

# Sustainability of Canada's Agri-Food System — A Prairie Perspective

Faculty of Agricultural and Food Sciences  
University of Manitoba

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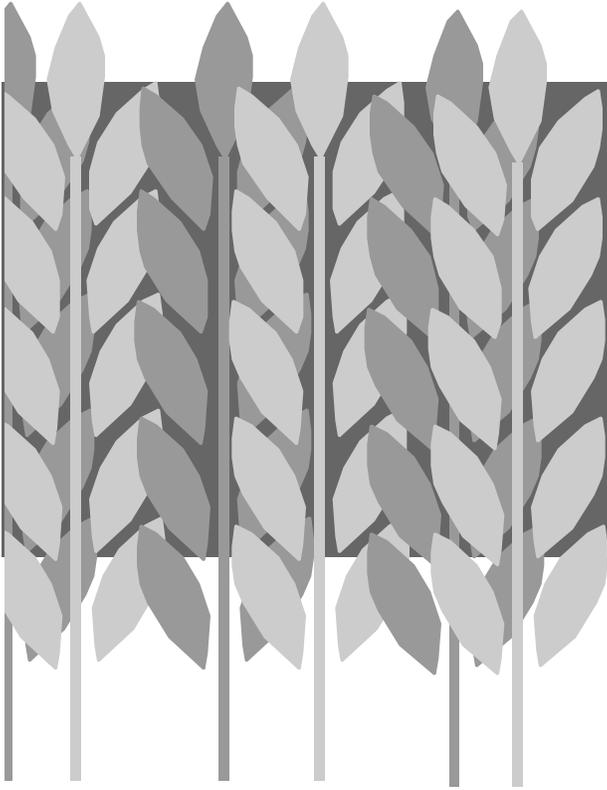
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# Sustainability of Canada's Agri-Food System — A Prairie Perspective

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University of Manitoba

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## PREFACE

IISD has launched a project to better understand and promote sustainable development within the Great Plains region of Canada and the United States. This vast region is truly a breadbasket for the world and a highly significant regional ecosystem from the perspective of biodiversity, climate change and conservation of soil and water. The Plains have long been associated with major dynamics in the flow of people, and rights of land and water use. These are becoming focused on issues of community sustainability and livelihoods. IISD is seeking a better understanding of policy shifts required to build sustainable development into decision-making locally and regionally.

The University of Manitoba Faculty of Agriculture produced this report, drawing upon a number of sources of financial support. It is unusual for an entire university faculty to commit effort on a comprehensive analysis. This overview is limited to Canadian Prairies, but in a context of a changing world marketplace. The unifying theme is the role of science and technology in achieving a sustainable system of agricultural production, in ensuring a safe, nutritious food supply, and in preserving the quality of air, water and land. The document is an important backdrop for policy discussions, and for informing students, farm groups and others on the subject of sustainability.

Dr. Clay Gilson, a member of the Faculty and an IISD Board Member, is well known for his commitment to sustainable agriculture. He was a catalyst for this document through his leadership of a Science Council of Canada project on sustainable agriculture. Allen Tyrchniewicz and several other IISD staff members assisted in the production of this report.

We invite comments from readers not only about what is covered but also whatever is missing from this study. Certainly, the field of agricultural sustainability in North America has not reached a full stage of maturity. IISD believes the type of information described must be linked to issues of global and regional ecosystemic change and to local concerns of community sustainability and livelihoods.

Arthur J. Hanson  
President and CEO,  
IISD

## ACKNOWLEDGEMENTS

On behalf of the faculty I would like to thank the Governments of Manitoba (Environmental Innovations Fund) and Canada for financial support of the project. Although it is no longer in operation, the Science Council of Canada with the cooperation of the Agricultural Institute of Canada Research Foundation, provided financial support as well as the original initiative for the project, for which we are grateful. The encouragement and assistance of Janet Halliwell and Bill Smith of the Science Council contributed greatly to the general expedition of the report. The advice of Robert Sopuck and Tom Pringle of the Government of Manitoba was particularly helpful in providing a context of sustainability.

Faculty members offered their expertise and views in various sections of the report. They gave generously of their time, not only in researching and writing their material, but also in chapter and group discussions. As a result, the document is of both an interdisciplinary and integrated nature. Contributors are listed here by chapter and I take this opportunity to publicly thank them for their efforts.

Divergent viewpoints are natural and appropriate to an academic setting. These variations in perspective have assisted in producing what we feel is not only a thoughtful but dynamic and forward-looking document. In the interest of coherence, the editors have in some cases had to limit or reconcile divergent viewpoints.

The faculty was well served by a small coordinating and steering group. Faculty members Ian Morrison and Daryl Kraft provided the main leadership in developing the concept, preparing the introductory and final chapters and steering the project to its conclusion. E. A. Poyser and Brenda Chorney supported the faculty by coordinating the implementation phase and bringing together seminars, drafts and the final report. In the end, Brenda brought it all together and deserves our special thanks.

I believe the project provided an excellent opportunity for the faculty to review its research and teaching function within the broad concept of the agri-food system and its sustainability. I have no doubt that the experience gained through developing an integrated strategy will augur well for the faculty's contribution to the service of the agri-food industry and the cause of sustainable development.

Finally, publication of this document, after the unfortunate demise of the Science Council, would not have been possible without the cooperation of the International Institute for Sustainable Development (IISD). The institute's interest in the project and willingness to become the vehicle for this joint publication has meant that the information and ideas inked herein will be publicly available. The work of the Faculty will, therefore, not have been in vain. We thank Dr. Arthur Hanson, CEO of the IISD, for his foresight and support.

James I. Elliot,  
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## 1. INTRODUCTION AND HISTORICAL BACKGROUND

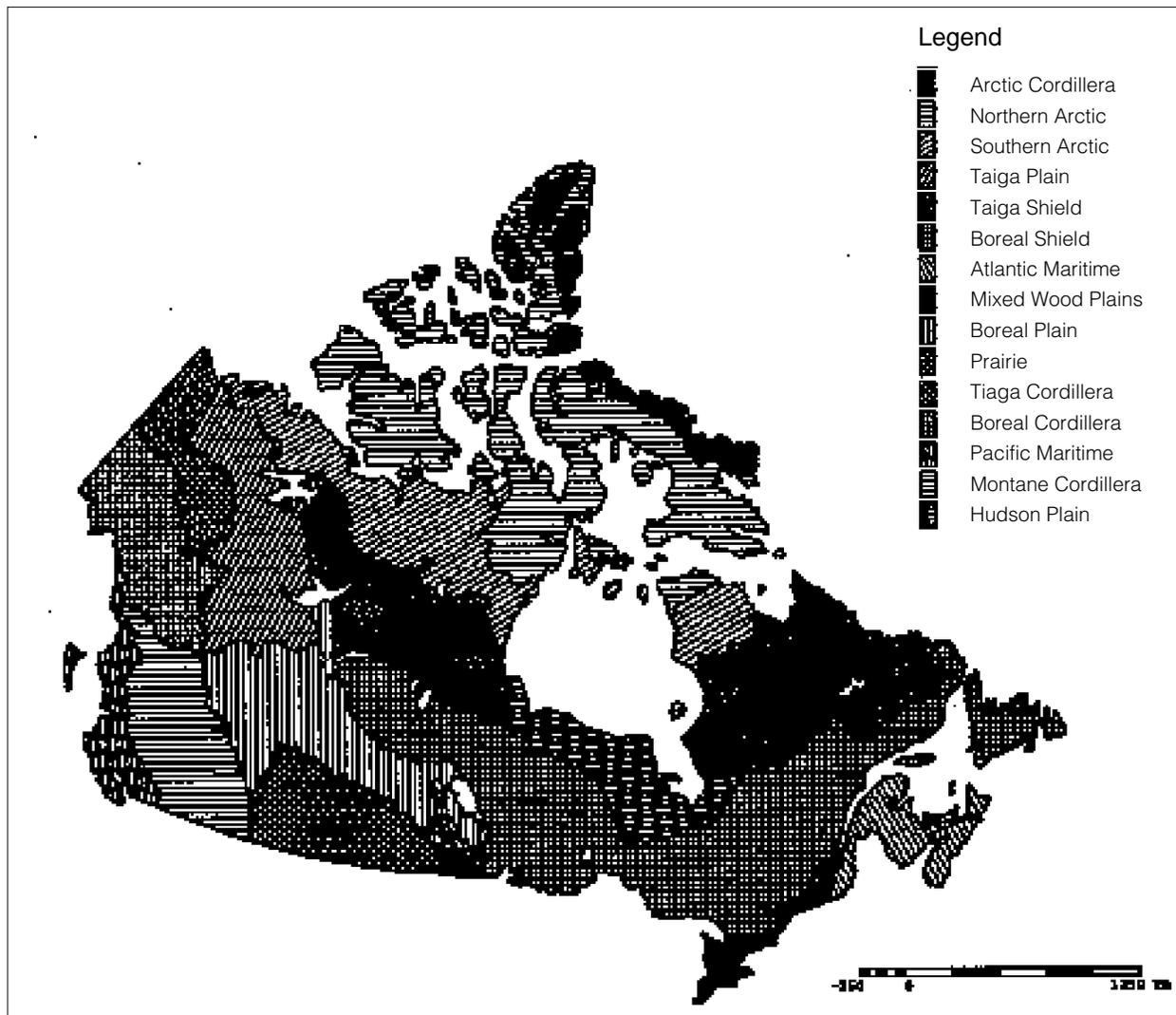
The Canadian Prairie and Boreal Plain is located in the southern half of Alberta, Saskatchewan and Manitoba. Shown as zone 7 in Figure 1.1, it represents 113 million hectares, or 11.3 percent of the area of Canada. Agriculture became part of the landscape over 100 years ago, and farming operations now impact on 49 percent of the area. Most native Prairie communities of plant and animal life have been exposed to the plow. Some species have disappeared, some have expanded their range, and new species have been introduced.

