGEMENT PRACTICES INFLUENCING EROSION

Despite the well-recognized benefits of permanent practices such as grassed waterways, shelterbelts and strip cropping to control wind and water erosion, most farmers rely on crop residues and a resistant soil surface to control erosion from annual cropland. This strategy is usually, but not always, effective in years with good soil moisture and crop residue production. Drought, fire, insect or disease problems, straw harvesting for industrial purposes, use of summerfallow, or low residue crops such as canola and lentils, will reduce or eliminate the margin of safety and increase erosion risk.

In the absence of other soil conservation practices, the amount of residue required to control wind and water erosion varies with many factors. These include the erosivity of the rain or wind event, local topography, soil erodibility, surface roughness and the anchorage of the residue. Dyck (1985) recommended that sandy loam, clay,

Table 3.2 Soil redistribution (t/ha/yr) by soil zone from 21 sample sites in Saskatchewan[1].

Soil Zone	Net Soil Export	Mean Soil Loss	Mean Soil Gain
Brown	- 8.2	- 19.7 (91)[2]	+ 11.4 (65)
Dark Brown	-11.2	- 19.2 (246)	+ 14.7 (78)
Black	- 5.2	- 18.6 (158)	+ 19.1 (93)

Source: Pennock and de Jong 1990

Note: [1] Estimated from soil ^{137}Cs concentrations.

[2] (#) = # sample points from an 8 by 4 grid with 25m between transects.

Table 3.3 Wheat yields and residue carryover in kg/ha from continuous cropping on a Swinton silt loam under zero till near Swift Current, SK[1].

Year	Yield	Anchored Standing Residues	Unanchored Residue	Total Residues
1983	1 755	877	6 277	7 154
1984	343[2]	168	3 008	3 176
1985	521[2]	348	3 180	3 528
1986	2 855	667	2 440	3 107
1987	1 600[2]	618	1 712	2 330
1988	653[2]	279	3 067	3 346
1989	_	1 083	2 183	3 266

Source: Yield data from Tessier et al. (1990); Residue data from McConkey (1999)

Note: [1] Straw measured after harvest

[2] Years with growing season precipitation less than the 100 year average

and loam soils need 2 000, 1 500, and 1 000 kg/ha of standing wheat residue respectively to control wind erosion. To control water erosion, Dyck (1985) recommended 780-1 100 kg/ha of residue on 6-9% slopes, and 1 100-1 700 kg/ha on 10-15% slopes.

Under minimum and zero tillage systems, crop residues decompose more slowly than with intensive tillage. Residues may still be more or less intact for up to three years, depending on the crop type and climatic conditions. Consequently, residue from previous crops may accumulate and continue to control erosion after a low residue crop or a crop failure. Table 3.3 details yields and residue levels from a silt loam in a continuous wheat zero till regime near Swift Current, Saskatchewan. Annual and growing season precipitation was below the 100 year average for all years except 1983 and 1986. Despite low crop yields there was sufficient residue carried over from previous crops to control erosion.

Larney et al. (1994a) reported that for Prairie soils under continuous cropping in higher moisture areas, crop residue levels are generally adequate to control erosion, but that fine and coarse textured soils in the Brown soil zone in summerfallow rotations are susceptible to erosion under conventional and minimum tillage systems. They also noted that irrigated land growing annual crops is frequently at risk to erosion due to the use of intensive tillage practices coupled with low residue crops. Summerfallow after oilseed and pulse crops in the Brown soil zone of Saskatchewan may retain less than 600 kg/ha (Anderson 1968), leaving fields at risk to erosion.

The effects of conventional, minimum and zero tillage systems on dry soil aggregation in continuous wheat and wheat-fallow rotations on three soils in the Brown soil zone of Saskatchewan were reported by Tessier et al. (1990). Under most conditions, soils in zero tillage systems had better aggregation than those in conventional or minimum tillage systems (Table 3.4). However, the soils were poorly aggregated under many treatments, with a sandy loam being in an erodible condition throughout the experiment under all tillage regimes. A silt loam was in an erodible condition each year after fallow under conventional tillage, three out of six years under minimum tillage, and once under zero tillage. In continuous wheat, the silt loam soil was in an erodible condition four out of six years under conventional tillage but not under zero tillage. Aggregation of a clay soil under continuous wheat was quite variable; it was in an erodible condition three out of six years under conventional tillage and once under zero tillage.

Tessier et al. (1990) reported on average crop residue levels after fallow from the above experiment. Chemfallow left significantly more residues than minimum tillage on all three soil types. Conventional tillage was used only on the silt loam, and, on average retained 940 kg/ha residues, leaving this field in an erodible condition. Minimum tillage left sufficient residues to control erosion only on the silt loam, while chemfallow provided adequate residues on the silt loam and clay soils but not on the sandy loam. Residue levels on the continuously cropped fields were not reported but, based on crop yields and the aggregation data in Table 3.4, the sandy loam was

Table 3.4 Effect of tillage on soil erodibility (% aggregates <0.84mm) measured in October under continuous wheat and wheat-fallow rotations on three soil textures in the vicinity of Swift Current, SK.

Soil texture	Year	Continuous wheat		Wheat on fallow			After fallow			
		Conv	Zero	Conv	Min	Zero	Conv	Min	Zero	$S\bar{x}$
Silt loam	1983	42^{b}	36^{b}	40^{b}	41^{b}	40^{b}	67^{a}	62^{a}	35^{b}	2.3
	1984	61^{b}	50^{c}	75^{a}	70^{a}	54^{c}	71^{a}	63^{a}	54^{c}	2.0
	1985	68^{ab}	49^{de}	62^{bc}	70^{ab}	57^{cd}	76^{a}	56^{1}	45^{c}	3.3
	1986	57^{b}	41^{d}	54^{bc}	49^{2}	39^{d}	66^{a}	58^{b}	49^{c}	2.2
	1987	68^{a}	46^{c}	69^{a}	69^{a}	50^{bc}	65^{a}	56^{b}	35^{d}	2.1
	1988	76^{b}	56^{d}	83^{a}	76^{a}	65^{c}	80^{ab}	80^{ab}	62^{cd}	2.1
Sandy loam	1983	77^{bc}	70^{b}		76^{bc}	79^{b}		91^{a}	70^{b}	2.0
	1984	84^{a}	76^{a}		81^{a}	74^{a}		87^{1}	76^{b}	3.0
	1985	92^{a}	87^{ab}		84^{1}	84^{b}		87^{1}	87^{ab}	2.2
	1986	92^{a}	87^{ab}		85^{1}	81^{b}		87^{1}	87^{ab}	2.7
	1987	89^{a}	77^{bc}		80^{1}	74^{cd}		83^{b}	77^{bc}	1.9
	1988	93^{a}	85^{b}		85^{b}	79^{c}		94^{a}	85^{b}	1.8
Clay	1983	49^{bc}	43^{c}		51^{bc}	51^{bc}		71^{a}	51^{bc}	3.3
	1984	56^{ab}	43^{c}		63^{ab}	42^{c}		66^{a}	42^{c}	3.6
	1985	59^{a}	48^{b}		63^{1}	50^{b}		60^{1}	50^{b}	3.0
	1986	55^{a}	39^{c}		64^{1}	50^{b}		60^{1}	50^{b}	1.5
	1987	60^{a}	56^{ab}		73^{1}	64^{a}		65^{1}	64^{a}	3.2
	1988	82^{a}	72^{b}		82^{1}	81^{a}		82^{a}	81^{a}	1.1

Source: Tessier et al. 1990

Note: [1] Data were excluded from the analysis of variance since they represent occasions when no tillage was required or performed on the minimum tillage fallow treatments.

Conv = conventionally tilled fallow or preseeding tillage only on continuous wheat;

Min = minimum tillage fallow;

Zero = zero - tillage fallow or seeding

Conventionally tilled fallow was not performed on the sandy loam and the clay soils because of a high risk of erosion on these plots.

Means followed by the same superscript within years and soil textures are not significantly different at the 0.05 level of probability (Duncan’s new multiple range test)

Soils with > 60% surface aggregates < 0.84mm diameter are in an erodible condition (Anderson and Wenhardt, 1966) likely at risk to erosion under conventional tillage and somewhat at risk under zero tillage from 1985 to 1989. The wheat on the clay soil was hailed in 1983 and 1986, and there was a crop failure in 1988, leaving the clay soil somewhat at risk to erosion in 1988 and 1989 even under zero tillage.

Larney et al. (1994b) and Johnston et al. (1994) evaluated summerfallow management systems for overall erosion risk on a clay loam soil in a wheat-fallow rotation at Lethbridge between 1977 and 1991. The data are summarized in Table 3.5 and can be interpreted by noting that Bisal and Ferguson (1970) recommended that soils with 40% aggregates greater than 1 mm diameter would require about 500 kg/ha of 15 cm high standing wheat residue to be protected against wind erosion. They further recommended that soils with 30% aggregates and 20% aggregates were estimated to require 1 000 and 2 700 kg/ha standing wheat residue respectively, for soil protection.

It is likely that residues remaining after summerfallow with the one-way disc and the heavy-duty cultivator would be flat and partially standing, leading to the conclusion that these fields would probably be vulnerable to erosion. The remaining treatments would be stable against erosion based on the average data presented here. However, substitution of low residue crops, crop depletion due to pests or disease, or reduced yields during drought would likely result in all treatments being vulnerable to erosion.

The trend towards direct seeding, less fall tillage and an increase in intensity of rotations at the expense of summerfallow, has probably reduced tillage erosion. Additional reduction of tillage erosion could be achieved by using less erosive implements, reducing tillage speed and further reducing tillage frequency and intensity.

Better crop residue management through direct seeding and substitution of herbicides for tillage have substantially reduced, but not eliminated, the risk of erosion. PFRA crop residue surveys have consistently recorded low levels of residues on Saskatchewan cropland after seeding. The 1998 survey found that 62% of seeded fields and 12% of fields which were to be summerfallowed in 1998 had less than 550 kg/ha crop residue and were at risk to erosion (PFRA unpublished data). It is unlikely that residue levels were any higher in Alberta or Manitoba.

It can be concluded that more than 50% of annually cropped fields are exposed to erosion each year on the Prairies. The reduction of summerfallow and

Table 3.5 Summerfallow practices in relation to crop residue levels, and soil aggregates > 0.84 mm for a clay loam soil at Lethbridge, AB.

Fallow Treatment	Tillage Operations	Residue Cover kg/ha[4]	% Aggregates >0.84 mm Fall	% Aggregates >0.84 mm Spring[4]
One-way Disc	2	408	60.6	42.5
Chemfallow	0	1 514	47.8	36.4
H/D Cult[1]	3	669	56.8	42.9
W/B Cult[2]	3	1 174	52.5	38.6
W/B & Herbicides[3]	1	1 248	49.7	36.5

Source: Johnston et al. 1994

Note:
[1] Heavy Duty Cultivator
[2] Wideblade Cultivator
[3] Glyphosate during fallow with 1 pass with a wideblade cultivator in the fall of the fallow year
[4] Both measurements taken before seeding

fall tillage, combined with the adoption of direct seeding systems, has narrowed the period during which soils are exposed. However, there remains ample opportunity for erosion from fields in high disturbance seeding systems. Severe and widespread erosion could still occur during extreme climatic events and especially during a period of years with back-to-back droughts.

> ***The fact that serious erosion events are infrequent can create the perception that erosion has been controlled by improved farm management. In the 1970s, it was commonly believed that the residue from high crop yields would control erosion. Dust storms in 1979 and 1981 soon focussed more attention on soil conservation when it was realized that intensive tillage during summerfallow and the incorporation of soil applied herbicides was leaving the soil exposed to erosion.***

Probabilities of Erosion

Soil redistribution from wind and water action is dominated by extreme events resulting from highly erosive storms impacting on poorly protected soils (Chepil et al. 1962; Wischmeier 1962; Larson et al.1997). For example, two large rainstorms totalling 116 mm in June 1990, caused serious water erosion near Deerwood, Manitoba. Adjacent PFRA water erosion plots lost an average of 175 t/ha and 145 t/ha soil, respectively from conventional and minimum tilled plots in a wheat-oilseed rotation (PFRA unpublished data). Analysis of rainfall data indicates that the precipitation energy received in 1990 would recur, on average, once in 30 years. Soil eroded from the conventional and minimum till plots in 1990 was 70% and 73%, respectively, of the total soil eroded during the operation of the plots from 1986 to 1993.

The low probability of severe erosion events presents problems for farmers. Some soil conservation practices are costly or inconvenient, so farmers must weigh the benefits of practices against the cost. An incorrect land management decision by a farmer may result in severe erosion damage and a long-term reduction in soil productivity. Society as a whole must decide if the soil is to be treated as a renewable resource and, if so, who should pay to protect the soil against sporadic severe weather.

Conclusions

There is indisputable evidence that soil erosion on the Canadian Prairies seriously depletes soil productivity and can cause environmental degradation. In addition, there is no question that serious erosion, well beyond the rate of soil formation, occurred in Saskatchewan between the 1960s and the 1980s. Conditions were similar in many other areas of the Prairies.

Since the 1980s there has been a large reduction in summer-fallow area and a significant uptake of soil conservation practices such as direct seeding. However, field monitoring in Saskatchewan in 1997 and 1998 showed that the majority of seeded fields were still dangerously exposed to erosion.

Adoption of minimum and zero tillage systems will not necessarily eliminate soil erosion. Occasionally fields will erode after summerfallow, low residue crops, drought, disease, fire, or injudicious straw harvesting. Further work is needed to evaluate the probabilities and significance of such events in relation to soil sustainability.

Zero tillage and low disturbance, direct seeding systems, when combined with continuous cropping rotations, can control erosion and reverse some of the damage done in the past. These practices will not replace the fine soil fractions which have been lost, or recover the rooting volume, but given adequate fertilization, the equilibrium levels of soil organic matter can be increased. This will enhance the physical, biological and chemical properties of the soil and increase its productivity.

Very severe wind and water erosion is dominated by infrequent occurrences when highly erosive events impact exposed soil. Such events may only happen once during the farming lifetime of an individual farmer, making it difficult to justify the expense and inconvenience of many soil conservation practices.

In many circumstances, permanent soil conservation management such as shelterbelts, strip cropping and grassed waterways are required to supplement crop residue management systems. However, these practices may be problematic for large farm equipment.

Research and public awareness programs are required to enhance and demonstrate the effectiveness of conservation practices, and to develop new soil conservation systems. In situations where permanent conservation practices are required to adequately control erosion, there is a need for government to support these practices in order to maintain the productivity of soils in the Canadian Prairies.

Soil Salinity on the Prairies

Saline soils are those that contain enough soluble salts in the root zone to adversely affect the growth of most crop plants. Saline soils are caused by a combination of geological, climatic and cultural conditions. Salinity arising from pre-settlement conditions is often referred to as *historic salinity*, while saline areas believed to arise primarily from post-settlement management (cultural conditions) are often called *saline seeps*. The distinction between these two categories, however, has not always been clear to those estimating the extent of salinity or its projected spread.

Water from precipitation during fallow or idle periods between crops is thought to be the primary source of the more recent saline seeps (Black et al. 1981). However, there is evidence that some suspected seeps may simply be a cycling of historic salinity due to changing climate and weather (Harker et al. 1996).

Figure 3.5 is a simplified diagram which illustrates a possible mechanism for salinization. PFRA's 1983 publication, *Land Degradation and Soil Conservation Issues on the Canadian Prairies* describes the process of salinization in greater detail.

SALINITY EFFECTS

The effect of salinity on soil quality can result in changes in physio-chemical processes such that there is a reduction in the capabilities of the plant to

Photo by Dave Reede

Conservation tillage practices improve soil quality, thereby increasing opportunities for crop diversity.

extract moisture from the soil. This is due to the direct chemical effects of salt disrupting the nutritional and metabolic processes of the plant, or to the indirect effect of salt altering the structure, permeability, and aeration of the soil (Brown et al. 1983).

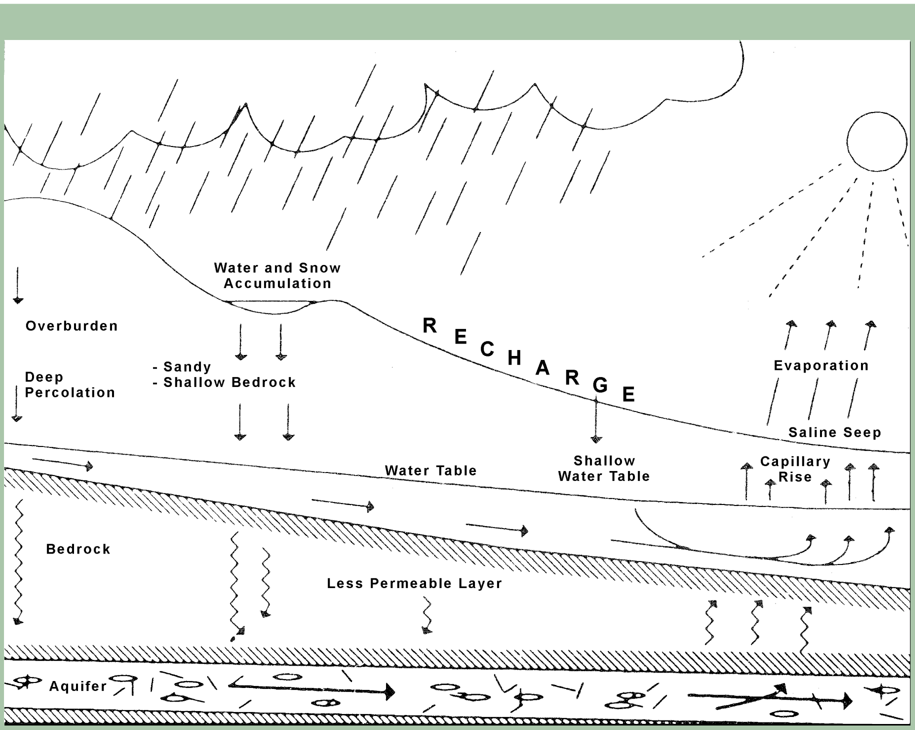
The extent to which plant growth is affected by salinity depends on several factors: soil texture, salt distribution in the soil profile, salt composition, plant species and variety, weather sequences, and proximity of the root zone to water sources.

The distribution of salts within a soil is heterogeneous. As a consequence, measuring the response of a crop grown in saline conditions can yield highly variable results (McColl et al. 1986; Eilers 1998). Despite this variability, plant varietal differences and some differences due to the kind of salt present, the response of a given crop to salinity is sufficiently common that crops can be classified according to their salt tolerance. Ongoing research is defining the classification process for Canadian crops, particularly with respect to variety tolerances and effects of specific ions (Stepphun and Wall 1999).

The 1984 Expert Committee on Soil Survey classified saline soils according to their moderate to strong salt content at two different depths (Table 3.6). However, effects on plant growth suggest that yield reductions of 10-20% in wheat and other sensitive crops are attributed to low-level salt concentrations (Steppuhn 1996). Although separating the effects of *invisible salinity* from water deficits in the field remains difficult, it is known that reduced plant growth results from a combination of the two (Bresler et al. 1992).

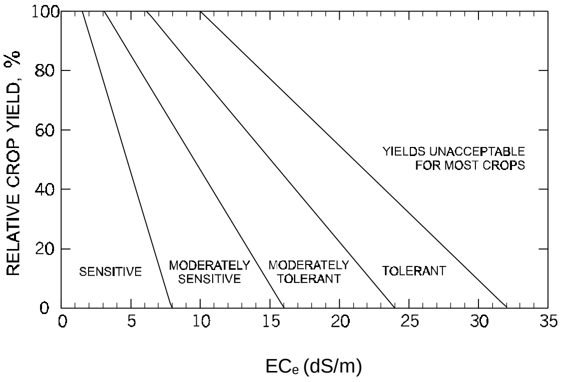
Figure 3.6 generalizes different crop salinity tolerances, showing percent of yield reduction for different tolerance groups as salt concentrations increase. This relationship seems to hold true for trees and shrubs, but not for a number of grass species. Although trees react to salinity in much the same manner as do annual crops, trees may be even more sensitive to salinity (Woods et al. 1993).

Relative productivity of an irrigated forage (from the second year of a southern Alberta trial) reveals that some species yield more at higher salinity levels (McKenzie et al. 1994). This contradictory trend was attributed to the fact that higher moisture contents are often associated with increasing salinity. Table 3.7 provides relative salinity tolerances for a number of annual field, forage



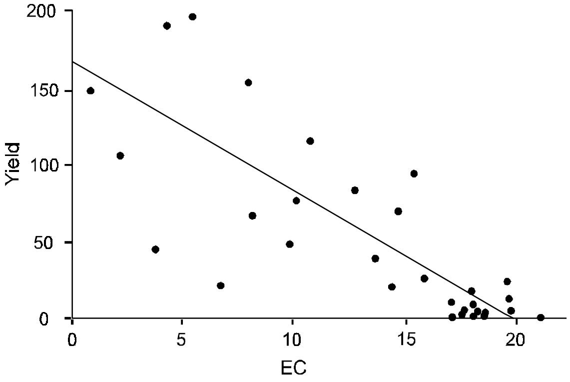
Source: Alberta Agriculture 1986

Figure 3.5 The salinization process.



Source: Richards 1954

Figure 3.6 Divisions for selecting crop tolerance to salinity.



Source: McColl et al. 1986

Figure 3.7 Linear regression of barley yields vs. electrical conductivity.

and vegetable crops. Figure 3.7 illustrates a simplified linear response between crop yield and ECe (electrical conductivity of the saturated extract) in decisiemens per metre (dS/m) for a barley variety. In general, as salinity increases, crop yield decreases. The effect of salinity on other crops is often greater.

The variable extent of soil salinity concentrations is due to the dynamic nature of salt movement as influenced by management practices, water table depth, consumptive water use, rainfall and salinity of the perched water table (Rhoades and Corwin 1984). Wilson (1964) found that soil samples taken 0.6 m apart in southern Manitoba (at the same depth, at the same time) had up to ECe 6 dS/m difference. The large number of such variables involved in the formation of saline seeps make interpretation of data within and across studies difficult.

Other effects of salinity are often reported but seldom given a monetary value. Some of these losses occur from mired machinery, loss of inputs such as seed, fertilizers, and sprays that provide insufficient crop production and inefficiencies of farm-

Table 3.6 Classification of soil salinity (dS/m).

Depth (cm)	Non	Weak	Moderate	Strong	Very Strong
0 - 60	<2	2 - 4	4 - 8	8 - 16	>16
60 - 120	<4	4 - 8	8 - 16	16 - 24	>24

Source: Eilers 1984

ing fragmented fields. Loss of production or death of livestock and the cost of hauling better quality water for livestock and domestic use are either unknown or unreported. Deterioration of surface and shallow groundwater sources in Montana is deemed to be equally as serious as the loss of arable land (Miller 1980). Water sources on the Canadian Prairies might be similarly affected by the natural process of salinization.

CAUSES OF SALINITY

Soil Water

Water is the medium that transports salts. Water in excess of the available water-holding capacity of the soil may contribute to saline conditions. The geologic material through which water passes is usually the source of the salt. When the water table comes near the soil surface, evapotranspiration concentrates salts at, or near, the surface. The critical depth of the water table in the non-irrigated semi-arid Prairie region is approximately 2 m, and for

Table 3.7 Relative Tolerance of Crops to Salinity.

Degree of Salinity Tolerated (Electrical Conductivity dS/m)	Annual Field Crops	Forage Crops	Vegetable Crops
Non to Slightly Saline (0-4)	Soybeans Field beans Fababeans Peas Corn	Red clover Alsike Timothy	Peas Beans Onions Celery Radishes Cucumber Carrots Corn (sweet)
Moderately Saline (4-8)	Canola Flax Mustard Wheat Fall Rye Oats 2 - Row barley Safflower	Reed canary Meadow fescue Intermediate wheat Crested wheatgrass Bromegrass Alfalfa Sweet clover	Tomatoes Lettuce Cabbage Potatoes Peppers Spinach Asparagus Garden Beets
Severely to Very Severely Saline (8-16)	Barley may produce some crop but this land best suited to tolerant forages	Altai wild ryegrass Russian wild ryegrass Slender wheatgrass Tall wheatgrass Beardless wild ryegrass Levonns alkaligrass Alkali sacaton Salt meadow grass	

Source: Henry et al. 1987

the more humid central and northern agricultural regions, it is about 1.5 m (VanderPluym and Harron 1992).

Steppuhn and Curtin (1992) identified five conditions necessary for the formation of root-zone salinity:

- evapotranspiration exceeds precipitation, resulting in frequent moisture deficits
- subsurface water (from precipitation or irrigation) is transported upward through the soil
- subsurface waters dissolve salts or mix with saline groundwaters
- internal drainage (away from the root zone) is restricted for part of the year
- a hydraulic connection exists between the near surface and salt-bearing strata.

Weather and Climate

Moisture deficits, drought and periods of above average rainfall can create a climate conducive to saline seep development. Annual weather variability can have a major influence on saline lands, often causing seeps to form or enlarge after wet years, with little or no increase in dry periods (Miller and Bahls 1976).

In a southern Alberta study using air photos, changes in historical (long-term) salinity on the Blood Indian Reserve were tracked over a period of 55 years. Despite significant visual fluctuations, changes in dryland salinity could not be correlated with increasing cultivation or with changing crop/fallow ratios. Salinity changes appeared to be mainly a function of climate and weather patterns. These findings suggested that saline sites were not expanding, but that apparent increases were simply a recycling of salts within historically saline lands (Harker et al. 1996).

Land Management

Land management is believed by many to be the major influence on recent saline seep development and expansion. Choice of crops, summerfallow practices, snow management and drainage allow some control over water entry into soils and water movement below the root zone.

The breaking of the Canadian Prairies for agriculture and the use of summerfallow may influence the formation of saline seeps. In Alberta, Christie (1976) found that the area in saline seeps on pasture lands (Peigan Indian Reserve) doubled between 1961 and 1970, while seep-area under cultivation ratio tripled. A salinity study in Stark County, North Dakota, showed a 2.5 fold increase in saline seeps, primarily on pasture land between 1950 and 1975. By comparison, areas primarily in crop-fallow showed 7-14 fold increases (Miller et al. 1974). Nevertheless, it can be difficult to differentiate cultural from climatic effects.

Implementing practices that reduce the accumulation of soil water in excess of crop needs may help control salinity. In some cases small Prairie wetlands have dried up after a few years of planting the surrounding area with smooth brome grass and alfalfa (Van der Kamp et al. 1998). Judicious use of well-maintained shelterbelts and barrier strips such as tall wheatgrass, or stubble cut at different heights, standing stubble, and ample crop residue can all contribute to more evenly distributed moisture under continuous cropping. Most effective is the use of deep-rooted crops such as alfalfa in the associated groundwater recharge area (where percolating surface waters can contribute to groundwater flows). This can be accompanied by cropping strategies to use precipitation before it moves beyond the root zone.

Improvement in saline hydrologic conditions can be achieved in a relatively short time (2-5 years), if the major part of the recharge area is appropriately cropped. This can reduce the amount of water that percolates through the soil, thereby lowering the water table and reducing the potential for salts to move upward into the root zone with the evapo-transpiration of water (Black et al. 1981).

A study in Manitoba compared 1986 and 1992 surveys of an area planted to a variety of grasses near The Pas, Manitoba. There was a sharp decline in severely saline areas, and two hectares that had been severely saline improved to only slightly saline (Theile and LeSann 1995). At a site in southern Alberta,

Saline lands may be recent seeps as a result of post-settlement management, or historic in nature.

after 15 years in a mixture of salt tolerant grasses, the water table dropped from 0.3 to 4.27 m below ground. The EC (bulk electrical conductivity) in the top 6.25 cm of soil had fallen from greater than 16 dS/m to 1.5 dS/m. At 0.30 m depth, the EC was unchanged at 12.4 dS/m (Wood 1997).

ASSESSING EXTENT OF SALINITY

Initial detections of salinity are usually visual. The presence of salt crusting or salt tolerant weeds are obvious indicators. Less obvious signs may be a slight reduction in crop yields, darkening in stubble colour, more luxurious crop growth than the rest of the field, rank weed growth, prolonged wetness particularly under summerfallow, and/or cloddiness when cultivated. These signs often occur at the base of breaks in topography, in low-lying areas, or near places that accumulate water or snow. Newly developed seepage areas may also be a clue to impending salinity.

Electromagnetic (EM) induction sensors such as the EM_{38} (and to a lesser extent the EM_{31} and EM_{34}) are used at the field scale to measure and monitor soil salinity in large areas. Although these instruments provide remote and rapid measurements (Rhoades and Corwin 1984), this method is not recommended for fields with substantial heterogeneity other than salinity (Lesch et al. 1992).

Coupling of electromagnetic meters with global positioning systems (GPS), and using a geographic information system (GIS) to process data, can give a rapid and locationally accurate estimate of salinity (Lachapelle et al. 1993). An added advantage of GPS is that elevation can be recorded at the same time, and data is in digital form so that overlaying with other digital information such as soil maps is an easy operation (Kwiatkowski et al. 1995).

Satellite imagery and aerial photography have been commonly used to visually map salinity. However, soil salinity can be difficult to detect due to its wide range in spectral reflectance. The effectiveness of salinity mapping is, at times, limited by an incomplete appreciation of the factors essential to its consistent detection, mapping and monitoring (Harker et al. 1988). Although the spread of salinity has been documented for many local sites, there is a temptation to extrapolate beyond these conditions, creating the possibility that broader-scale estimates may be misleading.

Using a standard methodology, Soil Survey teams have produced salinity maps of each Prairie province. This process included the compilation, evaluation and verification of existing salinity maps. Air photo interpretation, geographic and land form characteristics, as well as a number of soil and plant indicators aided in the process. Field verification used diagnostic clues and electromagnetic induction techniques. Soils were classified as having strong surface salinity when the 0-60 cm depth was ECe 8 dS/m or more. Saline areas were divided into six categories, based on the percentage of a soil polygon affected by salinity. In cases where subsurface salinity (60-120 cm depth) was identified, this was classified into one of three subsurface categories.

Methods of controlling salinity include:

- ***preventing and retarding the accumulation of water and salts in near-surface positions***
- ***lowering groundwater tables to reduce salinization rates***
- ***removing salts from the root zone***
- ***controlling the amount of water penetrating recharge areas***
- ***growing salt-tolerant vegetation.***

(Steppuhn and Curtin 1992)

The small-scale maps produced by Soil Survey were derived using information gained from more detailed surveys. Eilers et al. (1997) have suggested that the total extent of moderate or more severe salinity (resulting in a 50% reduction in productivity for the Prairie region) is 1.4 million hectares. Figure 3.8 shows the location of five salinity risk classes across the Prairies. Within each Prairie province, the combined extent of primary and secondary salinity leading to a 25% reduction in productivity (VanderPluym and Harron 1992) was found to be:

- Alberta - 0.65 million ha
- Saskatchewan - 1.34 million ha
- Manitoba - 0.25 million ha.

Based on soil samples submitted by farmers to the Saskatchewan Soil Testing Lab (1992-1994), an additional 10 million hectares have been estimated as slightly salinized in Western Canada, with ECe between 1 and 4 dS/m (Steppuhn 1996). Estimates of the extent and severity of salinity appear to suffer from a lack of consistent terminology, lack of standardization and lack of sufficient mapping detail to assess status other than in rather gross terms. The variability of salts in the soil may be such that distinguishing between very low and moderate salinity classes is not possible.

IMPLICATIONS FOR CONTROL

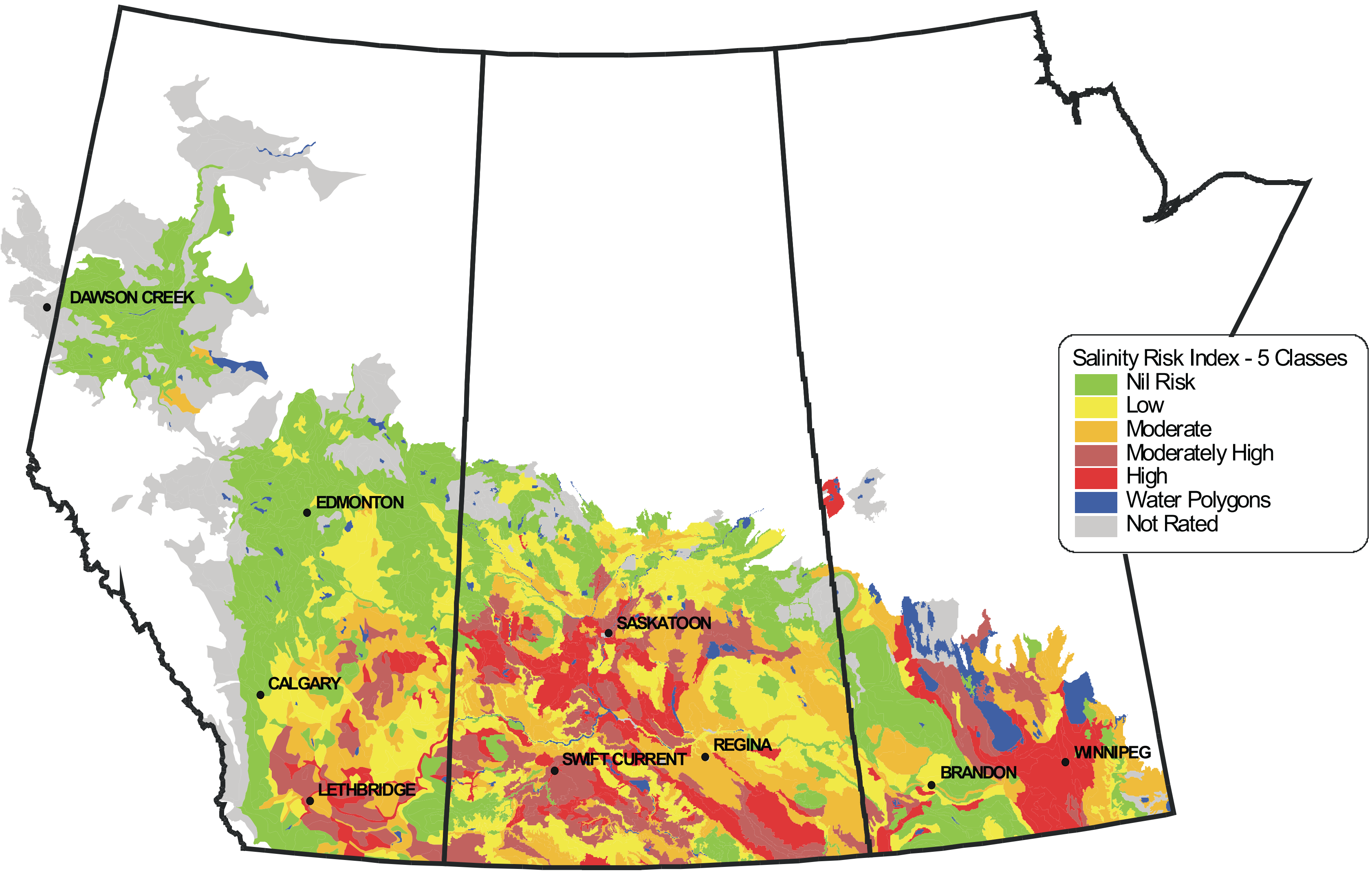
Wide variation in estimates of salinity extent and severity makes it difficult to project economic loss. However, we do know that after the breaking of the Prairies, some of the most productive farmlands rapidly became saline, representing a significant loss in productive capacity.

Some saline areas have developed as a consequence of land management, and the spread of some of these may be alarming. However, attributing economic loss to all saline lands would be similar to applying losses to all sandy lands because they don't produce as much as soil of heavier texture.

If a historically saline area is planted to a non-tolerant crop, should the loss in yield be attributed to soil salinity or to a lack of proper crop management? In the case where a farmer seeds saline lands to tall wheatgrass and earns more from the saline lands than from cropped land, is salinity considered an economic loss or a gain?

Economic assessments should be confined to crops suited to saline seeps and their respective recharge areas.

Cropping for salinity control is far from a precise science. The accumulation of water in near-surface positions can be prevented by improving drainage of surface depressions. Removal of tall grasses and willows may reduce surface accumulations of snow, but removal of willow rings around sloughs can actually hasten slough-ring salinity by trapping less snow



Source: Eilers et al. 1997

Figure 3.8 Soil landscape component Salinity Risk Index.

and increasing evapotranspiration. Continuous cropping and selection of high moisture-use crops can use water before it has a chance to leach beyond the root zone. Where moisture is more limiting, the practice of flex cropping (planting when sufficient subsoil moisture is available) should be encouraged.

Lowering the groundwater table sufficiently to prevent capillary water from moving into the root zone is the most effective means of dealing with salinity directly within the saline seep. Growing deep-rooted perennial plants will promote leaching of salts. The rate of reclamation may be reasonably rapid if the seeps are newly formed and the quantity of salt to be leached is small. On the other hand, saline areas that have accumulated salt over a long period of time may require decades of leaching. Additional water for leaching may be accumulated through snow trapping, or through the use of chemical fallow instead of cultivated fallow.

Water management on recharge areas is integral to reclamation. Water entering recharge zones can raise water tables overall, increasing the salinity problem in the discharge area. Identifying the recharge zone can be important for control, and establishing deep-rooted perennials on recharge areas has proven beneficial. Controlling salinity means managing saline lands (whether historic or seeps) according to their salt and water content. In many cases, that may mean utilizing saline lands for forage rather than annual crop production.

Conclusions

Although salinity is clearly a problem on the Canadian Prairies, a number of strategies exist that may mitigate its effects. The history and current salinity status of the land should be primary considerations in determining specific conservation practices and whether and where individual crops are grown. Also required is a sound knowledge of associated surface and groundwater management practices. The extent to which the effects of salinity can be controlled hinges upon the effective management of affected lands according to their salt and water content.

The extent to which salinity can be controlled hinges upon the effective management of affected lands according to their salt and water content.

Soil Organic Matter on the Canadian Prairies

Soil organic matter (SOM) is a vital component of the soil fabric. SOM is comprised of a variable mixture of chemical components, ranging from relatively undecomposed plant litter to a highly decomposed inert fraction, which is unaffected by land management practices.

Within this wide range of decomposition products, lies the *dynamic* or *active* fraction of SOM. It is comprised of soil microflora and micro and meso-fauna (soil microbial biomass), together with the products of decomposition, including humic substances and organic constituents. SOM contains the elements: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S) and phosphorus (P). The most abundant element is C, accounting for about 58% of the mass of soil organic matter. Changes in soil organic carbon (SOC) are proportional to changes in SOM. Accordingly, SOC may be used as a substitute for describing soil organic matter.

The conversion of native Prairie to agricultural land has resulted in changes to soil organic matter. Approximately 25% of the original mass of SOM has been lost due to annual crop production. There have been changes to the constituents of SOM chemical composition of carbohydrates, humic and fulvic acids, fatty acids and the source of carbohydrates. The nature of the change is strongly linked to the composition of plant species and the frequency of bare fallow in rotations (McGill et al. 1988). Changes to the chemical nature of SOM have been found to directly contribute to cation exchange capacity, soil aggregation and structural stability and the persistence of organic matter in soils. The quality of SOM in a particular soil is equally, if not more important to overall soil quality, than the total amount present (Dinel et al. 1998).

As SOM increases, soil acts as a sink for atmospheric carbon from CO_2. This ability to accumulate carbon helps counteract the emission of the greenhouse gas carbon dioxide (CO_2). SOM also acts as an environmental filter. It can retain and transfer heavy metals and pesticides and frequently helps reduce the incidence of plant pathogens (Monreal and Kodama 1997; Monreal 1999).

Because 83% of Canada's agricultural land is located on the Prairies, SOM in Prairie soils dominates national accounts of SOM (Smith et al. 1997). With such large accounts of SOM, the Prairies could play an important role in offsetting greenhouse gas emissions through carbon sequestration.

THE DYNAMIC (OR ACTIVE) FRACTION OF SOM

The dynamic fraction of SOM contains labile components, including carbon (C) and nitrogen (N) in faunal or microbial biomass, most of which originates in plant litter. The turnover time of this fraction ranges from a few years to several decades, with a typical half-life of approximately 10 years. Common terms used to describe portions of this fraction include: light fraction organic matter (LFOM), light fraction organic carbon (LFOC), particulate OM, macro-organic matter (MOM), mineralizable C and N (C_{min}, N_{min}), coarse OM, and OM in macroaggregates (Janzen et al. 1997). Gregorich and Janzen (1996) have described dynamic SOM as *"play[ing] an important role in determining the structure and function of the soil ecosystem by acting as an energy source for heterotrophic organisms and as a reservoir of relatively labile C and plant nutrients"*.

The size of the dynamic pool of SOM depends on the relative rates of plant litter input, and the rate of SOM decomposition. The first process is linked to crop yield and the amount of litter and crop residues returned to the soil. Equally important in managing SOM is the rate of SOC decomposition to CO_2. Practices that suppress decomposition rates will lengthen the turnover time of dynamic SOM, resulting in SOM accumulations (Janzen et al. 1997).

THE INFLUENCE OF SOM ON SOIL PROPERTIES

Soil organic matter has a very high potential cation exchange capacity (CEC). The high CEC enables the SOM to hold cationic plant nutrients, such as Ca^{2+}, K^{+}, Na^{+}, and Mg^{2+} within the rooting zone and reduce nutrient losses through leaching. This reactivity also helps buffer against changes in pH due to fertilizer or atmospheric deposits of acidic compounds (Curtin et al. 1996; Curtin and Rostad 1997). Similarly, SOM may also help attenuate the environmental effects of heavy metals such as lead and copper in soils (Liang et al. 1991; Sheppard and Thibault 1992). Soil organic matter provides an important source of nutrients. Soils that have built up substantial SOM reserves, such as those in the Black soil zone, may release more nitrogen for crop production, as measured by potentially mineralizable N. Soil organic matter also increases the water holding capacity of a soil. Therefore, building up organic matter levels in soils through zero tillage or low disturbance direct seeding, when combined with extended rotations and adequate fertilizer inputs, could improve moisture status under dry conditions.

The enhanced rates of organic matter accumulation observed under forages is due to the infrequent use of tillage and large root mass.

Soil organic matter and soil aggregates are intimately associated with one another. This relationship is important since soil aggregation affects many soil processes, including air and water exchange and percolation through soils, soil erodibility and soil tilth. On one hand, soil organic matter is widely regarded as an aggregate-stabilizing agent as a result of processes involving specific biochemical and chemical components of SOM (Monreal, 1999). Fuller et al. (1995) and Boehm and Anderson (1997) report that the binding agents are mainly persistent roots, fungi, hexose carbohydrates and mucilages. At the same time, soil aggregates are also believed to protect organic matter against degradation (Campbell et al. 1996; Franzleubers and Arshad 1997).

Tillage practices can influence both aggregate stability and SOM content. For example, compared with conventionally tilled soils, zero tillage increased soil organic carbon storage in aggregates between 1.0-5.6 mm diameter of surface soils relative to SOC quantities stored in smaller aggregates (Campbell et al. 1996). Zero tillage may also increase the total amount of SOC in the 0-5 cm soil depth, compared with the amount of SOC in the same depth of a conventionally tilled soil.