Agriculture's impact on Prairie plant and animal life will continue. The challenge to sustainable agriculture is threefold. It includes exporting food to a growing world population, maintaining a stable and diverse agroecosystem, and sustaining a farming industry which is competitive in the global economy.

This chapter provides a framework for analyzing sustainable agriculture, including an historical perspective of Prairie agriculture and a discussion of how the industry has changed.

**Figure 1.1**

*Terrestrial  
Ecozones of  
Canada.*



## Overview of Sustainable Agriculture

Sustainability is the capacity of a system to endure over time. Agriculture involves the systematic management of organisms within an ecosystem to produce food and fibre for human consumption. A sustainable agricultural system depends not only on the endowment of natural resources, but on humanity's labour and the capital society has accumulated through knowledge, institutions and such human-constructed artifacts as roads, buildings and machines. Therefore, a conceptual framework to evaluate the rate at which food and fibre can be produced over time must incorporate the people employed in agriculture, the knowledge available to them, the social institutions that guide their activities, the tools they work with and the endowment of the natural resources.

### A Framework for Analysis of Sustainable Prairie Agriculture

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*Sustainable agriculture involves determining the annual production of crops and livestock which can be maintained by the natural resources, people, capital and institutions in the Prairie region.*

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As summarized in Figure 1.2, a systems approach analyzes sustainable agriculture in terms of stocks, flows and activities. Agricultural output is a flow represented by an arrow for crops, livestock and food. This arrow connects activities involving the production, processing and distribution of food with the population, which is a fixed stock. Yearly output of Prairie agriculture is dominated by crops — cereal grains, oilseeds, pulses, leguminous and grass forages — and by such livestock production as beef, milk, pork, poultry, meats and eggs. Sustainable agriculture involves determining the annual production of crops and livestock which can be maintained by the natural resources, people, capital and institutions in the Prairie region. Whether yearly cereal crop production of 50 million tonnes or 75 million tonnes is sustainable depends upon the resources available, their management and the risk society is willing to bear.

In 1980, the Canadian Wheat Board (CWB) forecasted that by 1990 grain exports would require Prairie production levels exceeding 55 million tonnes. A symposium of agricultural scientists suggested the available resources and technology made the targeted output feasible. Few questions were raised with respect to the effect upon soil and water quality, or ecosystem diversity and stability. If the targeted output was to be achieved with minimal ecosystem disturbance, the date may have had to be postponed.

### Natural Processes and Resources

In the absence of human influence, the capacity of the natural resources to produce food and fibre is determined by ecosystems.

The four basic components of an ecosystem are the abiotic environment, producers, consumers and decomposers. These components are very complex and, as illustrated in Figure 1.2, are called natural processes.

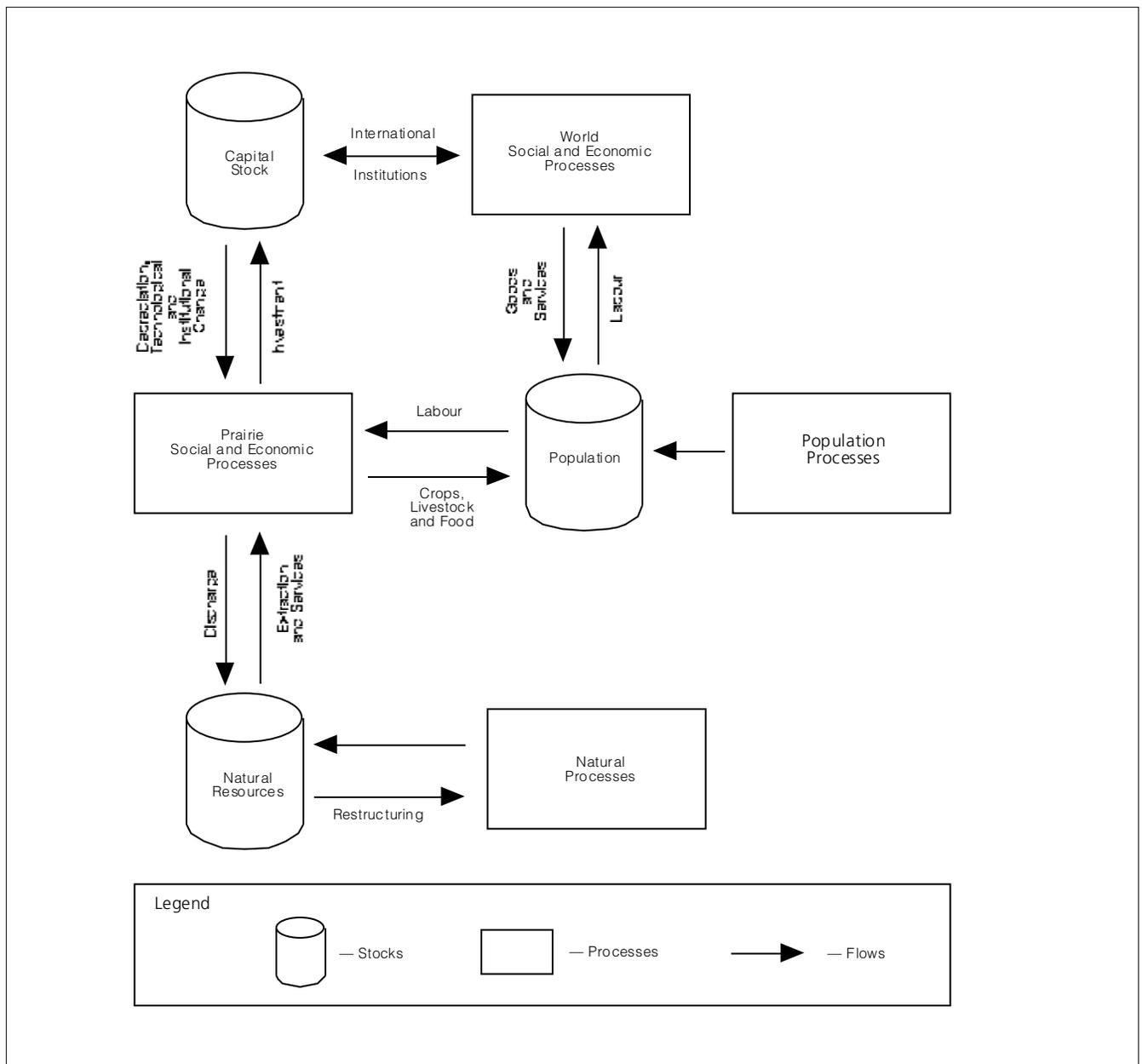
Prior to the white man's Prairie settlement and the evolution of "modern" agriculture, Canadian Prairie ecosystems were characterized by a diverse combination of plants (producers) and animals (consumers). Plant communities were determined by the soil's physical characteristics and moisture conditions. Animals, in turn, were influenced by the available vegetation, while soil decomposers and the physical characteristics of soil were influenced by the plant and animal populations. The majority of vegetation in the area consisted of a mixture of perennial grasses, forbs and shrubs. The exact species varied with the soil type and moisture availability. For example, short grass species were concentrated

in the Brown soil zones while tall grass species predominated in the moist Black soil zones. A few drought resistant shrubs were present in the drier regions, while larger shrubs and trees occupied moist regions. Animal populations consisted of large herbivores (bison, pronghorns, mule deer), rodents (prairie dogs, snowshoe hare), waterfowl (mallard and pintail ducks), carnivores (coyote, fox) and invertebrates (grasshoppers). Interactions between the plant, animal and soil components kept the general ecosystem in a more or less balanced state over time.

An ecological equilibrium imposes constraints on the overall limits of natural resources. Agricultural activities, however prudent, destroy parts of original nature, disturb ecological balances and significantly reduce the levels of some biological systems. A

**Figure 1.2**

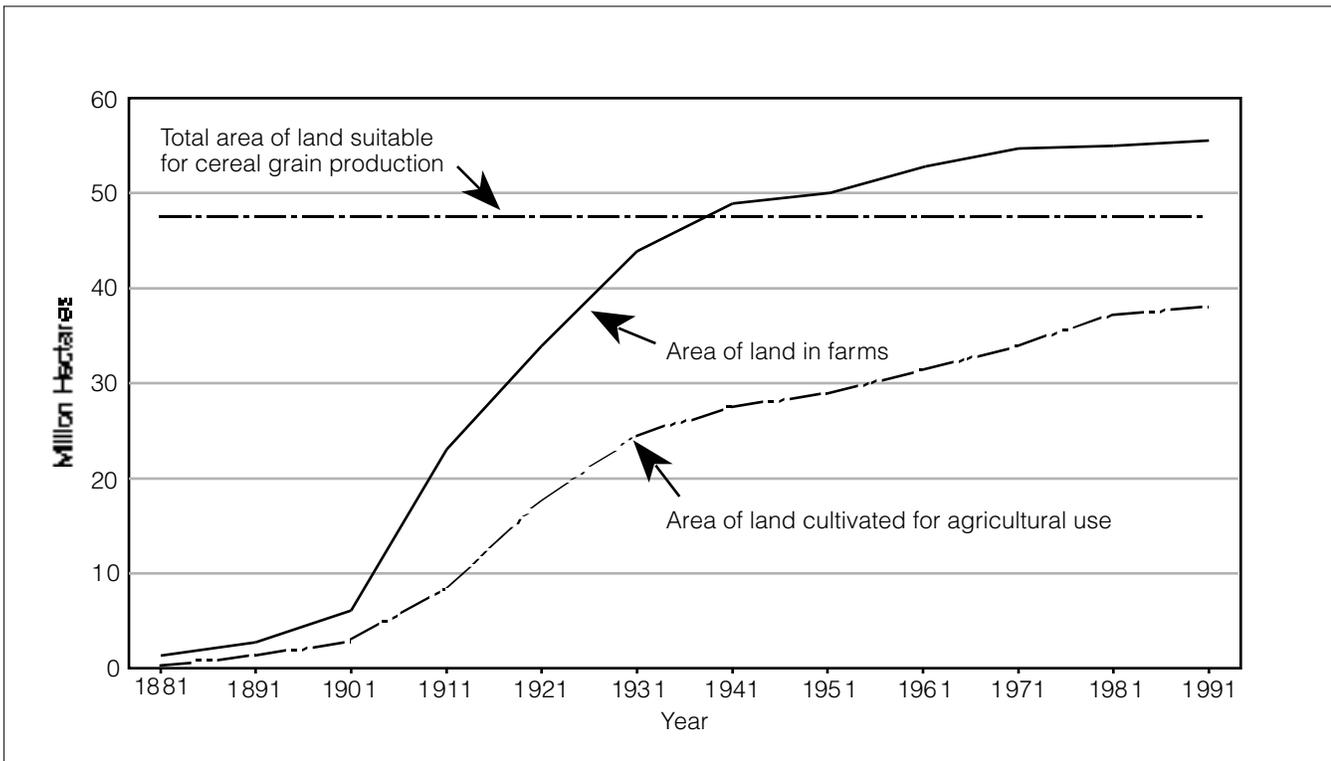
*Framework for Analysis of Sustainable Prairie Agriculture.*



*External shocks such as drought, floods and unseasonal frosts have periodically disrupted plant and animal populations and will continue to do so.*

sustainable agroecosystem implies that farming can attain an equilibrium that is integrated into the overall ecological system. However, a steady-state equilibrium is obtainable in neither a natural ecosystem nor an agroecosystem. External shocks such as drought, floods and unseasonal frosts have periodically disrupted plant and animal populations and will continue to do so. Equilibrium means the system will tend to return to a more stable state.

The natural resource limits depicted in the lower part of Figure 1.2 include the water and arable land of the Prairies, the finite supplies of minerals and fossil fuels used by agriculture, and the ecological balances of the natural processes. A total of 47 million hectares, or a third of the Prairie agricultural area, is suitable for arable agriculture. Climate and soil characteristics limit plant production to perennial forages or native grasses and shrubs in the remaining area. Figure 1.3 shows that the current area cultivated for annual and perennial crop production (approximately 38 million hectares) is beginning to approach the area capable of arable agriculture.



**Figure 1.3**

*Area of Improved Land and Total Land in Prairie farms.*

The area owned or leased by farmers is approaching 60 million hectares, but this represents only 44 percent of the Prairie ecozone. The remainder is predominantly Crown land managed by the provincial governments. Forestry, parks and recreation are the primary external influences of the ecosystems in these areas.

#### *Agroecosystems in Gray and Black Soil Zones*

Figure 4.1 in the chapter on Land shows a map of the soils zones of the Prairies. The Gray and Black soil zones represent two-thirds of the area suitable for cereal grain production.

These are the more moist regions of the Prairies, receiving between 400 and 500 millimetres of precipitation and having lower evapotranspiration than the Brown and Dark Brown soil zones. Relatively high levels of biomass can be produced in this region. Due to the higher moisture levels, a number of cropping options are available, including cereals, oilseeds and pulse crops. The most productive soils are used to produce annual crops, and only in certain instances are they used to grow perennial forages. Inorganic fertilizers and pesticides are used in intensive crop production.

Monogastrics such as hogs and poultry are located in grain-growing areas, often near larger urban centres. These animals eat feed, wheat, barley, corn, canola meal and other feedstuffs, creating a local demand for grain. Monogastrics produce manure which is used as fertilizer for crops. While this manure must be viewed as an important resource, its high weight to nutrient content makes it expensive to transport long distances. Therefore, farmers will often only apply manure on the fields closest to the barns, which can lead to an accumulation of nitrates below the rooting zone of most crops.

Other than providing some manure and providing an alternative market for weather-damaged grains or feed grains, monogastrics such as hogs and poultry have contributed little to the stability of the Prairie ecosystem.

Ruminants such as beef cattle are an important component of sustainable agricultural systems. They require the incorporation of perennial crops into the crop rotation, which adds diversity and stability to the agroecosystem and potentially reduces the need for inorganic inputs. In the Black and Gray soil zones, cow-calf production is limited to land not suited to cereal grains.

Some soils in the Gray soil zone have poor structure and farmers in these areas include a higher proportion of perennial legumes in their crop rotations. These annual/perennial crop rotations are essential for the long-term sustainability of these soils.

#### *Agroecosystems in the Dark Brown and Brown soil zones*

The Dark Brown and Brown soil zones represent one-third of the area suited for wheat production (see Figure 4.1, Chapter 4). A combination of low precipitation and high evaporation cause these areas to be the driest region of the Prairies. Total biomass production per unit area is limited by moisture availability. Similarly, fewer cropping options are available to farmers. Cereal production represents the bulk of annual crop production and summerfallow plays a larger role in crop management systems than it does in the Black and Gray soil zones. Soil erosion and salinity are a serious problem here.