SOM CHANGE

Concentrations of soil organic matter within a specified depth of soil can change for four primary reasons:

1. tillage-induced dilution of SOM in upper soil horizons by mixing with soil from lower horizons (the upper horizon may have been naturally thin, or it may have been truncated by erosion)

2. incorporation of low OM-containing sediment (deposited by erosional processes) into the Ap horizon (ploughlayer) by tillage
3. changes in the ratio of additions/removals of plant materials, manure additions and compost
4. selective removal of the organic fraction by wind or water erosion.

In contrast to changes in SOM concentration, the total mass of SOM in a soil profile is changed only by mechanisms 3 and 4 above. Shallow soils may be tilled below the depth of the original Ah horizon. Tillage mixes soil from the surface (A horizon), which has a higher SOC concentration, with soil from the B horizon, which has a low SOC concentration. Compared to the original Ah horizon, the mixed Ap horizon is thicker, and the SOC concentration is lower; however, the mass of SOC has not changed. Figure 3.9 provides a comparison between an uncultivated soil profile and a cultivated soil profile.

Erosion may redistribute SOC within a field, or it may remove it entirely, depositing it into ditches and waterways, or onto landscapes many kilometres away. Although redistribution by erosion will alter the concentration of SOC in a given sample, changes in the total mass of SOC within the regional landscape are usually small.

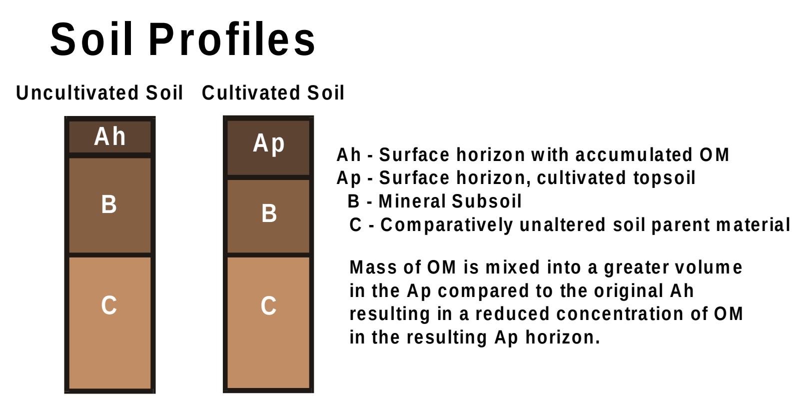


Figure 3.9 Soil profiles, uncultivated and cultivated soils.

MEASUREMENT: CONCENTRATION VS. MASS

Measurements of SOC are made on soil samples of a few grams each. These samples represent large and highly variable soil masses and volumes. As a result, it is difficult to represent SOC on a regional geographic basis (Ellert et al. 1999). Variation in mass of SOC due to management must be separated from variability due to landscape position by sampling specific sites over time.

Literature on proportional changes in SOC can be ambiguous. Such ambiguity arises from at least three sources. The first source of ambiguity in SOC content relates to measurement. SOC is not consistently reported in one form of measure; it is reported in either mass (kg/ha) or concentration (g/kg). The two ways of calculating SOC can yield contrasting results. For example, change in mass may be only half as great as change in concentration.

Concentration of SOC is an important parameter relative to soil physical properties, soil chemical reactivity and soil fertility. Mass of SOC is pertinent to estimations of SOC mass balances, C budgets, greenhouse gas emissions and landscape level models. Although inter-convertible through soil bulk density, the two measures are not substitutes for each other, nor is one measure superior to the other. They simply answer different questions. For example, when answering a question related to soil fertility, the measure of concentration to a specific depth may be used, whereas a question related to C budgets would be addressed using a mass measure.

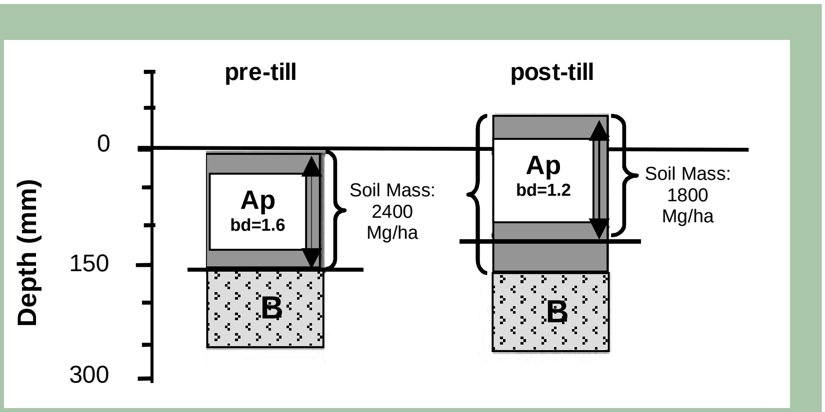


Figure 3.10 Tillage-induced changes in soil horizonation, bulk density (bd Mg/m^3) and mass; tillage increases the thickness per unit area (i.e. volume) occupied by the same mass of soil and organic C, thus misrepresentations are inevitable for calculations based on a fixed 0 to 150 mm layer (indicated by the double arrow) and quite likely for calculations based on identification of the boundary between the Ap and B horizons.

The second source of ambiguity in reporting of SOC changes is a lack of equivalent soil mass. Organic matter storage in soils depends on soil thickness and soil bulk density. Ellert and Bettany (1995) noted that many researchers quantified SOM storage as a product of concentration, soil bulk density and soil thickness. This calculation does not account for differences in soil mass when comparing different sampling sites using the same thickness of soil or equivalent horizons. Due to site variability or tillage induced changes, the mass in a slice of soil from one treatment often exceeds that of another slice of the same thickness (Figure 3.10), which may result in misinterpretation of the data.

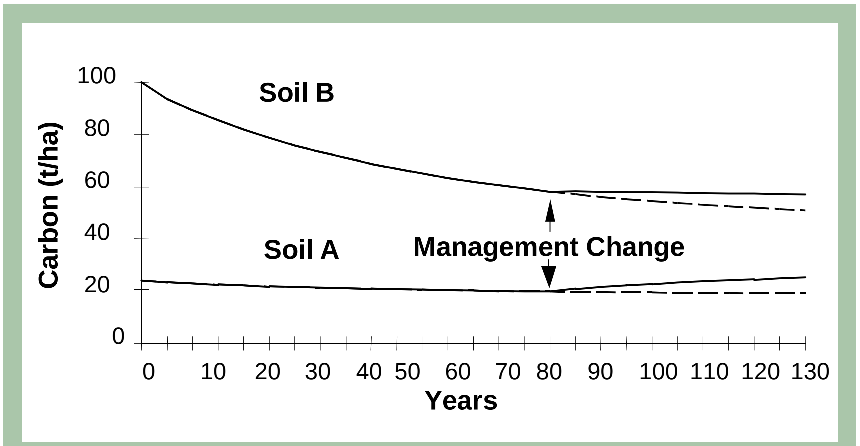
Equivalent soil mass is best suited to comparisons of small homogeneous plots in close proximity which have not been subject to erosion. At the landscape level, SOC modeling and the use of spatial statistics, coupled to soil sampling protocols including each genetic horizon (down to the C horizon), is less ambiguous (Monreal 1999).

The third source of ambiguity is related to the way changes in SOC are reported. Often there is a failure to distinguish between actual gains and avoided losses of SOC. Carbon storage in the soil is sensitive to the condition of the soil at the time a management practice is implemented. Figure 3.11 illustrates how the mass of SOC present at the introduction of a new management practice affects the outcome of the SOC change. Application of the same management practice at the same point in time resulted in a carbon gain for soil A, but only slowed the loss of carbon for soil B. When implementing management changes that may increase the mass of SOC, or reduce its rate of loss, the rate of C gain (Mg/ha/yr) increases at first, but subsequently declines. As a result, it may be misleading to extrapolate rates of change in SOC from a few short-term field measurements.

Simulation models have been used to predict SOC trends across the Prairies. Model projections of change in the mass of SOC in the Prairie soils range from a decrease to a slight increase. Several models will reasonably mimic the data from long-term field plots. However, when two such models were made operational at the regional or provincial scale, the SOCRATES model predicted gains in SOC for a small area in Alberta (Izaurralde et al. 1996), while the CENTURY model predicted losses for Alberta as a whole (Smith et al. 1997). These results illustrate the fact that modeling results from any natural system require careful interpretation. Beyond the obvious concerns about how well the model mimics the real world, other considerations include data availability, data applicability, scaling issues and the temporal and spatial variability of input parameters.

IN-FIELD AND REGIONAL DISTRIBUTION OF SOM

Typically, soil moisture deficits increase from the Black and Gray to the Brown soil zone, similarly SOM levels decrease along this gradient. Between one-half to two-thirds of the total SOM may be present in the surface (Ap) horizon of a cultivated Chernozem. Data in Table 3.8 demonstrates the variation in SOC in Ap horizons across Chernozemic Great Groups in Alberta.



Source: McGill et al. in prep.
Note: At year 80, the addition rate of C was increased. The dashed lines after year 80 indicates the SOC trend if no management change had taken place.

Figure 3.11 SOC content of two soils with contrasting initial starting amounts of SOC subjected to cropping systems that add identical amounts of C.

A major challenge to monitoring the content of SOM in the field is the ambiguity inherent in describing these changes on landscape or toposequence units (Smith et al. 1997). Sampling the soil to define SOM differences within the field may have more merit than simply attempting to determine a mean concentration for the field. The spatial variability of SOM within one field may be difficult to address, even with the best sampling plan. Another issue that arises is the need to distinguish between the absolute removal of SOM (oxidative losses) and redistribution of SOM within the region through soil erosion (Ellert et al. 1999). One way of overcoming these challenges is to incorporate landform analysis within studies examining SOM content and composition in the field (van Kessel et al. 1994).

Soil organic matter concentrations are generally lower on the slopes and shoulders of fields than in depressions. Even this variability can be reduced by limiting erosion and thereby the redistribution of SOM (Boehm and Anderson 1997). Generalizations made from data collected along catenas (landscape slope from upper to lower positions) in

Table 3.8 Status of SOC in Ap horizons of Chernozemic soils of Alberta, by Great Group.

Great Group	Concentration (g/kg)	Bulk Density (Mg/m^3)	Mass (Mg/ha)	Fraction of total SOC in Ap horizons (%)
Brown	14	1.40	27.24	60
Dark Brown	27	1.20	45.36	56
Black	42	1.10	84.55	65
Dark Grey	33	1.20	63.36	64

Source: Reinl 1984

Table 3.9 Carbon concentrations in soils along a catena from Waldheim, SK.

Slope Position	Depth (cm)	Total C (g/kg)	^{14}C Age (yr Before Present)
Summit	0 - 10	24.0	575 ± 80
Midslope	0 - 15	21.0	270 ± 45
Toeslope	0 - 15	27.0	216 ± 45
	15 - 22	6.2	635 ± 55
	22 - 52	4.2	930 ± 55
Depression	0 - 18	24.0	Modern
	22 - 35	5.2	700 ± 55
	60 - 70	4.5	4 870 ± 60

Source: Martel and Paul 1974

Saskatchewan predict that organic carbon (and P, N and S) will increase from the upper slope positions to the lower positions following the localized moisture redistribution patterns (Roberts et al. 1989; Verity and Anderson 1990). Typical carbon concentrations found at different slope positions are detailed in Table 3.9.

Wheat yields may follow this pattern, with reduced production on the eroded knolls and increased production in the enriched lower slope areas (Verity and Anderson 1990). Within an individual catena, the SOC in the midslope position best represents the typical SOC content of the soil zone. Texture is another regional governor of SOC content. Fine-textured soils retain more SOC than coarse or medium textured soils. However, absolute amounts and distribution of SOM are governed by management and landscape factors (Pennock and van Kessel 1997).

SOM AND SOIL EROSION

Soil degradation resulting from erosion and the associated depletion of soil productivity leads to a reduction in crop yields and fewer returns of organic matter back into the soil. Erosion also selectively redistributes surface soils to lower landscape positions where the greatest amount of soil carbon is stored. As a result, areas subject to erosion are not only losing SOM as a result of redistribution, but also receive less crop residues to replenish the SOM.

The conversion of native grassland to agricultural cropland results in the rapid decline of SOM as a result of mineralization and the eventual adjustment to a new SOM equilibrium. Maintaining a new equilibrium and curbing further SOM losses depends upon controlling erosion, which has been shown to be the dominant force contributing to SOM declines in lands that had been under cultivation for over 23 years (Gregorich et al. 1998). Data reported by Gregorich and Anderson (1985) showed that erosion accounted for 20% of carbon losses after 23 years of cultivation, compared to 40-55% of carbon losses after 54 years of cultivation. A further estimate of carbon losses resulting from erosion of coarse textured soils on the Prairies is given by de Jong and Kachanoski (1988), who stated that approximately 50% of carbon losses are a result of erosion. Fortunately, management practices aimed at increasing SOM can also reduce erosion.

Manure, imported topsoil, sludges and residues may all be applied to eroded or low organic matter soils to improve the soil organic matter concentration and productivity. The addition of manure may increase organic matter concentrations in eroded soils for a duration of three years (Dormaar et al. 1997).

Additionally, application may result in wheat yields that equal, or greater than wheat yields on non-eroded areas.

THE DYNAMIC FRACTION OF SOM AS AN INDICATOR OF SOIL QUALITY CHANGES

Due to the highly labile nature and relatively short turnover time of dynamic SOM, both positive and negative changes resulting from land management will be easier to observe in this fraction than in total SOM (Carcamo et al. 1997). As a result, the assessment of total SOM may not be the most effective means of reporting SOM quality changes (McGill et al. 1998).

Changes that influence the dynamic pool of SOM include the quantity, chemistry and accessibility of residue additions, and environmental factors such as moisture, temperature and precipitation affect microbial activity (Gregorich and Janzen 1996). Conditions such as high temperature and moisture result in increased rates of SOM decomposition. Gregorich and Janzen (1996) noted that since farming practices impact most of the identified influences, soil organic matter quality will be significantly affected.

Recent studies have shown that assessment of a number of dynamic SOM attributes can be used as effective indicators of SOM quality change. Commonly studied attributes include total SOC and soil organic nitrogen, light fraction and microbial (particulate) matter, C_{min} and N_{min}, microbial biomass, soil carbohydrates and enzymes (Gregorich et al. 1994). Carcamo et al. (1997) noted that the quantity and quality of C and N rich LFOM determines the carbon stabilization efficiency and ultimately the amount of soil carbon evolved. The mineralizable fraction of OM is a major source of plant nutrients, so changes to this soil fraction will affect the fertility of the soil resource.

Campbell et al. (1997a) found that tillage treatments influenced mineralizable C and N after seven years, whereas it took 11 years before changes to total organic C and N, microbial biomass and specific respiratory activity were observed. In a study on the effects of conservation management practices on SOM attributes, Bolinder et al. (1999) found that light-fraction-N (LF-N), macro-organic matter-N (MOM-N), MOM-C, LF-C and microbial biomass-C (MBC) were significantly sensitive to conservation management practices. Campbell et al. (1999b) also found that the more labile SOM constituents were more influenced by the positive treatments of increased cropping frequency, fertilization, legume-

An extensive survey of SOM masses in Alberta's agricultural soils concluded that in the absence of erosion, the elimination of fallow on annual cropland would have the greatest effect in reducing carbon losses from soils and promoting carbon retention (McGill et al. 1988).

Table 3.10 Rate of SOC change for the 0-30cm depth of agricultural soils on the Canadian Prairies by province.

	1980		1985		1990		Area		C loss
	Rate[1]	Total[2]	Rate[1]	Total[2]	Rate[1]	Total[2]	Sampled k/ha	Total k/ha	1910-1990 %
MB	-76.7	-0.488	-73.2	-0.466	-66.1	-0.421	1 161	6 369	25.6
SK	-39.3	-0.800	-36.5	-0.744	-22.5	-0.458	3 419	20 376	20.6
AB	-84.0	-1.080	-79.9	-1.030	-74.5	-0.956	2 189	12 829	27.9

Source: Smith et al. 1997
Note: [1] kg/ha/yr based on the slope of a 10 year regression centered on each particular year.
[2] Mt/yr

green manure and legume-grass hay crops than were total organic C and N.

Another study on seasonal trends and crop rotation effects on selected soil biochemical attributes by Campbell et al. (1999a) found that all biochemical attributes (except MBC) showed higher values for continuous wheat than for fallow-wheat rotations. After 29 years of fallow-wheat rotations, it was estimated that organic C and N concentrations were approximately 15% lower than a continuous wheat rotation. The labile constituents (excluding MBC) were degraded by much more during the same period. For example, C_{min} and N_{min} were degraded by 45%, and LF-C and LF-N by 60-75%. Campbell et al. (1999a; 1999b) also found that due to the seasonal variability (temperature, soil moisture and precipitation) exhibited by the labile components of SOM, several measurements should be taken over the season.

In a study on the effect of tillage and crop rotations on the light fraction of SOM in chernozemic soils of Saskatchewan, Liang et al. (1999) found that for all three soil zones (Black, Brown, and Dark Brown) greater proportions of LFOC/SOC were associated with continuous cropping, compared to crop rotations which included fallow. This demonstrated that LFOC is a sensitive indicator of change in SOC. However, the impact of tillage systems on the amount of LFOC was not as consistent as the impact of crop rotations. As a result, LFOC was not found to be a sensitive indicator of change in SOC resulting from tillage systems (Liang et al. 1999).

Managing Soil Organic Matter Levels

The concentration and mass of organic matter in soil is extremely sensitive to land management practices. Immediately after the prairie sod was broken, the steady-state concentrations of SOM in native grasslands began to decline. Recent estimates suggest that 14-40% of the mass of SOC originally in the Canadian Prairies has been lost since cultivation began (Smith et al. 1997; McGill et al. 1988). Table 3.10 shows the rate of SOC change in Prairie agricultural soils by province as estimated using the Century model. Cultivation has also diluted the concentration of SOC in surface soils by mixing organic matter-rich A horizons with the underlying B horizons (Reinl 1984; McGill et al. 1988). In light of the large proportion of SOC present in the Ap horizon, land management practices that avoid further exposure or dilution of SOC should be strongly encouraged.

Dormaar and Smoliak (1985) demonstrated that it is possible to restore SOM to pre-cultivation levels by allowing land to revert to native species and by using moderate grazing intensities. However, on land in the Brown soil zone of southern

Alberta which had been under cultivation for just 15 years, it was estimated that at least 55 years of less intensive land use would be required to return to original SOM levels. The time required to recover to the previous quality of SOM was determined to be greater than 75 years for soils in the Brown soil zone, and greater than 150 years for soils in the Black soil zone (Dormaar et al. 1990).

Chernozems in the Brown soil zone will likely recover more successfully than those from the Black soil zone due to the poorer quality and less stable SOM in the Brown soil zone (Dormaar 1975). Soils with a high mass of SOC must support a high productivity just to maintain SOC content, while soils with little SOC would require lower productivity to maintain or increase SOC content.

Forage crops (native and tame grasses, and legumes) contribute substantially more to SOM than the traditional cereal grains (Campbell et al. 1991a). The enhanced rates of organic matter accumulation observed under grasses and hays is likely due to the infrequent use of tillage on land growing perennial crops, and the large root mass typical of grasses (Soon and Arshad 1996).

A large number of experiments conducted on the Prairies have found that use of summerfallow in a crop rotation will contribute to the degradation of SOM quantities. Continuously cropped soils have annual inputs of residues and root mass, and the period during which soil moisture conditions are sufficiently high to favor SOM decomposition is shorter (Campbell et al. 1995). During the fallow period, the carbon stored as SOM is mineralized and lost. Soil organic nitrogen is converted to NO_3, which is then available for growth of subsequent crops (McGill et al. 1986; Voroney et al. 1989; Campbell et al. 1991a; Bremer et al. 1994).

A wheat-summerfallow rotation causes a more rapid decline in soil organic matter than a wheat-wheat-fallow rotation. This was demonstrated in a study of a Dark Brown Chernozem in which the SOC content of the soil decreased by 17, 21 and 23% following 80 years of cultivation under continuous wheat, fallow-wheat-wheat and fallow-wheat, respectively (Monreal and Janzen, 1993).

Increased cropping frequency and fertilization both increase the amount of plant biomass produced in a field. While some research conducted on Chernozemic soils in Saskatchewan suggests that leaving straw on the field following harvest may not be essential to maintaining organic matter levels (Campbell et al. 1997a;

Organic matter loss due to erosion can be reduced by planting field shelterbelts. Shelterbelts reduce soil losses from moderately coarse and medium textured soils (deJong and Kowalchuk 1995).

Campbell et al. 1991b), other research differs (Campbell and Zentner 1993). The main interpretation of such findings is that the role of the root biomass remaining in the soil following harvest may be much more important than previously believed. Roots may contribute far more to SOM maintenance than do equivalent amounts of straw.

The amount of SOM in the top 15 cm of soil under annual crop rotations on the Prairies varies with the amount and nitrogen content of above-ground crop residues left on the field (Campbell and Zentner 1993). In years of poor production, SOM was observed to decrease in soils (Campbell and Zentner 1993). Supplying adequate nutrients as fertilizer to the crop will promote production of plant biomass, which through decomposition also contributes to soil nutrient supplies (Malhi et al. 1997).

Summerfallow may also indirectly contribute to decreasing SOM concentrations by leaving the soil vulnerable to erosion for a season. Insufficient crop cover resulting from summerfallow tillage and residue decomposition leads to erosion, which will reduce organic carbon contents primarily on knolls and shoulders of slopes within the field (Boehm and Anderson 1997). Residue in varying stages of decomposition helps to aerate and loosen soils (Boehm and Anderson). Fallow reduces residue levels thereby increasing soil bulk density.

In regions that are able to control erosion and eliminate summerfallow and still remain economically successful, it is likely that a new quasi steady-state of SOM could be re-established in as few as 10-20 years. Nyborg et al. (1995) reported continuous cropping with adequate fertilization and reduced tillage of two soils, one of which had a high starting mass of SOC, increased mass (or avoided loss) of SOC by 8-37% within a decade. Reducing the fallow frequency to just once within an extended rotation (from 7-15 years) is also beneficial to preserving SOM concentrations and quality in soils (Boehm and Anderson 1997).

Reduced soil disturbance by using conservation tillage should increase or stabilize SOM due to less aeration of the soil, increased residue inputs and the minimization of SOM losses by erosion. However, detection of this stabilization or increase may require more time than is usually allotted to soil experiments. Comparing conventional, minimum and zero tillage on a Brown Chernozem, no treatment effects were observed after three years of conservation tillage management, nor were any differences in SOC masses detected after 7 years. Only after 11 years of consistent conservation tillage was a significant increase in SOC detected in the plots that were zero tilled, compared to those that were minimum or conventionally tilled (Campbell et al. 1997b).

CONCLUSIONS

Organic matter is a vital soil component having a major effect on soil physical and chemical properties. These properties, in turn, influence many factors including crop yields, soil carbon storage and mitigation of the environmental impacts of the agricultural industry.

Much has been learned about the role of SOM, but a great deal of research is still required to scale-up information from test-tubes and long-term research plots to local, regional and national soil landscapes (Monreal 1999).

Water Quality

Water quality is critical to the health of all living organisms, from fish and aquatic insects, to wildlife and humans. It varies dramatically in streams, lakes and rivers across the Prairies, reflecting the many differences in landscapes and land uses.

Water quality is typically characterized in terms of physical properties and chemical and biological constituents. Quality is also evaluated in terms of its intended use – human or livestock consumption, recreation, aquatic life or irrigation. In Canada, water quality is typically evaluated according to how it complies with the *Canadian*

Water Quality Guidelines prepared by the Canadian Council of Ministers of the Environment.

The water quality characteristics most relevant to agricultural landscapes on the Prairies are nutrients (primarily nitrogen and phosophorus), agricultural pesticides, pathogens and physical parameters such as sediments, temperature, dissolved oxygen, salts and metals.

Natural conditions and processes which affect Prairie water quality include:

- the timing, duration, intensity and geographic distribution of precipitation and runoff events
- natural stream channel erosion
- the physical and chemical characteristics of soil through which water passes, as well as the distance water travels through the soil
- topography and the physical and chemical characteristics of surface materials
- hydrography, or the presence of wetlands and lakes, along with the physical characteristics of such water bodies
- the presence and concentration of wildlife (e.g. beaver) that can change the physical characteristics of water bodies.

Human activities that have an impact on water quality are similarly varied. They include agricultural production and forest harvesting, industrial and municipal point-source discharges, urban runoff, poorly constructed or uncapped wells, point and non-point sources of air pollution, dams and diversions, mining operations and gravel pits.

In recent years, there has been increased attention on the impact of agricultural activities on water quality, recognizing that agriculture is having an adverse effect in some Prairie watersheds (Canada-Alberta Environmental Sustainable Agriculture Water Quality Committee 1998). Agricultural sources of water contamination include:

- erosion and runoff from fields to which fertilizers, pesticides and manure are applied
- runoff and wastewater from livestock operations
- leaching of land-applied contaminants to groundwater.

A further breakdown of agricultural activities and associated impacts is provided in Table 3.11.

Studies in the United States indicate that the key area of water quality concern related to field runoff is the transport of sediments into surface waters. It is not clear, however, how important sedimentation from field runoff is on the Canadian Prairies (Anderson et al. 1998a; Environment Canada 1990). The sediments themselves, and the nutrients or chemicals adsorbed to soil particles, can lead to water quality impairment. Accelerated soil erosion can exacerbate sediment transport and water quality degradation. This can result from cultivation of steep slopes near water bodies, livestock overgrazing particularly on steeply sloped pastures and trampling of stream bank vegetation. Land drainage and stream channelization to assist runoff in agricultural areas are other major potential causes of increased sediment loading to streams.

Poorly-managed irrigation and excessive application of manure can further increase the risks to water quality associated with field runoff. Wind erosion and the deposition of *blowdirt* also play a role in the sedimentation of water bodies. When wind-blown soil is deposited in ditches and drainage courses, it can be readily transported to water bodies during the next runoff event.

Manure and waste water from livestock operations are also major sources of aquatic pollutants. Runoff from feedlots and winter feeding sites containing high concentrations of bacteria, phosphorus, ammonia and other contaminants often enters Prairie streams with no treatment. Allowing livestock uncontrolled access to waterways directly adds nutrients and pathogens to the water as well as increases shoreline erosion.

The risk of contaminants leaching to groundwater is of greatest concern in areas where exces-

Table 3.11 Water quality impacts associated with agricultural activities.

D Direct Impact I Indirect Impact N No Impact

	Disturbance Activity									
Potential Impact	Vegetative Clearing	Streambed Disturbance	Withdrawal of Water	Dams	Cultivation	Irrigation & Drainage	Contaminants	Grazing	Fertilizer & Pesticide Application	Intensive Livestock
General point-source pollution	I	I	I	D	I	I	D	D	I	D
General non-point-source pollution	D	D	I	I	D	D	D	D	D	I
Increased upland surface runoff	D	I	I	I	D	D	I	D	N	D
Increased sheetflow with surface erosion and gully flow	D	I	I	I	D	D	I	D	N	D
Reduced groundwater recharge	D	I	D	D	D	D	I	D	N	D
Reduced groundwater contribution to baseflow	D	D	D	I	D	D	I	D	N	N
Pollution of groundwater	I	I	I	I	I	D	D	I	D	D
Increased streambank erosion and channel scour	D	D	I	D	D	I	I	D	N	D
Increased surface water sediment, salinity and turbidity	D	D	I	D	I	D	D	D	D	D
Increased surface water nutrient concentrations and possible eutrophication	D	D	I	D	D	D	D	D	D	D
Increased surface water exposure to solar radiation and temperature extremes	D	D	D	I	D	I	I	D	N	D
Increased surface water temperature	D	D	D	D	I	I	I	D	N	I
Reduced dissolved oxygen concentration	D	D	D	D	I	I	I	D	I	D

sive quantities of manure or farm chemicals are applied to the land (especially in irrigated areas), and under improperly designed livestock wastewater containment facilities. This risk is of significant concern because it is more difficult to monitor and evaluate changes to groundwater, and groundwater quality can be difficult to rehabilitate. Once contaminated, especially by toxic organic compounds, groundwater will likely remain contaminated (MacDonnell and Guy 1991).

WATER QUALITY STUDIES ON THE PRAIRIES

Agricultural development on the Prairies has resulted in widespread land clearing and drainage, soil erosion, water withdrawals, livestock concentration, land application of manure and inorganic fertilizer and the use of pesticides. This development has had a similarly widespread and adverse effect on water quality. This conclusion is based mainly on interpretation and extrapolation of the impact of specific agricultural practices and related activities (McGarry 1987; Miller et al. 1992; Waite et al. 1992; Green 1996; Grift 1997; Hill et al. 1997; Olson et al. 1997; Anderson et al. 1998b; Anderson et al. 1998c). Although few regional assessments of agriculture's impact on water quality have been done in Saskatchewan, assessments have been undertaken in both Manitoba and Alberta.

The Manitoba water quality index tracks water quality trends over time for all areas of the province, including the Prairie ecozone where the majority of Manitoba's agriculture occurs. Seventy-seven of 80 monitoring sites were classified as fair for water quality and three sites as good (Manitoba Environment 1997). All of the rivers and streams in the Prairie ecozone were classified as fair, which implies that conditions often depart from desirable quality. Water quality trends have not changed substantially over time with the exception of the Valley River (located in an agricultural watershed), which has fallen from good to fair in the water quality ratings since 1991.

> ***It is generally accepted that the greater the level of agricultural intensity, the greater the risk to groundwater and surface water quality (Canada-Alberta Environmentally Sustainable Agriculture Water Quality Committee (CAESA) 1998). This is a significant conclusion given current objectives to expand and intensify agricultural production across the Prairies.***

Index-type data have been compiled since 1992 for six major rivers in Alberta. Ratings for 1997 are shown in Table 3.12. While no trends in the ratings for these watercourses are correlated with agriculture, in general, water quality tends to be poorer downstream of significant urban, industrial or agricultural development (Alberta Ministry of Environmental Protection 1999).

Alberta Agriculture, Food and Rural Development and Alberta Environment recently developed a water quality index for agricultural streams. Stream classifications using the index have not yet been calculated, but the province will begin annual reporting in 2000. Indexed data are not yet available for Saskatchewan.

In some areas, agricultural activities have been shown to produce significant localized effects which exceed water quality guidelines. But in general, the ecological and health-related impacts on water quality resulting from agricultural development have not been studied on the Canadian Prairies. Thus, the overall significance of agriculture's impact on water quality across the Prairies is not well understood.

The following sections provide a discussion of the key water quality parameters relevant to agriculture.

NUTRIENTS IN SURFACE WATER

Numerous studies reveal, both qualitatively and quantitatively, evidence of localized impacts from agricultural activities on the nutrient (i.e. phosphorus and nitrogen) loadings of surface waters on the Prairies (Mitchell 1992; Anderson et al. 1995; Green 1996). Nutrient levels in small watersheds have been strongly correlated with the level of agricultural intensity in the watershed (Anderson et al. 1998b). The level of pesticide and fertilizer use has been positively correlated with nutrient levels in streams. Near cattle operations, stream concentrations of phosphorus appear to be directly related to cattle numbers and associated manure volumes (Mitchell and Hamilton 1982).

Eutrophication is often the main issue resulting from nutrient loading of surface waters on the Prairies. Sediment-associated eutrophication in small water bodies appears directly related to farmland erosion (Environment Canada 1990). However, on a regional scale, the significance of agricultural sources of nutrients on the quality of surface water bodies is not clear. In many small surface waters, it appears that naturally occurring processes of eutrophication are being accelerated by agricultural contributions of nutrients. In others, it is simply not known whether water bodies were eutrophic, or are becoming so due to agricultural loadings.

NUTRIENTS IN GROUNDWATER

The primary concern associated with nutrient contamination of groundwater relates to the health of humans and livestock that consume this water. In that regard, nitrate-nitrogen is the primary compound of concern.

Nutrients in groundwaters can be derived from natural sources (geologic environment), or from anthropogenic sources (septic systems, municipal landfills, leaky sewer lines, land spreading of sewage or sludge, leaks or spills of industrial chemicals, intensive livestock operations, spreading of manure and application of fertilizer on agricultural lands). The vulnerability of an aquifer to pollution from surface sources is controlled by the flow system, the geology and the climate.

Studies suggest that nutrient contamination of deep groundwater (i.e. greater than 30 m) is not currently widespread, or of significant cause for concern on the Prairies (for example, see Table 3.13). However, for one aquifer in Manitoba, tritium analysis indicated that recharge to wells having the highest level of nitrate had occurred since 1953 (Betcher 1997). This suggests steady nitrogen transport through fairly thick till layers over several decades. This could mean that current results are only the beginning of high nitrate occurrences in groundwater in the area. However, this condition has not been observed elsewhere in the Prairies.

Table 3.12 **Water quality rating and percentage compliance in 1997 with recreational, aquatic life and agriculture water quality guidelines for six major rivers in Alberta.**

Basin	Use[1]		
	Recreation	Aquatic Life	Agricultural
Smoky/Peace Rivers			
at Watino	P - 75%	F - 90%	F - 95%
at Fort Vermillion	P - 75%	F - 91%	G - 96%
North Saskatchewan River			
at Devon u/s of Edmonton	F - 94%	G - 98%	G - 99%
at Pakan d/s of Edmonton	U - 47%	F - 90%	G - 99%
Red Deer River			
at Hwy 2 u/s of Red Deer	F - 86%	F - 94%	G - 99%
at Morrin d/s of Red Deer	P - 75%	F - 91%	G - 99%
Bow River			
at Cochrane u/s of Calgary	G - 100%	G - 98%	G - 100%
below Carseland d/s of Calgary	U - 61%	F - 88%	G - 98%
Oldman River			
at Hwy 3 u/s of Lethbridge	F - 86%	G - 96%	G - 99%
at Hwy 36 d/s of Lethbridge	U - 66%	F - 88%	G - 99%

Source: Alberta Environmental Protection 1999

[1] Compliance with *Alberta Ambient Surface Water Quality Interim Guidelines*

Note: Ratings: Good (G) = 100 – 96%; Fair (F) = 95 – 86%; Poor (P) = 85 – 71%; Unacceptable (U) = < 70 %

d/s = downstream; u/s = upstream

Studies suggest that nitrate saturation of the soil near feedlots and in areas which receive excessive manure applications could pose potentially serious and widespread problems to groundwater (Riddell and Rodvang 1992). Shallow, unconfined aquifers are considered most at risk. Similar studies have found that nitrates accumulate in the soil profile in dryland areas due to manure applications, or from applications of chemical fertilizers that exceed crop requirements. The extent to which this build-up in the soil profile affects groundwater depends on how soon after application rainfall is received, as well as the general climate of the area (i.e. total rainfall amounts) (Olson et al. 1997).

PESTICIDES IN SURFACE WATER

Studies clearly show that low concentrations of agricultural pesticides are ubiquitous (20-100% detection rates in agricultural watersheds) in surface waters (Anderson 1995; Anderson et al. 1998c; Buckland et al. 1998; Currie and Williamson 1995). Pesticides can be transported to surface water bodies through direct application, runoff, leaching, aerial drift and atmospheric deposition. Movement of materials with runoff can occur with overland (surface runoff) or sub-surface movement of water. As well, improper handling of pesticides can lead to spills, leaks and inadvertent back-siphoning into water supplies.

Data suggests that surface waters in some irrigated areas, and other areas where use of pesticides is relatively higher, are more vulnerable to agricultural pesticide contamination. In contrast, a four-year study on South Tobacco Creek in Manitoba found that the principal pathway for several pesticides to enter the aquatic ecosystem was from rainfall or atmospheric deposition (Rawn and Muir 1997).

While agricultural pesticides are frequently detected in surface waters, they have rarely been found to exceed guidelines for human and livestock consumption, or for aquatic life. An exception is a recent study of water quality in Saskatchewan wetlands in which Donald et al. (1999) found that guidelines for the protection of aquatic life are often exceeded by some compounds. They projected that 9-24% of wetlands sampled in early July, in three of the six years of study, had pesticide levels exceeding guidelines for the protection of aquatic life. In many cases, pesticide levels exceeded the more stringent irrigation guidelines across the Prairies, particularly in irrigation canals, streams and small lakes in high-intensity agriculture areas.

While guideline exceedences for most uses are generally rare, many pesticides do not have guidelines. Consequently, it is difficult to comment on the environmental significance of their presence in surface waters. As well, current guidelines are for single compounds only, so the implications of the co-occurrence of low levels of multiple compounds are unknown.

Pesticide monitoring in small agricultural watersheds has only just begun. As a result, little can be said about the trends in pesticide concentrations over time in these basins. As well, evaluation of long-term trends using monitoring data gathered from large rivers and streams is difficult because changes in monitoring methods complicate the analysis. Evaluation of long-term trends is also complicated by the continual evolution of the agri-chemical industry.

Table 3.13 Non-compliance with Canadian water quality guidelines.

Water source	Nutrient tested	# of samples	Human drinking	Livestock drinking
Deep wells	Nitrate +Nitrite	448	0.6%	0%
Shallow wells	Nitrate +Nitrite	376	13%	0.3%

Source: CAESA 1998.

PESTICIDES IN GROUNDWATER

The problem of agricultural practices contributing pesticide residues and byproducts to groundwater has only recently received attention. As a result, there is little that can be said regarding levels and trends of pesticides in groundwaters across the Prairies.

Studies of herbicide leaching have demonstrated that recently applied herbicides can rapidly leach to shallow groundwater if there is a rain or irrigation event immediately after the application (Hill et al. 1995, 1997; Miller et al. 1992, 1995a, 1995b; Rodvang et al. 1992). Thus, shallow groundwater overlain by sandy soils under irrigated lands is most vulnerable to agricultural pesticide contamination. Even without a heavy rainfall, leaching still occurs, but is delayed. This potential for leaching has also been found in clay loam soils, suggesting that widespread, low-level herbicide contamination of shallow groundwater can occur where leachable herbicides are applied repeatedly to the same field. Pesticides can also find their way into groundwater via spills and leaks near water wells, and by inadvertent back-siphoning from spraying equipment into water supplies.

PATHOGENS

Eutrophic conditions can be natural or human-induced. Either way, water quality can be severly affected, as shown by this dugout.

By definition, pathogens are disease-causing organisms. Consumption and, in some cases, contact with contaminated water can pose health risks to both humans and livestock. Further, some pathogens are of particular concern because they can be difficult to remove from water with conventional treatment methods. For example, *Cryptosporidia* are resistant to chlorination. Monitoring for these kinds of pathogens has been stepped-up across the Prairies to better understand current health risks, as well as to identify opportunities to reduce contamination.

Pathogens are found in almost all surface waters on the Prairies. Their presence is attributable to a number of natural and anthropogenic sources, including agriculture. To date, a general relationship between agricultural intensity and levels of pathogens in surface and groundwaters has not been established (see Table 3.14). Nor has any strong seasonal trend in levels of pathogens been observed.

The most likely source of significant pathogenic contamination of surface water from agricultural activity is related to intensive livestock production. Runoff from cattle wintering areas and feedlots acts as a point source of contamination, as do wastewaters from dairy and hog operations. Allowing livestock direct access to surface water bodies significantly increases the risk of contamination. Manure application to agricultural land can also potentially create a non-point source of pathogenic contamination. However, the likelihood that this would be a significant contributor is low unless rainfall is received soon after application, or unless the material was frozen (and stayed frozen) soon after application, contributing to runoff in the spring.

SEDIMENTS

Agricultural activities can contribute to increased sediment loading in a number of ways. Activities may alter the hydrologic response of a watershed by producing more rapid runoff with higher peak flows and shorter durations due to drainage and land clearing. Tillage practices may affect the relative vulnerability of soil to erosion, and concentrated animal traffic adjacent to water bodies may result in the removal of vegetation and trampling of banks. Agriculture can also contribute to the effects of sedimentation on the environment by increasing the quantity of chemical constituents adsorbed to soil particles that are eroded and transported by wind and water.

In general, sediment loadings from upland areas on the Canadian Prairies are a concern mainly for water bodies and drainage channels in small watersheds, or in those portions of watersheds that are internally drained and seldom spill. Larger stream and river systems

Table 3.14 Water quality tests for a variety of surface and groundwater sources in Alberta.

			Non-compliance with guidelines (CCME 1997)		
WATER SOURCE		Number of samples	Human drinking	Irrigation	Recreation
Deep wells		FC = 37	2%	0%	N/A
Shallow wells		FC = 376	5%	0%	N/A
Dugouts	Pilot survey	FC = 112	68%	0%	0%
	Northern survey	FC = 80	20%	0%	0%
Streams	High intensity	FC = 32	94%	25%	9%
		TE = 32	N/G	N/G	38%
	Moderate intensity	FC = 25	100%	68%	44%
		TE = 17	N/G	N/G	82%
	Low intensity	FC = 31	90%	16%	6%
		TE = 31	N/G	N/G	39%
Irrigation canals	Supply source	FC = 91	96%	14%	8%
	Return flow	FC = 407	95%	33%	18%
		E Coli = 159	N/G	N/G	27%

Source: CAESA 1998
Note: FC - fecal coliform; TE - total enterococci; E. coli - Escherichia coli; N/G - no guideline; N/A - not applicable

seem relatively unaffected (Environment Canada 1990).

Based on two years of data from a small agricultural watershed in south-central Alberta, researchers concluded that runoff from cattle wintering grounds adjacent to streams can contribute suspended solids in sufficient amounts to cause increases in concentrations and mass loads in the receiving water body. However, the relative contributions from soil erosion and manure to the increased suspended solids were not determined (Anderson et al. 1998a). Further, overland and in-stream flow regimes tend to have a greater influence on sediment loading potential than agricultural intensity. Thus, water erosion would be expected to be of less concern in agricultural streams located in low-runoff areas.

The primary effect associated with sediment loading of water bodies is increased turbidity levels, which tend to adversely affect fish and fish habitat. Currently, this effect does not appear to be significant in major rivers and streams. The significance of sediment loading in small watersheds across the Prairies has not been studied, and the extent to which agricultural activities are generally responsible or have aggravated conditions is not clear.

TEMPERATURE

Elevated water temperatures can have significant impacts on the availability of oxygen to aquatic organisms. Higher temperatures increase the solubility of many chemical compounds, and may also influence the effect of pollutants on aquatic life. Aquatic organisms have both an upper and lower limit on the temperatures required for optimal growth, spawning, egg incubation and migration; the limits varying with species. Changes in temperature regimes can therefore alter the distribution and species composition of aquatic ecosystems.

Activities which reduce streambank vegetation such as cultivation to the edge of a water body or intensive livestock grazing, can result in increased in-stream water temperatures. Agricultural activities that contribute sediment to a water body can also indirectly increase water temperatures by decreasing water depth and/or increasing heat absorption from solar radiation. For instance, irrigation contributes to elevated water temperatures in two ways. If a large quantity of water is withdrawn for irrigation the water body may experience a significant decrease in water volume or flow, resulting in shallower water and higher temperatures. Return flows from the irrigated area may absorb heat from the soil, which will impact the water body into which it is discharged.

Finally, water control structures in rivers and streams can also dramatically alter in-stream temperature regimes.

The temperature regimes in lakes, rivers and streams across the Prairies are highly variable, generally reflecting the ambient climatic conditions, with the response time related to the ratio of surface area to the volume of water in question. With the exception of large dams on major water courses, the impact of human activities or agricultural influences on water temperature is not well-documented.

DISSOLVED OXYGEN

The primary issue associated with dissolved oxygen (DO) is the effect it has on aquatic life. Aerobic organisms cannot survive under conditions where DO levels fall below a certain value. The value varies by organism. Although a single minimum acceptable value for all organisms is not appropriate, it has been found that DO concentrations of less than 7.27 mg/litre produce detrimental effects on mixed freshwater fish populations including salmonids. Dissolved oxygen concentrations of less than 5.63 mg/litre have been shown to have detrimental effects on mixed freshwater fish populations with no salmonids (Davis 1975).

Any agricultural activity that results in an increase in organic and inorganic matter in the water (inorganic fertilizer, manure and other wastes and sedimentation), or which contributes to elevated water temperatures (irrigation, loss of vegetative cover and/or morphological change resulting from

Eliminating direct access to water sources and providing water through remote systems reduces contamination of the water supply and contributes to herd health.

sedimentation), has the potential to indirectly lower DO levels in that water body. However, there is little data available that can be used to separate the natural effects of climate on DO from anthropogenic influences on the Prairies.

SALTS

Salts from both naturally occurring and human-induced sources can be transported to surface and groundwaters via rain and irrigation, water leaching or runoff. The main sources of salts are irrigation return flows, soil and mineral weathering, fertilizers, crop residues and animal manure. When source waters contain high enough levels, salts can become concentrated on or near the soil surface, where they can adversely affect soil quality and the growth of vegetation. High levels of salts can also be detrimental to animals that consume either the plants or the water.

Generally, the salinization of surface waters does not appear to be a significant issue across the Prairies, but data is limited. In a review of historical water quality data (1977-1996) from six irrigation districts in Alberta, Cross (1997) found that source water quality met irrigation guidelines for conductivity and sodium adsorption ratio (SAR) 100% and 99% of the time, respectively. Guidelines for conductivity and SAR were met 93% and 96% of the time in return flows, respectively. While some degradation in salinity occurs from source water to return flow, by the time return flows reach the river system, dilution reduces salinity concentrations to below guideline levels. Harker (1983) came to a similar conclusion regarding dilution effects of saline tile drainage effluent.

While surface water salinity levels on the Prairies appear to be low, much higher levels can be found in groundwater. Elevated levels of total dissolved solids in groundwater are common and are often associated with natural sources, such as mineral leaching. However, some studies have shown increases in groundwater conductivity over time can be attributed to leaching of irrigation water (Miller et al. 1992). While these studies indicate that significant leaching of salts to groundwater can occur, there are no data to indicate such leaching is a widespread problem in irrigated areas of the Prairies.

HEAVY METALS

Heavy metals (arsenic, cadmium, chromium, copper, nickel, zinc, selenium), alone or in combination with agri-chemicals, can have a variety of adverse effects on the use of water. At certain concentrations and exposures, heavy metals can have a toxic effect on humans, livestock, plants and aquatic life.

Agricultural sources of heavy metals include fertilizers, pesticides, manure and irrigation water. Heavy metals are derived from natural sources and human-induced sources such as the electronics and pharmaceutical industries.

There is little information on heavy metal concentrations in small streams on the Prairies. Most of the data on heavy metal concentrations in surface water is limited to mainstem rivers. These data suggest that heavy metal concentrations are generally comparable to natural background levels (Green and Beck 1995). An exception may be mercury, which appears to be at relatively high levels. It is difficult to determine whether these mercury concentrations are natural or human-induced.

Historical data from irrigation return flows in southern Alberta suggest that heavy metal concentrations increase as water travels through an irrigation district. Aquatic guidelines were most frequently exceeded for copper, aluminum and chromium, followed by iron, manganese and zinc. There were no violations of guidelines for nickel, selenium or arsenic, and only a few for lead (Cross 1997). No trends in concentrations were apparent from the data.

In groundwater, heavy metals are relatively common, although concentrations vary, as do the sources. In a review of 813 farmstead wells, Fitzgerald et al. (1997) found the following exceedences of drinking water guidelines: 2.5% for arsenic, 1% for barium, 0.2% for chromium, 1.6% for lead, 3.4% for selenium, and 0.3% for uranium. While the authors speculated that some of the higher concentrations of elements detected may be attributable to human activity (e.g. lead, zinc, chromium and aluminum), they felt that the majority were due to natural geological conditions.

Conclusions

In some areas of the Prairies, agricultural activities have had significant localized effects on water quality, as measured by exceedences of water quality guidelines. However, assessments of the ecological and health-related impacts of agriculture on water quality across the Canadian Prairies have generally not been conducted. Such assessments are needed to better define the significance of agriculture's impact on water quality as well as to understand the potential benefits of adopting land use practices that minimize risks to water quality.

While the overall significance of agriculture's impact on water quality across the Prairies is not well understood, it is generally accepted that the greater the level of agricultural intensity in an area, the greater the risk to ground and surface water quality. This is significant in light of the desire for expansion and intensification of agricultural production across the Prairies.

Riparian Areas

Riparian areas are *the ribbons of green* associated with the lush vegetation bordering rivers, creeks, streams, lakes and wetlands. They are a significant feature of the landscape formed from the interaction of water, soil and vegetation (Adams and Fitch 1998). The broad definition of riparian contains the word wetland, which means it includes both lentic (still water) and lotic (flowing water) wetlands. The functions of both types have a great deal of overlap, however, some functions are independent of the other.

Lentic wetlands occur as still water basins that are either permanent or intermittent, and lack a defined channel and floodplain. These can include lakes, reservoirs, marshes, fens and seeps. The functions provided by these wetlands include sediment trapping, shoreline maintenance, water storage, aquifer recharge and wave energy dissipation (Riparian Wetland Research Program 1999).

Lotic water bodies such as creeks, rivers and streams either periodically or continuously transport flowing water within a defined water channel and include a floodplain. Functions associated with lotic systems include water energy dissipation, water table recharge, sediment trapping and transport, water filtering, and increased water availability.

Three characteristics of both lentic and lotic wetlands identified by Hansen et al. (1995) in his *Classification and Management of Montana's Riparian and Wetland Sites* include:

- wetland hydrology
- hydric soils
- hydrophytic vegetation.

Riparian areas perform many functions and their state of health is important to a number of ecological processes. While riparian areas occupy less than 5% of the landscape, they are home to the majority of wildlife species and are important sources of, and refuges for biological diversity.

In ecological terms, riparian areas must perform at least six basic functions. The National Resource Conservation Service (1999) describes these functions as:

- habitat - the spatial structure of environment which allows species to live, reproduce, feed and move
- barrier - the stoppage of materials, energy and organisms
- conduit - the ability of the system to transport materials, energy, and organisms
- filter - the selective penetration of materials, energy and organisms
- source - a setting where the output of materials, energy and organisms exceeds input
- sink - a setting where the input of water, energy, organisms and materials exceeds output.

In the riparian setting, these functions take the form of specific attributes such as sediment filtering, streambank building, water storage, aquifer recharge, fish and wildlife habitat and dissipation of stream energy (Hansen et al. 1995).

ASSESSING RIPARIAN FUNCTION

Ecological function is not always easy to see a the field level. Hence, a number of assessment methods have been developed to both quantify and qualify the function and health of riparian systems. These assessments have been developed in response to management of public or crown lands, mainly in the United States. Most assessment methods examine the hydrology, vegetation and soils of a riparian system to produce a final assessment of its health or ecological functioning.

The Bureau of Land Management (BLM) of the United States Department of Agriculture has developed a system to assess the functionality of riparian-wetland areas (United States Department of Agriculture - BLM 1998). It describes the process of assessing proper functioning condition based on the following elements:

Riparian areas are dynamic linear ecosystems that occupy less than 5% of the landscape.

Riparian areas contribute to biodiversity, trap sediments, and improve water quality.

Hydrologic

- floodplain inundated in relatively frequent events (1-3 years)
- active/stable beaver dams
- sinuosity, width/depth ratio, and gradient are in balance with the landscape setting (i.e. land form, geology, and bioclimatic region)
- riparian zone is widening
- upland watershed not contributing to riparian degradation.

Vegetation

- diverse age structure of vegetation
- diverse composition of vegetation
- species present indicate maintenance of riparian soil moisture characteristics
- streambank vegetation is comprised of those plants or plant communities that have root masses capable of withstanding high streamflow events
- riparian plants exhibit high vigour
- adequate vegetative cover present to protect banks and dissipate energy during high flows
- plant communities in the riparian area are an important source of coarse and/or large woody debris.

Erosion and Deposition

- floodplain and channel characteristics (i.e. rocks, coarse and/or large woody debris) adequate to dissipate energy
- areas of deposition are revegetating
- lateral stream movement is associated with natural sinuosity
- system is vertically stable and resistant to down cutting
- stream is in balance with the water and sediment being supplied by the watershed (i.e. no excessive erosion or deposition).

Based on these elements the BLM has assigned riparian areas into three possible class ratings: *proper functioning condition; functional - at risk; and nonfunctional.*

Proper functioning condition refers to riparian or wetland systems with adequate vegetation, landform or woody debris that allow them to perform the basic riparian functions such as dissipate energy, filter sediments, etc. Functional - at risk refers to areas with soil, water or vegetation attributes that make them susceptible to degradation. Nonfunctional categories of riparian areas are areas where soil, water or vegetation fails to perform the basic riparian functions.

The University of Montana has developed an assessment index for natural riparian functions (Thompson 1999). The assessment produces a rating where riparian health is described as: *"the ability of a stream (including the channel and its riparian zone)*

Degraded riparian zones can be rehabilitated successfully, often with minor changes to management.

to perform certain functions. These functions include sediment trapping, bank building and maintenance, water storage, aquifer recharge, flow energy dissipation, maintenance of biotic diversity, and primary production".

The assessment examines factors related to vegetation, soils and stream hydrology to determine the relative health or functioning capability of riparian areas. The specific attributes considered include:

- amount of the floodplain and streambank covered by plants
- percentage of streambank with a deep, binding root mass
- percentage of the riparian zone covered by noxious weeds
- percentage of the site covered by disturbance-induced undesirable herbaceous species
- degree of browse utilization of trees and shrubs
- woody species establishment and regeneration
- amount of decadent and dead woody material
- percentage of site with human-caused bare ground
- percentage of streambank structurally impaired (altered) by human causes
- amount of hummocking and pugging caused by hoofed animals
- channel incisement (vertical stability).

SUMMARY OF ASSESSMENTS

To date, there has been little done to assess the state of riparian function and health across the Prairies. In the late 1980s, a small ad hoc committee of federal and provincial governments, university and non-government personnel involved in wildlife management, grazing and ecological planning, was formed to discuss issues related to riparian management. The resulting publication, *Riparian Areas: An Undervalued Saskatchewan Resource*, was published in 1992 through the co-operation of a number of stakeholder agencies and with funding provided by the Canada-Saskatchewan Agreement on Environmental Sustainability. It was the first information guide in Saskatchewan to focus attention and awareness on riparian issues.

With the inception of the Canada-Saskatchewan Agriculture Green Plan Agreement (CSAGPA) in 1993, riparian management projects were incorporated into local and regional work plans. The first extensive demonstration of riparian management was undertaken by the Prairie Resources Division of PFRA. Five sites were selected, three sites were with private producers, one was a provincial grazing co-operative and the fifth site was a PFRA Community Pasture. A comprehensive grazing management plan was developed for each livestock operation.

The Jackson operation near Cabri, Saskatchewan, one of the private sites currently monitored by the Saskatchewan Wetlands Conservation Corporation (SWCC), has reported improved conditions in both the riparian and upland fields. The streambanks are more fully vegetated with a decrease in areas disturbed by livestock hoof action. This site has also experienced an increase in deep-rooted vegetation, along with additional flourishing age classes of willows and other riparian shrubs. The implementation of a grazing management plan has also led to improvements in livestock distribution and in the range condition of the adjacent upland sites.

In 1996, SWCC conducted a riparian inventory within 16 watersheds. Five hundred and seventy-five randomly selected sites were assessed for plant species composition and density, channel characteristics, streambank stability, water quality, upland land use and impacts on the riparian zone (Harrison and Lynn 1996).

The inventory results showed that two introduced species, smooth bromegrass (*Bromus inermis*) and Kentucky bluegrass (*Poa pratensis*) were the dominant vegetation species. Tall shrub species such as willow (*Salix spp*.) and dogwood (*Cornus sp*.), which are important indicators of proper riparian function, were dominant at less than 5% of the sites. In 64% of the sites, less than 10% of the riparian area had exposed soil (excellent condition class). The mean percentage of exposed soils was 8% within the riparian area as a whole, and 14% for the streambank. Just 17% of the sites exhibited bank collapse or hummocking attributable to livestock grazing. Ten percent of the grazed sites had fecal deposits that were considered significant (occurring in more than 25% of the riparian zone). Damage or alteration of riparian areas from cultivation was noted at only 13% of the sites, with significant sedimentation into the stream from cultivated fields adjacent to the riparian area observed at 20% of the sites. Direct seeding of cropped fields adjacent to riparian areas was observed at only 1% of sites. (Harrison and Lynn 1996).

In comparison, the United States has conducted a great deal of research on assessing, monitoring and managing riparian areas. The riparian health ratings are based on 2,594 stream reach evaluations in Montana and Idaho using the Riparian and Wetland Program health assessment (Figure 3.12). Thirty percent of Montana's riparian areas and 37% of Idaho's fell into the nonfunctioning category. In the functioning but at risk category, Montana had 45% with Idaho at 48%. In the healthy category, Montana had 25% and Idaho 15%.

SWCC has initiated work on programs designed to increase awareness of riparian management. The Prairie Shores Program, with North American Waterfowl Management Plan funding, has started to integrate proper grazing techniques into overall riparian management plans for large blocks of Provincial Crown Lands adjacent to the Quill Lakes. The program was initially intended to provide habitat for piping plovers (*Charadrius melodus*), a Canadian species at risk, but has since expanded to provide general riparian ecosystem benefits in a more integrated manner. In 1998, the Canada-Saskatchewan Agri-Food Innovation Funds (AFIF) and Eco-Action 2000 allowed SWCC to launch its Streambank Stewardship Program. The program included a Landowner's Guide and several fact sheets to provide landowners with information and assistance on effective management and stewardship of riparian areas.

SWCC and the Partners For the Saskatchewan River Basin have developed a volunteer monitoring program. The program works with 13 volunteer organizations throughout the Saskatchewan River Watershed to monitor riparian condition, water quality parameters and macro-invertebrate species and populations at selected sites within the watershed.

In Alberta, all riparian assessments and activities have been carried out by the Alberta Riparian Habitat Management Program under the *Cows and Fish Program*. Cows and Fish was initiated in 1992 as a partnership of producer groups, conservation groups and federal and provincial government agencies. The partners work in co-operation with ranchers to improve grazing management to benefit livestock, fish and wildlife. The founding partnership includes Alberta Cattle Commission, the

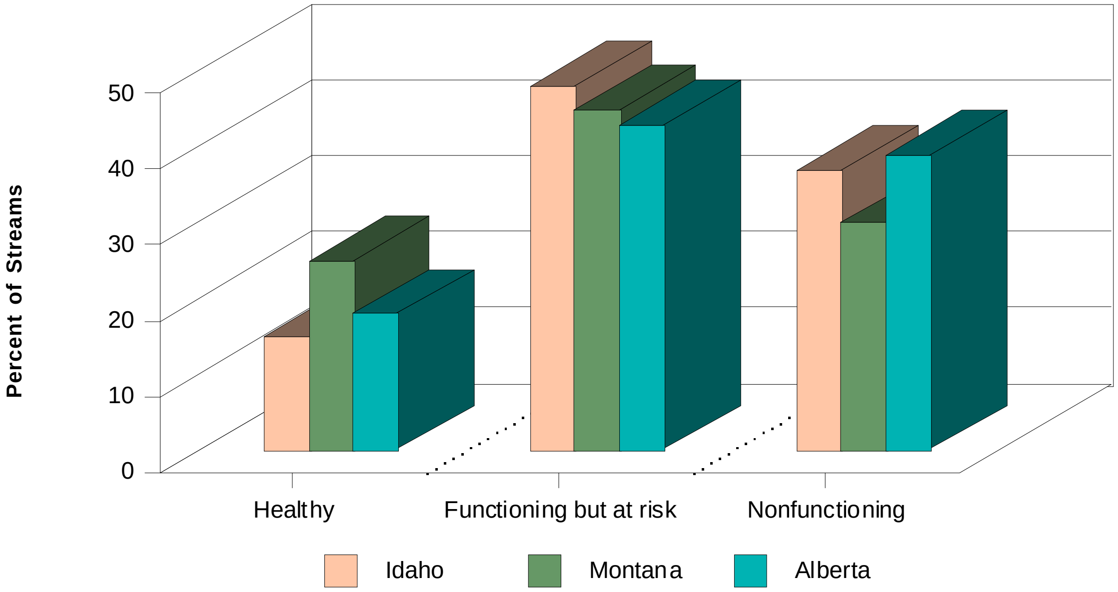
Canadian Cattlemen's Association, Trout Unlimited, Alberta Agriculture, Food and Rural Development (Public Lands), Alberta Environmental Protection (Fish and Wildlife), the Prairie Farm Rehabilitation Administration and the Department of Fisheries and Oceans. The program has generated a great deal of interest and focused attention on riparian issues on a province-wide basis.

Work on the Prairies to date has utilized the riparian health assessment model developed by the University of Montana. In Alberta, 140 stream reaches have been evaluated for riparian health. Much, if not all of this work, has been completed in the southwestern portion of the province. Figure 3.12 shows the riparian health of selected streams in Alberta, in comparison to selected streams in Montana and Idaho. Some 39% of the stream reaches evaluated in Alberta are in the non-functioning category. The functioning, but at risk category makes up 43%, while 18% of stream reaches are in the healthy category.

The Riparian and Wetland Research Program from the University of Montana is undertaking a two-year study in Alberta and Saskatchewan to classify the plant communities and identify management recommendations for riparian areas in the Prairie Ecozones of the two provinces (Godfrey et al. in press). The assessment methodology is the same as that used for Montana riparian areas (Hansen et al. 1995) and is also being considered for use in several additional Great Plains and Intermountain states.

In Manitoba, the first riparian demonstration project sites were initiated in the 1990s as a component of the Canada-Manitoba Agreement on Agricultural Sustainability (CMAAS). Riparian enhancement techniques offered to landowners included fencing of riparian areas, off-stream watering sites and seeding of buffer strips.

In the mid-1990s, the Manitoba Habitat Heritage Corporation (MHHC) started its Green Banks Program with several other



Source: Fitch 1999; Thompson 1999

Figure 3.12 Health rating of selected Montana, Idaho, and Alberta streams.

funding partners (Manitoba Sustainable Development Innovations Fund, Manitoba Water Services Board, Manitoba Cattle Producers Association, Manitoba Conservation Districts, TransCanada Pipe Lines and several local producer groups). The focus of this program has been to demonstrate recommended grazing practices and provide technical support and cost-shared assistance for improved management of riparian areas.

The Manitoba Department of Natural Resources (now Manitoba Conservation) has completed systematic assessments for several watersheds, including the Souris, Little Saskatchewan, Upper Whitemud and Dauphin Lake watersheds (Sopuck 1999). A Fisheries Enhancement Initiative managed by the Fisheries Branch of the Manitoba government has engaged in a number of riparian enhancement projects and demonstrations in several Manitoba watersheds. Enhancement activities included riparian fencing, off-stream watering sites, corral relocations and in-stream fisheries enhancement (Sopuck 1999).

MANAGEMENT IMPACTS

Annual Cropping

Agricultural activities of early civilizations began several thousand years ago within the floodplains adjacent to many of the world's river systems. As agricultural activities intensified, the impacts to riparian areas and rivers became more evident with increased soil erosion, sedimentation and contamination of river systems by pollutants such as nutrients and pesticides. To alleviate the negative impacts of annual cropping near rivers, management alternatives have been required.

Buffer strips have proven to be an efficient method of controlling agricultural runoff. Buffer strips (also referred to as vegetative filter strips, grass strips, riparian plantings, riparian forests and buffer zones) are important for water quality and quantity, streambank stability, fish and wildlife habitat and biodiversity. Their function is to provide localized erosion protection and to filter nutrients, sediments and other agricultural pollutants from runoff. Buffer strips have also been effective in other industries including logging, and strip mining, and for collecting runoff from intensive livestock operations (Helps-Lammers et al. 1991).

Buffer strips are not intended to be the only tool in soil erosion control. Their effectiveness increases with the establishment of multi-species strips that contain seeded species of grass, shrubs and trees. Multi-species buffers provide a more complete package of protection for streambanks and the maintenance of water quality.

The effectiveness of buffer strips has been demonstrated in the United States (National Resource Conservation Service 1999), where it was found that well-designed and maintained buffer strips can potentially remove:

- 50% or more of nutrients and pesticides
- 60% or more of certain pathogens
- 75% or more of sediments.

The recommended width of buffer strips for riparian zones is highly variable and site specific. Width is related to factors such as slope, soil texture above the slope, soil erodibility and type of strip vegetation (Eastern Canada Soil and Water Conservation Centre 1995). *The wider the better* is an axiom that has been used in journals and by land managers. However, the width depends on whether the priority for the land parcel adjacent to the stream is for water quality and bank stabilization or for economic value as seeded area for annual cropland.

Livestock Grazing

In terms of extensive ranching operations, the link between grazing and riparian areas is one that goes back to the original settlement of the Prairies. Water for livestock was the limiting resource and ranchers were not willing to limit livestock access to riparian areas. However, livestock tend to congregate in riparian and wetland areas and over-utilize forage, compared to the adjacent upland areas (Kauffman and Krueger 1984). While there has been considerable research done on riparian areas in the Western United States, there has been very limited documentation and research into riparian grazing management in Western Canada. For this reason, citations from the Northern Great Plains and Intermountain states are used.

Grazing management in riparian areas is a complex system with no simple solutions. Each situation should be considered on a site-specific basis (Platts 1990). Any discussion of grazing must address a number of principles that impact the quality and function of riparian areas. These include timing and frequency, intensity and distribution of animals.

Within the Prairie ecosystem, there is no best time to graze in the riparian zone. There are advantages and disadvantages for grazing during any time of the year. The ability of a particular stream to withstand the impacts of grazing depends on the riparian zone condition and its ability to function, as well as the goals of the overall management plan for the area.

Livestock should be managed to minimize the impact of cattle on riparian zones.

The two most critical periods are late spring when soils are saturated due to excessive streambank moisture, and late fall when shrub species are most susceptible to damage by browsing. In Montana, the greatest damage to streambanks occurs in late June to early July when livestock use was lowest but soil moisture was high (Marlow 1985). In late fall, cattle are more likely to preferentially browse riparian shrubs over grasses and forbs, due to the reduced nutritive quality and palatability of the herbaceous species. Shrubs such as willows are critical to proper functioning of streambanks, and their numbers can be reduced significantly by browsing, trampling and uprooting of young seedlings (Clary and Webster 1989; Kovalchik and Elmore 1992).

Riparian vegetation can respond both positively and negatively to grazing impacts. Defoliation removes the apical dominance of the plant and results in a thicker, more lush stand. Defoliation also forces the plant to utilize organic reserves to regrow leaves and replenish its root system. This will only occur if there is sufficient soil moisture to stimulate activity. In the spring, there is greater potential for sufficient soil moisture to be present, but after mid-July, generally only minimal regrowth occurs for riparian vegetation species (Sheeter and Svjecar 1997).

Grazing intensity can affect a wide range of riparian functions, although American studies are varied as to whether these effects are all negative. Two studies conducted at the same location produced conflicting results. The first showed higher concentrations of ammonia, nitrate, soluble and total phosphorus, chloride, total organic carbon and oxygen demand in stream runoff after cattle grazing had occurred (Schepers and Francis 1982). At the same site, the chemical quality of the runoff from the grazed pasture was actually better than that of the ungrazed pasture, cropland or urban areas (Doran et al. 1981). Livestock also significantly add to fecal coliforms within runoff and stream water. Fecal coliform counts were directly related to the presence of livestock on a riparian area that was moderately to heavily grazed (Stephenson and Street 1978). Nutrients in cattle urine and feces are more likely to be transported by overland flow when soil moisture is high, or when soils are frozen (Heathman et al. 1985).

Livestock distribution and the ability to control the amount of time that cattle spend grazing or resting is another essential consideration for proper riparian management. Riparian areas only occupy a small proportion of the total land within a pasture, usually less than 5%. However, these areas may produce as much as 20% of the forage and receive 80% of the use (Kauffmann and Krueger 1984). A study of livestock behavior showed that cattle grazed the riparian zone 12-20 times more than other pasture areas during the first third of the summer grazing season (Bryant 1979).

Vegetation removal, although a concern, is not the only impact associated with livestock grazing. Other impacts include soil compaction, bank trampling and degraded water quality from livestock waste entering the watershed (Ehrhart and Hansen 1997).

Two tools most often used by producers to change riparian grazing patterns are fencing into smaller pastures, and development of off-stream watering sites. Of the two, off-stream watering sources are perhaps the most important and valuable tool in conserving streambanks and riparian areas. Anecdotal reports indicate that livestock will selectively choose water from a trough over dugout water where they are required to walk into the dugout to drink.

Other means of improving livestock distribution to minimize riparian impacts include:

- creating stable access points to encourage livestock to cross streams at specific locations
- placing salt and mineral blocks as far away from watering points as possible
- moving gate locations away from riparian areas, installing drift fences or obstacles to disrupt routine herd activities
- using riders or herdsmen to move livestock out of riparian areas
- altering the home range of the cattle herd, or not letting them establish one by rotating herds in different locations
- building exclusion fencing, as a last resort for severely degraded riparian areas.

Other factors
This section has focussed on two components of agricultural land use, in particular annual cropping and livestock grazing, and their impacts on riparian areas. However, other activities of concern, include intensive livestock operations, winter feeding areas for livestock, drainage of wetlands and channelization of creeks. These activities can alter, destroy or reduce the functioning capabilities of streams, rivers, wetlands and watersheds. Other industrial sectors and extensive land uses outside the scope of agriculture, such as, logging, mining, road construction and urbanization may impact and threaten riparian areas.

Rangeland and Seeded Forages

While rangeland and seeded forages are clearly important to livestock production, these lands have more recently been recognized for their importance to wildlife habitat, biodiversity, recreation, carbon sequestration and as sources of genetic and other plant material. Rangelands and perennial forages cover vast areas on a diversity of landscapes, making forage one of the Prairies' largest crops.

The Prairie ecozone, covering 3.7% (46 680 799 ha) of the Canadian land base, is the northern-most extent of the Northern Great Plains. The Boreal Plains and Boreal Shield terrestrial ecozones combined represent a total forest region covering 22.3% of the landbase (281 664 565 ha), making up the largest terrestrial ecozone in Canada. Some grassland is interspersed within the boreal forest region of the Peace River area of Alberta and British Columbia. The Montane

Cordillera terrestrial ecozone covers approximately 3.9% (48 989 784 ha) of the country, and stretches from British Columbia to central and southern Alberta, Figure 3.13 (Ecological Stratification Working Group 1995).

Within each terrestrial ecozone, there are a number of ecoregions and agronomic systems. The structure (abiotic and biotic component) and function (energy flow and nutrient cycling) attributes of each natural or artificial biological system will determine the health, efficiency and vulnerability of that system (Heitschmidt 1993). Examples of these systems include the rangeland ecosystem (natural), the agro-ecosystem (artificial) and the wetland ecosystem (natural or artificial).

Natural rangeland ecosystems have been defined as lands which provide forage for domestic livestock and wildlife species, but due to edaphic, topographic or geologic constraints, are not suited to commercial farm or timber crops (Heady 1975). The description of rangeland should therefore include all non-cultivated land found in all of the major terrestrial ecozones, to recognize the many uses and benefits of native rangeland beyond agriculture.

Prairie rangeland encompasses many different natural ecosystems, with the health of each individual ecosystem hinging on its functional and structural integrity. A high level of biological diversity within a natural rangeland ecosystem is usually associated with functional stability and higher primary productivity (O'Connor 1995; Solbrig 1995). Managing grazing lands to minimum standards of good range condition will allow land managers to meet most production and environmental objectives.

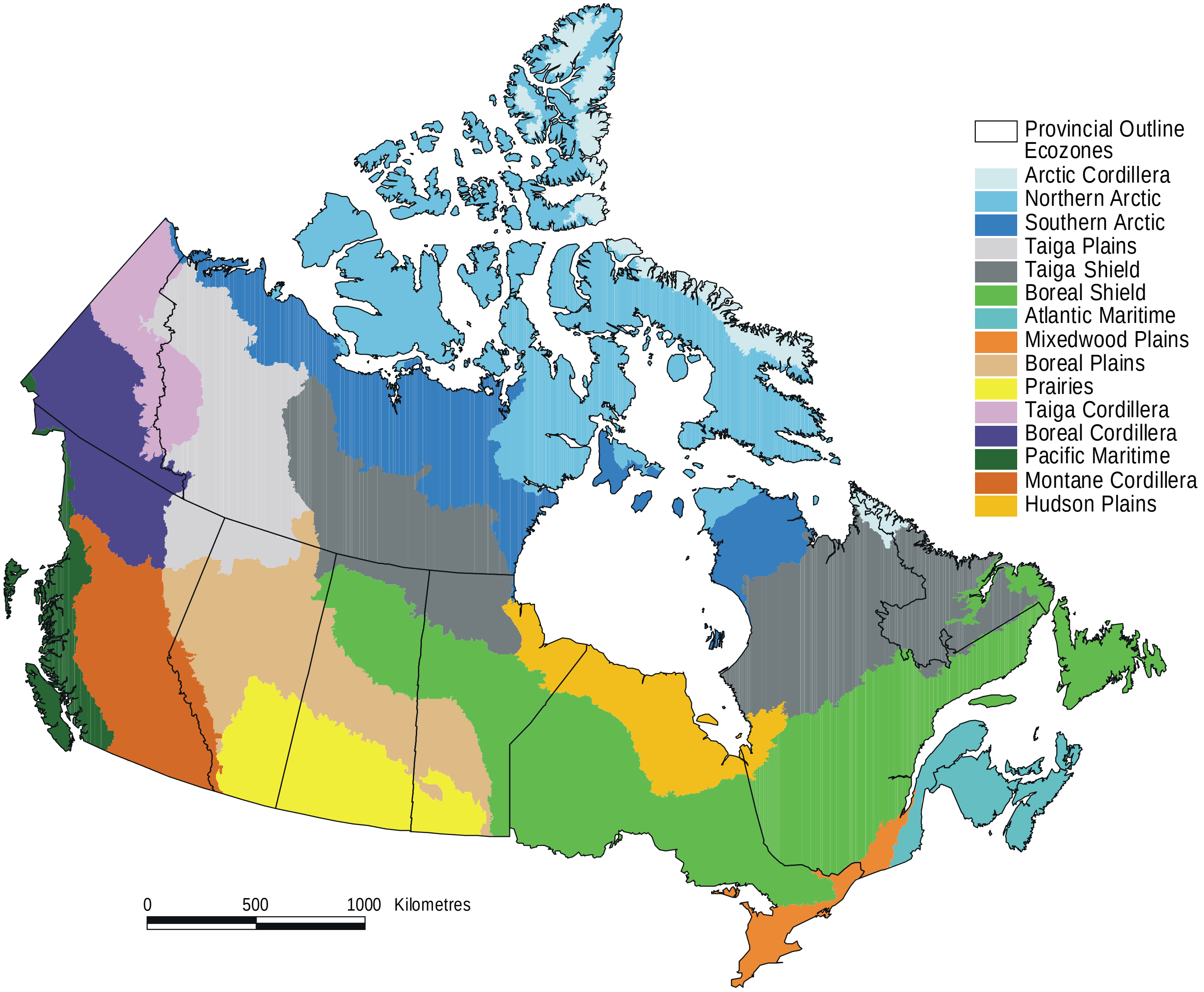
Range condition relates the present state of the range to the natural potential or climax community. *Excellent* condition greater than 75%; *good* native range condition is classified as having 50-75% of the biomass made up of the original or climax vegetation; *fair* condition 25-50%; *poor* condition less than 25% (Abouguendia 1990). Excellent condition greater than 95%; good tame pasture condition is classified as having 75-94% of the biomass made up of the species which were seeded; fair condition 51-74%; poor condition less than 50%.

Excellent and good condition rangelands and pasture lands are dominated by taller, more productive and often more palatable plants. As range condition declines, the less palatable, shorter growing and less productive species dominate. Biomass production is also reduced. Range condition is not a measure of year-to-year variability in production, however, it is directly related to yield potential of the site. Better range condition is directly correlated with higher biomass production.

CURRENT STATUS

There has been no formal assessment and inventory of the range sites or condition of native rangeland across the Prairies. However, all public land agencies have some form of land inventory or range classification system. In some jurisdictions, simple assessments are used as the basis for setting fees or rent, while other jurisdictions carry out detailed inventories of vegetation and range condition. In some circumstances, these are developed into formal range management plans, which are then used to guide land management decisions.

Alberta Public Lands has a formal system for surveying range in its jurisdiction. Range surveys have been conducted on over 200 000 ha of Alberta public land since 1986, using methods described by Robertson and Adams (1991) and Wroe et al. (1988). These surveys are often directed at those lands where range use conflicts exist. A comprehensive range inventory is required with every grazing lease renewal.



Source: Ecoregions Working Group 1989

Figure 3.13 Ecozones of Canada.

Maintaining large blocks of healthy native vegetation is a key contributor to biodiversity.

PFRA has conducted detailed biophysical inventories and range condition assessments on 55 of its 87 community pastures, or approximately 560 000 ha. This information forms the basis of range management plans developed for each of these pastures. The goal is to inventory the community pastures on a 10-year cycle to monitor trends and adapt management to changing conditions and knowledge.

Other public land agencies on the Prairies have less detailed range condition assessment and survey procedures, but are currently in the process of examining their protocols. On private land, there is no formal range inventory system, thus assessments have not been widely conducted. Any inventories and management plans that have been developed were done in co-operation with provincial departments of agriculture, the Grazing and Pasture Technology Program in Saskatchewan, or Ducks Unlimited Canada. Recently, there has been an increase in range management plans being developed by leading edge producers.

As part of the Prairie Agriculture Landscapes project, rangeland professionals were contacted to share data and opinions regarding rangeland condition on the Prairies. They estimated the percentage of rangeland in each condition class for the areas they were familiar with, or had data on. Estimates were based on field observations and inventory data. While the information is based on only a small portion of rangeland across the Prairies, it gives an indication of direction.

The survey found that more than half of Prairie rangeland is in less than good condition. Some areas reported over three-quarters of the land to be in less than good condition. This means that, through improved management, there is room to increase rangeland and cattle production and to contribute further to biodiversity and soil organic matter.

A number of factors have contributed to the decline in range condition. These include economic pressures in the agricultural community to maximize production, little emphasis on extension in the field of range management in the past and a perception that there was no economic incentive to maintain good range condition. In reality, rangeland can be managed to improve its condition and there are sound economic reasons to do so. Better condition will allow higher carrying capacities with the potential for increased economic returns and higher land values.

BENEFITS OF RANGELAND AND FORAGES

Biodiversity

Biological diversity is defined as the variability among and within living organisms from all sources including terrestrial, marine and other aquatic ecosystems, and the ecological complexes in which they are situated. This includes diversity within species, between species and within different ecosystems (AAFC, Environment Bureau 1997).

Rangelands can contribute to maintaining biodiversity in a number of ways. They support a wide variety of plant species on an array of soil and water gradients. This variety provides habitat for a diversity of animal species. Native wildlife evolved and thrived on native vegetation prior to cultivation, and thus are most adapted to these areas.

Every species requires a minimum amount of habitat to meet its life needs. Maintaining large blocks of healthy native vegetation is a key to biodiversity. Managing for good range condition will foster maximum plant diversity, that is, the largest variety of species with the largest populations (Pepper and Gauthier 1998). Some unique or rare species thrive on heavily grazed or impoverished sites. However, grazed land in good overall condition often has areas of both high and low use, thus providing sites for these species.

Rangeland with moderate levels of grazing has greater species richness than corresponding land with high intensity grazing or no grazing (Bai et al. In press). The goal should be to maintain an average of good condition across the land. If there is a diversity of plant species, it is reasonable to suggest that this would support a diversity of animal life. Large populations of many species maintains a source of genetics, medications and food for possible future use as science evolves. On open rangeland it is not possible to maintain the entire range in good condition due to heavier grazing pressure around watering sites, gates and preferred areas. In these areas, species of plants and animals which require areas of heavier grazing for habitat will thrive, thus a combination is required.

Seeded perennial forages can contribute to biodiversity as well. In contrast to annual crops, perennial forages provide year-round vegetative cover which, provides food and cover sources for many animal species. As a tame forage stand ages, other native and introduced species invade the stand, making the stand more diverse over time.

Wildlife and agricultural production have often been in conflict in the past. However, more and better quality habitat with increased emphasis on rangeland and forage management, and potential increases in hectares of perennial forage may reduce these conflicts in the future. Producers are seeing the benefit of improved range management for livestock, and this will have a positive impact on wildlife habitat and biodiversity.

Marginal Land and Soil Conservation

A healthy and vigourous vegetative cover is critical to soil and water conservation on both rangeland and tame forage land. The key to soil conservation on this land is maintaining a healthy plant community and allowing the litter and mulch to accumulate. Litter is a nutrient reserve and an intermediate link between vegetation and organic matter in the soil. Plants and litter slow water runoff, reduce evaporation from the soil surface, reduce soil temperature and prevent soil erosion.

Seeded forages are valuable for stabilizing gullies and steep slopes against soil erosion. Perennial forages can also be used to draw down the water table on saline land, thus reducing soil salinity.

Perennial forages can be grown successfully on land which is marginal for annual crop production. A selection of forage species is available for almost any marginal soil situation. For example, many species are adapted to light textured and low organic matter soils. These species have deep roots allowing greater access to moisture and nutrients. There are also species adapted to survive flooding, salinity and acidity. Together, these species provide soil protection, organic matter buildup and an economic return from land which is often either economically or environmentally unsuitable for annual crop production.

Forages and Rangelands as Carbon Sinks

Forage lands and rangelands play a significant role sequestering carbon, thereby mitigating greenhouse gases and reducing the impact of these gases on climate change. Land which has been degraded in the past through cultivation or overgrazing has the ability to sequester more carbon.

There are three practical ways to build up the soil's organic matter which will help to sequester greenhouse gases. These are:

- improved management of existing rangeland and seeded pasture
- re-seeding of degraded pasture
- seeding perennial forage onto both environmentally and economically marginal land.

Rangelands which have been overgrazed and are in a deteriorated or poor condition have reduced levels of soil organic matter (including carbon) compared to range in good condition. Over-grazing results in a greater harvest of organic material than is returned to the system. Poor condition rangeland has lower above-ground biomass than comparable rangeland in good condition (Abouguendia 1990; Coupland 1970). The below-ground biomass in native rangeland is 4-7 times greater than the above-ground biomass (Coupland 1970; Anderson and Coleman 1985). A reduction in above-ground biomass results in a corresponding reduction in below-ground biomass overtime, thus less organic material is returned to the system and the carbon in the soil is in a state of decline.

The decline of soil carbon can be reversed through the implementation of planned grazing systems. By improving range condition, taller, deeper-rooted species replace shorter, less productive species, slowly rebuilding the organic matter and carbon in the soil. Improving the condition on native and tame rangeland can result in an increase of 0.2 t/ha/yr for up to 20 years (Bruce et al. 1998). There is the potential to significantly increase soil carbon levels on up to half of the rangeland and seeded pasture on the Prairies.

Re-seeding is required where seeded forages are so degraded that there is not enough of the originally seeded species remaining to improve yields through management. Re-seeding introduces productive, deep-rooted species which contribute to the buildup of organic matter. Improved management of the newly seeded forage is required to build up soil organic matter, otherwise they will quickly degrade.

Re-seeding using sod-seeding technology to establish forages into chemically killed sod is superior to preparing a seed bed through cultivation. Cultivation will increase organic matter breakdown in the soil, reducing the benefit of establishing a new forage stand. Additional greenhouse gas sequestration benefits would be realized by including a legume when re-seeding land. Legumes are highly productive and add a greater amount of nitrogen to the organic matter in the soil, increasing greenhouse gas sequestration. Re-seeding degraded pasture land can result in increases of up to 0.8 t/ha/yr of carbon for 20 years (Bruce et al. 1998).

The most dramatic carbon storage results are seen when perennial forage is seeded to formerly cultivated land. Seeding environmentally and economically marginal land would provide the most significant contribution of all forage management practices as a soil carbon sink for greenhouse gases. There are 1.8 million hectares of CLI class 4-6 land in the lower crop insurance soil ratings (environmentally marginal for annual crop production) currently in cultivation. These lands have the potential to sequester 0.8 t/ha/yr of carbon, having lost organic matter through decades of cultivation, organic material removal and erosion.

Commodity prices and freight rates are currently dictating the conversion of some annual croplands to perennial forages. In addition, many producers are improving range management due to the productivity benefits and as better information becomes available on management practices. For producers to implement management practices solely to sequester carbon, there must be an economic benefit (Table 3.15).

Improved management of fair and poor condition native range and re-seeding poor condition tame forage stands results in economic benefits on the production side. Producers could implement these practices and realize benefits even without applying any value to the sequestered carbon. Any future monetary value that would result from carbon credits would be a bonus. The costs of fertilizing tame forage stands and improving good condition rangeland would have to be offset by at least the equivalent of the monetary loss per tonne of carbon sequestered to be economically viable for a producer.

Multiple Uses

A number of other activities take place on rangeland, some of which can be conflicting. The most direct conflict occurs on public land where competing uses include different management approaches. There are also on-going struggles regarding access to these public lands. Livestock production, mineral extraction and environmental goals are the activities most often in conflict.