The majority of Prairie rangeland is located in this region. While most of the rangeland is uncultivated, overgrazing can jeopardize the sustainability of this resource. Water and security of feed supply are the major limitations to animal production on the Prairies. Rangeland is used mainly for cow-calf operations, and feed quality is not a high priority. Some grain is used to supplement the diet of cows and yearlings, but other than in feedlot, finishing grains make up a small fraction of feed supply. Mixed farm operations are limited, with the majority of farmers involved either in intensive grain production or cattle operations. Ruminants play a much greater role in these soil zones than monogastrics.

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*Water and security of feed supply are the major limitations to animal production on the Prairies.*

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*Recycling and the Agroecosystem*


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*A sustainable agriculture requires that wastes do not overload the assimilative capacity of the natural ecosystems.*

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Much of the total agricultural production on the Prairies is used for purposes other than human consumption. For example, straw is either incorporated back into the soil as a means of solid waste disposal, or burned. Manure from livestock operations presents another solid waste disposal problem, although with both manure and straw an opportunity exists to return nutrients to the soil. Whey from cheese processing is a liquid waste management problem. How these wastes are managed depends largely on the costs of controlling the unwanted by-products and the regulations concerning their disposal. Matter and energy cannot be destroyed. Therefore, the choice is either to dispose of the waste on land or into the air or water. A sustainable agriculture requires that wastes do not overload the assimilative capacity of the natural ecosystems.

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*Today, the Prairie farm population is just less than 10 percent of the regional population.*

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**Population and Population Processes**

The population of the Prairie provinces is relatively sparse, with 4.5 million people living in a region of 176.3 million hectares. The Prairie population directly involved in farming has been declining since 1936 when it represented 50 percent of the provincial populations. Today, the Prairie farm population is just less than 10 percent of the regional population. The outside world population (5.2 billion) has and will likely continue to be the predominant consumers of Prairie agricultural output.

Population processes in Figure 1.2 represent demographic factors, such as the numbers of males and females and their ages, fertility rates and mortality rates. These factors underpin present and future population levels in any nation. A stationary population is one in which the birth rate is constant and equal to the death rate, the age structure is constant and the growth rate is zero. Estimates of a stationary population are based upon long-run implications of recent fertility and mortality trends and a number of assumptions which appear to be underlying the trends. The World Bank currently foresees a stationary population of 10 billion if such factors as famine, disease and government policy do not alter the historical trends. Given the trends, a stationary population will not be attained within the next century and, therefore, world population levels are expected to increase at annual rates of between 1.2 and 1.7 percent. Whether the world population grows at either of these rates, it is only sustainable if the global food production, processing and distribution system is sustainable. Malthus suggested in the early 19th century that as population expansion outgrew the capacity to produce food, the world would run short of it. Malthusian pessimism still prevails in Sahara Africa. Technological progress, which has been primarily responsible for expanding food production elsewhere, has barely begun to occur in this area.

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*Prairie production represents 2 percent of global grain, rice and vegetable oil output.*

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Most of the technological advances within agriculture have occurred in the past century, when the global population grew by 3.5 billion people. Besides the scientific discoveries which were instrumental in producing more food, the agricultural industry has used more land, irrigation water, fossil fuels and minerals in the production process. Whether the agricultural industry can continue to feed the growing population and remain sustainable is a complex issue and can only be addressed in a global context. The sustainability of Canadian Prairie agriculture is just one component in the larger global setting.

Today, Prairie production represents 2 percent of global grain, rice and vegetable oil output. With just under 5 million people, the region normally exports two-thirds of its

annual crop production as bulk commodities, flour, vegetable oil or in the converted form of live animals or red meats. Annual agricultural exports in the 1980s accounted for over \$5 billion per year and represented 25 percent of all exports from the region.

Saskatchewan, with over 66 percent of its exports originating from agriculture, was the province most dependent upon the farming industry. Grain exports alone account for supporting over 90,000 Canadian jobs.<sup>1</sup>

### **Prairie Social and Economic Processes**

Agricultural production and food processing activities are characterized by the institutional arrangements (which play a co-ordination role), technology, inputs and outputs. Institutions may be described as the various aspects of social activities that influence and regulate individual behaviour. In other words, institutions represent established arrangements in society and established ways of doing things. They involve the working rules of society.

#### *Property Rights*

In Canada, the most significant institutional factor that affects the use of land, air, water and biological resources is the concept of property rights. Property rights are characterized on the basis of whether the right is exclusive and/or transferable. Exclusivity allows the owner of the right to prevent others from using the privileges defined by the right. For example, plant breeders' rights entitle the developer of a crop variety to exclude others from using the seed without approval. A strict fee simple land title (unrestricted ownership) allows the owner to use land as he or she wishes. Transferability means the right may be assigned to someone else. In other words, the plant breeder may transfer the exclusive control held in the right to another individual, corporation or legal entity. Private property conveys the rights of exclusivity and transferability to the individual holding the right.

Markets are the vehicle through which private property is transferred. Market prices are established through the exchange of property rights. For example, a willing buyer and seller will negotiate the price to be paid prior to transferring the title to farmland. The value at which a buyer is willing to appraise farmland will depend upon its crop production capability, location and property rights relative to other real estate. Property right restrictions limiting an owner's options, such as easements on drainage or zoning restrictions, may lower the price just as would the relatively lower quality soils.

Market failure, in terms of prices not accounting for all costs, has been attributed to leading to an unsustainable system. In every market transaction, one party receives payments and gives up products or services. The purchaser is expected to pay the full cost of the item, and expects to get full and sole claim to its use. Sometimes those who pay the costs do not receive all the benefits, and sometimes the payments made for an item do not cover all the costs of producing it. An example of the first type is a tenant who includes alfalfa in the rotation to improve soil structure and reduce erosion but who will not be able to receive the potential increase in crop yields before the lease expires. An example of

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*In Canada, the most significant institutional factor that affects the use of land, air, water and biological resources is the concept of property rights.*

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<sup>1</sup> Calculated from export and employment figures in *Manitoba/Western Canada Red Meat Industries: Strategies and Impact Analysis*, by J.A. MacMillan and G. De Matos, University of Manitoba, 1992, Table 3, p. 5.

the latter is the farmer who drains sloughs and cultivates the land but fails to account for the loss in wildlife. In either of these instances, the system of organizing production fails to take account of all the people affected by the decision. In the first case, the crop rotations actually used will likely not include enough alfalfa, and in the second case, too much land is being drained. In the latter case, if the farmer had to pay for the loss of wildlife, the cost of drainage would rise and some land might remain in its natural state.

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*Many air, water and soil quality problems can be traced to some variation of market failure.*

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Many air, water and soil quality problems can be traced to some variation of market failure, where the one who created the costs was not made to pay for it and the one who created the benefit was not completely rewarded for it. Solutions to this problem normally involve redefining property rights and creating another institutional arrangement to replace the market.

Status rights have emerged as the predominant institution adopted to regulate use of natural resources. Status rights are proclaimed in statutory law and normally designate a public agency (licensing bureau, commission, conservancy association or marketing board) with the authority to delegate exclusive use status to individuals, corporations or other legal entities. The exclusivity cannot, however, be transferred to some other entity without the approval of the designated agency. For example, in Manitoba, the Clean Environment Commission determines the status an entity has with respect to the type, amount, timing and location of waste disposal.