Table 3.15 **Yield and economics of changes in management practices to increase carbon sequestration.**

Management Practice	Cost $/ha	AUM increase per ha	Return $/AUM	Benefit less cost $/ha	Net profit (loss) $/tonne C
Native Range Condition					
Improve Poor to Good+	1.48	0.12	1.12	1.28	6.36
Improve Fair to Good+	1.48	0.07	0.60	0.00	0.06
Improve Good to Good+	1.48	0.03	0.30	(0.74)	(3.68)
Tame Forage Management					
Fertilizer (56 kg N/ha)	44.73	0.50	4.65	(33.24)	(59.78)
Fertilizer (112 kg N/ha every 2 years)	37.31	0.50	4.65	(25.82)	(46.44)
Re-seed poor condition stands	9.88	0.70	6.51	6.20	8.46

Source: Howden 1998

Public land agencies are placing a greater focus on multiple land use planning and co-ordinated resource management to minimize conflicts between users and to develop consensus. Private land managers also receive many requests to use their land for purposes other than grazing. These activities can include everything from livestock grazing and habitat conservation, to mineral extraction, logging, wild crafting, hiking, and snowmobiling. These opportunities enable producers to supplement agricultural income by charging other users for access and use of the land. Each producer has a unique approach to multiple uses of their land. Generally, activities which have the best economic return, with minimal impact on the current operation, will be favored.

STRESSES TO RANGELANDS

Six factors have been found to place significant stress on the quality and quantity of native grasslands on the Canadian Prairies. These include:

- cultivation of native rangeland
- deteriorating range condition
- invasive plant species
- fragmentation
- brush encroachment
- industrial activity.

Cultivation of Native Rangeland

Most of the historic native grassland on the prairies has been cultivated or re-seeded to tame forage species. The only native rangeland remaining is on land that is unsuitable for annual cultivation. Rangelands in the most arid part of the Prairies, on stony land, very light textured soils, and soils dominated by salinity or solonetzic profiles, are all that remain. This is not a true representation of the historic native grasslands of the Prairies.

Today, the grasslands that formed the high quality farmland of the central Prairies are all but extinct. This has undoubtedly meant the loss of plant species that may have once existed on these highly productive lands, and has narrowed or eliminated habitat for many animal species. Habitat loss is a major reason for population declines of the majority of Prairie species listed as at risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Committee on the Recovery of Nationally Endangered Wildlife 1998).

Cultivation and re-seeding to introduced forage species has long been practiced to improve the production of native rangeland. But, over the long term, production has not actually increased, because the land only has the potential to produce a given amount of biomass. Cultivation speeds up organic matter mineralization in the soil and causes a temporary increase in nitrogen available to the plant (Whitehead 1970). This available nitrogen results in a temporary production boost. Both seeded introduced and native species have high initial productivity, but in the longer term, will return to an equilibrium with existing environmental conditions and yields resembling that of the native range (Redmann et al. 1994). The technology is not currently in place to quickly re-establish native rangeland that is representative of the historical vegetation of the site. Rather, the process to re-establish native range is a long and evolutionary one.

Deteriorating Range Condition

Good range condition is the recommended goal of Prairie rangeland managers. Current conditions are significantly below this level, but recovery is achievable with moderate capital improvements and changes in management. The economic benefit of improving range condition is not widely recognized. An increase in one range condition class (i.e. from fair to good) can result in a 25% increase in carrying capacity, if improved management practices are sustained.

A common misconception concerning range management is that range condition can only be improved by reducing stocking rates. In fact, range condition can often be improved with management changes and/or fencing and water development. Reducing stocking rates without changing management practices may not have an effect on range condition.

Invasive Species and Fragmentation

Introduced grasses, primarily smooth brome and crested wheatgrass, are intermingled with blocks of native rangeland, and along the ditches of all highways and grid roads. These highly competitive plants have invaded native rangeland in areas where competition is reduced. The seed is spread to new areas by the wind or animals, or through reclamation seedings on industrial sites. They often enjoy a competitive advantage under grazing systems as livestock will preferentially graze the less mature and more palatable native species, putting little stress on the invaders. These species spread when competition is reduced, and they cause a significant danger to the integrity of native rangeland.

Fragmentation is a term used to describe small pieces of native rangeland which are separated by large areas of cultivation. Fragmentation is a major cause of population declines of many wildlife species. Many species require larger areas of native rangeland to carry out their life cycle. The reduced size of these fragments makes it easier for predators to find prey, and the distance between fragments limits feeding locations and makes locating breeding partners difficult.

Industrial Activity

Industrial activity such as oil and gas exploration has had an impact on native landscapes. The rangeland that is broken to accommodate roads to well sites, and the areas around wells themselves fragment habitat for a number of wildlife species. In the past, abandoned sites have been reclaimed using introduced plant species, which has resulted in the invasion of these species onto native rangeland. More recently, reclamation regulation and technology have improved, with sites now required to be representative of the vegetation and landscape characteristics present prior to industrial activity. Industry must continue to focus on minimizing impacts on existing rangeland by concentrating as much activity as possible on one site, sharing roads between companies, and running roads along fencelines wherever possible.

Brush Encroachment

Black soils were formed under grassland vegetation, but the elimination of large prairie fires and the herds of bison that once roamed the region has resulted in the expansion of trees and shrubs onto the grasslands. Currently, aspen is expanding onto formerly open grassland in the Black and Gray soil zones at a rate of 0.5-5% per year (Bowes 1998), displacing grassland species with forest species in the process. This change in vegetation has ecological and production ramifications.

Forest is not the natural climax community of the Black soil zone. Prior to European settle-

Invasive plants such as leafy spurge are threatening the integrity, health and productivity of rangelands.

ment, the Black soil zone had 10-30% tree cover, depending on the site and moisture regime. The most problematic forest species include balsam poplar *(populus balsamifera)*, trembling aspen (*populus tremuloides)*, western snowberry (*Symphoricarpus occidentalis*), and bur oak (*Quercus macrocarpa*). The greatest concern to producers is that forage production is reduced by 80% under forest as compared to grassland.

Current methods used to slow the expansion of brush cover include prescribed burning, controlled grazing, herbicides, brush mowers, bark scrapers and roller/choppers. Single treatments have had limited success and research indicates that an integrated approach using a combination of control practices is most effective. Brush control practices have not yet been widely accepted among producers, and reliance on single treatments has resulted in a continued expansion in brush cover.

EFFECTS OF MANAGEMENT DECISIONS AND PRACTICES

Rangeland management decisions are influenced by two main forces: the economics of agriculture, particularly the profitability of producing annual crops, and availability of information to producers on the most recent range management technology. Decisions made by producers and land managers have greatly impacted the landscape and productive capacity of range and forage lands, and will continue to do so in the future.

Vegetation and soil biota play an important role in rangeland ecology. They can greatly affect the soil properties and processes that control the availability of water and nutrients essential for the maintenance of above-ground plant community composition (Manske 1993). Other factors such as overgrazing and soil disturbance can directly or indirectly accelerate rangeland soil degradation. This can change the micro-environment (i.e. soil temperature, soil water content, evaporation/precipitation ratio) and dramatically alter the overall soil micro/meso fauna activities in a rangeland ecosystem (Herrick and Whitford 1995; Dormaar et al. 1996). Rangeland ecosystems are a highly complex interaction of soil, vegetation, climate, grazers and disturbances such as fire; hence, the vulnerability of this unique Prairie agricultural landscape to human activity.

Cultivation of the Canadian Prairies has contributed to the development of a prosperous society. More than 60% of the land is now cultivated (Prairie Conservation Action Plan Committee 1998). Most remaining native rangeland today exhibit specific limitations for cultivation, such as rocks, sand, salinity or thin soils. Soils that would be considered productive for annual cropping are now very difficult to locate in their uncultivated state. Nonetheless, the appropriate use of rangeland resources for livestock production in the southern portions of Western Canada is probably the best expression of sustainable agriculture in Canada today (Horton 1994).

Native prairie that was broken, but was not suitable for cultivation, eroded badly during the 1930s. In many areas, this land was subsequently re-seeded to introduced forage species. Today, introduced species such as crested wheatgrass, Russian wild rye, and smooth bromegrass, among others, are used extensively in the Prairie region. Recent research suggests that crested wheatgrass and Russian wild rye cannot achieve or maintain the chemical quality of soils possible under native rangeland (Dormaar et al. 1995). In addition, root mass and organic matter are significantly lower in crested wheatgrass and Russian wild rye stands compared to native range. More information is required to make confident predictions on the sustainability of agronomic systems, particularly regarding the effect of improved management practices on the soils (Dormaar et al. 1995).

Seeded forages have performed a valuable role in farming operations. Introduced species have enhanced diversification by allowing producers to use legumes in annual crop rotations to build up soil organic matter and to produce a variety of salable products. Seeded forages are more prevalent in the moister Black and Gray soil zones, where a greater amount of native grassland has been broken for cultivation.

Introduced forage species also provide habitat for a number of wildlife species. Though not as valuable as native rangeland, perennial forage provides much better habitat than cultivated land (Godwin et al. 1998). Seeded forages play a major role in revegetating eroding annual cropland and stopping significant topsoil loss. In addition, early-growing introduced grasses take significant pressure off native rangeland in the spring, when repeated grazing can have a negative effect.

A number of Canadian-developed grass and legume varieties have been seeded across the landscape. Varieties have been developed for a range of soil types and environmental conditions. Recent research has focussed on specific goals such as improving seedling vigour in Russian wild rye and cicer milk vetch, reducing bloat and increasing the leaf:stem ratio of alfalfa and developing a dual-purpose bromegrass. Significant research has also been conducted into the development of ecovars (local varieties with some selection carried out) to be used in reclamation.

Overgrazing jeopardizes the sustainability of both native and seeded forage systems by reducing fertility and water holding capacity of soils (Dormaar and Willms 1998). By reducing the amount of plant material available as litter, overgrazing increases soil temperature and decreases water holding capacity, magnifying the effects of drought on forage productivity. Unhealthy forage stands are also vulnerable to domination by less productive species and weed invasion.

Seeded forages play a major role in revegetating eroding annual cropland, and stopping significant topsoil loss.

New methods of range condition assessment are currently being evaluated. There has been significant research and discussion about the relevance of using the climax community concept. New systems being employed in some jurisdictions are using a desired plant community approach, or a more soil-based approach, which rates whether the system as a whole is at risk to deterioration.

The Natural Resource Conservation Service in the United States has begun introducing a new procedure for evaluating rangeland health. Rangeland health is defined and evaluated as the degree to which the integrity of the soil, vegetation, water and air, as well as the ecological processes of the rangeland ecosystem, is balanced and sustained (United States Department of Agriculture, Natural Resource Conservation Service 1997). All systems – both new and old – still use an ecological approach, and rate the health of a community in relation to a baseline. There is some hesitance to change because the current system is extensively used and provides an understood baseline of information upon which to base management decisions.

CONCLUSIONS

Grazing and forage management on farms and ranches has slowly evolved over the past 20 years, with planned grazing systems much more common and accepted today. These systems are generally developed to maintain or improve production on an individual operation. In recent years, conservation organizations have realized the benefits of healthy rangelands and recognized that grazing livestock can actually maintain or improve wildlife habitat. Good grazing management can accomplish both production and environmental goals, with good range condition as the measure and objective of both goals.

Good range condition is achievable in a livestock production system, and is the generally accepted standard of the range management profession. Land managers must be provided with information regarding the benefits of improving rangeland condition, as well as the expertise to implement management changes. A survey of native vegetation and corresponding condition (similar to the soil surveys) should be carried out across the Prairies to accurately map vegetation types and confirm range condition. This type of information could be used by land managers as a starting point for management planning, and would be invaluable to wildlife and environmental programs and greenhouse gas mitigation strategies.

The past decade has seen a significant increase in extension and education in the field of range and forage management. Extension of basic range management principles is key to maximizing profits for Prairie livestock producers. Healthy forage stands are more productive, and thus more profitable.

Management using an ecosystem-based approach can enhance the inherent capability of rangeland-based operations to respond to environmental stresses. Traditional technology transfer on basic range management technology includes invasive weed control, increasing cow-calf herd profitability, and use of tame grasses in complementary grazing systems. New challenges impacting the livestock sector include riparian management, understanding livestock-wildlife interactions, biodiversity and livestock grazing, and grazing in forested areas.

Rangelands are very complex systems which are affected by past management and current climate, the interactions of which we are still learning. Effective future management will require recognizing, and appropriately responding to the legitimate concerns of conservation and environmental movements with regard to these complex issues (Horton 1994).

Good range condition is achievable in a livestock production system and should be the goal for land managers from an economic and environmental perspective.

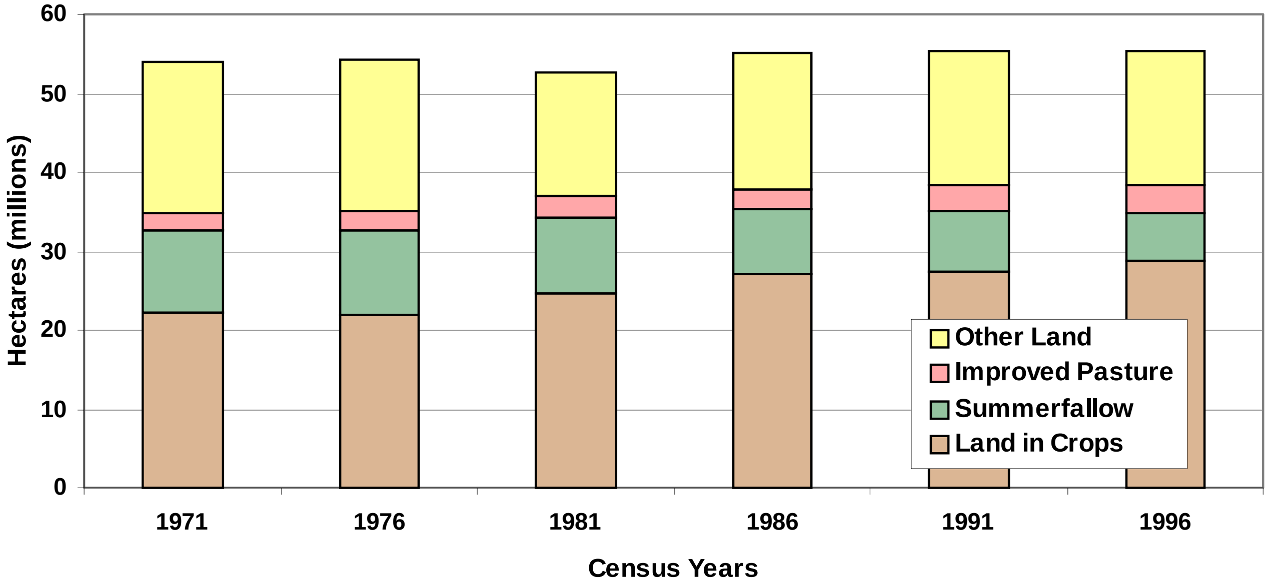
Chapter 4: Land Use and Farming Systems

Introduction

Since the settlement of the Prairies in the 19th and early 20th centuries, land use and farming practices have evolved to match the various climates and soil types on the Prairies and adapted to changing markets, technology and transportation systems. The abandonment of farms in the Special Areas of Alberta during the early 1920s, and southwestern Saskatchewan in the 1930s, provides evidence of these adjustment processes. More recently, since the 1980s, there has been a reduction in summerfallow and an expansion of crop varieties, particularly in areas of higher moisture.

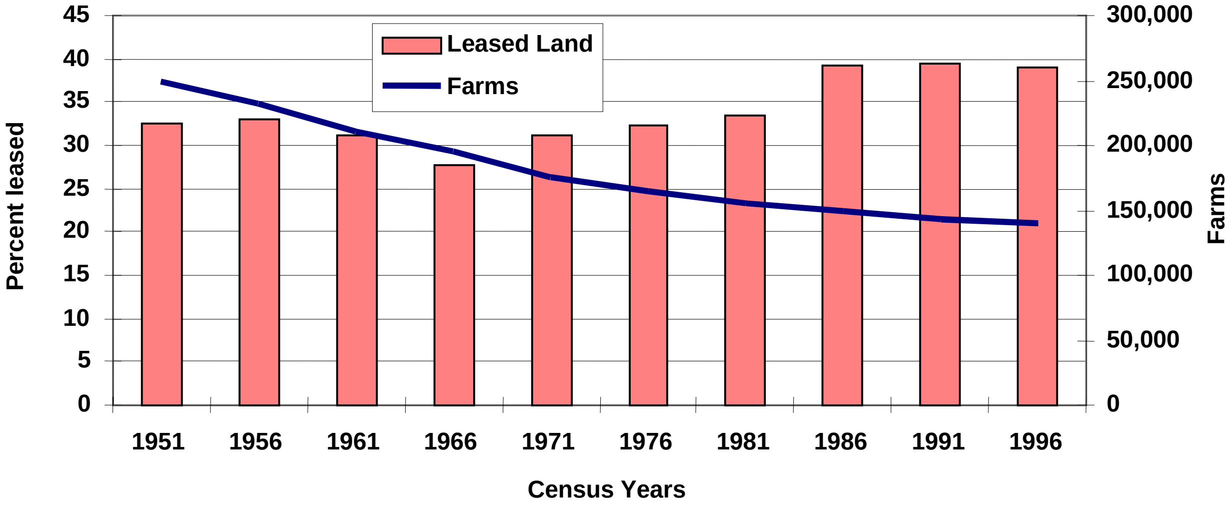
The total land reported on farms has remained relatively constant (1971-1996). However, a reduction in summerfallow area since 1981 has resulted in additional land being cropped (Figure 4.1). This reduction in summerfallow is attributed to a number of factors, including economic circumstances and technological change. Conservation programming over the past 20 years has done much to communicate and demonstrate appropriate land management techniques.

Over the past 20 years, 35-40% of farmland has been rented (Figure 4.2). This raises concerns since public programs designed to promote long term land stewardship may not be as effective on rented lands, where shorter term revenues may be the primary goal.



Source: Census of Agriculture

Figure 4.1 Prairie land use.

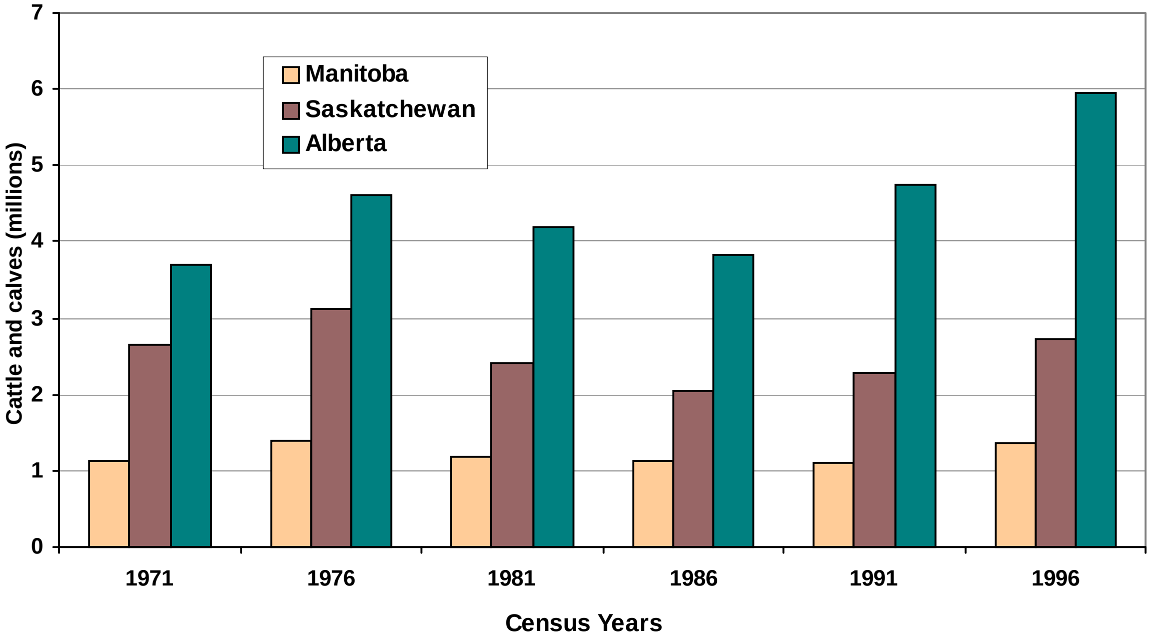


Source: Census of Agriculture

Figure 4.2 Number of farms and percent of agricultural land leased on the Prairies.

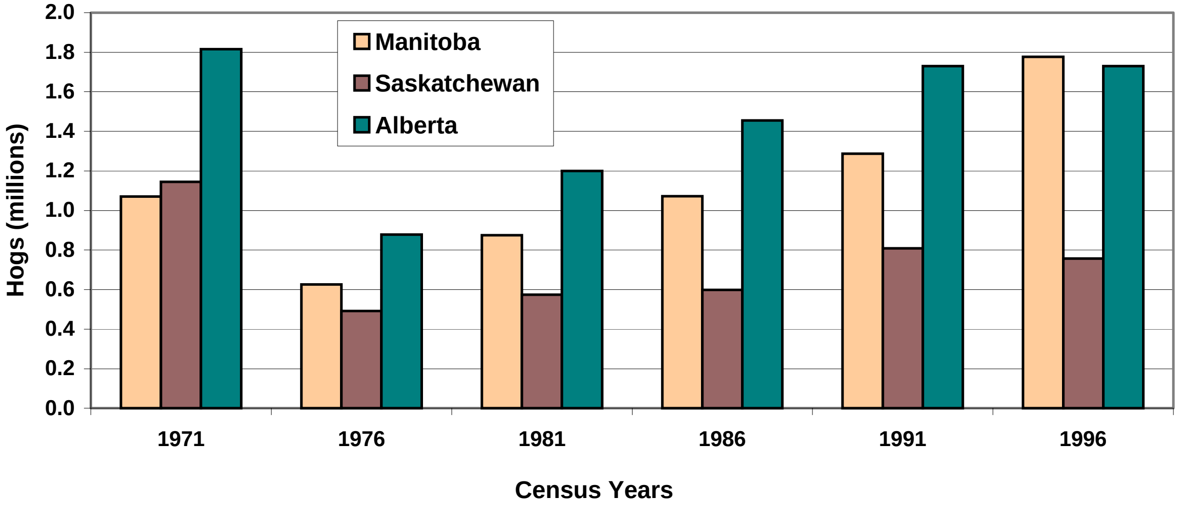
Trends and populations of livestock (cattle, hogs and poultry) since 1971 are illustrated in Figures 4.3 to 4.5. Overall, cattle numbers have been increasing since 1986, with production highest in Alberta (Figure 4.3). Cattle populations in Manitoba and Saskatchewan in 1996 approach, but have not attained, the peaks of 1976. Land for pasture and feed grains to meet the demands for increased cattle numbers may be in short supply in some regions where there is competition for higher valued crops.

Hog numbers have rapidly increased in Manitoba and Alberta since 1976, with Manitoba's hog population surpassing Alberta's (1996 Census of Agriculture).



Source: Census of Agriculture

Figure 4.3 Cattle and calf populations.

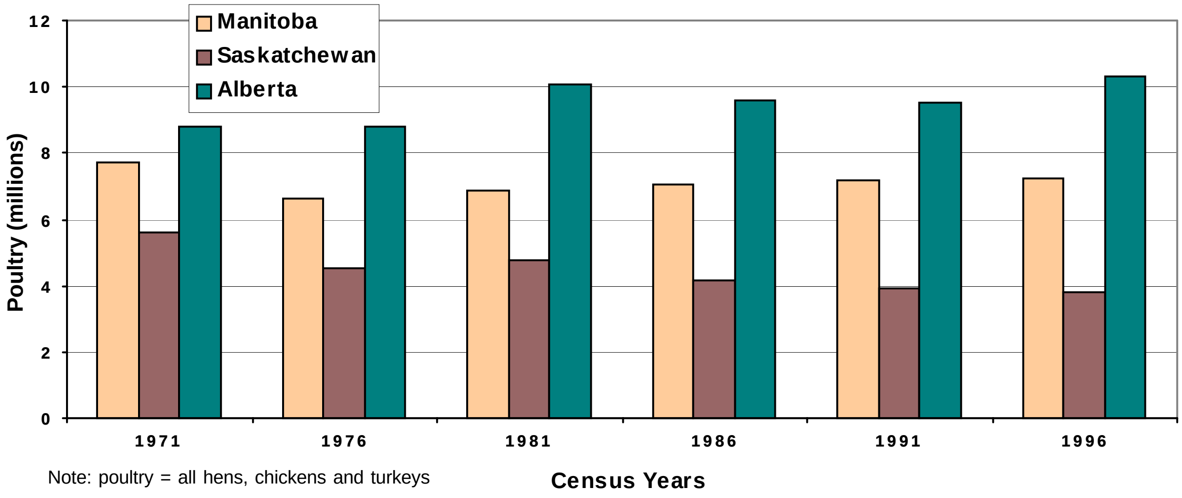


Source: Census of Agriculture

Figure 4.4 Hog populations.

Recent hog processing developments in Manitoba, coupled with changes to freight rates for export grains, bode well for continued expansion of that province's hog sector over the next few years. Despite Saskatchewan's aggressive target to increase production, a rapid decline in the number of smaller operations has resulted in little change in hog numbers for the period presented in Figure 4.4. However, forecasts for both Saskatchewan and Alberta suggest rapid increases in intensive hog production.

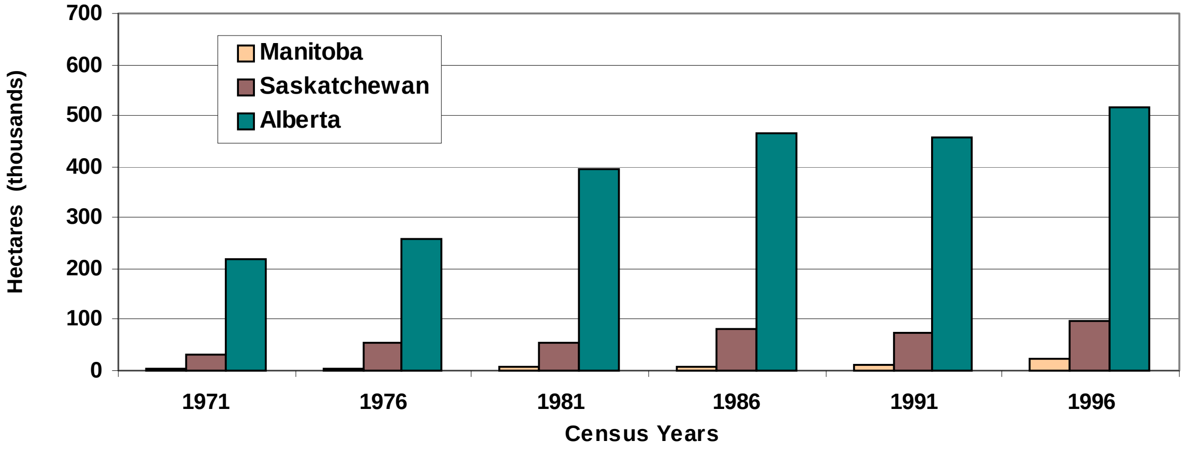
The poultry population has remained relatively constant (1971 to 1996) due to supply management (Figure 4.5). However, concentration of production has increased significantly as the number of chicken producers had declined from 69,670 to 11,617. The remaining farms show that significant intensification has occurred due to economies of scale with confined production techniques. As with the hog and beef sectors, there is renewed interest in additional poultry



Note: poultry = all hens, chickens and turkeys

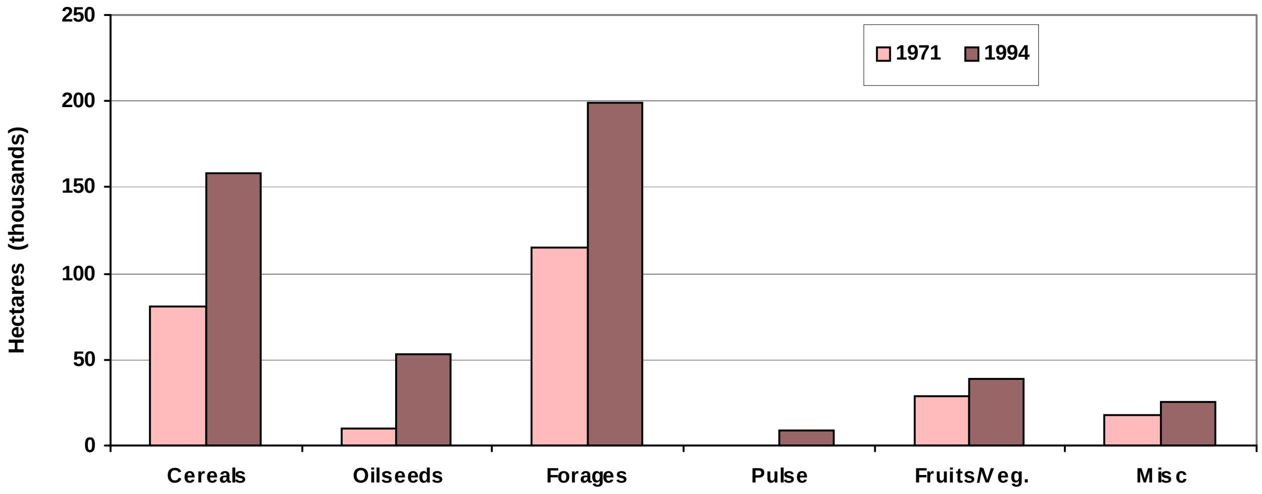
Source: Census of Agriculture

Figure 4.5 Poultry populations.



Sources: Census of Agriculture and PFRA

Figure 4.6 Prairie irrigation area.



Sources: 1971 Census of Agriculture; Alberta Agriculture Food and Rural Development 1994; Saskatchewan Agriculture and Food 1994; Manitoba Agriculture1994.

Figure 4.7 Trends in Prairie irrigated crops.

output due to the comparative cost advantage of production in the Prairie region.

Irrigated area has nearly tripled (1971 and 1996), with Alberta having most of the growth (Figure 4.6). The 636 000 hectares of irrigated land in the Prairie provinces represents an important sub-set of agricultural land use and production activity. Although the majority of irrigated areas are cropped to cereals and forages (Figure 4.7), the output supports a diverse and vibrant processing and value-added sector. For instance, irrigation provides the consistent yields and quality necessary to support potato processing in the Prairie region.

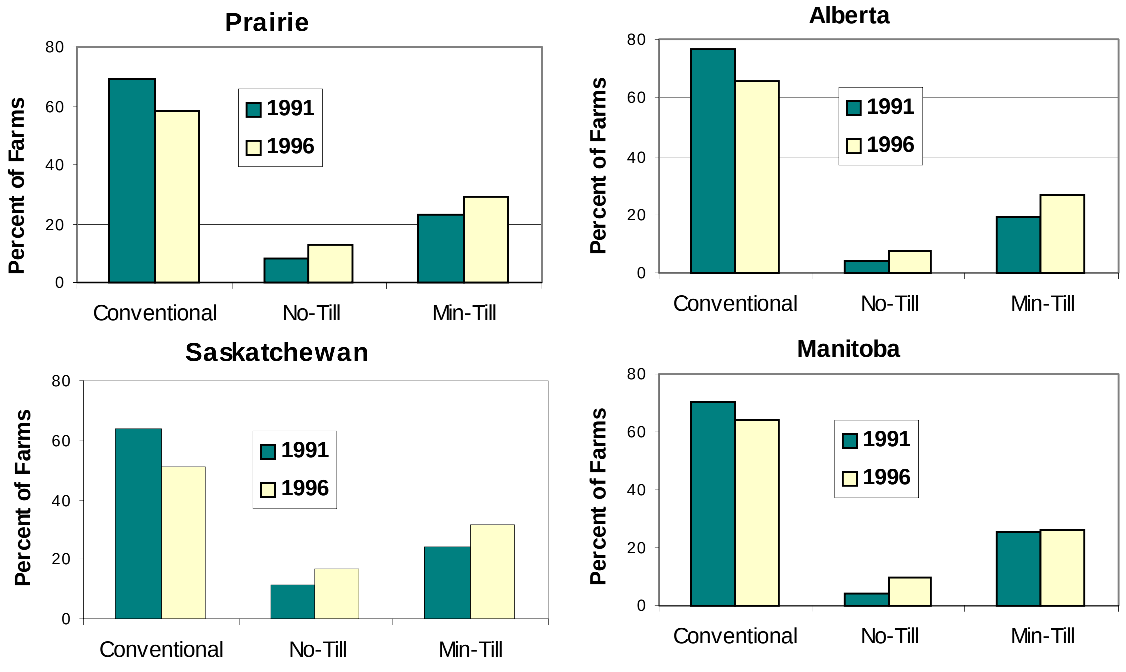
The 1991 and 1996 Agricultural Census also solicited input from producers on the adoption of conservation tillage. In general, there has been significant acceptance of reduced tillage technologies between 1991 and 1996 (Figure 4.8). In all provinces less conventional tillage is being reported, while no-till and minimum tillage on the cultivated land base is increasing.

Both historically and in the recent past, there have been changes in land use and land practices on the Prairies. The remainder of this chapter explores in more detail the relationship between current land use and farming practices in different landscapes across the Prairies. Information from this study can be used to identify the location of current practices and to evaluate the potential of Prairie landscapes to adapt to future economic and environmental scenarios. It may also be used to predict where future changes are most likely to occur.

Defining Land Practices Groups and Landscapes

It has long been understood that the ability and opportunity for agricultural systems to change is limited by landscape characteristics (Dumanski and Kirkwood 1988). For this discussion, landscape characteristics include soil, land form, vegetation and climate factors.

Studies that relate land use to landscape usually begin by classifying the landscape, and then describe the biological characteristics and land use of each landscape type (Huffman et al. 1993). In this study, areas with similar agricultural practices and land uses were grouped together first. Then the soil and landscape types found within each group were characterized, identifying the range of land-



Source: Census of Agriculture

Figure 4.8 Percent of farms using conventional, no-till and min-till practices across the Prairies.

scapes that are associated with a given set of agricultural activities. Two data sets were used in this study, the Soil Landscapes of Canada (SLC) (Centre for Land and Biological Resources Research 1996) and the 1996 Census of Agriculture.

The Soil Landscapes of Canada is a series of maps and associated databases that portray soil and land characteristics, or attributes, for all provinces and territories in Canada. The maps have been compiled at a scale of 1:1,000,000. Each SLC map area, or polygon, is described in terms of a standard set of attributes that includes soil development, soil parent material, mode of deposition, texture class of parent material, local surface form, slope gradient, kind of rock or surface material except water, and spatial occurrence of these attributes within a polygon. These attributes are factors that are important for plant growth, general land management, regional planning, terrain sensitivity and environmental sustainability. A polygon may contain one or more distinctive soil landscapes.

Statistics Canada conducts a Census of Agriculture every five years in which producers are required to report information on:

- operating arrangements and tenure
- land use and crops grown
- crop inputs and cultivation methods
- farm sales and capital value.

The standard product for the agriculture census is summarized and reported at a Consolidated Census Subdivision level, which generally corresponds with rural municipalities or counties. This level of reporting does not permit analysis on a landscape basis.

For the past four censuses (1981-1996), the Research Branch of Agriculture and Agri-Food Canada has contracted Statistics Canada to link the Census of Agriculture to SLC polygons. For the 1991 and 1996 Census data, this linkage was achieved using the *farm headquarters processing* technique (Hiley et al. 1994). The process involves spatially matching the legal location of each farm headquarters to a polygon. The characteristics of all farms associated with each polygon have been summarized. The resulting databases allow comparison of farm management and farm practices to landscape attributes and can be analyzed and displayed using geographic information systems (GIS) technology (Hiley 1999). In this study, the individual soil components of the SLC polygons were grouped into eleven distinctive *Prairie soil landscapes* and the SLC polygons were consolidated into thirteen *Land Practices Groups* of similar land use and farming practices using the Census of Agriculture data.

PRAIRIE SOIL LANDSCAPES

To identify the relationship between land practices and soil landscapes, SLC polygons were linked to the soil component table of SLC version 2.2 for the attributes:

- DRAIN (soil drainage - e.g. well drained, poorly drained)
- DEVEL (soil profile development - e.g. Orthic Black Chernozemic, Brown Solonetzic)
- SLOPE (landscape slope - e.g. less than 4%, 10-15%)
- LOCSF (landscape surface form - e.g. undulating, rolling)
- PMDEP (soil parent material - e.g. morainal, lacustrine).

A detailed description of the attributes is provided in the Procedures Manual and User's Handbook for the SLC (Shields et al. 1991).

Each soil component in 1,245 SLC polygons was described using these five attributes and grouped into common soil landscape descriptions based on key soil attributes that affect agricultural capability. The distribution of these soil landscape descriptions is depicted in Figure 4.9.

Not all land within the SLC polygons that define the agricultural area of the prairies is used for agriculture. The agricultural area of the Prairies includes all of the land in the SLC polygons, not just the agricultural portion. It was not possible to determine which soil components were in agricultural use.

Soils in the Prairies have been classified into five major soil zones based on soil profile development and resulting soil organic matter (Figure 4.10). Within these zones, eleven Prairie soil landscapes were identified and described.

Strongly sloping to hilly
Soil landscape components that have slopes greater than 10% would be classified as Canada Land Inventory (CLI) 4T, 5T or 6T, and are marginal to unsuitable for cultivation (Brocke 1977). These soil landscapes are

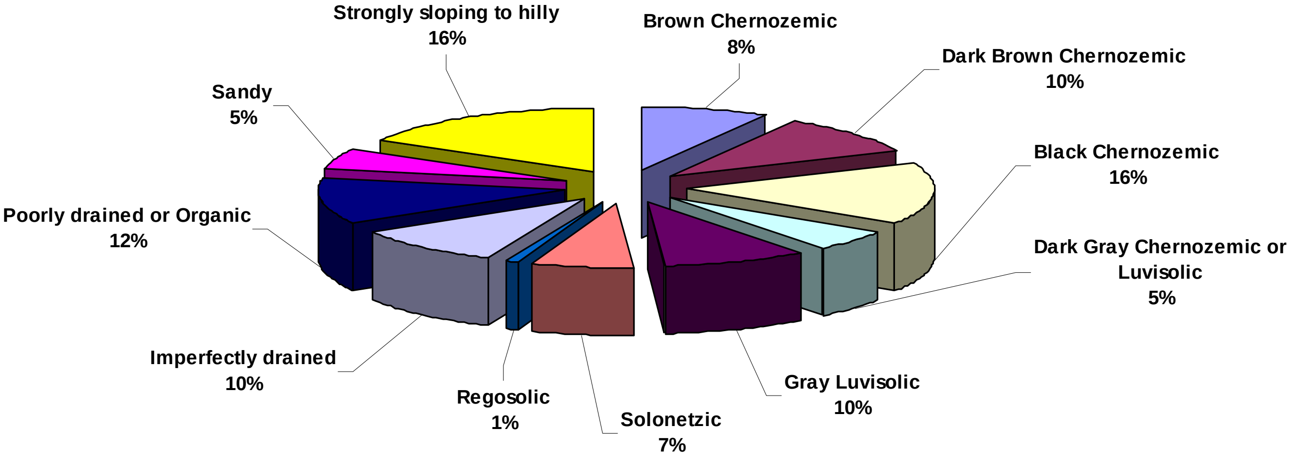


Figure 4.9 Distribution of Prairie soil landscapes in PAL SLC polygons.

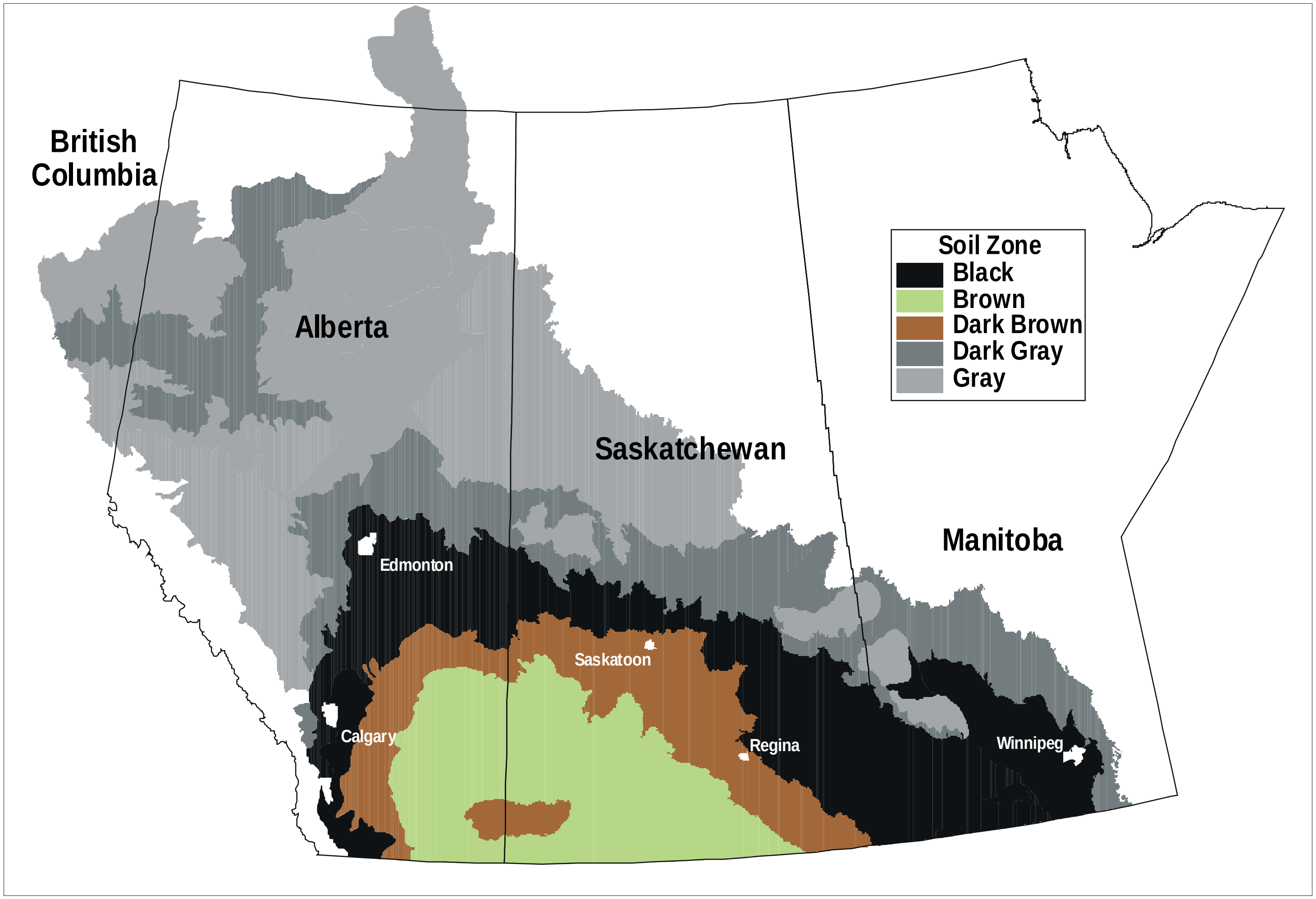


Figure 4.10 Soil zones of Western Canada

found in all soil zones and make up 16% of the land in the agricultural area of the Prairies. For this study, all soil components that had slopes greater than 10% are included in the strongly sloping to hilly landscape.