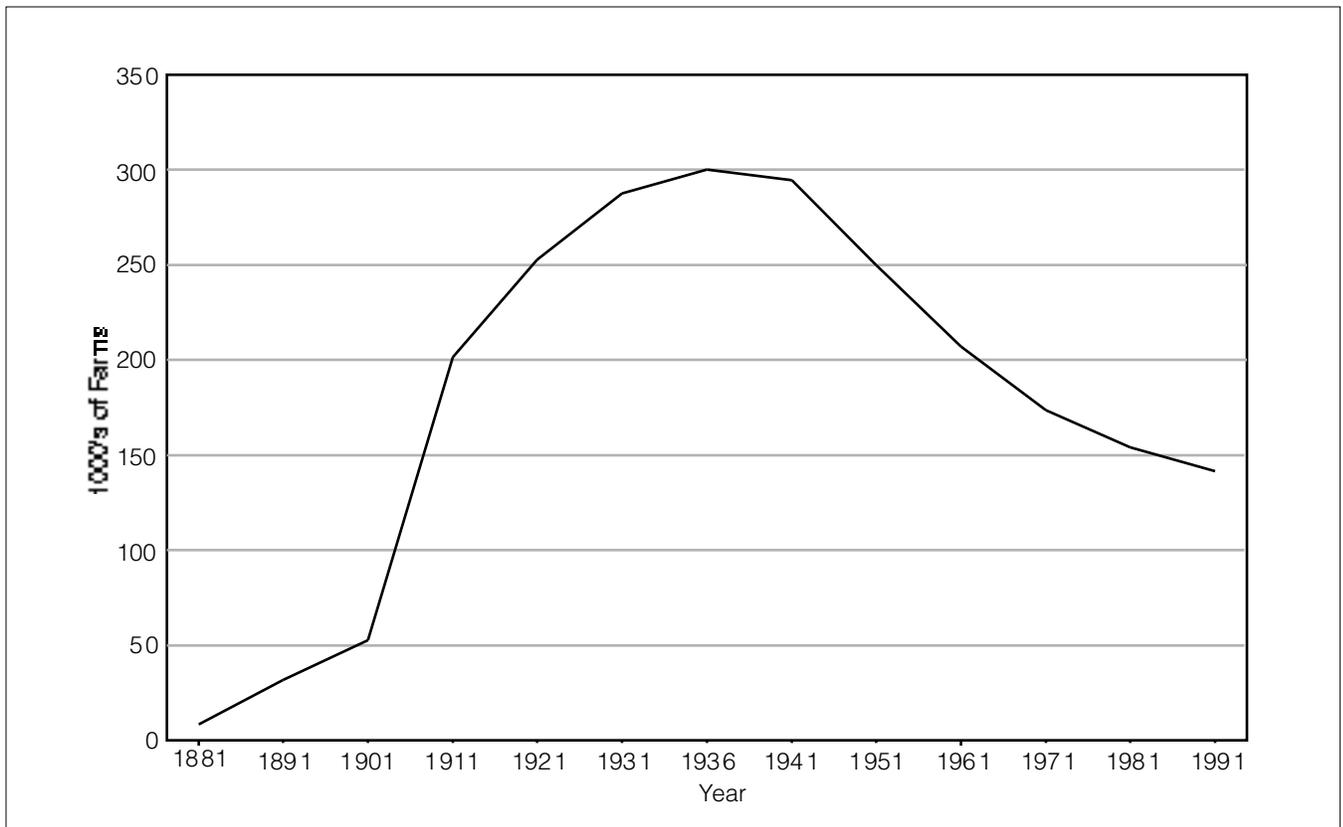
Water rights are owned by the province and statutory regulations determine how individuals may use water. A license provides an individual use of the water within the terms of the agreement. Every license has an expiry date and cannot be transferred to another user without the approval of the minister or the designated agency. Allocation issues arise when water supplies cannot meet the requests of all applicants. Normally, the administrative agency recommends who should obtain a license on the basis of priorities set forth in the statute. However, the guidelines are subject to political interpretation. The volume and quality of water which must remain in a stream, lake or aquifer in order to sustain aquatic life is one of many interests competing for limited supplies. In this institutional setting, all competing uses are recognized, whereas in a market setting users who are unable to enter into the bidding are overlooked. However, the outcome in the institutional setting may be no different if the environmental interests are a low priority.

In 1990, a review of the pest management regulatory system recommended that the federal government appoint a pest management regulatory agency with the authority to register or regulate pesticides. Pesticides cannot be made available for public use unless the manufacturer and distributor have a license. This status right is granted by the federal government following extensive tests to establish the potential effect upon human health and the environment. The review, licensing and monitoring process is an example of an institutional arrangement designed to take into consideration all affected parties, not just the farmers and manufacturers.

The distribution or control of property rights and the responsibilities individuals have in property are written in laws by government and interpreted by the courts. As such, they are part of the capital stock in Figure 1.2. The use of natural resources is affected by the laws that define the powers of an agency and its ability to delegate authority to others. If the ensuing use is not in the long-term interest of society, institutional reform involves legal revision of property rights.

*Family Farms, Agribusiness and Education*

Several other institutions also have important effects upon Prairie agriculture. The family farm represents the primary social and business unit which plans resource use in Prairie agriculture. Family farms provide the money invested in the business, from savings or borrowed funds which are based upon savings. Liability from losses because of low grain prices, crop failure, or reduced livestock sales falls entirely upon the family business. Labour is also provided predominantly by the family, except when augmented during the peak times such as seeding and harvesting. Funds available for the household are closely linked to the income generated from the family business. Under adverse economic circumstances, the support and protection of the family can result in depletion of not only savings, but also the natural resources controlled by the farm.



While the number of farms on the Prairies increased steadily until 1936, Figure 1.4 shows that by 1991 the number of farms had fallen to less than half the 1936 peak. Individual farms have been able to expand their production of crops and livestock because of mechanization and purchased inputs. Today, the family farm is more reliant upon other sectors of the economy. These organizations include marketing firms and suppliers of machinery, fertilizer, pesticides and financial management services. In addition, Prairie agriculture has some unique institutions, including provincial marketing boards, the Canadian Wheat Board (CWB), and cooperatives, which manufacture and distribute inputs, and store, process and distribute outputs. Financial institutions not only include

**Figure 1.4**

*Total Number of Prairie Farms.*

private banks or credit unions with specialized financial services, but also government-owned farm lending agencies.

Education involves those institutions which expand and transfer knowledge from one generation to the next. Educational institutions, such as primary schools, universities, research bodies, and extension programs, provide the social structure for organizing the development and transmission of knowledge. Increased knowledge affects natural resource use through greater understanding of the ecosystems and development and implementation of new technologies.

Education was an integral point of the Dominion Land Policy in 1870, with 5 percent of the Prairie land reserved to support local schools. Dominion Experimental Farms followed shortly after in 1886. In these stations, scientists continue the work of developing new approaches to crop and livestock production. This institution can point to many development successes, such as new rust resistant varieties of wheat, oats, barley and rye. Provincial governments have taken on the responsibility of agricultural education, extension and setting up the structure for farm organizations. These activities are too numerous to list, but range from soil conservation to networks for women in agriculture to youth programs through 4-H clubs. Three Prairie universities grant degrees in agriculture while diploma programs are available at three colleges in Alberta and the Universities of Saskatchewan and Manitoba.

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*Knowledge required by farmers grows in relationship to the sophistication of the technology used.*

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Knowledge, in terms of the managerial capability of the farmer and the technology available to the industry, is pivotal in attaining the full potential of science. Every census of agriculture reveals that more and more farmers have taken post secondary education. The investment per operator in agriculture is higher than most industries in Canada and the knowledge required by farmers grows in relationship to the sophistication of the technology used.

#### *Inputs*

Many inputs for crop and livestock production are acquired from other industries. Input prices depend upon costs of production and distribution, market competition and regulations legislated by local, provincial and federal governments. Whether the input prices adequately reflect the society's willingness to conserve natural resources or maintain ecosystems depends upon the restrictions placed upon industry. For example, the primary sources of plant nutrients are finite. Nitrogen is manufactured using natural gas, and phosphorus and potassium are mined. Fertilizer prices, when adjusted for inflation, have tended to fall. This suggests that plant nutrient shortages are not imminent, but a sustainable agriculture should be anticipating a cropping system less dependent upon non-renewable resources.

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*Unpriced inputs include surface and groundwater supplies, air, natural fauna and flora.*

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The levels at which privately owned inputs are used and how they are combined is largely determined by their prices, output prices and the available technology. Unpriced common property inputs, such as sunshine, precipitation and carbon dioxide, represent important contributions to crop production, but their levels of availability are subject to natural processes. Other unpriced inputs include surface and groundwater supplies, air, natural fauna and flora. Capital expenditures to store precipitation or expedite drainage are attempts to adjust the effects of natural processes to enhance agricultural production. Social control over these resources is largely exercised through status rights. Input usage

results from a mixture of market related incentives, regulations, technology and natural processes. Sustainability involves the dynamic interaction of market forces, regulation and scientific developments.