Poorly drained or Organic soils

Soil landscape components that have poor to very poor drainage, and/or are Organic or Gleysolic soils, are generally unsuitable for cultivation without drainage. Saline soils are included in this soil landscape. These soils are found on slopes of less than 10% and a variety of landforms and parent materials. Poorly drained or Organic soils occupy 12% of land in the agricultural area of the Prairies.

Solonetzic soils

Solonetzic soils have a high level of sodium that result in a B horizon which is sticky when wet, and hard when dry (Toogood and Cairns 1973), making them difficult to cultivate. These soils often have high levels of salinity and sodicity in the subsoil. Solonetzic soils are found in the Brown, Dark Brown, Black and Gray soil zones and occupy 7% of the land in the agricultural area of the Prairies.

Imperfectly drained soils

Soil landscape components with restricted drainage limit cultivation and reduce fertility. These soils are found in all soil zones and occupy 10% of the land in the agricultural area of the Prairies.

Since 1971, the Prairie agricultural land base has remained constant at approximately 55 million hectares.

Sandy soils

Soil landscape components that have rapidly to excessively drained soils, usually on fluvial or eolian parent material, have limited water-holding capacity. These soils have moderate to severe restrictions for cropping, particularly in the drier areas. Sandy soils occur on 5% of the land in the agricultural area of the Prairies.

Brown Chernozemic soils

Brown Chernozemic soils develop in the semi-arid mixed-grass prairie in the drier areas of the Prairies (Acton et al. 1998). For this study, only well-drained or moderately well-drained soil components that have slopes less than 10% are included in this group. These soils generally have a CLI rating of 3M or 4M. Brown Chernozemic soils occur on 8% of the land in the agricultural area of the Prairies. This soil landscape has been further divided according to parent material or slope within each Land Practices Group.

Dark Brown Chernozemic soils

Dark Brown Chernozemic soils are found in moister grassland areas than the Brown Chernozemic soils, and form a transition from the Brown to the Black soils. For this study, only well-drained or moderately well-drained soil components that have slopes less than 10% are included in this group. These soils generally have a CLI rating of 3M. Dark Brown Chernozemic soils are found on 10% of the land in the agricultural area of the Prairies. This soil landscape has been further divided according to parent material or slope within each Land Practices Group.

Black Chernozemic soils

Black Chernozemic soils develop in the fescue-dominated aspen parkland, where biomass production is greater than in the Brown and Dark Brown soil zones (Acton et al. 1998). For this study, only well-drained or moderately well-drained soil components that have slopes less than 10% are included in this group. These soils are the most productive arable land and occupy 16% of the land in the agricultural area of the Prairies. This soil landscape has been further divided according to parent material or slope within each Land Practices Group.

Dark Gray Chernozemic or Luvisolic soils

Dark Gray Chernozemic and Dark Gray Luvisolic soils are transitional between the Black Chernozems developed under grassland and the Gray Luvisols developed under aspen forest. For this study, only well-drained or moderately well-drained soil components that have slopes less than 10% are included in this group. These soils generally have a CLI rating of 2H or 3H due to lower heat units. Dark Gray Chernozemic or Luvisolic soils occur on 5% of the land in the agricultural area of the Prairies. This soil landscape has been further divided according to parent material or slope within each Land Practices Group.


Photo by Dave Reede

The Black Chernozems are among the most productive arable soils and occupy 23% of the land in the agricultural area of the Prairies.

Gray Luvisolic soils (well to moderately-well drained and less than 10% slopes)

Gray Luvisolic soils are developed under the aspen forest of the Boreal Plains. These soils do not have the organic matter-rich A horizon associated with the grassland soils. For this study, only well-drained or moderately well-drained soil components that have slopes less than 10% are included in this group. These soils generally have a CLI rating of 3H due to lower heat units. Gray Luvisolic soils occur on 10% of the land in the agricultural area of the Prairies. This soil landscape has been further divided according to parent material or slope within each Land Practices Group.

Regosolic soils (well to moderately-well drained and less than 10% slopes)

Regosolic soils constitute a small, but distinctive group of Prairie agricultural soils. Regosolic soils are weakly developed and do not meet the criteria for other soil groups (Canada Soil Survey Committee 1978). These areas include alluvial flood plains and rock outcrops, and vary considerably in agricultural capability. For this study, only well-drained or moderately well-drained soil components with slopes of less than 10% are included in this group. Regosolic soils are found on only 1% of the land in the agricultural area of the Prairies.

ANALYSIS OF LAND PRACTICES GROUPS

The criteria for Land Practices Groups was developed through:

- a statistical analysis of the Census of Agriculture
- expert review
- defining the criteria.

The process resulted in 13 distinct Land Practices Groups of similar land use and farming practices.

In the first step of the process, eight variables from the 1996 Census of Agriculture were initially used to group the SLC polygons. These included chemical and fertilizer inputs per cultivated hectare and the area of pasture, number of beef cows, area of cereal crops, area of summerfallow, area of oilseeds, area of flax and area of pulses per farm. Data from 1,215 SLC polygons in Alberta, Saskatchewan and Manitoba were analyzed by both k-means clustering and hierarchical clustering. Each clustering technique produced 15 separate clusters that when cross-tabulated yielded 55 distinct groups of SLC polygons.
These 55 groups were manually combined into 32 groups, based on visual inspection of the eight variables. To further group similar land uses, the data were expressed as very high, high, medium, low, or very low in terms of percentage hay and pasture, cereals, summerfallow and broadleaf crops such as oilseeds, flax and pulses. Using this approach, the 32 groups were further reduced to 15 groups based on similar general patterns of land use. At that time, data became available for 30 polygons in the B.C. Peace River region and these polygons were added to the appropriate group.

The 15 preliminary groups were mapped on a Prairie-wide basis. For the purposes of the map, 1,666 polygons were used. Of those 1,245 were grouped by land practices, 137 polygons represented water bodies and 286 had no Census of Agriculture data. The *No Data* polygons either were non-agricultural polygons in the agricultural zone (such as the Pasquia Hills in northeast Saskatchewan), or contained data that had been suppressed by Statistics Canada due to the small number of producers (less than 15 farm headquarters) within the polygon.

PFRA soil conservationists from across the Prairies reviewed the preliminary maps and identified a number of cases where the analysis and mapping did not concur with their knowledge of farming in their districts. Five issues were identified:

- the groups needed better descriptions
- specific polygons appeared to be assigned to inappropriate groups based on the key land use attributes
- two groups (5 and 11) did not represent distinct farming types because they contained too much variability in key land use attributes
- areas with suppressed census data were not being considered in this analysis
- irrigated land was not considered separately.

Although the clustering technique provided a method of reducing the total variability of all of the variables within a group, it did not minimize the variability in key variables that defined the group. Therefore, the statistical analysis was used to provide conceptual models of Land Practices Groups that were used to create specific criteria through expert opinion. For instance there were groups representing areas of extensive pasture, high amounts of summerfallow or more diversified cropping. Using the conceptual models from the preliminary groups and selecting key or defining variables, the relationships between specific groups became more apparent. The final classification resulted in 13 Land Practices Groups (Groups 5 and 11 were deleted).

These are defined by a combination of the proportion of land in pasture, summerfallow, crop mix, farm size and level of crop inputs. The criteria used to differentiate Land Practices

Groups are depicted in Table 4.1. To aid in understanding the relationships between the Land Practices Groups, they were placed into 5 major groups.

After fitting the polygons into appropriate groups, there still remained a few polygons that did not fit the criteria exactly, or could be placed within more than one group. These polygons were generally placed into the same Group as surrounding polygons with similar characteristics. The polygons from the original Group 5 and Group 11 were placed into other appropriate groups and these groups no longer appear.

Areas of *No Data* were considered as a single group for this study. Agricultural census data for these polygons are not available to put them into Land Practices Groups. The *No Data* group represents 3.0% of agricultural land and 1.4% of farms.

Irrigation, the total value of assets and the value of crop machinery were also examined. These factors did not correlate well to farming practices. Small irrigation projects were generally scattered across the Prairies with several located close to

Table 4.1 Criteria for determining Land Practices Groups.

<table>
<tr><th>Variable</th><th colspan="7">Criteria/Group</th></tr>
<tr><td>Pasture</td><td colspan="2">Dominantly Pasture
Pasture >70%</td><td colspan="2">Majority Pasture
Pasture 40-70%</td><td colspan="3">Majority Cultivated
Pasture < 50%</td></tr>
<tr><td>Farm Size</td><td>Group 3
Large Farms
(> 540 ha)</td><td>Group 6
Small to Large Farms
(< 540 ha)</td><td colspan="2"></td><td colspan="3"></td></tr>
<tr><td>Crop Inputs</td><td colspan="2"></td><td>Group 12
High Inputs
(> $64/ha)</td><td>Group 9
Low Inputs
(< $64/ha)</td><td colspan="3">Majority Cultivated with Flax
(Flax > 2%)</td></tr>
<tr><td rowspan="6">Summer-fallow</td><td colspan="4" rowspan="2">With Flax</td><td>Medium Summerfallow
(15-30%)</td><td colspan="2">Very Low Summerfallow
(< 15%)</td></tr>
<tr><td>Group 15</td><td>Group 14
Medium Pasture
(20-50%)</td><td>Group 7
Very Low Pasture
(<20%)</td></tr>
<tr><td colspan="4"></td><td>Majority Cultivated, high summerfallow
(Summerfallow > 25%)</td><td colspan="2">Majority Cultivated, low summerfallow
(Summerfallow < 25%)</td></tr>
<tr><td colspan="4">With Pulses</td><td>Group 13
Pulses > 4%</td><td colspan="2">Group 2
Pulses > 2.6%</td></tr>
<tr><td colspan="4">With Oilseeds</td><td>Group 4
Oilseeds > 8%</td><td colspan="2">Group 13
Oilseeds > 24%</td></tr>
<tr><td colspan="4">Cereals</td><td>Group 1
(not Group 4 or 13)</td><td colspan="2">Group 8
(not Group 2 or 13)</td></tr>
</table>

Note: colours in the table correspond to the Major Group colours in the legend in Map 4.1

major rivers. The amount of irrigated land is included in group data summaries (Table 4.4).

Other factors in the Census were examined to determine whether there was a relationship between the SLCs and these farming practices. Intensive livestock operations such as hogs, feedlots and poultry do not appear to be associated with any particular landscape. The location of these types of operations may be more dependent on factors such as access to markets, investment capital, infrastructure, and perhaps historic government programming and promotion. The data on large operations is often suppressed by Statistics Canada to maintain the confidentiality of respondents.


Photo by Dave Reede

Irrigation produces high yields and consistent quality of crops used to support a viable processing industry.

OTHER LANDSCAPE CHARACTERISTICS

By establishing the spatial relationship between the soil landscape and land use practices, a better understanding of the state of soil resources can be inferred. Although a comprehensive analysis was not completed, an attempt was made to describe the Land Practices Groups in terms of soil erosion, soil salinity, soil quality, soil organic matter, water quality and biodiversity.

The descriptions of the Land Practices Groups were used together with erosion risk maps developed by application of the Universal Soil Loss Equation and the Wind Erosion Equation to estimate overall erosion risk on annual cropland. The ranking of erosion risk is a comparison of Land Practices Groups and is not an estimate of actual erosion rates.

The soil salinity risk was evaluated by applying the salinity risk classes for the SLC polygons (Eilers et al. 1997) to the cultivated land in each Land Practices Group.

Soil organic matter and quality is enhanced by practices that minimize disturbance and maximize perennial land cover. Loss of soil organic matter is a more serious concern in cropland than in pasture. Perennial land cover was estimated by the percentage of cropland in alfalfa, hay and forage seed production. Level of disturbance is indicated by percentage of cropland that is summerfallowed and the percentage of cropland reported in conservation tillage. In addition, the percentage of farms with cropland reporting conservation tillage, and the percentage of farms reporting summerfallow that did not report tilled fallow were determined.

The vulnerability of surface water quality to agricultural activities within the *Majority Cultivated* Land Practices Group was evaluated using a methodology modified from Cross et al. (1995). Using this method, each SLC polygon was typed according to three classes of runoff and sediment delivery potential and ranked according to agricultural intensity, including fertilizer and pesticide use and animal density, to determine vulnerability classes. The proportion of cultivated land in each surface water vulnerability class was calculated for the nine Majority Cultivated Land Practices Groups.

All landscapes, including agro-ecosystems, provide some habitat for wildlife and contribute to the ecological balance of biodiver-sity. However, across Canada's prairie agricultural landscapes, various human activities, including agriculture, have reduced the area and quality of natural landscapes for wildlife. Analysis of these landscapes shows that, in general, the highest quality wildlife habitat is in areas with native vegetation.

Neave et al. (1999), show that the amount of farmland in *Natural Land for Pasture* (native vegetation) and *All Other Land* (farmstead, woodlots and wetlands) categories supports the most wildlife habitat use units, and can be used as an indicator of wildlife habitat availability and biodiversity. In the Prairie Agricultural Landscape study, this indicator was extended to each of the 13 Land Practices Groups and expressed both as a percentage of farmland in each group and as a percentage of total land in native vegetation.

Land Practices Group Descriptions

In this section, all 13 Land Practices Groups are described in terms of location, soil landscapes, agricultural capability and land practices. Brief comments are made with respect to the state of the land resources in the areas of soil quality, soil organic matter, soil erosion, soil salinity, water quality, range management and wildlife habitat availability. The information is organized by Major Land Practices Groups and is summarized in several tables and charts.

The distribution of Land Practices Groups is depicted in Map 4.1. The Agricultural Census data is summarized by Land Practices Group for land area statistics (Table 4.2), forage and cattle production (Table 4.3), and annual cropping (Table 4.4). Land use by all Land Practices Groups is depicted in Figure 4.11, while the distribution of forage and grazing for Dominantly Pasture and Majority Pasture is shown in Figure 4.12, and annual crop mix is shown in Figure 4.13. For each group, there is a table with the distribution of soil landscapes (Tables 4.9 to 4.21). There are also tables that describe, for each Land Practices Group, the salinity risk (Table 4.5), soil conservation efforts (Table 4.6), risks to surface water quality (Table 4.7), and distribution of natural vegetation (Table 4.8).

MAJOR GROUP - DOMINANTLY PASTURE

Two Land Practices Groups, where more than 70% of total farm area was used for pasture and hay, were identified as *Dominantly Pasture*. The most significant variable to distinguish between the two groups was farm size. Farm size included both the pasture and cultivated land. On the Prairies, 25% of farms are larger than 539 hectares. A value of 540 hectares was used to distinguish between *Dominantly Pasture, very large farms (Group 3)*, where the average farm size (total farm area divided by total number of farms) was greater than 540 hectares, and *Dominantly Pasture, small to large farms (Group 6).*

Dominantly Pasture, very large farms (Group 3)
Group 3 is found mainly in southeastern Alberta and southwestern Saskatchewan as well as parts of the Interlake area of Manitoba. The group comprises the most marginal of the Prairie landscapes for annual crop production (Table 4.9). The hummocky, knob and kettle and ridged moraines are too steep for successful cultivation and represent almost a third of the Group 3 area.

These areas occur in all soil zones, from the Brown Chernozems to the Gray Luvisols. A good example of this landscape is the area northwest

Table 4.2 Summary of farm land, farm numbers, farm size and crop inputs in Land Practices Groups.

Land Practices Group	SLC land Area ('000 ha)	SLC land Area (% of total)	Agricultural land (% of SLC)	Number of farms	Number of farms (% of total)	Total farm area ('000 ha)	Total farm area (% of total)	Farm size (ha)	Herbicide Fertilizer ($/ha)
3	6 231	8.4	76.0	4 185	3.0	4 736	8.8	1 131	49
6	5 482	7.4	49.8	9 922	7.1	2 730	5.0	275	88
12	8 507	11.4	67.3	20 909	15.0	5 725	10.6	273	94
9	8 239	11.1	59.3	9 780	7.0	4 887	9.0	500	39
13	1 396	1.9	101.3	2 715	2.0	1 414	2.6	521	36
4	3 656	4.9	98.9	6 576	4.7	3 617	6.7	550	43
1	5 614	7.5	97.6	9 642	6.9	5 477	10.1	568	27
7	4 569	6.1	95.1	13 254	9.5	4 345	8.0	327	99
14	3 583	4.8	91.0	10 327	7.4	3 260	6.0	316	99
15	5 057	6.8	92.0	12 036	8.6	4 651	8.6	386	58
10	3 491	4.5	44.3	4 125	3.0	1 545	2.9	374	87
2	6 835	9.2	93.2	19 294	13.8	6 369	11.8	330	78
8	6 960	9.3	77.5	16 789	12.0	5 396	10.0	321	77
no data	4 915	6.6							
	74 536	**100.0**	**72.7**	**139 554**	**100.0**	**54 154**	**100.0**	**389**	**68**

Note: colours in the table correspond to the Major Group colours in the legend in Map 4.1

Table 4.3 Summary of land use related to cattle production in Land Practices Groups.

Land Practices Group	Pasture and Hay (%)[1]	Farms with					Cattle (#/cattle farm)	Farms with	
		Unimproved pasture (%)[2]	Improved pasture (%)[2]	Forage seed (%)[2]	Alfalfa (%)[2]	Hay (%)[2]		Cattle (%)[2]	Beef cows (%)[2]
3	81	81	47	1.7	44	21	262	75	70
6	78	78	45	0.7	40	36	132	72	64
12	56	56	46	2.6	48	26	154	66	58
9	57	57	44	1.6	40	25	138	66	61
13	19	19	30	0.6	19	10	93	39	36
4	20	55	30	0.5	21	11	115	46	42
1	21	52	28	0.3	18	9	109	41	38
7	13	13	24	4.1	31	10	75	33	28
14	30	30	34	2.1	47	18	99	57	50
15	21	21	31	0.7	30	14	96	46	42
10	28	28	35	13.0	34	23	98	38	34
2	25	51	33	2.4	30	17	105	46	41
8	30	30	36	2.4	35	18	125	53	47
Average	**40**	**60**	**37**	**2.2**	**35**	**19**	**128**	**55**	**49**

[1]percent of farmland [2]percent of farms

Note: colours in the table correspond to the Major Group colours in the legend in Map 4.1

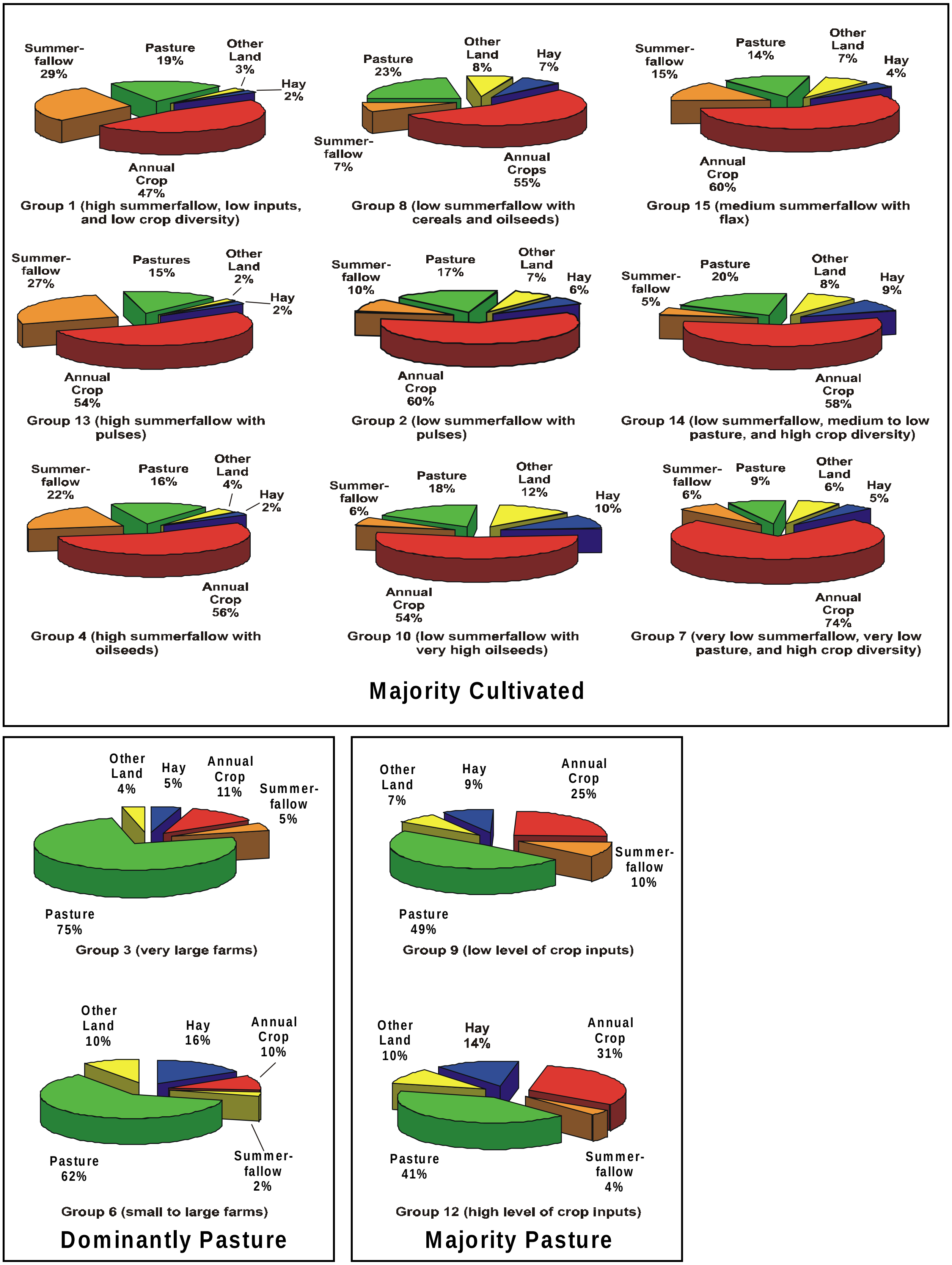


Figure 4.11 Proportion of total farmland in different land uses in each Land Practices Group.

Table 4.4 Summary of land use related to annual crop production in Land Practices Groups.

Land Practices Group	Cultivated land ('000 ha)	Cropland (%)^{1}	Irrigation		Summerfallow		Cereals			Oilseeds		Flax		Pulses		
			Land (ha)	Farms (%)^{2}	Land (%)^{3}	Farms (%)^{2}	Land (%)^{3}	Wheat farms (%)^{2}	Barley farms (%)^{2}	Land (%)^{3}	Canola farms (%)^{2}	Land (%)^{3}	Farms (%)^{2}	Land (%)^{3}	Pea farms (%)^{2}	Lentil farms (%)^{2}
3	764	82	56 598	14.8	25	42	59	31	27	6	12	0.1	1.6	0.2	1.6	0.8
6	333	75	45 952	7.2	17	17	66	8	22	3	5	0.1	0.4	0.1	0.8	0.3
9	1 703	89	12 272	3.4	26	52	60	44	34	7	18	0.3	1.8	0.4	2.3	1.1
12	1 967	86	169 583	6.4	12	28	71	31	46	12	22	0.4	1.8	0.7	2.6	0.2
13	1 145	97	16 120	8.8	33	87	53	75	38	6	28	0.5	5.0	6.2	8.6	24.2
4	2 810	96	32 083	4.1	29	83	55	86	51	12	48	0.7	6.7	1.3	6.7	4.8
1	4 169	97	29 397	5.5	39	89	56	79	29	2	9	0.1	2.5	0.9	2.4	6.1
7	3 498	94	8 312	1.6	9	46	62	75	60	17	56	5.3	25.8	4.9	17.7	1.6
14	2 023	92	8 809	1.4	9	41	66	64	49	15	40	5.1	20.9	1.9	6.8	1.6
15	3 446	96	5 356	1.0	20	68	59	74	50	13	42	4.3	21.1	2.2	8.6	4.1
10	884	94	476	1.0	12	37	53	54	41	31	55	0.1	2.1	2.1	9.1	0.1
2	4 478	93	78 865	3.8	14	52	61	66	54	16	49	0.7	4.8	5.8	17.9	4.3
8	3 326	89	135 397	5.6	13	43	65	57	53	15	39	0.3	2.6	0.7	4.6	0.4
	30 545	**90**	**599 227**	**5.1**	**19**	**50**	**62**	**54**	**43**	**11**	**30**	**1.1**	**5.7**	**1.8**	**6.3**	**2.7**

[1] percent of farms [2] percent of farms with cultivated land [3] percent of cultivated land

Note: colours in the table correspond to the Major Group colours in the legend in Map 4.1

Table 4.5 Percent of total farm land in salinity risk classes by Land Practices Groups.

Land Practices Group	Salinity Risk Nil (%)	Low (%)	Moderate (%)	Moderately High (%)	High (%)	Not Rated (%)
3	27	18	19	18	9	9
6	41	2	15	14	3	24
12	59	12	9	8	4	7
9	35	23	21	4	6	11
13	0	2	15	42	41	0
4	7	10	22	24	36	0
1	2	12	24	42	20	0
7	19	23	28	2	28	0
14	35	23	16	11	15	0
15	13	30	42	12	4	0
10	72	7	0	0	0	22
2	23	31	26	10	7	4
8	48	25	7	12	5	2
Average	**29**	**19**	**20**	**15**	**12**	**5**

Note: colours in the table correspond to the Major Group colours in the legend in Map 4.1

Table 4.6 Permanent cover, summerfallow and conservation tillage practices in Land Practices Groups.

Land Practices Group	Land Permanent cover (%)[1]	Summerfallow (%)[1]	Conservation tillage (%)[1]	Farms Conservation tillage (%)[2]	Conservation summerfallow (%)[3]
3	29	29	33	26	30
6	62	18	21	11	28
12	32	11	33	20	40
9	27	29	30	26	37
13	3	33	40	35	39
4	4	28	44	45	42
1	4	39	33	36	36
7	6	8	38	32	46
14	14	9	38	29	41
15	7	20	45	40	43
10	21	11	34	25	49
2	9	14	46	31	50
8	12	12	40	30	50
Average	**14**	**20**	**39**	**29**	**43**

[1] percent of cultivated land [2] percent of farms with cultivated land [3] farms not reporting tilled summerfallow as a percent of farms reporting summerfallow

Note: colours in the table correspond to the Major Group colours in the legend in Map 4.1

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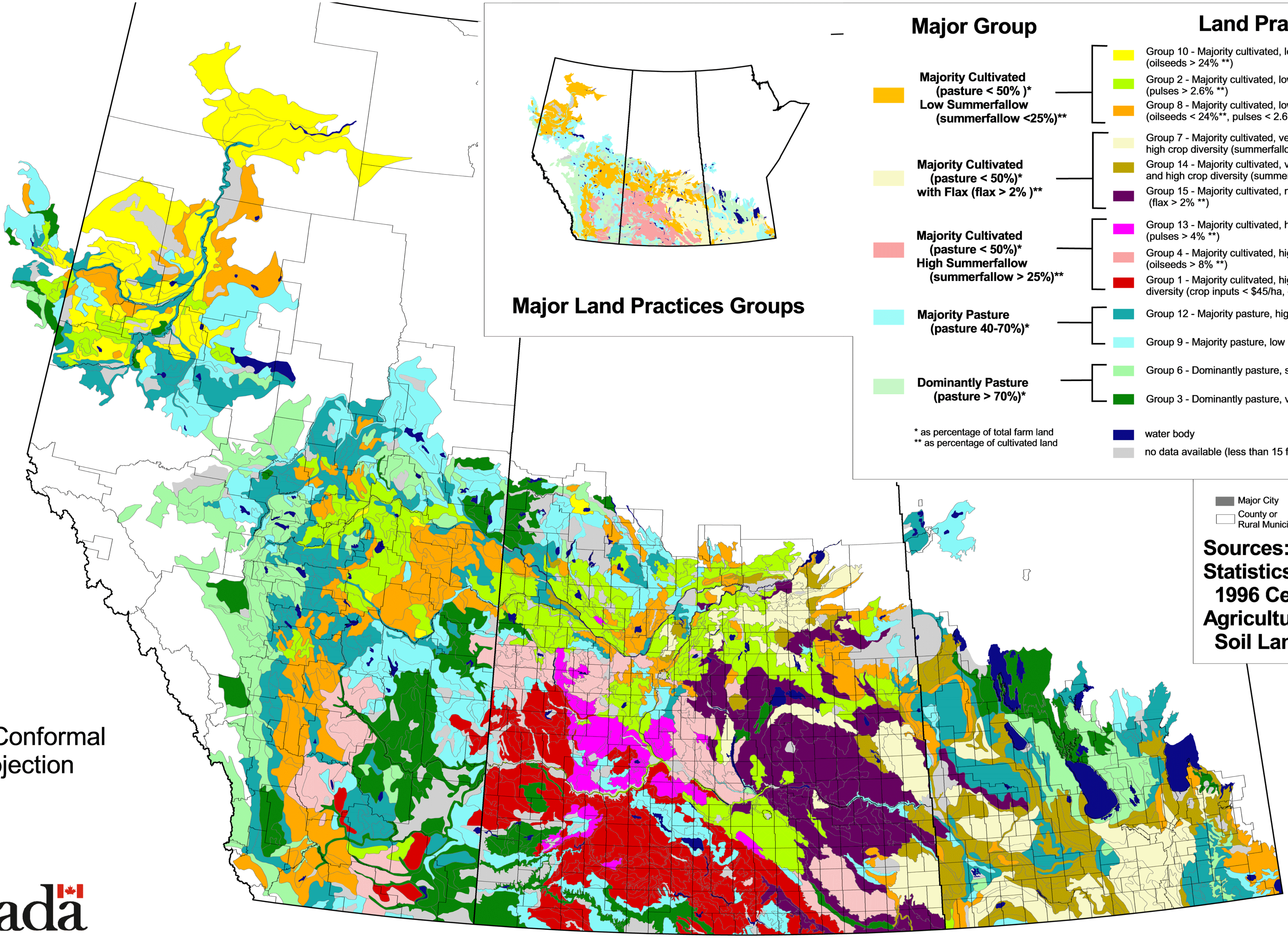
Prairie Farm Rehabilitation Administration | Administration du rétablissement agricole des Prairies

Prairie Agricultural Landscapes - Land Practices Groups



Major Land Practices Groups

	Major Group		Land Practices Group
■	**Majority Cultivated (pasture < 50%)* Low Summerfallow (summerfallow <25%)****	■	Group 10 - Majority cultivated, low summerfallow with very high oilseeds (oilseeds > 24% **)
		■	Group 2 - Majority cultivated, low summerfallow with pulses (pulses > 2.6% **)
		■	Group 8 - Majority cultivated, low summerfallow with cereals and oilseeds (oilseeds < 24%**, pulses < 2.6%**, flax < 2%**)
■	**Majority Cultivated (pasture < 50%)* with Flax (flax > 2%)****	■	Group 7 - Majority cultivated, very low summerfallow, very low pasture, and high crop diversity (summerfallow < 15%**, pasture < 20%*, flax > 2%**)
		■	Group 14 - Majority cultivated, very low summerfallow, medium to low pasture, and high crop diversity (summerfallow < 15%**, pasture 20-50%*, flax > 2%**)
		■	Group 15 - Majority cultivated, medium summerfallow with flax (flax > 2% **)
■	**Majority Cultivated (pasture < 50%)* High Summerfallow (summerfallow > 25%)****	■	Group 13 - Majority cultivated, high summerfallow with pulses (pulses > 4% **)
		■	Group 4 - Majority cultivated, high summerfallow with oilseeds (oilseeds > 8% **)
		■	Group 1 - Majority culitvated, high summerfallow, low crop inputs, and low crop diversity (crop inputs < $45/ha, oilseeds < 8%,** pulses < 4%**)
■	**Majority Pasture (pasture 40-70%)***	■	Group 12 - Majority pasture, high level of crop inputs (crop inputs > $65/ha)
		■	Group 9 - Majority pasture, low level of crop inputs (crop inputs < $65/ha)
■	**Dominantly Pasture (pasture > 70%)***	■	Group 6 - Dominantly pasture, small to large farms (average farm size < 540 ha)
		■	Group 3 - Dominantly pasture, very large farms (average farm size > 540 ha)
		■	water body
		■	no data available (less than 15 farms in polygon)

* as percentage of total farm land
** as percentage of cultivated land

■ Major City
□ County or Rural Municipality

Sources:
Statistics Canada,
1996 Census of Agriculture
Agriculture and Agri-Food Canada,
Soil Landscapes of Canada

Lambert Conformal
Conic Projection

NAD83

Canada

PFRA ARAP

Table 4.7 Percent of total cultivated land in surface water quality vulnerability classes in *Majority Cultivated* Land Practices Groups.

Land Practices Group	Risk to Surface Water Quality Low Vulnerability (%)	Vulnerable (%)	High Vulnerability (%)	Very Highly Vulnerable (%)
13	86	10	5	0
4	60	23	13	5
1	77	15	7	0
7	69	19	10	1
14	72	2	16	9
15	83	16	0	0
10	80	6	12	1
2	56	19	23	2
8	44	26	19	11
Average	**66**	**17**	**13**	**4**

Note: colours in the table correspond to the Major Group colours in the legend in Map 4.1

Table 4.8 Native vegetation in Land Practices Groups.

Land Practices Group	Native vegetation (%)[1]	Native vegetation (%)[2]
3	71.3	20.7
6	58.7	9.8
12	39.8	14.0
9	46.6	14.0
13	14.5	1.3
4	16.4	3.6
1	18.1	6.1
7	12.8	3.4
14	23.5	4.7
15	17.9	5.1
10	23.8	2.3
2	18.5	7.3
8	23.3	7.7
	30.1	**100.0**

[1] native pasture and other land as a percent of farm land
[2] native pasture and other land as a percent of column total
Note: colours in the table correspond to the Major Group colours in the legend in Map 4.1

of Loon Lake, Saskatchewan, along the Alberta border.

The large area of Solonetzic soils, particularly in southeastern Alberta and southwestern Saskatchewan, make up almost a fifth of the landscapes in Group 3. This landscape can be described as well-drained Brown Solonetzic soils developed on undulating to hummocky till plains, as well as knob and kettle moraines. Minor amounts of Brown Chernozemic and Gleysolic soils are associated with this landscape. The hard soil structure of these soils make them difficult to cultivate, particularly in the drier areas of the Prairies.

Imperfectly to poorly drained soils, ranging from saline flats to peat bogs, make up almost another fifth of this group. In most cases, these lands are not cultivated. The Great Sandhills in southwestern Saskatchewan are an example of very sandy, rapidly drained Regosols and Brown Chernozems on undulating to hummocky eolian or fluvial material. The sandy nature of the soils make them highly susceptible to wind erosion and active dunes may be present.

Less than a quarter of the land in Group 3 is moderately to well-drained Chernozemic or Luvisolic soil that could be considered arable. Almost all of the cultivated land in Group 3 is found on Brown or Gray soils that are associated with lands that are marginal for cultivation.

Three-quarters of the land in the SLC polygons that form Group 3 are used for agriculture, primarily for cattle production. Cattle were reported on 75% of farms, with an average of 262 cattle per farm with cattle. More than 80% of the farmland is in pasture or hay, and a relatively high proportion grew alfalfa (44%) and tame hay (21%). Average farm size is almost three times the average for the Prairies.

Less than one-fifth of the land within this group is used for annual crop production. Annual cropping in Group 3 is characterized by low crop diversity. The area has a low percentage of land in oilseeds, pulses or flax and has a high amount of summerfallow. A summerfallow-cereal-cereal rotation is common on cultivated Group 3 soils. Oilseeds and other crops replace the first wheat crop in this rotation on about one-tenth of the land.

Overall wind erosion risk for annually cropped soils in Group 3 is moderate, due in part to the large proportion of summerfallow. Sandy soils adjoining the Great Sand Hills are at extreme risk to wind erosion, while Solonetzic soils, which form a large portion of this group, are at low risk.

Overall water erosion risk is low due to the infrequent erosive storms and lower volumes of snowmelt in the Brown Soil Zone. Solonetzic soils on morainal topography will be at moderate risk to water erosion due to poor drainage.

The risk of tillage erosion is low. Considering the proportion of forage, overall risk of erosion in Group 3 drops to low.

Although Group 3 contains many areas of Solonetzic soils, the proportion of farmland in each salinity risk class is close to the Prairie average. Twenty-seven percent of the land faces a moderately high to high salinity risk.

Table 4.9 Landscapes of Group 3

Dominantly pasture, very large farms

Landscape	Area (ha)	Percent of Group
Strongly sloping to hilly	1 939 660	31
Moderately to well-drained Chernozemic or Luvisolic soils	1 381 123	22
Solonetzic soils	1 169 828	19
Imperfectly to poorly drained or Organic soils	1 125 309	18
Sandy soils	614 881	10
Total	**6 230 802**	**100**

Table 4.10 Landscapes of Group 6

Dominantly pasture, small to large farms

Landscape	Area (ha)	Percent of Group
Strongly sloping to hilly	1 631 402	30
Well-drained Luvisolic or Chernozemic soils	1 600 141	29
Poorly drained or Organic soils	1 192 263	22
Imperfectly drained soils	824 703	15
Sandy soils	233 592	4
Total	**5 482 103**	**100**

The farmlands in Group 3 are dominated by permanent cover. The relatively small area of cropland in Group 3 has nearly one-third summerfallow, and conservation tillage has been adopted on less than one-third of the land. The cultivated portions of this group may be losing soil organic matter.

Group 3 is a very important area of natural biological diversity. Nearly three-quarters (71%) of farmland in Group 3 was in native vegetation in 1996, representing one-fifth of all the native vegetation in the agricultural lands of the Prairies.

Dominantly pasture, small to large farms (Group 6)

Group 6 landscapes are found along the foothills of Alberta and in the Interlake area of Manitoba. These areas are marginal for cultivation, mainly due to topography or drainage (Table 4.10). A third of the group is on hummocky, knob and kettle, rolling or dissected lands that are too steep to cultivate. This limitation can be found in all soil zones, from the dry Browns to the moist Grays. Another area in this group includes imperfectly to poorly drained soils such as the highly calcareous soils of the northern Interlake in Manitoba.

Over one-fifth of the land in Group 6 is moderately to well-drained Gray Luvisolic soils that could be considered arable, while another 7% is Brown to Dark Gray soils that are associated with lands marginal for cultivation. Almost all of the cultivated land in Group 6 is found on these two soil landscapes.

Because Group 6 is found mostly along the fringes or limits of the agricultural area, less than half of the land in the SLC polygons that form this group is used for agricultural production, and is primarily devoted to cattle production. Cattle were reported on 72% of farms, but the number of cattle per farm (132 cattle per farm with cattle) is significantly less than Group 3, and close to the Prairie average. The percentage of land in pasture and hay is similar to Group 3, but Group 6 has three times the proportion of land in hay as Group 3. Group 6 also has a higher proportion of farms with tame hay (36%) compared to Group 3.

As in Group 3, less than one-quarter of farmland is used for annual crop production. Annual cropping is primarily cereals with summerfallow. The main cereals are barley and oats, due to the limited growing season. Only 8% of Group 6 farms grew wheat. This group has a low percentage of land in oilseeds, pulses or flax. It has less summerfallow and higher input costs than Group 3. Approximately two-thirds of the annually cropped land is in a summerfallow-cereal-cereal rotation. The remainder is in a cereal-cereal-oilseed/pulse rotation.

Wind erosion risk on annual cropland in Group 6 is moderate to high in southwest Alberta due to the dry and windy climate and the high proportion of summerfallow. Wind erosion risk is low on the imperfectly drained soils of the Interlake and Westlake regions of Manitoba. Annually cropped sandy soils in Group 6 may be at high risk to wind erosion.

Tillage and water erosion risk are moderate due to the hummocky topography in much of the area. The overall erosion risk for this group is low because a high proportion of the land is in forage production.

The land in Group 6 is at low to negligible risk to salinity. Group 6 is in an area that receives relatively high rainfall and low evaporation, reducing the potential for salinization.

The farmland in Group 6 is dominated by permanent cover. The relatively small area of cropland in Group 6 has less than one-fifth summerfallow, but the adoption of conservation tillage has occurred on less than one-quarter of the land. The cultivated portions of this group may be losing soil organic matter, although the Gray Luvisolic soils have low organic matter levels initially.
Group 6 is an important area of natural diversity. Nearly three-fifths (59%) of farmland is in native vegetation, representing one-tenth of the native vegetation in the agricultural lands of the Prairies.

MAJOR GROUP - MAJORITY PASTURE

Two Land Practices Groups, where between 50% and 70% of total farm area was used for pasture and hay, were identified as *Majority Pasture*. Several polygons, which did not fit the criteria for *Majority Cultivated* groups and had more than 40% pasture and hay, were added to *Majority Pasture* groups. The intensity of cropping on the cultivated land was the variable which distinguished the two groups. The intensity of cropping was measured by the dollar value of inputs per cultivated hectare. The median value for crop inputs on the Prairies is $65/ha. A value of $64/ha was used to distinguish between the *Majority Pasture, high level of crop inputs (Group 12)*, where the average inputs per cultivated hectare was greater than $64/ha, and *Majority Pasture, low level of crop inputs (Group 9).*

Majority pasture, high level of crop inputs (Group 12)

The landscapes of Group 12 represents a wide range of limitations to crop production, resulting in higher forage production than surrounding areas. Hilly landscapes are the dominant limitation for cultivation (Table 4.11). The large area of hummocky till near Stettler, Alberta is typical of this group. The edge of the foothills west of Calgary, and the Riding and Duck Mountains in Manitoba are also in this group. More than one-quarter of this group consists of imperfectly and poorly drained soils typical of the Interlake area in Manitoba. Excessive moisture and lack of heat units make annual cropping difficult.

Parts of the Eastern Irrigation District and Bow River Irrigation Districts near Vauxhall, Alberta are also represented in this group. These are Solonetzic and sandy areas that are managed as large grazing reserves, or have a high proportion of irrigated forage.

Over one-third of the land in Group 12 is moderately to well-drained Chernozemic or Luvisolic arable soils. These are mostly Black or Gray soils that are associated with marginal lands. Almost all of the cultivated land in Group 12 is found on these soils.

Two-thirds of the land in Group 12 is devoted to agriculture, including both cattle and annual crop production. More than half of the farmland is used for pasture and hay, while two-thirds of farms reported an average of 154 cattle. A relatively high proportion of farms grew alfalfa (48%) and tame hay (26%). Group 12 has 15% of all Prairie farms but only 10% of farmland, resulting in an average farm size (273 ha) that is less than three-quarters the average size for the Prairies. More than one-third (35%) of agricultural land in the group was used for annual crop production. Annual cropping is characterized by high cereals, low summerfallow and significant (12%) oilseeds. The area has a low percentage of land in pulses or flax. About one-quarter of the farms with cropland reported summerfallow. More farms reported barley than wheat, and chemical and fertilizer costs on cultivated land were high at $94/ha. Hay and alfalfa are often grown in rotation with cereals and oilseeds.

Wind erosion risk on annual cropland in Group 12 is moderate overall. The risk is less for more northerly polygons and for those in Manitoba due to low intensity winds and moist conditions. Sandy soils and annually cropped fields in the windy areas of Pincher Creek and the Blood First Nations land in Alberta are at high risk to wind erosion when exposed.

Overall, water erosion risk on annual cropland is low. The southern portion of the Foothills and north of the Swan Hills in Alberta have a high water erosion risk due to steeper slopes and the volume of snowmelt. Annual cropland adjoining the Duck and Riding Mountains in Manitoba is also at high risk to water erosion. Tillage erosion risk is moderate on cropland in hummocky till areas, but is offset to a degree by the predominance of cereals in the rotation. Overall erosion ratings for this group are low due to the high percentage of land in forage production.

The land in Group 12 is at low risk to salinity. Group 12 is in an area that receives higher rainfall and has lower evaporation, reducing the potential for salinization. Irrigated areas of Group 12 in Alberta have a significantly higher risk for salinity.

The farmland in Group 12 is dominated by permanent cover.

The extensive forage and rangeland areas across the Prairies reduce erosion and increase biological diversity.

Table 4.11 Landscapes of Group 12

Majority pasture, high level of crop inputs

Landscape	**Area (ha)**	**Percent of Group**
Strongly sloping to hilly	2 192 524	26
Well to moderately drained Dark Gray or Luvisolic soils	1 651 222	19
Well to moderately drained Brown, Dark Brown or Black soils	1 636 663	19
Imperfectly drained Black, Dark Gray or Luvisolic soils	1 365 620	16
Poorly drained or Organic soils	1 034 455	12
Sandy soils	626 633	7
Total	**8 507 117**	**100**

The cropland has about one-tenth summerfallow, but the adoption of conservation tillage has occurred on less than one-third of the land and farms. The cultivated portions of this group may not be losing soil organic matter.

Group 12 is an important area of natural diversity. Two-fifths of farmland is in native vegetation, representing almost one-sixth (14%) of the native vegetation in the agricultural lands of the Prairies.

Majority pasture, low level of crop inputs (Group 9)

The lands in Group 9 are found mainly in areas of steep topography, or in the Brown or Dark Brown soil zone, or along the margins of annually cropped land in Alberta and northwestern Saskatchewan. More than a quarter of this group consists of lands in knob and kettle moraines, typical of the Missouri Coteau (Table 4.12). These are generally too steep for cultivation, but fields will be developed in gently sloping areas within these landscapes. Associated with these landscapes are imperfectly to poorly drained depressions.

Another landscape in Group 9 is the sandy soil of the Brown and Dark Brown soil zone. In these areas, fall rye is often grown and used for pasture or cut for feed. The sandy land near Mortlach, Saskatchewan is typical of this landscape. The area has well-drained to rapidly drained Regosolic soils with the associated Brown or Dark Brown Chernozems developed on undulating to hummocky fluvial and eolian material. Stabilized sand dunes are common.

A significant portion of Group 9 occurs on well to imperfectly drained soils along the margin of cultivation in the Peace River area, northeastern Alberta and northwestern Saskatchewan. These areas have short growing seasons and limited heat units for a variety of crops. The area is suited to pasture, hay and feed grains.

Sixty percent of the land in Group 9 polygons is used for agriculture, including both cattle and annual crop production. Over half of the farmland is used for pasture and hay, while two-thirds of the farms reported an average of 138 cattle. A higher proportion of the pasture and hay was in native pasture compared to land in Group 12.

Over one-third (35%) of the agricultural land is used for annual crop production. Annual cropping in this group is characterized by high cereals, high summerfallow and significant (7%) oilseeds. The area has a low percentage of land in pulses or flax. Nearly half of the farms with cropland reported summerfallow. More farms reported wheat than barley. Chemical and fertilizer costs were low at $39/ha. Hay and

Table 4.12 Landscapes of Group 9

Majority pasture, low level of crop inputs

Landscape	Area (ha)	Percent of Group
Strongly sloping to hilly	2 206 826	27
Well to imperfectly drained Dark Gray or Luvisolic soils	2 167 009	26
Poorly drained or Organic soils	1 356 864	16
Well-drained Brown or Dark Brown soils	1 149 317	14
Sandy soils	789 247	10
Solonetzic soils	570 177	7
Total	**8 239 440**	**100**

alfalfa were often grown in rotation with cereals and oilseeds.

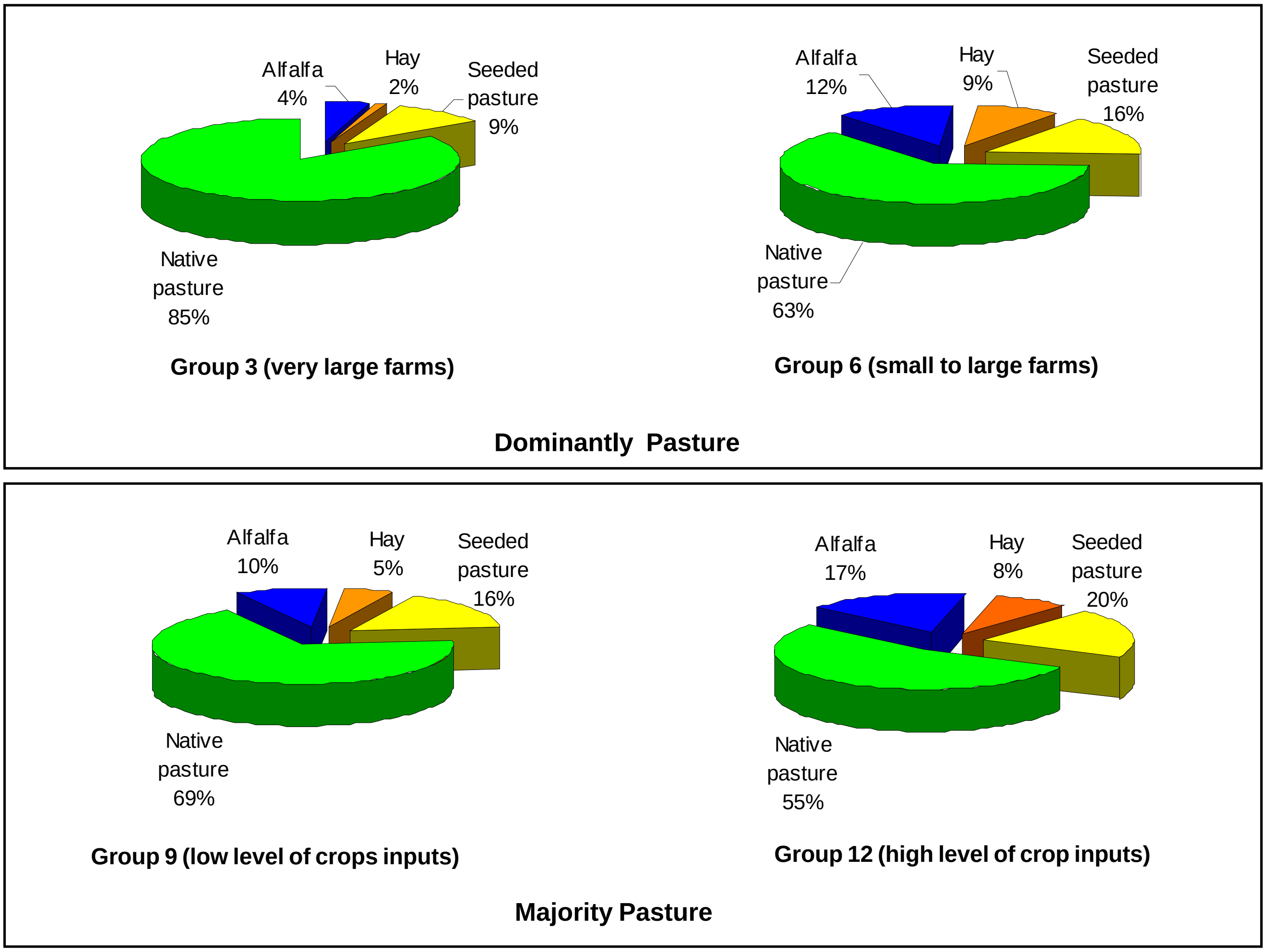
Cropland in Group 9 has a moderate wind erosion risk due to climatic factors and the large proportion of summerfallow. This is offset by the less erodible solonetzic and till soils over much of the area. Sandy soils near Mortlach and Old Wives Lake in Saskatchewan are at high risk to wind erosion.

Water erosion risk on cropland is generally low. However, areas on the edge of the Missouri Coteau are especially prone to gully erosion.

Tillage erosion risk on annually cropped land is moderate due to the high proportion of summerfallow. Considering the proportion of forage, overall risk of erosion in Group 9 drops to low. Group 9 soils have a low to moderate risk to salinity.

The farmland in Group 9 is dominated by permanent cover. The cropland has about one-third summerfallow and the adoption of conservation tillage has occurred on less than one-third of the land. The cultivated portions of this group may be losing soil organic matter.

Group 9 is an important area of natural diversity. Nearly half (47%) of farmland is in native vegetation, representing nearly



Group 3 (very large farms)

Group 6 (small to large farms)

Dominantly Pasture

Group 9 (low level of crops inputs)

Group 12 (high level of crop inputs)

Majority Pasture

Note: values are expressed as percent of hay and pasture land

Figure 4.12 Land used for pasture/forage production in Dominantly and Majority Pasture Land Practices Groups.

Table 4.13 Landscapes of Group 13

Majority cultivated, high summerfallow with pulses

Landscape	Area (ha)	Percent of Group
Well-drained Dark Brown soils (<4% slopes)	452 720	32
Well-drained Brown soils	431 979	31
Well-drained Dark Brown soils (5-9% slopes)	282 786	20
Brown or Dark Brown Solonetzic soils	126 574	9
Strongly sloping to hilly or poorly drained soils	101 901	7
Total	**1 395 960**	**100**

one-sixth (14%) of the native vegetation in the agricultural lands of the Prairies.

MAJOR GROUP - MAJORITY CULTIVATED, HIGH SUMMERFALLOW

Three Land Practices Groups were identified as *Majority Cultivated, high summerfallow* (Figure 4.13) where the summerfallow area exceeded 25% of the cultivated land. Crop diversity distinguishes the groups. The high summerfallow areas where pulses were a significant component of the cultivated land (pulses greater than 4%) were grouped as *Majority Cultivated, high summerfallow with pulses (Group 13)*. The polygons where crop diversity included canola and mustard (oilseed greater than 8%) with low levels of pulses, were called *Majority Cultivated, high summerfallow with oilseeds (Group 4)*.

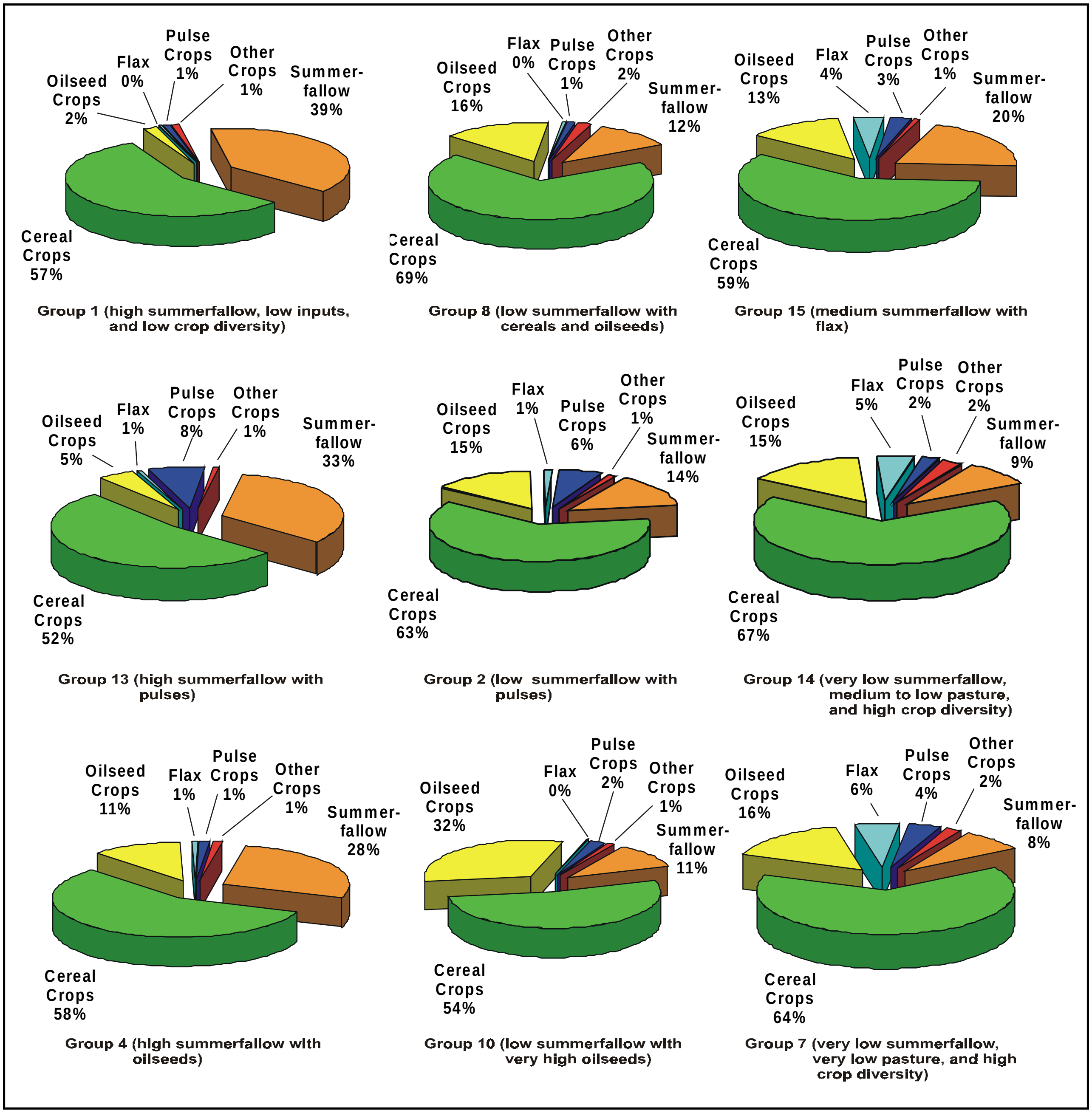
The remainder of the *Majority Cultivated, high summerfallow* polygons had low pulses (less than 4%), low oilseeds (less than 8%), and low level of crop inputs (less than $45/ha). Of all polygons on the Prairies, 75% had crop inputs that were greater than $40/ha, while 90% of Group 1 polygons had crop inputs of less than $40/ha. This group was described as *Majority Cultivated, high summerfallow, low crop inputs, and low crop diversity (Group 1)*.

Majority cultivated, high summerfallow with pulses (Group 13)

Group 13 is almost exclusively in the Brown and Dark Brown soil zone and is concentrated between Rosetown and Saskatoon, Saskatchewan. These are some of the more productive of the Dark Brown soils and are generally well-drained on gently undulating lacustrine or morainal deposits (Table 4.13). One-third of this group includes the more productive Brown soils like those near Swift Current, Saskatchewan. Some areas of steep topography and Solonetzic soils are associated with this group.

In Group 13, all of the land is used for agriculture, with almost all (81%) devoted to annual crop production. Annual cropping in this group is characterized by high summerfallow and significant pulses (6%) and oilseeds (6%). The area has a low percentage of land in flax. Nearly nine-tenths (87%) of the farms with cropland reported summerfallow, while more than one-quarter of farms reported canola (28%) and one-quarter had lentils (24%). Chemical and fertilizer costs were low at $36/ha, but were a third higher than Group 1.

Group 13 had the highest percentage of pulses in rotation and is the major lentil growing group. Common rotations in this group include summerfallow-cereal-cereal and summerfallow-oilseed/pulse-cereal. This group



Group 1 (high summerfallow, low inputs, and low crop diversity)

Group 8 (low summerfallow with cereals and oilseeds)

Group 15 (medium summerfallow with flax)

Group 13 (high summerfallow with pulses)

Group 2 (low summerfallow with pulses)

Group 14 (very low summerfallow, medium to low pasture, and high crop diversity)

Group 4 (high summerfallow with oilseeds)

Group 10 (low summerfallow with very high oilseeds)

Group 7 (very low summerfallow, very low pasture, and high crop diversity)

Figure 4.13 **Proportions of cultivated (annual crops plus summerfallow) land in various crop in the Majority Cultivated Land Practices Groups.**

had the most diversified cropping of the High Summerfallow groups.

Although only one-fifth of the agricultural land is used for hay and pasture, 39% of the farms reported cattle, resulting in a low average number of cattle per farm (93 cattle per farm with cattle). Just one-fifth (19%) of the farms reported unimproved pasture, and a relatively low proportion of farms grew alfalfa (19%) and tame hay (10%).

The proportion of oilseeds, pulses and summerfallow in the rotation combined with a relatively dry and windy climate result in a moderate wind erosion risk on annually cropped land in Group 13. Infrequent intensive rainfall and gentle slopes result in a low risk of water erosion. The risk of tillage erosion is also low.

Farmland in Group 13 is dominated by annual cropping. Permanent cover was reported on only 3% of all cropland. Agricultural land in Group 13 has about one-third summerfallow and the adoption of conservation tillage has occurred on less than two-fifths of the land and farms. The cultivated portions of this group may be losing soil organic matter.

Almost all of Group 13 has a low vulnerability class for surface water quality, mainly due to the low level of crop inputs and low runoff potential.

Less than one-fifth (15%) of farmland in this group has native vegetation and contains only 1% of the native vegetation for the agricultural lands of the Prairies. The contribution of Group 13 to wildlife habitat and biodiversity is limited by the high levels of annual cropping.

Majority cultivated, high summerfallow with oilseeds (Group 4)

Group 4 is comprised almost exclusively of Dark Brown soils in Alberta near Drumheller, Vulcan and Warner, and in Saskatchewan near Unity, Davidson and Estevan. These are mainly undulating morainal plains, or lake basins (Table 4.14). Associated with these soils are significant areas of Solonetzic soils. Minor areas of hilly or poorly drained landscapes are associated with the more productive lands of Group 4.

In this group, agricultural land is used mainly for annual crop production (78%). Annual cropping in this group is characterized by high summerfallow (29%) and high oilseeds (12%). The area has a low percentage of land in flax. Over four-fifths (83%) of farms with cropland reported summerfallow, while nearly half of farms reported canola (48%). Chemical and fertilizer costs were low at $43/ha, but were significantly higher than Group 1 at $27/ha.

Table 4.14 Landscapes of Group 4

Majority Cultivated, high summerfallow with oilseeds

Landscape	**Area (ha)**	**Percent of Group**
Well-drained Dark Brown soils (5-9% slopes)	1 183 103	32
Well-drained Dark Brown soils (<4% slopes)	856 017	23
Brown or Dark Brown Solonetzic soils	680 478	19
Well-drained Brown soils	411 208	11
Strongly sloping to hilly	388 393	11
Poorly drained soils	136 729	4
Total	**3 655 928**	**100**

Table 4.15 Landscapes of Group 1

Majority cultivated, high summerfallow, low crop inputs, and low crop diversity

Landscape	Area (ha)	Percent of Group
Well-drained Brown soils	3 209 957	57
Strongly sloping to hilly	720 739	13
Brown or Dark Brown Solonetzic soils	703 477	13
Well-drained Dark Brown soils	656 976	12
Poorly drained or saline soils	323 277	6
Total	**5 614 426**	**100**

Like Group 10, most of the non-cereal annual crop was oilseed. However, fallow was an important part of the crop rotation on most farms. Typical rotations include summerfallow-cereal-cereal and summerfallow-oilseed-cereal-cereal. This area is a slightly moister and more diversified version of Group 1. Only one-fifth (20%) of the agricultural land was used for cattle (115 cattle per farm with cattle). Cattle were reported on nearly half (46%) of the farms, and just over half (55%) of the farms reported unimproved pasture. Fewer farms reported cattle than had pasture. A relatively low proportion of farms grew alfalfa (21%) and tame hay (11%).

Group 4 falls mainly in the Dark Brown Soil Zone. Winds and evapotranspiration are less extreme than in the Brown Soil Zone resulting in annual cropland having a low to moderate risk of wind erosion. One polygon west of Last Mountain Lake is at high risk due to the interactions of hummocky topography with the wind.

Water erosion risk is low over most of the area due to infrequent rain storms and lower volumes of snowmelt. Solonetzic soils may occasionally be subject to gully erosion where water flow concentrates.

Tillage erosion risk is moderate on morainal soils due to the complexity of the surface topography.

Risk of salinity in Group 4 is higher than for the rest of the Prairies, but lower than the other high summerfallow areas (Groups 1 and 13). The more level landscapes of Group 4 present less potential for the salinization process. The vulnerability of surface water quality in Group 4 is similar to the vulnerability for all of the Prairies.

Farmland in Group 4 is dominated by annual cropping. Permanent cover was reported on only 4% of all cropland. The cropland in Group 4 has more than one-quarter summerfallow, and the adoption of conservation tillage has occurred on nearly half of the land and farms. The cultivated portions of this group may not be losing soil organic matter.

One-sixth (16%) of farmland is in native vegetation, and it contains only 4% of the native vegetation for the agricultural lands of the Prairies. The contribution of Group 4 to wildlife habitat and biodiversity is limited by its high levels of annual cropping.

Majority cultivated, high summerfallow, low crop inputs and low crop diversity (Group 1)

The soil landscapes of Group 1 are similar to Group 4 and represent the drier areas of cultivation on the Prairies. These are mainly (80%) in the Brown soil zone and have traditionally been the wheat-fallow land of southern Saskatchewan and southeastern Alberta.

The soils are well-drained on gently sloping hummocky moraines, or a complex of level to gently undulating lacustrine and morainal deposits (Table 4.15). One-third of the land is more marginal for cultivation due to strongly sloping topography and Solonetzic, poorly drained or saline soils.

In this group, agricultural land is used mainly for annual crop production (76%) which is characterized by high summerfallow (39%) and high cereals (56%). The area has a low percentage of land in oilseeds, pulses or flax. Nearly nine-tenths (89%) of farms with cropland reported summerfallow, while less than one-tenth of farms reported canola (9%), lentils (6%) or flax (3%). Chemical and fertilizer costs were low at $27/ha.

Little crop diversification, from cereals to oilseeds and pulses, has occurred. Fallow is an important part of the crop rotation. This area is a blend of summerfallow-wheat and summerfallow-wheat-wheat rotations.

Only one-fifth (21%) of the agricultural land is used for cattle (109 cattle per farm with cattle), with cattle reported on two-fifths (41%) of the farms. Half (52%) of the farms reported unimproved pasture and fewer farms reported cattle than had pasture. A relatively low proportion of farms grew alfalfa (18%) and tame hay (9%).

Most annual cropland within Group 1 has a moderate to high risk of wind erosion due to the dry, windy climate and the high proportion of summerfallow.

The overall risk of water erosion is moderate to low due to loss of winter snowcover from Chinooks. However, steeply sloping polygons on the Missouri Coteau are at high risk to water erosion, particularly gully erosion due to snowmelt. There is a high to moderate risk of tillage erosion on hummocky cropland due to the extent of summerfallow.

Over 60% of farmland in Group 1 is at a moderately high to high risk for salinity. The relatively high salt content of the soil parent material and the high evaporation rate in the Brown soil zone contributes to this high level of risk.

Group 1 has a lower vulnerability for surface water quality than the rest of the Prairies due to the low runoff potential and low level of crop inputs.

Farmland in Group 1 is dominated by annual cropping. Permanent cover was reported on only 4% of all cropland. Group 1 has about two-fifths summerfallow and conservation tillage has been adopted on about one-third of the farmland. The cultivated portions of this group may be losing soil organic matter.

Less than one-fifth (18%) of farmland was in native vegetation, accounting for 6% of total native vegetation in the agricultural lands of the Prairies. The contribution of Group 1 to wildlife habitat and biodiversity is limited by its high levels of annual cropping, but is much greater than the other high summerfallow groups.

MAJOR GROUP - MAJORITY CULTIVATED, WITH FLAX

Three Majority Cultivated groups had a significant component of flax in the crop mix. The *Majority Cultivated, with flax* polygons with very low pasture and very low summerfallow generally had a wide range of crop diversity that included flax, pulses and oilseeds. Where these polygons had pasture and hay on less than 20% of total farm area, summerfallow less than 15% of cultivated land and flax greater than 2% of cultivated land, they were placed in *Majority cultivated, very low summerfallow, very low pasture and high crop diversity (Group 7).*

The *Majority Cultivated, with flax* polygons that had a similar cropping pattern to Group 7, but had higher pasture (pasture and hay 20-50%) were considered as *Majority cultivated, very low summerfallow, medium to low pasture, and high crop diversity (Group 14).*

A related group of polygons had higher summerfallow, but similar pasture and flax as Group 14. Where the summerfallow exceeded 15% and flax was greater than 2%, the polygons were placed into *Majority Cultivated, medium summerfallow with flax* (Group 15).

Majority cultivated, very low summerfallow, very low pasture, and high crop diversity (Group 7)

Group 7 contains some of the most productive land on the Prairies, including the Red River Valley, Brandon area and parts of southwestern Manitoba and the Carrot River Valley of Saskatchewan. These lands are mainly well-drained, level lacustrine or till plains in the Black soil zone. Almost all of the land (87%) has less than 4% slopes, while less than 1% of the land is strongly sloping (greater than 10% slope) (Table 4.16). Poorly and imperfectly drained soils are typically associated with the level clays found in this group. The high productivity and uniformity of the soil landscape results in a high degree of crop diversity.

In this group, agricultural land is used mainly for annual crop production (80%). Annual cropping in this group is characterized by low summerfallow (9%), high oilseeds (17%), and significant pulses (5%) and flax (5%). Nearly half (46%) of the farms with cropland reported summerfallow, while over half (56%) of farms reported canola. One-quarter (26%) of farms reported flax and one-fifth (18%) peas. Chemical and fertilizer costs were high at $99/ha.

Group 7 has the lowest percentage of land in forages and the lowest number of cattle per farm on the Prairies. Crop production is the most intensified and diversified on the Prairies, with a mix of oilseeds, flax and pulses. No other group has a higher proportion of farms reporting canola, peas and flax. Other groups have a higher proportion of land seeded to one of these crops (e.g. Group 10 - canola, Groups 2 and 13 - pulses), but none have high values in all three. Cereal crops make up two-thirds of the seeded area. The basic rotation is cereal-cereal-canola/flax/pulse. Occasionally, summerfallow is inserted into the rotation, usually before canola. This group has a high frequency of small areas of summerfallow.

Just one-eighth (13%) of agricultural land is used for cattle (75 cattle per farm with cattle), with cattle reported on one-third (33%) of farms. One-eighth (13%) of the farms reported unimproved pasture. An intermediate proportion of farms grew alfalfa (31%) and tame hay (10%).

Overall wind erosion risk on annual cropland within this group is low. Clay soils may occasionally be at high risk to wind erosion when crop cover is depleted by excessive tillage, drought or low residue-produc-

Table 4.16 Landscapes of Group 7

Majority cultivated, very low summerfallow, very low pasture, and high crop diversity

Landscape	Area (ha)	Percent of Group
Well-drained Black till soils	1 908 990	42
Well to imperfectly drained lacustrine Black soils (<4% slopes)	1 545 264	34
Poorly drained soils	669 555	15
Well to imperfectly drained lacustrine Dark Gray or Luvisolic soils	444 922	10
Total	**4 568 731**	**100**

Photo Courtesy of Hoppe Farms

Innovative and appropriate management practices allow producers to successfully diversify and intensify crop production.

ing crops. Soils on the till plain are quite resistant to both wind and water erosion except for areas of steeper slopes and where large contributing areas result in gully erosion. In southern Manitoba, annual cropland within this group is at moderate risk to water erosion due to the frequent occurrence of high-intensity rainfall. The overall risk of tillage erosion is low except on steeper slopes.

Although over half of the farmland in Group 7 is at low or moderate salinity risk, a significant portion is at high risk. These higher risk lands are located at the edge of the lacustrine basins that typically have a higher incidence of salinity.

Despite the high level of crop inputs, the vulnerability of surface water quality is on a par with the Prairie average. The lower runoff potential due to level land and low cattle numbers offset the higher crop inputs.

The farmland in Group 7 is dominated by annual cropping. Permanent cover was reported on only 6% of all cropland. Group 7 has less than one-tenth summerfallow and conservation tillage has been adopted on about two-fifths of the land. The cultivated portions of this group may be gaining soil organic matter.

Less than one-fifth (13%) of farmland in this group is in native vegetation, and it contains 3% of the native vegetation in the agricultural lands of the Prairies. The contribution of Group 7 to wildlife habitat and biodiversity is very limited because of its high levels of annual cropping. Group 7 had the lowest percentage of farmland in native vegetation of all groups.

Majority cultivated, very low summerfallow, medium to low pasture, and high crop diversity (Group 14)

Group 14 is mainly found in Manitoba, surrounding the Group 7 lands. The soils are more variable and contain a greater proportion of marginal land (Table 4.17). Thirty percent of the land is sandy, poorly drained or strongly sloping, thus limiting cultivation and providing a higher proportion of grazing and forage land. The remainder of the lands in Groups 14 are generally highly productive Black lacustrine and till soils similar to those in Group 7.

In this group, agricultural land is used mainly for annual crop production (63%) which is characterized by low summerfallow (9%), high oilseeds (15%) and significant flax (5%). Two-fifths (41%) of farms with cropland reported summerfallow, another two-fifths (40%) reported canola. One-fifth (21%) of farms reported flax. Chemical and fertilizer costs were high at $99/ha.

Group 14 has nearly twice the proportion of farms reporting cattle and pasture than Group 7, and a very high proportion of farms had alfalfa and hay. Group 14 has slightly less diverse cropping than Group 7. A smaller proportion of farms grew canola, flax and peas, but continuous cropping is common. Rotations included cereal-cereal-canola/flax/pea, or cereal-cereal-cereal-canola/flax/pea. Occasionally, summerfallow is inserted into the rotation, usually before canola. This group has a high frequency of small areas of summerfallow.

Less than one-third (30%) of the agricultural land is used for cattle (99 cattle per farm with cattle), with cattle reported on over half (57%) of the farms. Nearly one-third (30%) of the farms reported unimproved pasture, while a high proportion grew alfalfa (47%) and tame hay (18%).

Overall wind erosion risk in Group 14 is low because much of this area has lower wind-speeds than other parts of the Prairies. Water erosion and tillage erosion risk is also low over much of the area due to the subdued topography. Risk of water erosion is high in the Pelican Lake and Rock Lake areas due to the combination of steeply sloping morainal topography and higher rainfall intensities in this part of Manitoba.

The salinity risk for Group 14 is average, with less than a quarter of farmland rated moderately high to high risk. Although three-quarters of the cultivated land in Group 14 has low vulnerability for surface water quality, the areas of high and very high vulnerability are greater than the Prairie average. The greater risk is due to high crop inputs and cattle on land that has a high runoff potential.

The farmland in Group 14 is dominated by annual cropping. Permanent cover was reported on only 14% of all cropland. The group has less than one-tenth summerfallow and adoption of conservation tillage has occurred on more than one-third of the land. The cultivated portions of this group may be gaining soil organic matter. Nearly one-quarter (24%) of farmland is in native vegetation, and it contains 5% of the native vegetation in the agricultural lands of the Prairies. The contribution of Group 14 to wildlife habitat and biodiversity is limited by its high levels of annual cropping. Groups 14, 10 and 8 have the highest levels of native vegetation in the low summerfallow groups.

Table 4.17 Landscapes of Group 14

Majority cultivated, very low summerfallow, medium to low pasture, and high crop diversity

Landscape	**Area (ha)**	**Percent of Group**
Imperfectly drained Black or Dark Gray soils (<4% slopes)	987 133	28
Well-drained Black soils (<4% slopes)	791 768	22
Well-drained Black soils (5-9% slopes)	425 513	12
Strongly sloping to hilly	423 822	12
Poorly drained soils	357 501	10
Well-drained Dark Gray or Luvisolic soils	318 332	9
Sandy soils	279 090	8
Total	**3 583 158**	**100**

Table 4.18 Landscapes of Group 15

Majority cultivated, medium summerfallow with flax

Landscape	Area (ha)	Percent of Group
Well-drained Black till soils	1 898 903	38
Well-drained Dark Brown till soils	937 475	19
Well-drained lacustrine or fluvial soils	819 261	16
Poorly drained or Organic soils	612 522	12
Well-drained Dark Gray or Luvisolic till soils	455 535	9
Dark Brown Solonetzic soils	229 619	5
Strongly sloping to hilly	104 055	2
Total	**5 057 370**	**100**

Majority cultivated, medium summerfallow with flax (Group 15)

Group 15 is the Black till plain of east-central Saskatchewan. The Indian Head area is a good example of this group (Table 4.18). Two-thirds of the soils are fairly uniform well-drained Black Chernozems developed on an undulating till plain that extends into the Dark Brown and Dark Gray soil zones. Sandy soils of the associated fluvial or lacustrine materials will likely be the sites for cattle grazing in this landscape, as would be the minor amounts of poorly drained, Solonetzic or strongly sloping topography.

In this group, agricultural land is used mainly for annual crop production (75%). Annual cropping is characterized by medium summerfallow (20%) and high oilseeds (13%). The area has a significant percentage of land in flax (4%). Two-thirds (68%) of the farms with cropland reported summerfallow, with nearly two-fifths (42%) reporting canola and one-fifth (21%) reporting flax. Chemical and fertilizer costs were slightly lower than average for the Prairies at $58/ha.

Group 15 is very similar to Groups 7 and 14, but has more summerfallow and less crop diversification. Summerfallow levels were similar to that in more arid regions, with the practice utilized as a risk management and cost reduction practice on Group 15 soils. The cropping pattern on two-thirds of the farms appears to be one year summerfallow followed by two years of crop. The remainder of the farms are continuously cropped. Broadleaf crops account for approximately one-quarter of the seeded land.

Pasture and cattle amounts were between the values for Groups 7 and 14. Only one-fifth (21%) of the agricultural land was used for cattle (96 cattle per farm with cattle), but cattle were reported on nearly half (46%) of farms. One-fifth (21%) of the farms reported unimproved pasture. A significant proportion of farms grew alfalfa (30%) and tame hay (14%).

The combination of less erodible till soils and a humid climate result in a low wind erosion risk on annual cropland in Group 15. Nevertheless, pockets of sandy soils such as those near Good Spirit Lake in east central Saskatchewan are prone to wind erosion.

Water erosion risk is generally low, rising to moderate in areas of steeper topography. Intensive tillage of some fields may lead to severe ephemeral gully erosion due to snowmelt. Tillage erosion is moderate due to the complexity of the morainal landscape.

Group 15 has a moderate to low risk of salinity. Although the group is dominated by a till landscape, the higher rainfall and lower evaporation reduces the potential for salinization.

Farmland in Group 15 is dominated by annual cropping. Permanent cover was reported on only 7% of all cropland. Group 15 reported one-fifth summerfallow, while the adoption of conservation tillage has occurred on more than two-fifths of the land. The cultivated portions of this group may not be losing soil organic matter.

Less than one-fifth (18%) of the farmland is in native vegetation, and it contains 5% of the native vegetation in the agricultural lands of the Prairies. The contribution of Group 15 to wildlife habitat and biodiversity is limited by its high levels of annual cropping.

MAJOR GROUP - MAJORITY CULTIVATED, LOW SUMMERFALLOW

The *Majority Cultivated, low summerfallow* polygons had summerfallow less than 25% and formed three groups, based on the crop mix. The first and most obvious was the significantly high oilseeds in the Peace River area. The amount of oilseeds in all of the polygons in *Majority cultivated, low summerfallow with very high oilseeds (Group 10)* is greater than 24%, and exceeds the one in four cropping year recommendations. Group 10 is also identified by a low component of flax (flax less than 2% of cultivated land).

The *Majority Cultivated, low summerfallow* polygons that have pulses but low flax formed another group. On the Prairies, 25% of the SLC polygons have more than 2.7% pulses in the rotation. Where the pulses exceeded 2.6% of the cultivated land, pulses exceeded flax and summerfallow was less than 25%, the category was *Majority Cultivated, low summerfallow with pulses (Group 2)*.

The last group was the *Majority Cultivated, low summerfallow with cereals and oilseeds (Group 8)*. These polygons had summerfallow less than 25%, oilseeds less than 24%, pulses less than 2.6% and flax less than 2%.

Majority cultivated, low summerfallow with very high oilseeds (Group 10)

Group 10 is almost exclusively located in the Peace River district. Half of the area consists of level or nearly level lacustrine deposits on Dark Gray and Gray soils, while only 19% is found on more sloping land (Table 4.19). There is no strongly sloping land in this group. Also in this group are Black and Gray Solonetzic soils, which are likely cultivated and poorly drained, and Organic soils that are not likely used for agricultural production.

Table 4.19 Landscapes of Group 10

Majority cultivated, low summerfallow with very high oilseeds

Landscape	Area (ha)	Percent of Group
Well to imperfectly drained Luvisolic or Dark Gray soils (<4% slopes)	1 685 361	48
Poorly drained or Organic soils	780 415	22
Well to imperfectly drained Luvisolic or Dark Gray soils (5-9%	649 515	19
Black or Gray Solonetzic soils	375 796	11
Total	**3 491 088**	**100**

Diversification into oilseeds and pulses has become profitable in several areas across the Prairies, however, producers must be aware of the increased erosion risk that accompanies these low residue crops.

Overall, Group 10 has the lowest amount of land that is used for agriculture (44%). Some of the land is devoted to forestry, while a high percentage is in unsettled areas of bogs and bush. Cleared agricultural land in this group is used mainly for annual crop production (60%).

Annual cropping is characterized by low summerfallow (12%) and high oilseeds (32%). Nearly two-fifths (37%) of farms with cropland reported summerfallow. More than half (55%) of farms also reported canola, but less than one-tenth reported flax (2%) or peas (9%). Chemical and fertilizer costs were high at $87/ha.

Group 10 soils have the lowest percentage of cereals and the highest percentage of oilseeds on the Prairies. Guidelines for rotation of canola for disease control include the recommendation that "canola should not be grown on the same land more than once every four years ..." (Saskatchewan Agriculture and Food 1999). Furthermore, "a three or four-year rotation is recommended to prevent or reduce the build-up of diseased crop residues" (Alberta Agriculture, Food and Rural Development 1999). The amount of land in oilseeds in 1996 (31%) exceeded the recommended rotation guidelines. This could be a unique response to growing conditions or canola prices during the census year, but expert advice from the area suggests that large canola acreage is common. Summerfallow was not a common practice in this group.

Less than three-tenths (28%) of the agricultural land is used for cattle (98 cattle per farm with cattle), and cattle were reported on less than two-fifths (38%) of farms. About one-quarter (28%) of farms reported unimproved pasture, and a high proportion grew alfalfa (34%) and tame hay (23%).

Overall wind erosion risk in Group 10 is low on annual cropland due to the lower windspeeds in the Peace River District. However, an area of sandy soils south of High Level is at moderate risk to wind erosion when inadequately protected by crop residue. Annual cropland in some areas of Group 10 is at high risk to tillage and gully erosion due to the long steep slopes and the high proportion of oilseeds grown on this land.

The farmland in Group 10 is dominated by annual cropping. Permanent cover was reported on 21% of all cropland. Approximately one-tenth of the group is summerfallowed, with conservation tillage adopted on about one-third of the land. The cultivated portions of this group may be gaining soil organic matter.

Nearly one-quarter (24%) of the farmland is in native vegetation, and it contains 2% of the native vegetation in the agricultural lands of the Prairies. The contribution of the agricultural portion of Group 10 to wildlife habitat and biodiversity is limited by its high levels of annual cropping. However, much of the non-agricultural portion of this group in native vegetation. Groups 14, 10 and 8 had the highest levels of native vegetation in the Low Summerfallow Groups.

Majority cultivated, low summerfallow with pulses (Group 2)

Group 2 is one of the largest groups and is found in the moister areas of the Prairies (Table 4.20). Although more than half of it is found in the Black soil zone, it extends from the Dark Brown to the Dark Gray soil zones, from southeastern Saskatchewan to the Peace River District. The majority of the group is located on the finer textured soils of mainly undulating landscapes. In contrast, marginal soils make up 20% of this group due to strongly sloping topography, sandy texture or poor drainage.

Agricultural land in this group is generally used for annual crop production (70%). Annual cropping is characterized by low summerfallow (14%), high oilseeds (16%) and significant pulses (6%). Half (52%) of farms with cropland reported summerfallow, while half reported canola. Close to one-fifth (18%) of farms reported peas. Chemical and fertilizer costs were high at $78/ha.

Group 2 reported highly diversified annual cropping. Oilseeds and pulses, and to a lesser extent than in Groups 7 and 14, flax, are significant components of the cropping system. Half of the farms reported summerfallow, but less than one-sixth of the land is fallowed. This suggests that half of the land is in a one-third fallow/two-thirds crop rotation, while the other half is continuous cropping with canola/pea/flax once in three or four years. The diversified rotations and higher moisture received in the area contribute to relatively high input costs for chemicals and fertilizers.

Half of the farms reported pasture and cattle, while one-third grow alfalfa. One-quarter

Table 4.20 Landscapes of Group 2

Majority cultivated, low summerfallow with pulses

Landscape	Area (ha)	Percent of Group
Well to moderately well drained Black soils (<4% slopes)	1 879 073	27
Well to imperfectly drained Dark Gray or Luvisolic soils	1 414 245	21
Well-drained Dark Brown soils	1 222 112	18
Sandy, Alluvial, poorly drained or Organic soils	888 700	13
Well-drained Black soils (5-9% slopes)	885 720	13
Strongly sloping to hilly	545 162	8
Total	**6 835 012**	**100**

(25%) of the agricultural land is used for cattle (105 cattle per farm with cattle), with cattle reported on nearly half (46%) of farms. Over one-half (51%) of farms reported unimproved pasture and a high proportion of farms grow alfalfa (30%) and tame hay (17%).

The high proportion of oilseeds and pulses which are characteristic to Group 2 increase overall wind and water erosion risk compared to cereals. Lower wind intensities than in the warmer and drier areas of the Prairies result in a moderate risk of wind erosion on morainal soils within the group. However, the Regina clays under heavy tillage regimes are exposed to freeze-thaw conditions resulting in them being highly erodible in the spring. Lacustrine soils adjacent to the South Saskatchewan River downstream of Lake Diefenbaker, and adjacent to the North Saskatchewan River in Saskatchewan are also quite susceptible to wind erosion.

Water erosion risk is low in Group 2 due to the gently sloping topography over much of the area, but may be greater in areas of hummocky topography. Snowmelt erosion may be a problem where water concentrates to form gullies. Tillage erosion risk is moderate to low due to the subdued topography over much of the area and also due to the low proportion of summerfallow.