*Outputs*

The outputs from Prairie agriculture and food processing involve primary products (grain and live animals), secondary products (flour and carcasses), finished products (bread and meat products) and waste products (nitrates and odours). Once again, the levels of each output and their relative importance in the Prairie economy depends upon the natural resource base, prices, technology and regulations. Grains and oilseeds are the predominant crops with legumes and grasses confined to soils which have conditions more limiting to plant growth.

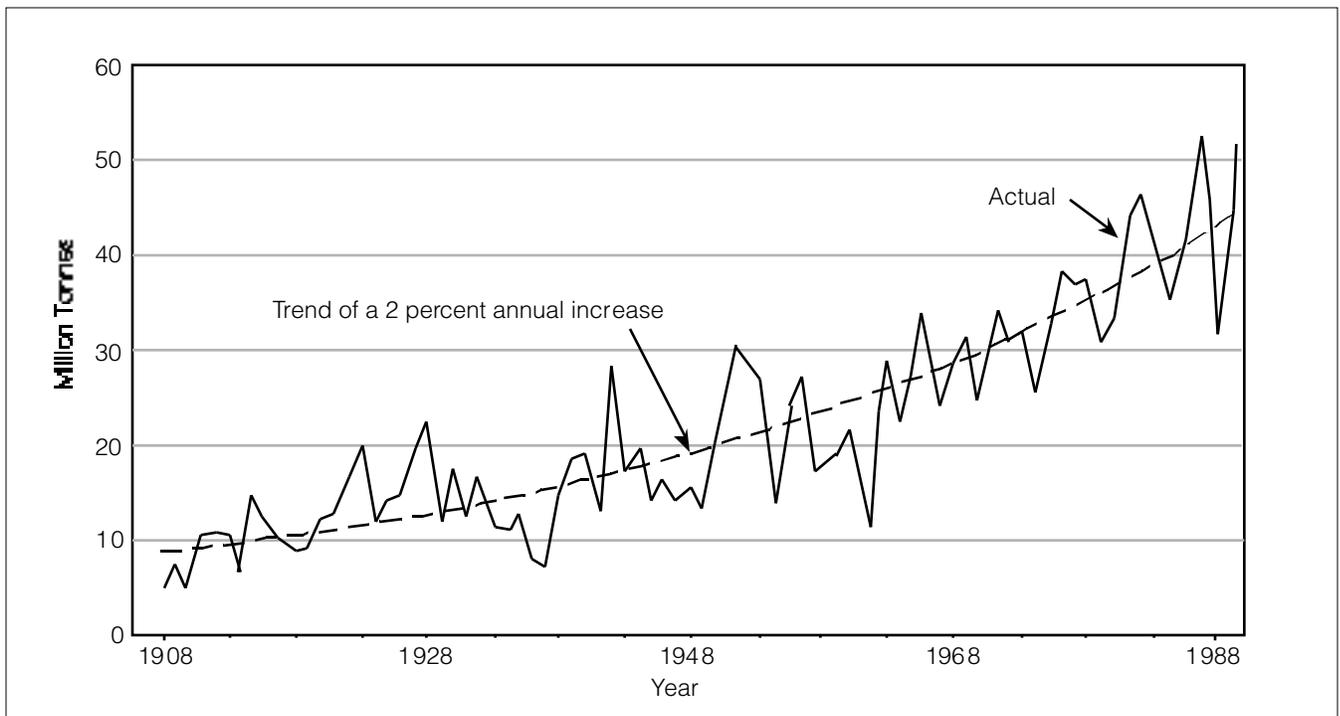
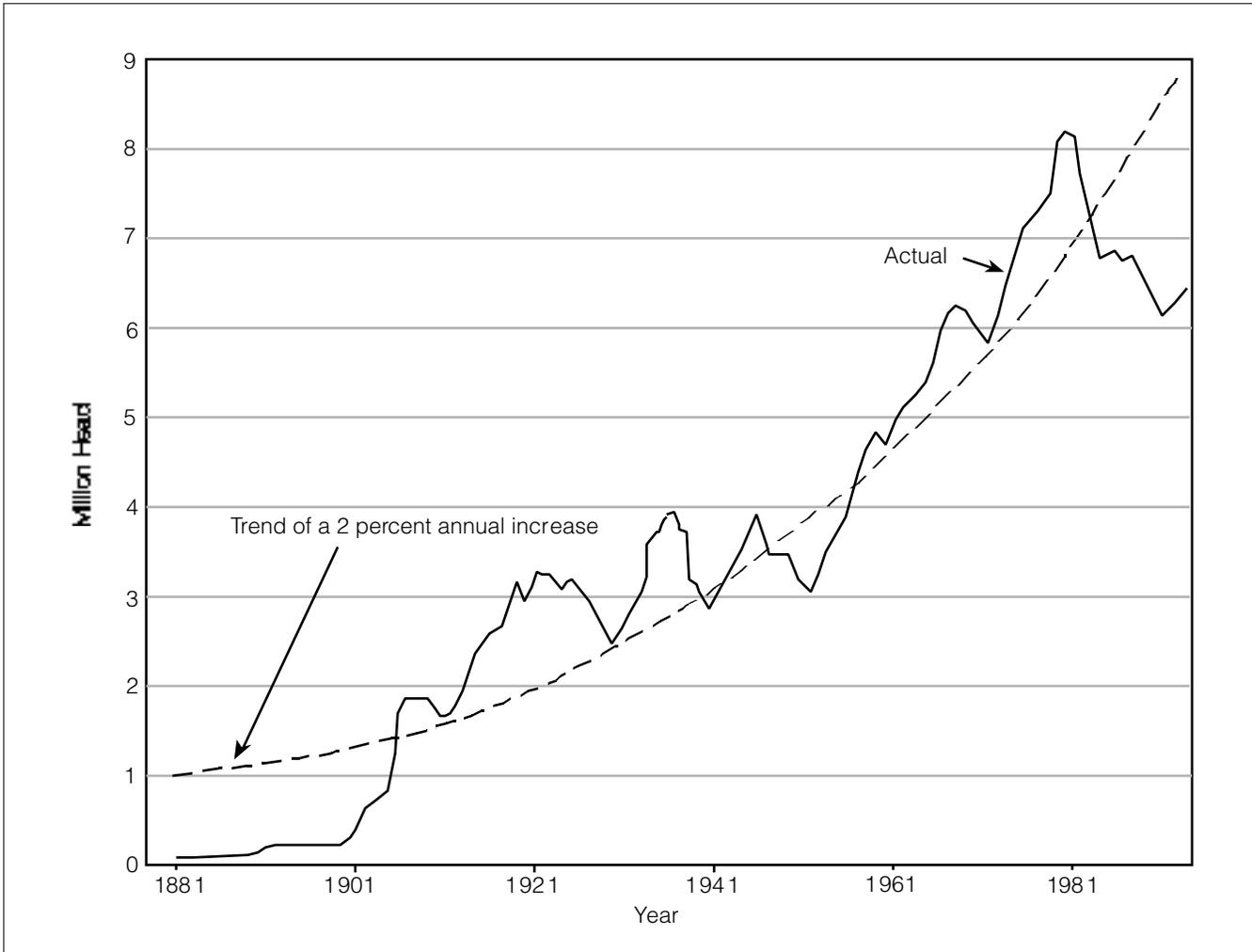


Figure 1.5 shows an upward trend in grain production of 2 percent annually over the past 85 years. The factors underpinning the output trend are the genetic potential of the crops seeded, pest control, soil nutrients supplemented by inorganic fertilizers and more land planted for cereal grains and oilseeds. Each component has contributed to the growth in production, but the influence varies from one decade to the next. For example, fertilizer use grew 14 percent annually in the 1960s and 1970s, but has declined since the middle 1980s. Also, there has been reduced dependency on summerfallow since 1980 with a corresponding increased reliance on herbicides. A continuation of the output trend becomes an even larger challenge for agricultural producers and scientists than it was in the past 100 years, given the limits of available land and the greater emphasis on ecosystem stability.

**Figure 1.5**  
*Cereal Grain and Oilseed Production on the Prairie Provinces, 1908-1988.*



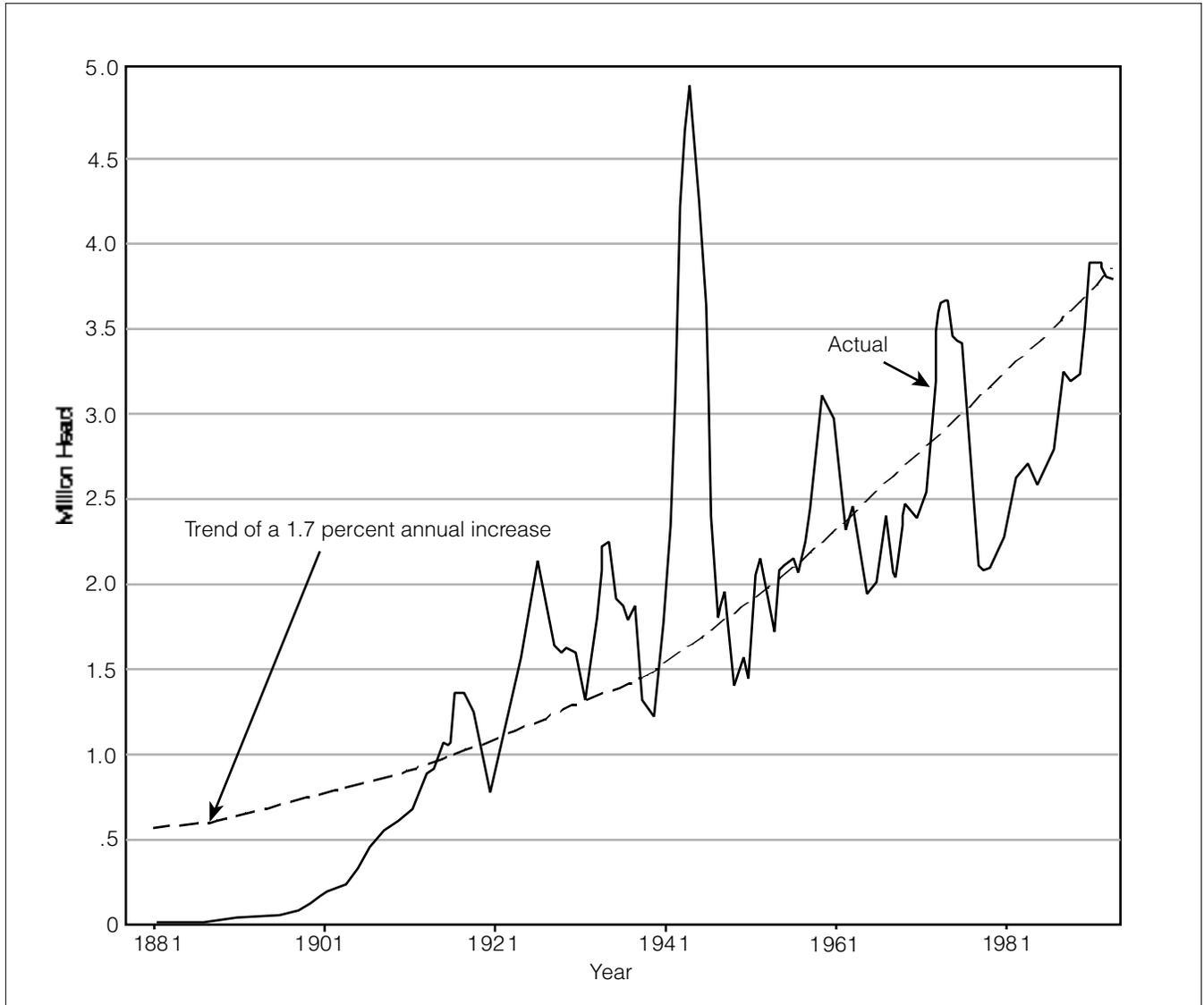
**Figure 1.6**

*Cattle Stocks on the Prairie Provinces, 1881-1991.*

Figures 1.6 and 1.7 show the levels of cattle and hog numbers in the Prairies since 1881. Upward annual trends of 2 percent for cattle and 1.7 percent for hogs are interrupted periodically with cyclical changes. Cattle numbers peaked in 1977 at over 8 million head and have not returned to the historical growth rate. Grain production and exports appear to have been the preferred enterprises in the 1980s. With the exception of the hogs produced in World War II, the swine industry is currently attaining record production levels.

#### Stock of Scientific Knowledge and Institutional Capital

The argument that sustainable agriculture depends exclusively upon the limits of natural processes and resources is only partially true. The level at which the farming community produces food and fibre depends as much upon improving our infrastructure, enlarging our scientific knowledge, and reforming our institutions as it does, for example, on preserving vast stretches of grasslands or regulating pesticides. The capital stock symbol in Figure 1.2 represents the state of knowledge, which has a direct bearing upon the Prairie agroecosystem. This form of capital cannot be diminished but only expanded if society



**Figure 1.7**  
*Hog Numbers 1881-1991: Prairie Provinces.*

invests in basic and applied research. Besides the scientific stock of knowledge, society also accumulates information through experiences with institutions which structure social interactions. In the Prairie provinces, some of the dominant institutions are private property, statutory regulations written by provincial and federal governments and social customs. In some cases, sustainability issues are linked to inflexibility of institutions to co-ordinate and regulate the interaction of people. Cultural and traditional values are incorporated in the institutions. Lastly, the capital accumulated in artifacts, such as buildings, equipment, roads and water storage and drainage systems, has a direct bearing upon the level of food production which can be sustained.

## Historical Overview of Prairie Agriculture Development

### Prior to Confederation

In 1670, the Hudson's Bay Company (HBC) was granted exclusive commercial rights to the area drained by the rivers flowing into the Hudson's Bay. The primary objective was the development of the fur trade. Agricultural interests were confined to providing seeds so that employees could produce their own grains and vegetables. Until 1774, most of the outposts were near the Hudson Bay where the combination of a limited growing season and permafrost resulted in minimal food production. A British parliamentary enquiry in 1749 challenged the exclusive rights held by the HBC on the grounds that the commercial potential of the region, particularly agriculture, was being neglected.

The first attempt at agricultural development involved the HBC granting Lord Selkirk 116,000 square miles in 1812. Lord Selkirk's Red River Settlement was located at the junction of the Red and Assiniboine Rivers, within what is now the city of Winnipeg. Twenty years later, in 1832, Lord Selkirk's estate was transferred back to the HBC. The struggle with nature included infestations of weeds, insects and birds, periodic drought and floods, and frost that damaged immature crops. The HBC could not rely on the settlers for sufficient food supplies to meet the needs of the HBC personnel scattered throughout the west. At that time, HBC management was undecided on whether to terminate agricultural development or extend further assistance.

In 1857, the exclusive licensing arrangement held by the HBC was reviewed again by the British government. A consultant was hired by the government to explore the agricultural potential of the Prairies. Captain Palliser's report concluded that: (1) the area around the Red River Settlement possessed excellent agricultural potential. A fertile belt of soil, about 100 kilometres in width, extended across the three Prairie provinces starting at the junction of the Red and Assiniboine Rivers in Manitoba and going north and west to Alberta with a northern boundary of the North Saskatchewan River; and (2) the area bounded by the United States border on the south and the fertile belt of soil to the north had minimal agricultural possibilities. This very arid region became known as the Palliser triangle and corresponds closely to the Brown and Dark Brown soil zones (see Figure 4.1, Chapter 4). Palliser's observations on this area are succinctly summarized in the following excerpt from his report: "This district, although there are fertile spots throughout its extent, can never be of much advantage to us as a possession."

In 1870, with fur supplies dwindling and buffalo meat becoming less available for outposts, the HBC was experiencing reduced earnings. The new Government of Canada struck a deal with the HBC and, for £300,000, bought all their land, timber and mineral rights, with the exception of 6.6 million acres.

### Prairie Agricultural Development and Confederation

The government of Canada envisioned the development of Prairie agriculture as a means of securing this area from potential United States encroachment. United States homestead laws were successful in attracting European immigrants. A comparable Canadian land development policy was proclaimed where the government of Canada offered settlers the title to 160 acres of land for \$10 if they cleared and cultivated the land.

Initially, settlement was directed through Palliser's triangle, as the government of Canada preferred the most southerly route for border defense purposes. A botanist, J. Macoun, was hired to evaluate a potential route just north of the U.S. border and suggested that Palliser's assessment was wrong. He believed that 25 million acres in the area that Palliser called "The Canadian Desert" was suitable for agricultural production, even with the low annual rainfall.