The salinity risk in Group 2 is low to moderate. Although the soil parent material in this group may have higher salt content than some of the other low summerfallow groups, higher rainfall and a lower evapotranspiration rate reduces the salinization potential. A quarter of Group 2 cultivated land has a high vulnerability for surface water quality. This is the result of higher than average crop inputs and the higher runoff potential of the landscape.

Farmland in Group 2 is dominated by annual cropping. Permanent cover was reported on only 9% of all cropland. Cropland has less than one-fifth summerfallow and conservation tillage has been adopted on more than two-fifths of the land and one-third of the farms. The cultivated portions of this group may not be losing soil organic matter.

Nearly one-fifth (18%) of farmland is in native vegetation, representing 7% of the native vegetation in the agricultural lands of the Prairies. The contribution of Group 2 to wildlife habitat and biodiversity is limited by its high levels of annual cropping.

Majority cultivated, low summerfallow with cereals and oilseeds (Group 8)

Group 8 soils are dominantly in the Black soil zone and represent the typical Prairie farmland found near Red Deer and Lloydminster, Alberta and similar areas in Saskatchewan (Table 4.21). The presence in this group of Black Solonetzic soils near Vegreville may explain the higher proportion of forage compared to Group 2, which has somewhat similar soils. The soils of this group extend into the Dark Brown and Dark Gray soil zones. Strongly sloping topography or poor drainage result in 20% of this group's soils being rated as marginal.

In Group 8, agricultural land is mainly devoted to annual crop production (62%) which is characterized by low summerfallow (13%) and high oilseeds (15%). Two-fifths (43%) of farms with cropland report summerfallow. Another two-fifths (39%) of the farms reported canola, while less than one-tenth reported peas (5%) or flax (3%). Chemical and fertilizer costs were high at $77/ha.

Annual cropping in Group 8 is primarily cereals and oilseeds. As in Group 10, very little diversification into flax and pulses has occurred.

This group had the highest cattle numbers per farm of all the *Majority Cultivated* Groups, suggesting that diversification to livestock has been more

Table 4.21 Landscapes of Group 8

Majority cultivated, low summerfallow with cereals and oilseeds

Landscape	Area (ha)	Percent of Group
Well to imperfectly drained Dark Gray or Luvisolic soils	1 819 068	26
Well to imperfectly drained Black soils (<4% slopes)	1 440 192	21
Well-drained Black soils (5-9% slopes)	1 230 870	18
Well-drained Dark Brown soils	943 709	14
Poorly drained or Organic soils	865 067	12
Strongly sloping to hilly	661 569	10
Total	**6 960 475**	**100**

common than diversification of cropping. Over one-quarter (30%) of the agricultural land is used for cattle (125 cattle per farm with cattle), and cattle were reported on more than half (53%) of farms. Unimproved pasture was reported on over one-quarter (30%) of farms, and a high proportion grew alfalfa (35%) and tame hay (18%).

Wind erosion risk of annually cropped land in Group 8 is low due to the loam and clay loam textures of the soils, the low amount of summerfallow in the rotation, and the combined action of low windspeeds and smaller moisture deficits characteristic of this group. Overall water erosion risk is also low, but moderate sheet, rill and gully erosion may occur in areas with hummocky topography such as east of Viking, Alberta. Tillage erosion risk is moderate in areas of hummocky topography.

Group 8 has a low risk of salinity, although some areas such as the Solonetzic soils near Vegreville have a moderately high risk. Group 8 has a significantly higher proportion of land rated as vulnerable, high and very high vulnerability for surface water quality relative to the rest of the Prairies. Higher than average crop inputs, large cattle numbers and the strong potential for runoff all contribute to the higher vulnerability. The area has more rainfall and generally has better natural drainage than other landscapes.

The farmland in Group 8 is dominated by annual cropping. Permanent cover was reported on 12% of all cropland. Group 8 has slightly over one-tenth summerfallow and the adoption of conservation tillage has occurred on about two-fifths of the land, and one-third of the farms. The cultivated portions of this group may be gaining soil organic matter.

Nearly one-fifth (18%) of the group's farmland is in native vegetation, comprising 8% of the native vegetation in the agricultural lands of the Prairies. The contribution of Group 8 to wildlife habitat and biodiversity is limited by its high levels of annual cropping.

Groups 14, 10 and 8 had the highest levels of native vegetation in the low summerfallow groups. Together, Groups 2 and 8 represent as much of the land in native vegetation as either Group 9 or 12, the two *Majority Pasture* Groups.

Relationships between Land Practices Groups

As anticipated, the Land Practices Groups indicate the adaptation of western Canadian agricultural producers to land capability. In general, the major areas of pasture land are found on the lands marginal for cultivation, summerfallow is concentrated in drier areas and there is more diversity of crops on the more productive land. Although this makes sense intuitively, this exercise has provided a spatial or visual representation of these relationships.

In addition to adapting to the landscape, producers have adjusted to marketing, transportation and policy conditions that exist in each province. The very high oilseed group (Group 10) for instance, has appeared to take advantage of high commodity prices and lower shipping costs to the West Coast by seeding almost a third of the land to canola and other oilseeds. Producers in western Alberta have used the cattle industry to process and market their grain production. Manitoba producers grow a wide variety of crops including flax and pulses, as well as oilseeds and grains. Some areas of Saskatchewan have retained higher levels of summerfallow than areas of comparable soils in Alberta and Manitoba. This response to the landscape may be due to an adherence to traditional farming methods.

In the drier areas, oilseeds have made significant gains in the Dark Brown soils, while in certain areas, pulses, and in particular lentils, have significantly increased. Lentils, that grow well in dry conditions, provide an opportunity for diversification and higher valued cropping in the Dark Brown and Brown soil zones. Common opinion is that the oilseeds and pulses will continue to increase, reducing both the acreage of wheat and summerfallow in southern Saskatchewan. The low input, high summerfallow area (Group 1) will be smaller.

Demands for pasture, forage and feed grains to support cattle herds will compete for land currently used to grow export crops.

Most of the high pasture areas will likely see little change. Group 3 (very large farms) is dominantly native grasses, while the cropping pattern on cultivated land is similar to Group 1 (low input, high summerfallow). The land is for the most part only suited to perennial forage production and there will be resistance from environmental concerns to extensive breaking and reseeding. Increased productivity can only be achieved through management of the native grasses to improve range condition. On the other hand, the other dominantly pasture group (Group 6) could see significant increases in forage productivity through more intensive management of tame pasture and hay.

The identification of Land Practices Groups provides a basis to predict changes in cropping, grazing and hay production across the Prairies. Each of the groups will behave differently to changing pressures due to commodity prices, market opportunities, transportation changes, technological advances, government policy and environmental concerns. The Land Practices Groups can then be used to identify where changing agricultural practices may present conditions that threaten the agricultural land resource.

Chapter 5: Issues Facing Management of Land Resources

Introduction

There are many issues facing today's farmers. Rising input costs and low commodity prices add to the complexity of the decision-making process. During a 1995 conference into Planning for a Sustainable Future - The Case of the North American Great Plains (Wilhite and Smith 1995), focus groups agreed that farmers faced:

- *heavy debt burdens*
- *lack of access to equity*
- *risk that is personal rather than corporate*
- *high transportation costs*
- *high costs for fertilizer and pesticides*
- *little leverage against big business firms*
- *no control over global commodity prices*
- *seemingly little political clout.*

Not much has changed. In an attempt to compensate for these conditions, there's an increasing tendency to farm more land, to diversify and take other measures. To some, producing more in the face of falling prices is not a solution (Dorosh 1998), and the consequences for the future management of the Prairie soil resource are uncertain.

In 1995, the *National Environment Strategy for Agriculture and Agri-Food* was written for the Canadian federal and provincial ministers of agriculture (AAFC 1995a). The report stated that, "Stresses on the resource base, new technologies and trade agreements, and increased public concern about the environment are just a few of the challenges facing the sector."

It further stated that sustainable development would require finding a balance among social, economic and environmental factors.

Social factors are affected by farm size, population shifts and the infrastructure needed to sustain a good quality of rural life. Economic factors include considerations such as changing markets and increased costs of production. The environmental component reflects changes to the soil and water resource and a heightened public awareness of environmental impact.

The issues affecting sustainability can be divided into four general levels:

- public
- environmental
- community
- on-farm.

Within each of these levels, specific issues and issue drivers (sub-issues) have been identified (see Tables 5.1-5.4). These issues and drivers are likely to affect one or all of three factors:

- market condition
- social/emotional attitudes
- cost of production.

Photo by Dave Reede

There are many issues that affect producers' decisions, some of which allow little or no control, including weather, market conditions and societal attitudes.

Public Level Issues

Table 5.1 provides an overview of the major public issues that currently affect, or are likely to affect producer decisions. These include issues of policies and legislation as well as issues involving international agreements.

Programs, Policies and Legislation

Government programs can be designed with incentives to encourage the achievement of goals deemed to be in the public good. These incentives can range from the distribution of information to cost-sharing, public recognition and the imposition of laws and regulations.

Policy and legislation can influence trade, markets and stewardship decisions. They can be designed such that market signals and comparative advantage provide incentives to producers and processors to expand. Expansion can put tremendous pressure on natural resources as producers try to provide raw materials for processing and export. At the same time, other policy and legislation may be designed to protect the environ-

CAMC projections require crop yield growth rates of more than double current trends; cattle numbers would increase by 700,000 head (15%), while hog numbers would increase by 5.5 million head (30%). It is unlikely that livestock numbers can be pushed much beyond these levels without Canada becoming a net feed grain importer. In the hog sector, significant growth is occurring in the Prairie region (AAFC 1998). For example, Manitoba's breeding herd expanded by 6.1% in 1999, and output of market hogs in 2000 is expected to grow by 5% to 4.9 million (Manitoba Agriculture and Food 1999).

ment (i.e. sustainability and biodiversity obligations), and encourage sustainable uses of the land so that future generations will enjoy diverse and healthy ecosystems.

An example of a policy driver based on the concept of expanding export targets is the Canadian Agri-Food Marketing Council's (CAMC) growth target of 4% of world agri-food trade. An AAFC paper evaluating the CAMC goal outlines areas where government might support industry in achieving this objective (AAFC 1998). Five priority areas were identified:

- increase the supply of factors of production
- increase productivity
- relax/eliminate regulatory constraints
- increase market access
- ensure environmental sustainability.

Achieving the CAMC goals will involve significant changes in order to increase primary production. Revision of policies related to supply management, grading, licensing and packaging systems, and significant growth in productivity and gains in international markets are essential to meet the export target.

In meeting the CAMC goal, bulk product exports would decrease, but production output would have to increase significantly to supply the growing demands of the processing sector. To achieve this target, it is forecast that one million hectares of new land would have to come into production in Canada, increasing the total cultivated area to 39 million hectares.

The CAMC proposal for a dramatic increase in agri-food exports has clear implications for environmental sustainability. Increasing pressures to produce more from a relatively static land base would result in:

- pressure to bring new lands into annual production. This could result in the conversion of pastures and other marginal lands into cultivated hectares, with impacts on wildlife habitat quality and biodiversity
- increased management intensity on cultivated lands, resulting in greater use of pesticides, fertilizer, genetically modified organisms (GMOs)
- increased manure production and associated nutrient management and waste disposal requirements, and the increasing hazard of non-point water pollution from runoff and leaching of cultivated lands.

International agreements such as the World Trade Organization (WTO) and the North American

The Agenda 21 report identified eight main environmental and natural resource issues that can be applied to Canada's agriculture and agri-food sector:

- ***conservation of soil resources***
- ***surface and groundwater quality***
- ***water quantity management***
- ***sustainable management of wildlife habitat***
- ***air quality and climate change***
- ***energy efficiency***
- ***pollution and waste management***
- ***conservation of genetic resources.***

Free Trade Agreement (NAFTA) may place pressure on Canada to severely restrict mechanisms that are deemed to be subsidizing the cost of production.

On the environmental side, Canada is committed to a number of conventions and obligations, particularly in relation to biodiversity. Depending on the methods used to meet these obligations, their cumulative effect as an issue driver and the resulting impact on land management practices may be far-reaching.

Agenda 21, developed at the United Nations Conference on Environment and Development, Earth Summit, provides an overall blueprint on how to make development socially, economically and environmentally sustainable. It explains that population, consumption and technology are the primary forces behind environmental change. Agenda 21 lays out what needs to be done to reduce wasteful and inefficient consumption patterns in some parts of the world, while encouraging increased but sustainable development in others.

Concern over diminishing genetic resources in animals was more specifically addressed at the Earth Summit. As a result of the meeting, Canada signed the Convention on Biological Diversity (United Nations Environment Programme 1992), and was one of the first countries to ratify it. The Convention is a legally binding international treaty that involves, among other issues, a commitment to develop a Canadian biodiversity strategy, and to carry out plans for the domestic and global conservation of biodiversity. The Canadian Biodiversity Strategy was formally endorsed by federal, provincial and territorial governments in April, 1996.

Agriculture and Agri-Food Canada, as a key responsible federal agency, has developed an action plan to assure the conservation and sustainable use of biological resources. These resources include animal, plant and microbial genetic resources important to the future of Canadian food production. The plan has identified four goals:

- promote sustainability in agro-ecosystems, while respecting natural ecosystems
- increase awareness and understanding of biodiversity in agriculture
- conserve and facilitate access to genetic resources that are important to agriculture and share knowledge, expertise and technologies in a fair and equitable way
- integrate biodiversity, conservation and sustainable use objectives in departmental policies, programs, strategies, regulations and operations.

As part of its strategy, the Government of Canada has established national programs for the conservation of farm, crop and animal genetic resources. Canada's genetic resources are at risk from an increasing specialization of agriculture which uses fewer

> ***When a particular variety of animal or plant has shown superior qualities, farmers will tend to use it in their operations. The concern is that if a disease particular to such a 'super' variety is introduced, it could eliminate production altogether. While clearly no one wants this to happen, the incentive to specialize in the quest for the best possible economic returns is a powerful motivator within the agri-food industry.***

breeds of plants and animals. The federal government is working to preserve and enhance the diversity of Canada's genetic resources by acquiring and developing, adapting, monitoring, utilizing and/or releasing plant, animal and other biological genetic resources. The diversity of these resources will provide the basis for enhanced resistance to diseases, insects and other environmental stresses (Government of Canada 1990).

Inherently linked to the issue of biodiversity is the sub-issue of wildlife and habitat conservation. Biodiversity may be defined as the diversity of life, and may be considered at the genetic, species and ecosystem levels. Canada's public, and in particular the environmental community, are strongly interested in the conservation of wild species and natural ecosystems. Agriculturalists rely on the conservation of domesticated species and genetic resources for the improvement of crops and animals.

Public and environmental issues concerning conservation of wildlife and habitat arise because agriculture impacts natural landscapes and modifies habitat, often at the expense of some wildlife species or populations. Today, few policy instruments remain which negatively impact habitat. However, increased management intensity, increased pesticide use, and pressures to bring new lands into agricultural production may negatively affect wildlife habitat and populations.

It should also be noted, however, that agriculture interacts positively with wildlife. Across the Prairies, there are a number of wildlife habitat success stories. Some of these include the Agricultural Rehabilitation Development Act (ARDA), the North American Waterfowl Management Plan (NAWMP), and recent initiatives to restore riparian health such as the *Cows and Fish* project in Alberta. Increasingly, producers are being asked to farm with wildlife and habitat in mind. At present, however, there are few economic incentives to encourage this. To continue to preserve Canada's diversity of wildlife, it may be necessary to:

- support land and water stewardship with fiscal incentives (so that farmers can capture value from maintaining wildlife habitat)
- encourage more use of conservation easements with tax incentives
- encourage adoption of best management practices
- provide compensation for wildlife damage and expanded prevention measures
- assist landowners and rural communities to take economic advantage of natural landscapes whenever possible
- support the acquisition (public and private) of new habitat sites.

In order to protect wildlife species and their habitats, federal *Species at Risk* legislation is under consideration for both private and Crown lands in Canada. The Species at Risk strategy would allow for quicker action to protect a species, rather than waiting until it is endangered or faces extinction as a consequence of human activity. Agricultural concerns with such legislation relate to potential restrictions on land use and lack of compensation for foregone economic opportunities.

Agricultural concerns with Species at Risk legislation relate to potential restrictions on land use and lack of compensation for foregone economic opportunities.


Photo courtesy of Ducks Unlimited Canada

The proposed Species at Risk conservation strategy also includes explicit reference to stewardship initiatives, promoting an approach that works both for farmers and wildlife recovery. In partnership with both government and conservation agencies, informed farmers may well be able to manage their lands for efficient agricultural production while minimizing impacts to species at risk.

A number of options might be used to influence land and biodiversity management. For example

- some sensitive areas may be legislatively prohibited from production
- whole-farm planning may facilitate maintenance or improvement of endangered habitat through awareness
- revenue generation may be linked to conserving species at risk, such that wildlife is considered an asset and not a liability when managing the land
- tax incentives may be offered for conservation activity.

INTERNATIONAL AGREEMENTS

The federal government represents the public in the issue area of international agreements involving other trading partners, and often the rest of the international community. Examples of drivers within this issue category include the Kyoto Protocol, the Convention on Biological Diversity, NAWMP, and NAFTA and WTO agreements.

Kyoto Protocol: In December 1997, representatives from Canada and 160 other countries met in Kyoto, Japan and agreed on new, legally binding limits for greenhouse gas emissions in the world's industrialized nations (United Nations 1998).

Under the agreement which has yet to be ratified, developed countries are to reduce emissions of six greenhouse gases: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride. A certain amount of flexibility was built into the agreement to allow developed countries to meet part of their commitments through emissions trading.

Canada committed to reducing greenhouse gas emissions to 6% below 1990 levels by the year 2012 (United Nations 1998). In 1995, at least 80% of Canada's total greenhouse gas emissions resulted from the use of coal, oil and natural gas to generate electricity and to power factories, homes and cars. At present, agriculture accounts for about 10% of Canada's greenhouse gas emissions (Jacques et al. 1997). Greenhouse gas emissions and related climate change issues may affect the agricultural industry in the areas of soil management, increased production of forage crops, reduced fossil fuel usage and cropping practices.

Agriculture and Agri-Food Canada, Environment Canada and non-government organizations such as Ducks Unlimited, have emphasized the development and adoption of best management practices in agriculture to reduce greenhouse gas emissions.

The Agriculture and Agri-Food Table on Climate Change has recognized that there are major opportunities to sequester carbon from best management practices. These include reducing summerfallow, no-till and reduced tillage, use of perennial forages/legumes, more efficient application of fertilizers and organic amendments. Estimates indicate that sequestering between 11 and 26 Mt of carbon dioxide per year is possible, depending upon adoption rates and incentives used (AAFC 2000).

Although progress has been made towards altering agricultural practices to make them more environmentally sustainable, agriculture's mode of operation will almost always be economically driven. If a practice is not financially viable, it will likely not exist, regardless of responsible stewardship or the environmental benefit.

NAFTA: The North American Free Trade Agreement (NAFTA) began January 1, 1994. The objectives of this understanding between Canada, Mexico and the United States are to facilitate the cross-border movement of goods and services between the territories of the parties.

The agricultural provisions of the U.S.-Canada Free Trade Agreement, which have been in effect since 1989, were incorporated into the NAFTA. Under these provisions, all tariffs affecting agricultural trade between the United States and Canada (with a few exceptions for items covered by tariff-rate quotas), were to be removed by January 1, 1998.

Mexico and Canada reached a separate bilateral NAFTA agreement on market access for agricultural products. The Mexican-Canadian agreement eliminated most tariffs either immediately, or over 5-15 year periods. Tariffs between the two countries affecting trade in dairy, poultry, eggs and sugar are maintained.

Since the implementation of NAFTA:

- ***Canadian agricultural exports to the U.S. have increased by 35%. Canada's exports to the U.S. surpassed $10 billion in 1996, increasing 19% from 1995 (AAFC 1998)***
- ***Canadian agricultural export growth to Mexico was 7.6% in 1996, representing an export value of Cdn $388 million from Cdn $361 million in 1995***
- ***U.S. exports to Canada and Mexico have increased by 20% and 12% respectively.***

WTO: The World Trade Organization (WTO), contains the Agreement on Technical Barriers to Trade, which commits signatories to work towards compatibility of standardization measures (WTO 1998). Another WTO agreement deals with sanitary and phytosanitary measures, including standards used to protect human, animal or plant life and health.

The WTO agreement sets down rules for the international trade of agricultural products and calls for substantial reductions in trade distorting subsidies. Under the WTO Agreement on Agriculture, members are to reduce tariffs on agricultural goods by 36% over six years, with a minimum reduction of 15% for each tariff line. A reduction of 20% has been achieved already. However, the successful interpretation and application of WTO rules is increasingly coming under question. The agreement is supposed to provide for better trade rules for agriculture and more secure access for Canadian agricultural products. The Organization of Economic Co-operation and Development has predicted that this agreement will contribute $8 billion to the Canadian economy by the year 2002.

In 1989, the European Union (EU) imposed a ban on imports of Canadian beef produced with growth-promoting hormones.

- ***Health protection measure - the EU argued that the ban on Canadian imports was a health protection measure. However, internationally accepted studies have consistently found that the growth hormones in question present no danger to beef consumers.***
- ***Dispute settlement - Canada requested a WTO dispute-settlement panel in 1996, after direct consultations with the EU failed to resolve the dispute. In August 1997, the WTO panel ruled that the EU's ban on imports of Canadian beef had to be lifted.***
- ***Non-compliance - Europe indicated it will not comply with the ruling. Subsequently, the WTO approved Canadian retaliatory trade action, but the European market for Canadian beef remains closed for the foreseeable future.***

The WTO goal is to eliminate trade barriers. However, sanitary and phytosanitary health protection standards are becoming a trade barrier issue. They could be used to protect domestic markets by setting standards and making food safety claims.

The reduction of barriers to trade may allow the export of commodities and products in which Canadian agriculture and agri-food producers have a comparative economic advantage. This will cause producers to examine a wider range of land use options, and may result in new cropping and land management strategies.

Environmental Issues

Issues at the environmental level include public perception of what agriculture may be doing to the land and environment in general, and public expectations of a plentiful supply of safe water, air and food (AAFC 1997). Issues include the effects of natural variability on the environment, and the way that farmers must compensate for natural variability. Issues and drivers are listed in Table 5.2, along with a brief discussion of a few of the conditions and possible changes to land management that may apply.

PUBLIC PERCEPTION

The way the public views agriculture's role in the environment has implications for land management change. Western Canadian farmers are largely seen as good stewards of the land, and Canada is viewed as a world leader in producing nutritious, safe food products (The Advisory Group 1994). Yet this trust is certainly not based on extensive public knowledge of the agricultural sector with less than 3% of North Americans directly involved in farming.

Recent surveys indicate that consumers and producers share common concerns regarding the impact of agriculture on the environment (The Advisory Group 1997). Yet the two groups often use different language to describe these concerns. Producers might express concern over proper disposal or management of wastes, loss of soil fertility and soil erosion. Consumers, on the other hand, often talk in terms of water pollution, loss of wildlife habitat and shortage of water supply.

Interests between consumers and producers can diverge when it comes to food safety and the use of chemicals, additives, or

GMOs. Many in the public would like to see a decrease or cessation in the use of agricultural chemicals. Yet producers are faced with a wide range of plant and animal pests, and generally rely on management schemes that use chemicals. Such differing views, and the distinctly different vocabularies of each group, highlight the critical need for improved communication between producers and the public (Finn and Vincent 1997).

The public is becoming more influential in agriculture and policy development, and wants to be increasingly consulted and informed about farm impacts (Prairie Research Associates 1998). Clashes might be minimized through an improved knowledge of each group's viewpoint and rationale. If communication does not improve, an uninformed public could increasingly conclude that agriculture is a threat to the environment and that food supplies are unsafe, and demand greater regulatory control.

Agriculture is widely viewed as responsible for managing soil and water resources wisely, and as being publicly accountable for doing so (Wayland 1990). As such, land stewardship is a driver of the public perception issue and society wants assurances that land and water resources left to future generations will be productive and healthy. Although most farmers view themselves as managing their land sustainably for future generations, some common practices might well reduce soil quality in the long run (AAFC 1995b).

Increasingly, agriculture will be expected to maintain soil and water resources as close to their natural, unspoiled state as possible. Where cultivation is practiced, it may increasingly be viewed as bad for the land, with erosion and degradation as consequences. Many believe that agricultural chemicals are an unnecessary input that is polluting the land.

Pressure will increase to manage agricultural lands within their natural state, specifically to:

- maintain grasslands as such, and return more lands to pasture
- reduce tillage (including less fallow) and increase crop residue cover in fields as a part of a holistic management approach

As intensive livestock operations (ILOs) locate closer to rural communities, or consumers seek to better understand the risks and benefits of different management practices, an effective communications strategy will be a key component in public consultations towards assuring flexibility in land management options. Such a strategy must be:

- ***informative – include effective dissemination of information on agricultural chemical application and use (including benefits and risks)***
- ***sensitive – reflect the overall effect of farm activities on the local economy, and the potential impact of land management change on the environment***
- ***open – provide information so the public may be comfortable with planned developments***
- ***clear – e.g. where biotechnology is viewed by many with suspicion, an effective communication plan and further research could allay concerns and clarify problem areas.***

Out of a commitment to good stewardship, or at least wanting to be perceived as good stewards, rising numbers of farmers may adjust land management practices accordingly. On the other hand, landowners may change their agri-chemical use and tillage practices to access or respond to a wide range of environmental and economic instruments designed to foster sustainable development (Harker 1997).

- lower chemical and fertilizer inputs.

Overall, expectations may favor a movement towards a low-input sustainable agriculture philosophy. That is, the use of cultivation, nutrients, manure, pesticides and other inputs at lower rates on an as-needed basis.

The public expects agriculture to have a minimal negative effect on the ecosystem. It requires reassurance that current practices are sustainable, and that the environment is not being harmed. This need for reassurance is complicated by the fact that existing sustainable relationships within agriculture are often not readily apparent.

Pressures to conserve wildlife habitat will increase, as will as efforts to sustain, and in some cases, restore lost biodiversity. This will include an increasing reliance on aquatic-use guidelines as the standard for environmental water quality, due in part to the sensitive nature of aquatic life, and a public distrust of the higher threshold levels of drinking water guidelines (Harker et al. 1998).

Ideally, agriculture must be seen as conserving, restoring and even enhancing natural ecosystems, while reducing dependence on large-scale monoculture practices (Wilhite and Smith 1995). This suggests producers should:

- reduce nutrient, pesticide and situation losses from agricultural lands in order to meet aquatic standards
- apply voluntary restraint to meet socially accepted environmental objectives, and to reduce the likelihood of the application of outside, and sometimes arbitrary, policies and regulations.

Abundant Safe Water, Air, and Food

Having plenty of safe water, air and food for human consumption is a chief public concern. Water supplies must be sufficient to meet domestic, industrial and recreational requirements. Water and air must be clean and free of objectionable colour, odour and taste. Yet, agricultural practices are often perceived as adversely affecting our supplies of water, air and food (AAFC 1995a).

The public expects food production to be efficient, socially responsible and adequate to feed a hungry world. At the same time, producers must be economically viable and protect themselves against the risk of low yields and crop losses. Some public concerns represent market opportunities. Consumers concerned with animal rights may wish to purchase products which have been raised in a free range environment. This will provide new opportunities for some farmers to fill niche markets.

Land management practices to address supply concerns might utilize an ethical approach that would:

- reduce inputs while contributing to enhanced water conservation
- use cleaner agricultural practices which could include BMPs that focus on reduced application and loss of farm chemicals
- consider emerging issues such as bio-ethical and animal rights concerns, the use of growth hormones, and GMOs.

On the other hand, the drive to maximize food supply will create incentives to bring more land under cultivation and into more intensive production. Split applications of fertilizer, as well as the over-application of fertilizer, pesticides and other inputs, could be used to assure that high production levels are achieved.

Agricultural practices are often seen as affecting food safety. Many consumers believe that organically grown food is natural and therefore better for you, that perfect food ought to be without blemishes or insect damage, and that food should be available at a low cost.

Concerns about the safe use of agricultural chemicals and biotechnology are involved as well. Water, air and food are expected to be free of pesticides, bacteria, excessive nutrients, heavy metals, growth hormones and dust. Organic food sales may grow if more problems are linked to agricultural chemicals. They should retain their own niche market regardless of these concerns. Increasing numbers of farmers will change their production practices to meet societal expectations of producing safe food. Others will adjust farming practices in an attempt to lower chemical inputs while maximizing overall profit.

Natural Variability

Natural variability in the ecosystem is an obvious issue related to the potential for land management change. This includes drivers such as severe weather conditions, climate change and incidence of pests and disease.

Agriculture must be prepared to address extremes in weather. Drought may be isolated or wide-spread. Flooding occurs periodically in susceptible areas. Risk from frost is an increasing hazard as diversification moves specialty crops further into the fringes of growing season extremes. Failure to compensate for such extremes can put sustainable agriculture and soil and water resources at risk.

Farmers may adjust cultivation practices to hedge against extremes in weather conditions. For example, a farmer might change a cropping and cultivation strategy to capitalize on a short-term market for replacement crops created by adverse weather conditions. Some producers will adopt soil conservation practices. Others will maintain a regime like crop/ fallow because it allows them to cautiously hedge against the possibility of drought and crop loss.

There has been increasing movement away from a *seed-and-pray* attitude, to one of longer-range field planning as reflected in:

- flex cropping according to spring subsoil moisture conditions versus pre-set decisions as a basis for crops planted

The agriculture and agri-food sector in Western Canada is poised for significant growth which will be influenced by a variety of factors. Global population is expected to be 6 billion by 2000, and 8.1 billion by 2025. Population growth in Canada will increase modestly at 0.9% annually, while world growth will be at 1.5% annually, suggesting that much of the demand for Western Canadian products will grow through exports. Economic growth in Asia is forecasted at between 6-12% annually over the long-term. The growth rate, coupled with a huge population base, opens up food and fibre opportunities in this region.

Assuring safety in water, air and food production may well require the adoption of land management practices that reduce or restrict inputs through methods such as:

- ***integrated pest management (IPM) – relying more heavily on techniques that reduce pesticide requirements***
- ***manure application – e.g. reducing seasonal application on frozen soils, in keeping with legislation and guidelines***
- ***cattle access – restricting direct access to water, through fencing away from ponds and streams, or limiting time and location of access by grazing animals***
- ***growth hormone and GMO use – may be voluntarily restricted.***

- increased efforts to maintain adequate crop cover to hedge against wind and water erosion
- choosing cropping strategies that avoid extremes in seeding and harvest dates
- using larger equipment to shorten required seeding and harvest windows.

Addressing specific and generalized threats from pests and disease can dramatically affect cropping ability. Increased risk of crop failure occurs in conjunction with certain crop and pest relationships such as fusarium wilt in wheat. Some farmers will alter overall land management to reduce the likelihood that their lands are a source of pests and disease. They may use increased tillage and crop rotation strategies to address problems, while at the same time reducing the total cost of agro-chemical use.

Farmers may adopt voluntary quarantines and cropping rotations to combat encroaching disease and weed problems. In other cases, non-native invader plant and animal species may warrant a chemical approach. Support will be given to research and development into pest resistant crops, including, to some extent, those relying on GMOs.

Agriculture must be prepared to address extremes in weather such as drought, flooding, and the risk of frost.

Community Level Issues

Community level issues that can influence on-farm management include demographic change, competing land use, rural infrastructure, and requirements for transportation and off-farm employment (Table 5.3).

Demographic Change

Drivers of demographic change include incidence of fewer farmers, older farmers, an increasingly educated labor pool and fewer small communities.

Census data points to a continuous decline in Prairie farm population. As farm sizes increase, there will be fewer farmers living on the land. The age of Prairie farmers is also on the rise, with the number of younger farmers declining (MacArthur 1998). Part of this increase may be due to the general aging of the population.

Between 1991 and 1996, younger farmers (under 35 years of age) decreased by 22% across the Prairies, while the number of farmers over the age of 35 continued to rise. Meanwhile, the number of farmers older than 54 increased by 6% in Alberta, but decreased by 6.7% and 8.6% in Saskatchewan and Manitoba.

The distribution of farm size is similar between age groups (Statistics Canada 1997), yet there may be little or no incentive for older farmers to move toward the larger land base that might be required for future farming. In fact, there may be a number of reasons for older farmers to avoid this type of expansion.

An increasingly educated labor pool, which is required for high-tech agricultural machinery, will demand higher salaries and better working conditions. Farming practices will have to adapt to these greater labor costs by taking steps that include:

- adopting high-tech trends (e.g. precision farming) particularly as the application of such technologies becomes more economically viable
- increasing farming intensity to help make such technology more affordable
- targeting inputs to control cost efficiencies.

Due to economic and social factors, it will continue to be difficult for small Prairie communities to survive. The most vulnerable will be those without local industry, and perhaps those affected by rail abandonment. Small communities that survive will have to find a niche in local industry or tourism. Other stable or growing *key communities* (Stabler 1992) will become stronger in the future. An example of this is the Winkler-Morden area of Manitoba, where the rural population continues to increase (Statistics Canada 1997) in response to local vision and cultural factors that encourage younger people to remain in the community.

If trading centre consolidation continues as predicted (Stabler 1992), then travelling distances between some farms and rural service centers will increase, resulting in higher transportation and shipping costs. Use of larger vehicles may be necessary to create efficiencies, requiring a greater investment in equip-

The climate is changing, but it is difficult to sort out anthropogenic from natural causes. International commitments for reducing greenhouse gases have been agreed to under the Kyoto Accords. In Canada, agriculture contributes about 10% of the greenhouse gases that may be affecting climate change (Jacques et al. 1997). The agricultural industry must be ready to adapt to climate changes by adjusting management strategies to reduce greenhouse gas emissions and possibly capturing benefits by sequestering carbon. As such, farmers may adjust tillage practices to capitalize on a potential market in carbon credits. But changing tillage techniques can be costly, and farmers may be hesitant to lock themselves into a cropping system based on the long-term storage of carbon, or on land and fertilizer practices to reduce greenhouse gas emissions if there is no clear economic benefit for them to do so.

ment and road infrastructure. Other effects may include a move to higher return specialized crops or livestock, and a decreased reliance on high-cost inputs to counter the increased cost of transporting commodities to service centers.

Competing Land Use

As a community level issue, competing land use is driven by factors such as rural residential development and local zoning requirements. Rural population will continue to grow in areas where the farming population is slowly replaced by non-farm residents. This is especially true of urban fringe areas and is mainly due to rural residential development and growth in the rural value-added industry, as well as recreational and tourism activities.

Land prices will continue to rise in areas affected by rural residential development and competing land uses. This, in turn, may lead to greater subdivision of land in affected areas, adding to:

- higher farm land prices, making it difficult to sustain inter-generational transfer of farms in the urban fringe area
- consumer participation in crop production through increased involvement in harvest and processing activities (e.g. strawberry picking)
- conflicting issues where non-farming interests may require livestock operations to relocate further away from residential and urban fringe areas
- increased fragmentation of wildlife habitat as parcels of land are subdivided.

Rural Infrastructure

Improvements to existing rural infrastructure and additional developments are needed to support the changing agricultural industry. Within the next ten years, additional infrastructure must be in place to ensure that the agricultural sector is not hindered by a lack of water, roads and other services. A key obstacle is the on-going lack of sufficient funding in rural areas to implement and maintain infrastructure requirements.

Local zoning requirements are used to regulate and restrict the location and use of buildings and land. A common land use restriction relates to the infringement of intensive livestock operations (ILOs) on nearby residential properties. Concerns are often raised by the spreading of manure on land near residential developments, or are related to soil and water quality implications from runoff and leaching.

Effective public consultation is crucial to ensuring that local concerns are addressed. Acceptable modifications to management practices can usually be found through such a process. Where agricultural management may be restricted by zoning requirements, limitations might be offset to some extent by:

- ***securing an increasingly dispersed land base to compensate for nutrient build-up and leaching hazard on manured lands***
- ***using composting, timely application, etc., where farming odours infringe on residential development, or runoff and bacterial contamination pose surface water hazards.***

Drivers of rural infrastructure include the need for improved communication systems and changes in the value-added industry. Diversification of farm production will rely on enhanced communications systems to help producers make timely decisions, apply best management practices and facilitate the sharing of experience. This includes having access to timely information such as weather and pest forecasting.

As Western Canada's largest manufacturing industry, food processing is likely to continue to increase to the extent that supporting infrastructure permits (Canada West Foundation 1997). The net effect will be reduced shipping of unprocessed raw materials and a move towards the CAMC value-added processing targets. Expansion and improvements to existing infrastructure need to be made in three key areas: production capabilities, processing facilities and post processing capabilities (including waste handling).

Water, waste-water, natural gas, and transportation infrastructure are key constraints on value-added processing (Kettler 1998). Historically, the federal government has made significant commitments to infrastructure development and there are expectations at the local level that senior governments will continue to do so. Decisions on where this development takes place will determine:

- the location on the landscape where certain crops and livestock will be produced (e.g. given irrigation supply, labor pools, high-voltage power, natural gas pipelines, etc.)
- useful by-products from local food processing operations that might be applied to the land as fertilizer and soil amendments.

Improvements to existing rural infrastructure and additional developments are needed to support the changing agricultural industry.

Transportation Change, Off-farm Employment

Changes in transportation infrastructure and policy, and opportunities for off-farm employment will continue to affect land management strategies. With the loss of the freight rate subsidy, farm costs for moving crops to export markets have increased. Longer transportation distances are a reality, as shipping point consolidation results in a system of inland terminals. This, along with removal of railroad lines, is causing increased road traffic and maintenance. There is, however, a possibility that future impacts on the transportation infrastructure will be less severe, given an anticipated increase in the application of low-pressure tire technology (Stabler 1999). Municipal governments are affected, as they are responsible for the maintenance of a significant amount of rural roads. They, in turn, may increase land taxes to compensate for higher maintenance costs. Farmers will tend to offset higher transportation costs and taxes by:

- diversifying into livestock and specialized crops with higher returns
- feeding grain locally rather than shipping at low or negative returns
- investing in larger trucking equipment or hiring semi-trailer units to ship grain or other farm products.

Opportunities for off-farm employment are critical considerations for most farmers. According to Statistics Canada (1997), farmers derive about 29% of total income from on-farm sources, with 50% of income coming from off-farm employment. The remainder is derived from interest, dividends, transfers, child tax credits, etc. Under these conditions, the long-term survival of farms depends heavily upon access to off-farm income. But off-farm employment opportunities, which were already on the decline before termination of the transportation subsidies, have been further reduced by the loss of the subsidies (Olfert and Stabler 1999). This is particularly relevant in rural communities of about 1,000 people, where up to 50% of the labor force may be local farmers.

The stability of off-farm employment revenue allows many farmers to structure farming operations around this income source, and to specialize in low-intensity cereal grain production, or cater to local market gardening requirements. The more a farm depends upon off-farm employment, the less diversified (in both crops and livestock) the operation is apt to be. However, access to either selling or working in small urban markets continues to decline and the magnitude of compensatory future adjustments to farming operations is expected to be substantial (Olfert and Stabler 1999).

ON-FARM ISSUES

Many issues and drivers are external to the farm gate, yet affect on-farm management. There are a number of issues over which the farmer has direct control, or which are particularly evident at the on-farm level. For example, the price of chemical fertilizer is determined by factors external to the farm gate. However, the farmer has control over the amount of fertilizer used, the method of application and the frequency of fertilizer use.

Issues within the on-farm level can be sub-divided into: the ability to take risk, considerations related to managing inputs and outputs, land tenure and adapting to technological advances (Table 5.4).

Ability to Take Risk

A farmer's land management decisions are unlikely to be determined solely by scientific or economic theory. Farmer values, traditions, the influence of peers and net returns all play a role in determining how each parcel of land is managed.

In many cases, farmers continue with a particular practice simply because they are familiar with it, and know that it will produce income at relatively low risk. They often gain confidence in a new technique from observing a neighbor's success, then applying the technique to their own operations. Statements such as: "My father farmed this way for years, why should I change" or "I can't afford to risk this crop on something new" are often expressed. These perspectives exemplify two key areas

Farmer values, traditions, the influence of peers and net returns all play a role in determining how each parcel of land is managed.


Photo by Dave Reede

that might be viewed as negative drivers to land use change. Limited experience with crop-soil-weather variability, as well as limited availability of capital are likely to promote the status quo.

Ability to learn from first-hand experience is restricted by the relatively short time during which any operator actually farms the land. Farmers might control a land parcel for only 30 to 40 years. Within this period, specific combinations of crop-soil-weather conditions may only repeat themselves a few times. Hence, the opportunity to use experiences gained under a particular set of circumstances might not arise again for several years, limiting a farmer's confidence in adopting new practices as a standard management tool. As a result, many farmers rely upon the wisdom of past generations in making management decisions.

As well, gaining solid experience about the effectiveness of new management practices (e.g. a particular seeding decision) requires time for convincing evidence to accumulate. A decision made in the spring of one year may not have full repercussions for nearly 14 months, when the crop is finally sold. During that time, a farmer must make additional management decisions without knowing the outcome of the previous year's choices. As a result, an operator may not be in a position to effectively consider the merits of a land use change for at least two years.

Everyday agronomic considerations have a major effect on land use decisions. These may be of a short-term nature, such as what, where and how to seed, tillage choice and what herbicide to use. Such decisions are often restricted by the sequence within a cropping rotation, past herbicide choices and current soil moisture conditions. These decisions may be overshadowed by concerns for the cost of inputs and the immediate potential to market the crop at a profit. Given limited experience with variability, and in view of current input and commodity prices, many farmers may be unwilling to risk a significant shift in management.

The availability of capital has a direct impact on land management. It determines what type of farming system is used and usually affects the type of machinery and infrastructure held by the farmer.

Lack of capital often forces a farmer to use the resources at hand such as older equipment and less efficient farming techniques which could result in lower yield and lower income. Ready capital might allow a farmer to increase machinery size and thereby manage a larger land base. It may allow new technology into the farming system such as direct seeding, conservation tillage and variable rate fertilization and seeding. On the other hand, financial risk can be reduced through using less capital, as cash flow may not always be sufficient to repay high debt loads.

In some situations, existing farming practices are only tolerated because lack of capital does not allow change. Extending crop rotations or diversifying farm production requires the capital to access the necessary land, machinery, and other inputs.

Managing Inputs & Outputs

The effective management of on-farm inputs is an obvious, ongoing priority. Less clear has been the requirement to effectively manage non-production outputs such as runoff and erosion, or the pesticides and nutrients that can be a part of runoff and leaching waters. In the past, the management of non-production output has often resulted from other management decisions. For example, direct seeding may have been adopted because it is a more profitable seeding system, with benefits to soil conservation being the secondary consideration.

It is critical to balance inputs in order to produce output at a profit. However, not all inputs can be managed. The weather, which provides moisture and heat is a prime example. Nevertheless, how inputs are managed can have a significant impact on the land. Input costs must be balanced with anticipated returns, while taking into account the risk that a specific input may prove ineffective. Related drivers include the management of agro-chemicals, manure, tillage practices, cropping choices and water and energy use.

Concerns abound about the potential health risks of prolonged pesticide use, as well as the immediate effects of spray drift on adjacent crops and shelterbelts. Farmers are increasingly wary of a build-up of herbicide tolerance in certain weed species that, together with other management techniques, can lead to a shift in the weed spectrum. Cost is a significant concern.

Photo by Dave Reede

Effective management of on-farm inputs is a priority. How inputs are managed can have a significant impact on land and on the profitability of a farming operation.

A classic example of nitrogen management in Western Canada has been the use of summerfallow in crop rotations over the past 20 years. The decision the farmer is faced with is basically one of both nitrogen (N) and herbicide application vs. summerfallow (where moisture is not limiting). The practice of summerfallow can reduce the N requirement of the crop, due to native soil N being mineralized during the fallow period. As fossil fuel and associated N prices continue to increase, more farmers may opt to fallow, further depleting levels of baseline N in the soil.

Producers will seek to reduce weed control costs and chemical inputs, in conjunction with a better understanding of reasonable weed control thresholds. More emphasis will be placed on farm health and safety requirements, resulting in an increase in spraying regulations and a narrowing of the range of chemicals for specific uses. An increase in specialized crops will require specialized pest control.

There will be a greater emphasis on:

- integrated pest management to reduce overall chemical use and cost
- environmental record keeping including the use of pesticide audits
- improved application using low volume nozzles, shrouds and wicks to counter drift and cost concerns
- herbicide rotation to address herbicide resistance
- pesticide specificity for bio-engineered (herbicide specific) crops
- biological controls to cut down on overall pesticide use
- reduced pre-emergent herbicides through conservation tillage, diversified cropping options
- controlling new weed/pest sources on areas of non-cropped lands (ditches, riparian).

Fertilizers make up a large portion of the expense of many farming operations, with 72% of producers using commercial fertilizers. Yet many farmers question the value of soil test results, even though others routinely assess soil fertility through soil tests and other consultations (AAFC 1995b). The gross cost of chemical fertilizer influences the rate at which it will be applied. For each crop, land, climate and farmer combination, a particular cost exists for applying the product for maximum return. Such decisions might have a similar impact on land management, to that of changing crop rotation or reducing crop/residue output.

In the past, fertility management has often focussed on supplying enough nutrient in a single pass to supply season-long cropping needs. This can lead to excessive in-field nutrient supply, which may result in crop damage and/or leaching losses. To reduce financial risk, there will be increased interest in split nutrient applications (e.g. applying supplemental N to winter wheat in the spring, after moisture availability has been verified). There may be a movement towards the precision application of fertilizer for both economic and environmental benefits, although crop yield benefits from this practice are uncertain. This uncertainty is especially true where yield may be limited by moisture availability rather than fertilizer placement. However, increased costs of fuel and farm labour could limit this as a viable option for the majority of crops grown (i.e wheat).

Emphasis on efficiency of chemical fertilizer use will include:

- split applications where increased costs are practical
- precision farming advances that result in higher yields for the same fertilizer cost. (custom applicators and larger farms may adopt this first)
- build-up of organic matter and associated fertility (e.g. through expanded use of legumes)
- some increased fertilizer use particularly on specialty crops
- micro-nutrient management and nutrient balancing for speciality crops grown on highly variable soil.

As a driver of input/output issues, manure management once largely revolved around N content, with secondary issues being manure volume disposal and associated odours. Increasing numbers, size and concentration of ILOs have highlighted a number of management problems. These include runoff, saturation and leaching issues associated with phosphorus and nitrogen, and the growing need for better odour control near ILOs.

Custom manure applicators, however, do not routinely have the capability to apply manure on a soil test or nutrient basis. This is because commonly used equipment has no mechanism to effectively control flow rates (Haag, 1999).

Emphasis on proper handling of manure from a nutrient, environmental and waste management perspective will increasingly dictate on which lands manure can be applied, and the amounts that can be used. This is especially true in view of escalating concerns about contamination of soil and water quality. Future trends in manure management will feature:

- a greater role for perennial forages as a nutrient management sink
- the contribution of custom applications as a strong, practical option for routine disposal
- composting to decrease volume, resulting in less bulk to haul away
- the use of new, cost-effective technologies (e.g. constructed wetlands) for nutrient management
- a greater use of organic (manure) fertilizer, due to increased availability near expanding ILOs.

Interest in irrigation is expanding as farmers seek to grow more speciality crops, particularly in Alberta and Manitoba. Demand for local water supplies is further exacerbated by greater local processing requirements for higher value crops such as potatoes. Energy costs also continue to rise, despite falling commodity prices.

Custom manure applicators do not routinely have the capability to apply manure on a soil test or nutrient basis. This is because commonly used equipment has no mechanism to effectively control flow rates (Haag, 1999).

The market value of an ever-decreasing supply of water will continue to rise, costing more to access and use. Specialization into certain crops will demand high water volumes, emphasizing the need to maximize moisture use efficiency by:

- improving water capturing technologies such as stubble management, shelterbelts and snow fencing
- using high stubble and other techniques will be used to assure adequate groundwater supplies are recharged from snowmelt and other sources
- growing crops such as alfalfa that are more deep-rooted and have a higher nutrient-extracting ability
- improving irrigation efficiency as water and energy pricing increase application costs.

Farmers will seek lower energy input systems to decrease the cost of production. Alternatives will include moving to less energy-intensive organic farming, as well as increased adoption of energy efficient equipment and innovative products such as solar grain dryers and solar pumps.

Land Tenure

Relationships in land tenure are changing on the Prairies (Statistics Canada 1997). These changes include a shift in the ratio of farmland ownership versus rental operation, the type of rental agreements being used, and approaches to ownership management (e.g. sole proprietorship versus partnership arrangements), and Treaty Land Entitlements.

Since the 1960s, there has been a steady increase in the percentage of rented Prairie farmland (refer back to Figure 4.2). The 1966 Census of Agriculture showed that approximately 27% of Prairie farmland was leased or rented, while the 1996 census showed 39% rented.

The type of rental agreement has also changed over the years (Figure 5.1). Some 40 years ago (1956), cash rent, as opposed to crop-share, accounted for 15% of the rental cost to farm operators on the Prairies. By 1996, 54% of rental costs were attributed to cash rent.

There has also been a decrease in the percentage of land managed under sole proprietorship in the past 25 years (Figure 5.2). In 1971, almost 92% of the farms on the Prairies were managed by sole proprietors, while partnerships accounted for 6%. Other categories (family-owned corporations, and non-family corporations, miscellaneous management) accounted for the rest.

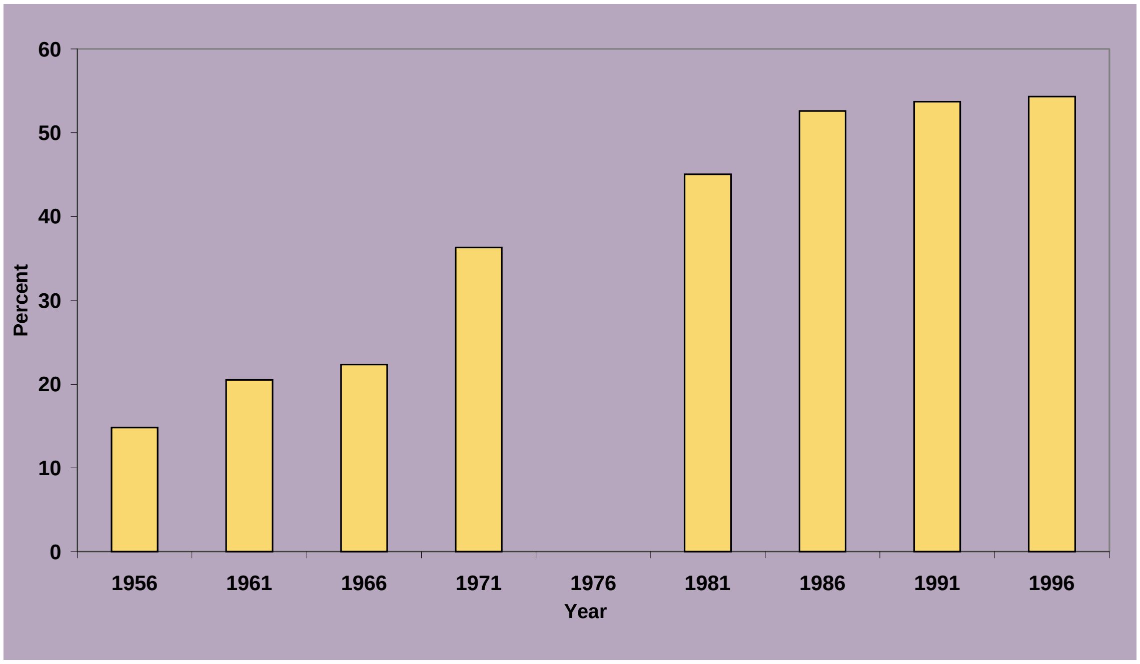
The 1996 census shows that only 65% of Prairie farms were sole proprietorships, while partnerships have risen to 25%, and family owned corporations to 7.5%. Group management approaches provide for a larger asset base and help to spread risk. Non-family corporations and other management categories account for less than 2% of holdings. There are no data available on how much total land is controlled by each management category.

The increase in rented land may not impact the stewardship of the land. However, if a renter is in a short-term lease and has no plans to renew, there will be little incentive to take proper care of the land.

Increasing numbers of cash rent landlords may not be living near their land. This is in contrast to landlords who still have crop-share agreements, with possibly more interest in land management decisions.

Current trends related to tenant farmers seem increasingly destined to detract from optimum soil management because

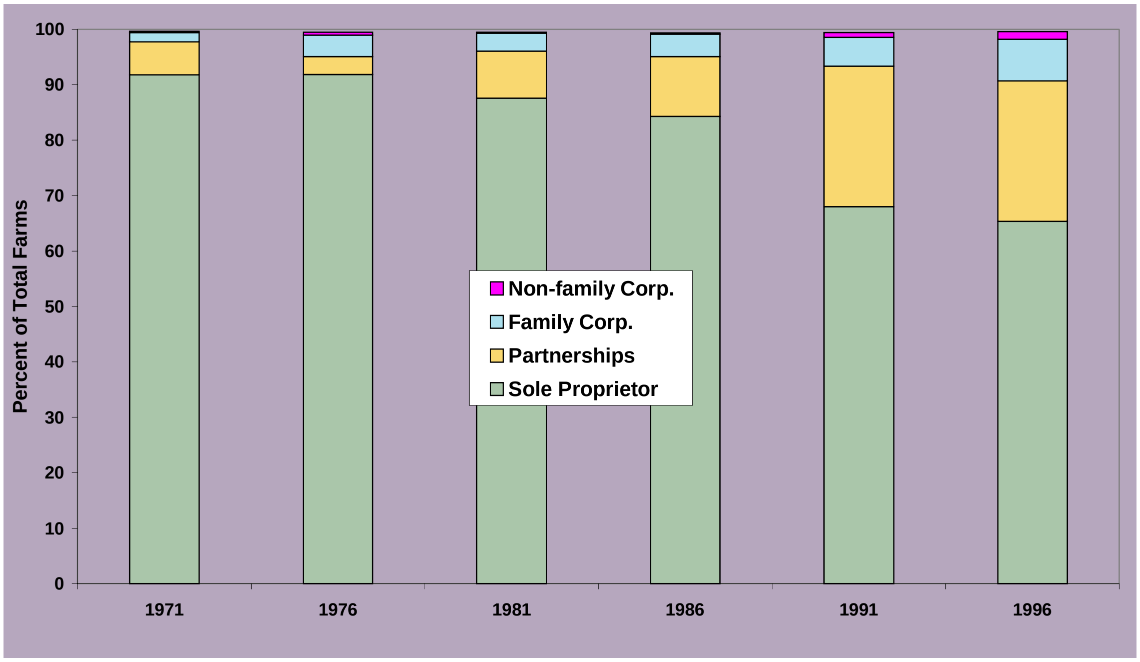
- a tenant farmer may opt to reduce inputs (e.g. fertilizer), due to low prices and tight margins, doing so first on rented land
- absentee landlords and the trend to cash rent may decrease incentives for good land management when the risk of farming rests largely with the operator
- traditionalist landlords may require tenants to keep a certain portion of lands in black fallow.



Source: Statistics Canada, Census of Agriculture

Note: data not available for 1976 Census

Figure 5.1 Cash rent as percent of total rent costs for Prairie farms (1956-1996).



Source: Statistics Canada, Census of Agriculture

Figure 5.2 Prairie farm management (1971-1996).

Technological advances
The repercussions of technological advances overlap greatly with many of the issues and effects previously mentioned. For example, the most significant change in technology in the past 60 years has been the increasing mechanization on the farm. Changes in biotechnology, the science of herbicides, advances in crop nutrient management and the introduction of precision farming will allow continued increases in production.

Coupling improved crop varieties with better equipment has allowed cropping on land previously considered marginal for agricultural production. When such lands are cultivated or altered to enhance production strategies, there may be a decrease in quantity or quality of natural vegetation and available wildlife habitat. This can result in decreases to biodiversity, reductions in water quality and increases in soil erosion.

Bio-engineering holds great promise as a means of increasing agricultural production (e.g. improved frost tolerance). Yet concerns regarding the use of bio-engineered crops reflect a wide-spread uncertainty as to the development and role of this expanding technology. Discomfort with the use of bio-engineered organisms revolves around the issue of transferring genes into unnatural hosts, and possible repercussions as to future weed or pest control strategies and food safety by the consuming public.

Questions about the suitability of biotechnology can have a significant effect on the market development of a crop, and influence the uptake of technology. Canadian producers are currently growing a few bio-engineered crops such as canola, and some contracts are being let to develop pharmaceuticals from genetically altered crops. There remain huge potential global markets for bio-engineered products in areas of the world where sufficiency of food supply is an issue and imports are essential for basic survival.

Changes in biotechnology could result in:

- various practices (rotations, pesticide use, nutrient application) being dictated by contract

Canada is utilizing Treaty Land Entitlement (TLE) with First Nations peoples as a way of allowing them to purchase new lands, in order to compensate for land shortfalls in settling previous treaties. Once purchased, it appears likely that many TLE lands will then be rented out. As well, current First Nation land tenure and assignment arrangements tend not to be long-term.

There may be little incentive for tenants to make improvements or investments to land where long-term tenure is not assured. Short-term approaches to land-use management will be favoured and may lead to possible degradation of land and water resources.

Marginal lands within TLE may not be contiguous, making livestock operations on them unlikely. Such lands require a high level of management to be successfully operated under cultivation.

Multinational corporations will increasingly gain control over on-farm inputs like seed and agricultural chemicals. This could result in a potential loss of flexibility for on-farm management decisions. Adoption of particular crops into farm rotations can require producers to use associated herbicide regimes to effectively control weeds in advance of subsequent crops (i.e. canola and wheat). On the other hand, biotechnology promises access to new product markets, increased cash flow and greater economic diversification.

- fewer pesticide options due to demands of biotech crops
- an increasing lobby from public or special interest groups against genetically engineered products
- product labeling requirements to differentiate transgenic products on a farm-by-farm, or a field-by-field basis.

Recent technologies are paving the way towards the precision application of seeds, nutrients and pesticides. These are aimed at assuring the optimum application of inputs, while improving profitability and reducing environmental impact. There are many unanswered agronomic questions related to precision farming. For instance, where will the precision application of fertilizer on a landscape pay the greatest dividend? The answer can change from year-to-year, depending on factors like growing season precipitation which may be more limiting to crop production than the precision application of inputs.

Precision farming technology is in the early stages of development and has yet to have widespread practical application. Its application is currently questionable for small grain operations due to the large capital cost involved and the skills needed to operate and understand the equipment. Nevertheless once applications are refined, precision farming may facilitate efficient application of farm chemicals, providing more uniform yields with overall higher production, improved land management and possibly greater net returns, especially for high-input, intensively managed crops.

As this technology becomes more user-friendly, and capital costs are reduced, uptake will improve. Initial clients are likely to be in high valued crops where a net income gain can be realized. Larger-scale field research will be fostered by the promise of increased production at reduced cost. This research will result in a better understanding of the effects of soil and climatic variability on crop yield from an on-farm, research and policy perspective.

CONCLUSIONS

The issues likely to affect changes in land management on the Prairies can be divided into four main levels of influence. These include public, environmental, community and on-farm considerations. Within these levels, individual issues will be affected by a specific set of drivers, the overall impact of which will almost certainly result in a change in land management practices.

Public level issues include policies and legislation and international agreements. Pressure will be placed on the soil and water resource base to meet CAMC-style export targets, while seeking to conserve natural biodiversity and wildlife habitat within farming systems. International trade will increase amidst an ever-tightening array of controls.

In seeking to maximize returns, some farmers will bring existing and new lands into more intensive production, whereas others will actually reduce inputs while expanding their land area. A few may reduce inputs to directly address environmental concerns. A widening range of crop markets will invariably subject some lands to radically different production techniques.

Environmental issues include those of public perception; the need for safe water, air and food; and the ability to cope with natural variability. There is an on-going need for agriculture to clarify its actions and become more accountable in the public mind, while sustaining sensitive lands and reducing negative effects on the environment. The public expects an ample supply of safe water, air and food, produced and protected in a socially responsible manner. This must be balanced against the economic necessity that farmers face in continually hedging their activities against the hazard of significant crop loss. Some farmers will increasingly employ conservation tillage practices, while others choose to dissipate risk by maintaining or increasing crop/fallow practices.

Agriculture must be increasingly proactive to avoid restrictive, perhaps unwarranted regulation. Reduced tillage and chemical inputs on some lands will coincide with increased efforts to maintain and enhance wildlife habitat. At the same time, competing market forces to feed a hungry world may result in ever-intensive production techniques on new lands. Some farmers will incorporate a longer-term view of crop planning, involving a wider use of reduced tillage, cover crops and straw mulching for soil stabilization and nutrient recycling. Still other farmers may be reluctant to lock themselves into any plan that is dependent on fixed, long-term practices.

Community level issues are those relating to demographic change, competing land use, rural infrastructure, transportation change and off-farm employment. There is little incentive for aging Prairie farmers to expand their land base. An increasingly educated rural labor pool will demand higher salaries. Rural communities will continue to decrease in size and number. Land prices will rise adjacent to urban areas, with urban/rural conflicts necessitating increased efforts at public resolution of concerns. Successful farm diversification will rely on availability of timely information for field management and marketing considerations. Rail line abandonment will result in the deterioration of existing roads, at least in the short term, with a compensating need by rural municipalities to increase tax revenues. Off-farm employment will continue to be the major source of farm revenue for many farmers.

Older farmers will be reluctant to invest in significant land management changes. They may compensate for their decisions by cutting back on inputs. Specialized farming techniques will help to offset escalating land prices. ILO operators will require access to a greater land base to facilitate manure management and adjust application techniques to comply with odour and runoff concerns. Farmers might compensate for higher taxes and transportation costs by producing higher value crops, feeding locally-produced grains to livestock, supporting other value-added ventures and contracting or purchasing larger trucking capacity. Access to the local job market will govern the degree to which farming operations are specialized.

On-farm issues involve considerations related to the ability to take risk, manage inputs and outputs, land tenure and technological advances. The inability to take risk tends to favour the status quo rather than promoting a significant change in land-use management. On the other hand, producers who can, will seek to reduce input costs as they acquire a better understanding of weed control thresholds, and place more emphasis on health and safety and environmental factors. Farmers will try to balance the cost-benefit of N derived from chemical fertilizer versus that from crop/fallow practices and a fallow year without a crop. ILO concentrations are bound to highlight issues of runoff and odour control.

Farmland rental is on the increase, while sole proprietorship continues to decline. Landlords are increasingly less connected to the land. Where treaty lands are rented out, agreements will likely be on a short-term basis. Short-term cash rent agreements will tend to discourage a stewardship approach to land management. Renters may tend to withhold inputs and degrade the soil to a greater extent than if they owned the land.


Photo by Dave Reede

Many farmers will continue to rely on the collective wisdom of past generations, and most farmers will tend to be conservative in their overall approach to change. Restricted cash flow, high input costs and low commodity prices will mean some farmers are unwilling (or unable) to risk significant change. Where change occurs, there will be greater emphasis on improved pesticide management, split nutrient applications and proper manure handling to reduce costs, increase efficiency and address environmental concerns. Efficiencies will continue to increase in water conservation, water application and energy use.

Biotechnology may cause multinational corporations to gain greater influence or control over on-farm inputs, resulting in a loss of flexibility in on-farm management decisions.

Farmer up-take of this technology may be slowed due to public concern over transgenic products and the need to market such crops separately. Precision farming applications will increase as associated costs decrease and agronomic relationships are clarified. In the short term, precision farming technology will largely be confined to large scale operations and custom applicators. ■

The agricultural region of Western Canada is a landscape full of opportunities. Government and producers need to work together to make Prairie landscapes more productive today, and into the future.

Table 5.1 **Potential Effect of Issue-Drivers (selected examples) on Land Management Practices (Influence of drivers on market/social/cost considerations and anticipated land-use change).**

PUBLIC LEVEL ISSUES	**Issue-Drivers** → { **Market Condition** (MC) **Social/Emotional** (S/E) **Cost of Production** (CP) } → **Land Management Change** → **Acceptable Net Return** (e.g., MC = organic premium, price paid; S/E = social pressure, altruistic concepts; CP = inputs, lost revenue)	
***Issues** & drivers* (Pressure for change)	***Market Condition, Social/Emotional, Cost of Production*** *(Reasons why change is likely to occur)*	***POSSIBLE LAND MANAGEMENT CHANGE*** (Anticipated practices and probable effects)
Policies & legislation • Export targets	• MC - anticipated demand for more raw products	• Pressure to bring new land into production, conversion of pastures and wetlands, increased farming intensity, use of more pesticides and chemical fertilizer, and more manure to spread.
• Marketing boards	• MC - mask market signals CP - cost changes as NAFTA removes protective tariffs	• Restricted markets can encourage inefficient production of commodities, due to status quo production methods.
• Sustainability and biodiversity	• S/E - public pressure to change production practices CP - regulations may force land out of production	• A small amount of land may be legislatively removed from production. Improve or maintain wildlife habitat; compensate by increasing intensity on other lands, resulting in more pesticides and fertilizer use.
International Agreements • Kyoto Protocol	• MC - tarriffs against countries not meeting Kyoto standards S/E - desire to be more environmentally friendly. CP - increases, as carbon costs of inputs and costs of new technology are passed on to producers, sale of carbon credits may offset these costs	• High carbon costs of inputs could change intensity of production, including chemical use, to decrease in the short term. More land brought into production as margins decrease on current hectares (low yields). As technology advances, production will increase.
• NAFTA, WTO	• MC - new markets, pressure on internal markets from US CP - decrease in some costs	• It is uncertain what will happen to production intensity. It may increase as a reaction to declining margins, or there may be pressure to compensate by bringing more pastures, grassland and wetlands into production.

Note: The above table / flow chart gives examples of how certain **Issue-Drivers** might influence one of three main decision factors: **Market Condition**, **Social/Emotional** considerations, and **Cost of Production** which in turn may result in **Land Management Change** in order to assure **Acceptable Net Return** (not shown in the table). Some view the **Social/Emotional** factor as a sub-set of **Cost of Production**. Nevertheless, the category attempts to identify social and altruistic reasons for changing land management. The column **Possible Land Management Change**, briefly describes a range of anticipated changes.

Table 5.2 **Potential Effect of Issue-Drivers (selected examples) on Land Management Practices (Influence of drivers on market/social/cost considerations and anticipated land-use change).**

ENVIRONMENTAL ISSUES	**Issue-Drivers** → { **Market Condition** (MC) **Social/Emotional** (S/E) **Cost of Production** (CP) } → **Land Management Change** → **Acceptable Net Return** (e.g., MC = organic premium, price paid; S/E = social pressure, altruistic concepts; CP = inputs, lost revenue)	
***Issues** & drivers* (Pressure for change)	***Market Condition, Social/Emotional, Cost of Production*** *(Reasons why change is likely to occur)*	***POSSIBLE LAND MANAGEMENT CHANGE*** (Anticipated practices and probable effects)
Public perception		
• Land stewardship	• S/E - wants to be perceived as taking good care of the land CP - costs increase if taxes imposed for erosion control	• Increase forage hectares, reduce tillage & fallow, lower chem inputs. Reduced erosion potential. Lower production.
• Ecosystem impact	• MC - increasing market for green products S/E - belief in desirability of habitat/biodiversity CP - access environmental incentives, avoid green taxes	• Reduce agri-chemical use and losses; preserve, restore/enhance natural ecosystems; balanced nutrient use, seek voluntary compliance versus control.
Human use water/air/food		
• Supply	• MC - price/demand for specific crops S/E - conviction of the need to feed a hungry world CP - hedge against the risk of low yields and crop loss	• Adjust management practices to suit crops in demand; maximize producing area; tendency to over apply fertilizer and pesticides to maximize production.
• Safety	• MC - perceived need for safe food and water S/E - fulfill societal expectation of safe food, water, & air CP - lower chemical input costs; integrated pest management (IPM)/fencing costs	• Lower chemical use and losses; apply IPM strategies; restrict cattle/water access, manure management; conform to regulations. Better chemical balance. Extra management.
Natural variability		
• Severe weather	• MC - market for replacement crops S/E - fear of being perceived as a poor manager CP - hedge against possibility of lost crops	• Extended rotations, flex-cropping, less fallow, less drainage, more trash cover. More stable soil conditions. Less flexibility in cropping choices.
• Climate change	• MC - possible market for carbon credits S/E - perception contributing to warming CP - reduce tillage costs	• Reduce tillage and store carbon where practical.

Note: The above table / flow chart gives examples of how certain **Issue-Drivers** might influence one of three main decision factors: **Market Condition**, **Social/Emotional** considerations, and **Cost of Production** which in turn may result in **Land Management Change** in order to assure **Acceptable Net Return** (not shown in the table). Some view the **Social/Emotional** factor as a sub-set of **Cost of Production**. Nevertheless, the category attempts to identify social and altruistic reasons for changing land management. The column **Possible Land Management Change**, briefly describes a range of anticipated changes.

Table 5.3 **Potential Effect of Issue-Drivers (selected examples) on Land Management Practices (Influence of drivers on market/social/cost considerations and anticipated land-use change).**

COMMUNITY LEVEL ISSUES	**Issue-Drivers** → { **Market Condition** (MC) **Social/Emotional** (S/E) **Cost of Production** (CP) } → **Land Management Change** → **Acceptable Net Return** (e.g., MC = organic premium, price paid; S/E = social pressure, altruistic concepts; CP = inputs, lost revenue)	
***Issues** & drivers* (Pressure for change)	***Market Condition, Social/Emotional, Cost of Production*** *(Reasons why change is likely to occur)*	***POSSIBLE LAND MANAGEMENT CHANGE*** (Anticipated practices and probable effects)
Demographic change		
• Fewer and older farmers	• MC - little attempt by older farmers to seek new markets CP - larger farms, bigger equipment, smaller margins	• Increased use of large machinery; fewer tillage passes, less intimate knowledge of the land; cumulative long-term effect due to the continued clearing of farmsteads and marginal lands.
• Fewer small communities	• MC - fewer markets, niche markets required S/E - isolation, loss of way of life CP - longer hauls, increased shipping costs	• Move to more specialized products and industry. Use of inputs may decrease, as overall costs rise with distance to servicing and costs of transportation.
Competing land use		
• Rural residential	• MC - opportunities for niche markets to be developed CP - increasing production costs for niche crops, and pressures on subdivision and land costs	• Greater specialization of cropping to increase net returns; implement odour control requirements; respond to recreational, habitat pressures. Move livestock operations.
Rural infrastructure		
• Communication systems	• MC - better access to weather, market, disease/pest information CP - timely information reduces pest control costs	• Greater flexibility in cropping, greater targeting as part of crop management (e.g. specific chemical inputs).
• Value-added industry	• MC - expanded opportunities to sell value-added product CP - lower transportation costs to processing markets	• Expanding hog and cattle industry, intensification of land use, manure and waste management issues.
• Transportation change	• MC - greater distance to market CP - increased road taxes; increased costs of shipping	• Increased diversification includes specialized crops with higher returns, and grain fed locally (e.g., hog and livestock production) to circumvent raw-product shipping costs.

Note: The above table / flow chart gives examples of how certain **Issue-Drivers** might influence one of three main decision factors: **Market Condition**, **Social/Emotional** considerations, and **Cost of Production** which in turn may result in **Land Management Change** in order to assure **Acceptable Net Return** (not shown in the table). Some view the **Social/Emotional** factor as a sub-set of **Cost of Production**. Nevertheless, the category attempts to identify social and altruistic reasons for changing land management. The column **Possible Land Management Change**, briefly describes a range of anticipated changes.

Table 5.4 **Potential Effect of Issue-Drivers (selected examples) on Land Management Practices**
(Influence of drivers on market/social/cost considerations and anticipated land-use change).

ON-FARM ISSUES

Issue-Drivers → { **Market Condition** (MC), **Social/Emotional** (S/E), **Cost of Production** (CP) } → **Land Management Change** → **Acceptable Net Return**

(e.g., MC = organic premium, price paid; S/E = social pressure, altruistic concepts; CP = inputs, lost revenue)

Issues *& drivers* (Pressure for change)	***Market Condition, Social/Emotional, Cost of Production*** *(Reasons why change is likely to occur)*	***POSSIBLE LAND MANAGEMENT CHANGE*** (Anticipated practices and probable effects)
Ability to Take Risk • Availability of capital	• MC - Intensive livestock operations involving multiple owners, outside money S/E - pressure to conform, adopt new ways CP - increasing interest rates, expense of technology	• Decisions from outside ILO owners, not operators. Larger equipment, larger farms, farming marginal lands. Risk of erosion, environmental pressures.
Managing inputs/outputs • Pesticides Nutrients/manure Water & energy	• MC - demand for niche markets, specialty products S/E - concerns over spray drift, health risks, water pollution, odour CP - concerns with over application, cost versus benefit, herbicide resistance, cost of fossil fuels and nitrogen	• Crop diversification, increased use of specialized chemicals, greater intensification, learning curve for new crops; move to organic farming, custom application, increased IPM; increased use of legumes in rotations, custom application, precision applications, irrigation.
Land Tenure • Ownership versus rental	• MC - increased land prices leads to more rented land S/E - need to be good land stewards CP - minimize investment, or maximize return on investment, due to increasing rental cost	• Tendency to less sustainable land use versus the desire to adopt best management practices; cropping practices which provide highest yield for lowest cost. Decreased quality of soil/water resources.
Technological Advances • Biotechnology	• MC - demand for uniformity of quality and supply CP - technology may lower or increase cost of production simplified pest control	• Intensive land use practices, alternative agronomic practices. Greater risk of resource depletion. More control by multinationals means less control for farmers.
• Precision farming	• CP - reduce cost of over application of chemicals	• Increasing precision management of crop varieties. Higher yield, perhaps higher profit.

Note: The above table / flow chart gives examples of how certain **Issue-Drivers** might influence one of three main decision factors: **Market Condition**, **Social/Emotional** considerations, and **Cost of Production** which in turn may result in **Land Management Change** in order to assure **Acceptable Net Return** (not shown in the table). Some view the **Social/Emotional** factor as a sub-set of **Cost of Production**. Nevertheless, the category attempts to identify social and altruistic reasons for changing land management. The column **Possible Land Management Change**, briefly describes a range of anticipated changes.

Chapter 6: Preparing for Growth

Agricultural Growth Issues

The Prairie agricultural industry must find a balance between the demands of economic viability and growth and managing the land to ensure long-term resource sustainability. However, it is economic considerations which will drive demand for, and production of, primary and processed goods. World trade in agriculture and food commodities is expected to rise dramatically over the next five to ten years in response to population growth and demand for food and non-food agricultural products. The Canadian Agri-food Marketing Council has challenged primary producers, processors and governments to significantly increase Canadian agriculture and agri-food exports to 4% of the world market. Managing the socioeconomic and environmental impacts associated with increased agricultural production will be critical to the long-term expansion of Canada's agricultural industry.

Practices such as conservation tillage, precision farming, integrated pest management, and range and riparian management systems are playing an important role in reducing environmental impacts resulting from agricultural intensification (Day 1996).

Expansion of Canada's Prairie agricultural industry is required to feed a growing world population and to capture a larger portion of global agricultural trade. It has been suggested that a significant portion of Prairie agricultural land has not reached its full productive capacity (Morrison and Kraft 1994). Increased agricultural production will require more intensive land use and improved productivity on existing crop and forage lands. However, there is a risk that more marginal lands will be brought into cultivated agricultural production. Improving landowner decision-making to match land use with land capability, as well as increasing efficiency and productivity, will be crucial to ensuring the ongoing sustainability of Prairie agriculture.

REVIEW OF AGRICULTURAL IMPACTS ON THE RESOURCE BASE

This document has highlighted the state of current Prairie land resources and emphasized the importance of proper land management in reducing the risks of environmental degradation associated with some agricultural practices. Four key resource groups have been identified:

- cultivated land
- rangeland/forage
- water quality
- riparian areas.

For each resource group, a number of potentially negative impacts and risks have been discussed, all of which could increase under conditions of agricultural expansion and growth. This report has also highlighted the many benefits of conservation farming. Both positive and negative impacts are critical in assessing agricultural growth potential.

For example, while intensification can increase production on a fixed land base, it also creates land management challenges. Intensifying livestock production on marginal lands and crop production on non-marginal lands may increase the risks for erosion, and soil and water quality degradation, as well as negatively impact wildlife habitat. Practices such as conservation tillage, precision farming, integrated pest management, and range and riparian management systems are playing an important role in reducing environmental impacts resulting from agricultural intensification (Day 1996). Continued promotion and implementation of conservation practices will be essential to ensure that long-term export capabilities in both the grain and livestock sectors are not hindered by poor land management.

Cultivated Land

The effects of erosion on crop yields and soil productivity can be significant. Erosion removes the soil fractions that contribute to nutrient availability and a good physical environment for plant growth. Erosion depletes the soil's capacity to grow crops, increases crop yield variability within fields and causes off-farm environmental impacts such as reduced water and air quality.

Conservation tillage minimizes these impacts and can improve soil productivity. Universal adoption of reduced tillage and low disturbance seeding systems would not eliminate soil erosion, but would significantly reduce its risk. Soils will still be exposed to erosion risk after low residue crops, drought, disease, fire, or excessive straw harvesting. Permanent soil conservation practices are required to supplement crop residue management systems. Further work is needed to identify areas which are unsuitable for annual crop production. Producers in those areas should be encouraged to convert to, or maintain, appropriate land uses such as perennial forages and cattle production.

The effects of intensification on soil organic matter and soil salinity are also of concern. Improper management can reduce soil organic matter quality and quantity, causing a reduction in soil productivity. Not only is soil organic matter a vital component of the soil fabric, it also provides a valuable sink for atmospheric carbon. Since Prairie soils have the capacity to store large amounts of CO_2 as SOM, they could play an important role in off-setting greenhouse gas emissions through carbon sequestration.

Better range management would reduce erosion potential, create wildlife habitat, and replenish deteriorated soil carbon levels.

Salinity can hinder the growth and productivity of most crops. To make most effective use of saline lands, they must be managed according to their salt content. Conservation practices and proper crop selection need to reflect the history, current salinity status and productive potential of the land.

Rangeland/Forage
Recent survey results suggest that a significant proportion of Prairie rangelands are in less than good condition. A number of factors contribute to this situation including economic pressures in the agricultural community to maximize production, limited extension activity in range management and a perception that there is no economic incentive to maintain good range condition.

Rangeland can, however, be managed to improve its condition and there are sound economic reasons to do so. Implementation of planned grazing systems, along with proven range management techniques, could significantly improve overall range condition. Better range condition will allow higher carrying capacities, with the potential for higher land values. Such a shift in range management would reduce erosion potential, create wildlife habitat and replenish deteriorated soil carbon levels. Improvements to range management will be essential to support the anticipated future expansion of the beef sector.

Water Quality
Water quality is critical to the health of all living organisms, from fish and aquatic insects, to wildlife and humans. It varies dramatically in streams, lakes, rivers and groundwater across the Prairies, reflecting the many differences in landscapes and land uses. In some areas, agricultural activities have been shown to produce significant localized effects on water quality. Agricultural sources of water contamination include:

- erosion and runoff from fields to which fertilizers, pesticides and manure are applied

- runoff and wastewater from livestock operations
- leaching of land-applied nutrients and chemicals to groundwater.

In general, the ecological and health-related impacts on water quality resulting from Prairie agriculture have received little attention. It is accepted, however, that the greater the level of agricultural intensity, the greater the risk to ground and surface water quality (Canada Alberta Environmentally Sustainable Agriculture Water Quality Committee 1998). This is a significant conclusion, given current objectives to expand and intensify agricultural production across the Prairies.

Implementation of proper land management practices will play an important role in reducing risks to surface and groundwater quality. These practices include implementing conservation tillage to reduce erosion and runoff, monitoring of nutrient application rates and ensuring livestock operations are properly designed within environmental standards.

Riparian Areas

The lush vegetation bordering rivers, creeks, streams, lakes and wetlands are described as riparian areas. They are a significant feature of the landscape formed from the interaction of water, soil and vegetation (Adams and Fitch 1995). Riparian areas provide fish and wildlife habitat, dissipate stream energy, filter sediments and nutrients, stabilize streambanks, store water and contribute to aquifer recharge and provide vegetation amenable to livestock grazing.

Intensification of agriculture without the adoption of appropriate soil and water conservation practices can result in increased soil erosion, sedimentation and contamination of river systems by pollutants such as nutrients and pesticides. Fortunately, riparian areas can be restored through effective management such as creating buffer strips to rejuvenate vegetative growth. Buffer strips have proven to be an efficient method of controlling agricultural runoff. Their function is to provide localized erosion protection and to filter nutrients, sediments and other agricultural pollutants before they reach the water.

REVIEW OF AGRICULTURAL TRENDS AND ISSUES

To plan for the future, it is important to have a solid understanding of the present state of land resources and the driving forces behind the ever-changing agriculture and agri-food sector.

The recent trends in government policy towards the removal of subsidies is resulting in increased diversification on the Prairies. Bradshaw and Smit (1997) suggest that subsidy removal may negatively impact environmental health in the long term due to increased individual risk, reduced income security and increased economic pressure to maintain marginal returns. However, the removal of grain transportation subsidies may encourage a more sustainable change in land use through conversion of cultivated land to perennial forages.

Technology has resulted in increased efficiency of production along with numerous conservation achievements in management of soil nutrients, manure and pesticides. However, intensification of agriculture has also been linked with environmental degradation. Higher use of inputs such as pesticides, fuels, fertilizers and irrigation have the potential to contribute to environmental degradation if improperly managed.

Growing awareness of the general public concerning environmental issues, along with increasingly stringent environmental legislation, will pose a challenge to the future of agricultural expansion. Significant attention to land management issues will need to be given to ensure agricultural expansion occurs in an environmentally sustainable manner.

Many environmentalists assume that sustainability cannot be achieved through intensive agriculture. However, Avery (1999) suggests that attempting to meet world food demands through low-input agriculture would result in the production of less food on more land, thereby reducing the availability of land for other potential and competing uses.

An expanding agricultural industry will find itself competing for water and land resources with rural and urban populations, other land uses and with other industries. Greater production and the continuing shift to speciality crops will require more water for irrigation, livestock and food processing. Increased pressure on the water supply could impact water quality, drive up water delivery costs, and reduce water availability. As a result, water could become a limiting factor for the expansion of the agriculture and agri-food sector on the Prairies (Morrison and Kraft 1999).

The consolidation of farm units, agricultural intensification and biotechnology are contentious issues that will affect the future expansion of the agricultural industry. Despite the potential of biotechnology and intensification practices to increase agricultural production and efficiency, public acceptance (locally, nationally and internationally) will ultimately determine their fate in the agriculture industry. Effective policies and strategies for communication and public education strategies need to be developed and implemented to gain public trust, understanding and acceptance.

MATCHING LAND USE TO LAND CAPABILITY

To increase agricultural production across the Canadian Prairies in both an efficient and sustainable manner, the relationship between land use and land capability must be clearly established. The potential of different management systems and different landscapes to adapt to future economic and environmental changes can then be determined.

The Land Practices Groups are based on the clustering of SLC polygons linked to the 1996 Census of Agriculture. The analysis of areas containing similar agricultural practices and land uses has provided a basis for identifying the range of landscapes which can support a given set of farming practices. The LPG also provide a means for comparing and analyzing future landscape uses.

Significant attention to land management issues will be needed to ensure agricultural expansion occurs in an environmentally sustainable manner.

FUTURE ACTIONS

Global markets will guide Prairie agricultural growth. However, through a consultative process with the agriculture and agri-food industry of Western Canada, a consensus-based agriculture industry growth scenario has been developed. A Scenario Analysis Model (SAM2) was also developed to assist PFRA in determining the potential impacts and implications of agricultural expansion, based on the current state of resources on the Prairies. Output from the model can be linked to Land Practice Groups. As a result, relationships between the crop and livestock production required to meet growth projections and potential changes in land use can be determined using a geographic information system.

A second modelling system has also been developed for PAL to assess the sustainability of management practices on annual cropland in relation to soil erosion and SOM. Output from this system can also be iteratively linked to the SAM2 model through the use of GIS.

PFRA will use the resource information contained within this technical document, along with output generated from the modelling systems, to help the agricultural sector realize its growth potential. The implications of predicted growth on rangeland and forage resources, cultivated land, water quality and riparian areas will be determined. Analysis of the opportunities will contribute to the development of strategies aimed at ensuring sustainable agricultural growth across the Prairies. The strategies will identify sensitive or priority areas that could benefit most from new programming, land use planning and resource conservation efforts. Ultimately, the strategies will aid in the development of effective agricultural policies.

A separate document entitled *Prairie Agricultural Landscapes: Foundations For Growth* will focus on the resource management implications arising from the growth projections. The *Foundations* report will discuss the scenario analysis modeling and its relation to the land practice groups developed by PFRA. It will identify resource management implications of growth targets. More importantly, the document will outline appropriate actions required to ensure the sustainability and integrity of Prairie agricultural landscapes in the face of unprecedented growth in the industry.

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SI (Metric) - Imperial Conversion Table

	SI Unit	SI Symbo	Imperial Equivalent
LENGTH	1 millimetre	mm	0.0393701 inches
	1 centimetre	cm	0.393701 inches
	1 metre	m	3.28084 feet
	1 kilometre	km	0.621371 miles
AREA	1 hectare	ha	2.47105 acres
	1 square kilometre	km^2	0.386102 square miles
VOLUME	1 litre	l	0.219969 imperial gallons
TEMPERATURE	degrees Celcius	°C	degrees Fahrenheit 1.8°C + 32
WEIGHT	1 gram	g	0.03527 ounces
	1 kilogram	kg	2.20462 pounds
	1 Megagram	Mg	1.102311 tons
	1 tonne	t	1.102311 tons