Land was surveyed and subdivided into 36 square mile components called sections. A section contained 640 acres. A quarter section was considered a basic farm settlement unit with a road access on at least one side. As agricultural development expanded, the Prairie landscape soon resembled a checkerboard design. Towns emerged along the rail lines as collection points for grains and livestock exports and distribution points for incoming supplies. Towns were located so that a round trip from most surrounding farms would not exceed one day by horse drawn wagon. School areas were much smaller. Two sections in every township were designated as school land.

Despite the availability of land and the completion of the transcontinental railway in 1885, the Prairies failed to draw an army of land seekers until 1900. Between 1881 and 1901, the number of farms grew from 10,000 to 55,176. This expansion was insignificant relative to the expansion during the following 20 years in which some 200,000 new farmers staked their claims to the Prairie landscape (see Figure 1.4). In 1881, only 113,000 hectares were cultivated. By 1900, two million more hectares were cleared and plowed. The pace of land development continued until 1921, by which time 16 million hectares were brought under cultivation in the Prairie region (see Figure 1.3).

The first wheat exported via an all Canadian route was a 27 tonne shipment of Red Fife in 1884. It landed in Britain 21 days from the time it left Brandon, Manitoba. By 1900, Prairie wheat exports, which were becoming known for excellent milling and baking qualities, exceeded half a million tonnes and grew to nearly 5 million tonnes by 1921. The principal export markets were Britain and Continental Europe. Red Fife, while prized by millers and bakers, matured too slowly and was damaged by frost in some years. Prairie farmers urged scientists to identify or develop an earlier maturing variety.

The system of Dominion Experimental Farms was founded in 1886, with the first Prairie farm established at Brandon, Manitoba in 1888. The first director of the experimental farms, W. Saunders, imported many varieties and tested their maturity alongside Red Fife. In 1904, his wheat breeding program developed Marquis wheat, a cross between Red Fife and an early ripening Indian wheat. Marquis had early maturing qualities and the desirable milling and baking qualities. Commercial production began in 1910 and remained the dominant variety in the Prairies for 25 years.

As the volume of grain sales grew, farmers complained about the grades and weights that were assigned to shipments. The railways and grain elevator companies were also accused of giving unfair access to shipping facilities. The Canadian Grain Act of 1912 was passed to standardize grading and weighing of grain and to regulate the operation of elevators, the distribution of railway cars and the licensing of grain merchants. The Grain Research Laboratory was established in 1914 to improve information about the qualitative characteristics of grain. Scientific procedures were used to assess moisture content, milling yields and baking qualities, which varied with each new crop and the condition under which the grain was harvested and stored.

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*Canada was the leading world wheat exporter by 1916.*

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The 1909 to 1919 period became known as the “Golden Era” of agriculture. Canada was the leading world wheat exporter by 1916. During World War I, increased productivity was sought from all parts of the Canadian economy. The Minister of Agriculture urged farmers to increase production for patriotism first and profitability second.

### **Post World War I Agriculture**

Lower commodity prices and regional drought caused financial stress on many Prairie farms following World War I. The Saskatchewan government appointed a royal commission and Alberta set up an investigative board to inquire into farming conditions. Both inquiries pointed to the advantages of a diversified mix of crops and livestock, the potential for irrigation, and the need to improve soil conservation. While summerfallow was considered to be absolutely essential, it required precipitation before moisture could be stored. During periods of protracted drought, the practice of “dust mulch” created ideal conditions for wind erosion and soil drifting.

Agricultural development became feasible once more when the moisture conditions improved in the latter half of the 1920s. The wheat economy prospered again. Immigration revived, and the agricultural settlement moved northward with expansion into the Peace River Region in Alberta and British Columbia. Capital infrastructure of 2,900 miles of railway lines were added, along with new towns and villages. The 1936 Census recorded over 300,000 farms. At its peak, the Prairie farm population was 1.3 million and represented over 50 percent of all people in the Prairie provinces.

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*The comparative prosperity of the latter 1920s and the limited availability of farm labour provided impetus for a mechanical revolution in the wheat based economy.*

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The comparative prosperity of the latter 1920s and the limited availability of farm labour provided impetus for a mechanical revolution in the wheat based economy. The number of horses in the Prairie region peaked at 2.2 million in 1926, as gasoline tractors began to replace draft horses. The harvester combine and farm truck first appeared in significant numbers at the end of the 1920s. Mechanization and fossil fuels replaced workers and draft animals. With less land required to grow food for draft animals, export grain production expanded. With mechanization, reliance on fossil fuels also increased.

By the end of the 1920s, the era of substantial new settlement was drawing to a close. Prairie prosperity appeared to be permanent. The Federal government transferred statutory authority over natural resources to the provinces in 1930. Any crown lands still remaining under the control of the Dominion Government were transferred to the provinces at the same time. Just as the authority over natural resources was transferred, the Canadian economy collapsed into a lengthy depression. The financial problems were compounded in the Prairie region by low grain prices and drought. Federal transfer payments reached unprecedented levels and the Prairie region became an area of population loss. Within the Prairies, people moved north to the parkland belt from the short grass prairie country.

World wheat trade following World War I became less dependent upon exports. A resurgence of nationalism and a movement toward self-sufficiency increased European production of wheat. Tariffs were raised, import quotas imposed, minimum domestic prices were increased and often permits were required on imports. By 1934, France and Poland had become exporters through export subsidies and other special assistance measures of their own. In addition, the declining world income contributed to falling grain prices and trade.

During this time, the banking system and grain market were reforming to address issues of importance to farm organizations. Decentralized grain trading had been suspended during the war, and sales and pricing regulated by an appointed board. The board was dissolved after the war, but farm organizations sought the reconstitution of the board when prices fell in 1920 and 1921. Unsuccessful in their efforts, the co-operative marketing organizations, which controlled a third of the country elevators, banded together to establish a pricing arrangement where individual farm sales were pooled together. By 1928, this pool was buying 60 percent of the Prairie crop. By 1929, as prices began to fall, the pool stored more unsold grain. As prices continued to fall, the co-operatives requested loan guarantees from the Prairie Provincial governments. The Provincial governments agreed, but as borrowing increased, they turned to the Federal government for assistance.

When prices continued to fall, the wheat pools became financially insolvent and the government had to cover the loan guarantee. The pool was now taken over by the Federal government which proceeded to stabilize prices through market intervention. By 1935, the agency operating the wheat pool was, in effect, a part of the government policy and the operation was formalized under the provisions of the Canadian Wheat Board Act (1935). In the early years, the Canadian Wheat Board (CWB) set a minimum price which was guaranteed by the Federal government. Grain merchants could buy grain in competition with the CWB and sell in domestic and international markets. The primary objective of the CWB was to underwrite the minimum price and provide price stability.

In 1935, the Prairie Farm Rehabilitation Administration (PFRA) was created to develop programs to address agricultural cropping practices, land utilization and water conservation. The most pressing problem was widespread soil erosion. Demonstrations of trash-covered summerfallow and strip farming reduced erosion on land most suited for grain production. Some land was reseeded to grasses and consolidated into community pastures. A tree nursery was established to encourage farmers to establish shelterbelts along fields most prone to wind erosion. Water conservation strategies involved providing design and financial assistance toward the construction of dams and dugouts on individual farms. Irrigation came from larger dams such as the St. Mary dam in southern Alberta.

Provincial governments in Alberta and Saskatchewan implemented resettlement schemes. Land management agencies were given authority to withdraw land from agricultural production and control grazing rates. Methods of cultivation switched from plows to cultivators which left stubble near the surface. Ongoing research at the experimental farms developed rust resistant wheat varieties (Thatcher in 1935, Apex in 1937, and Regent in 1934) which removed one of the greatest hazards to Prairie wheat production. But drought persisted.

### **World War II to 1970**

The outbreak of World War II raised Prairie farmer expectations for increased exports at higher prices. Canadian wheat had been a highly valued commodity in World War I. Between 1938 and 1940, the seeded area expanded by 10 percent and, when combined with above average yields, there was sufficient inventory to meet allied import needs for the next 2 years. In the spring of 1941, a program limiting the area seeded to wheat was

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*In 1935, the Prairie Farm Rehabilitation Administration (PFRA) was created to develop programs to address agricultural cropping practices, land utilization and water conservation.*

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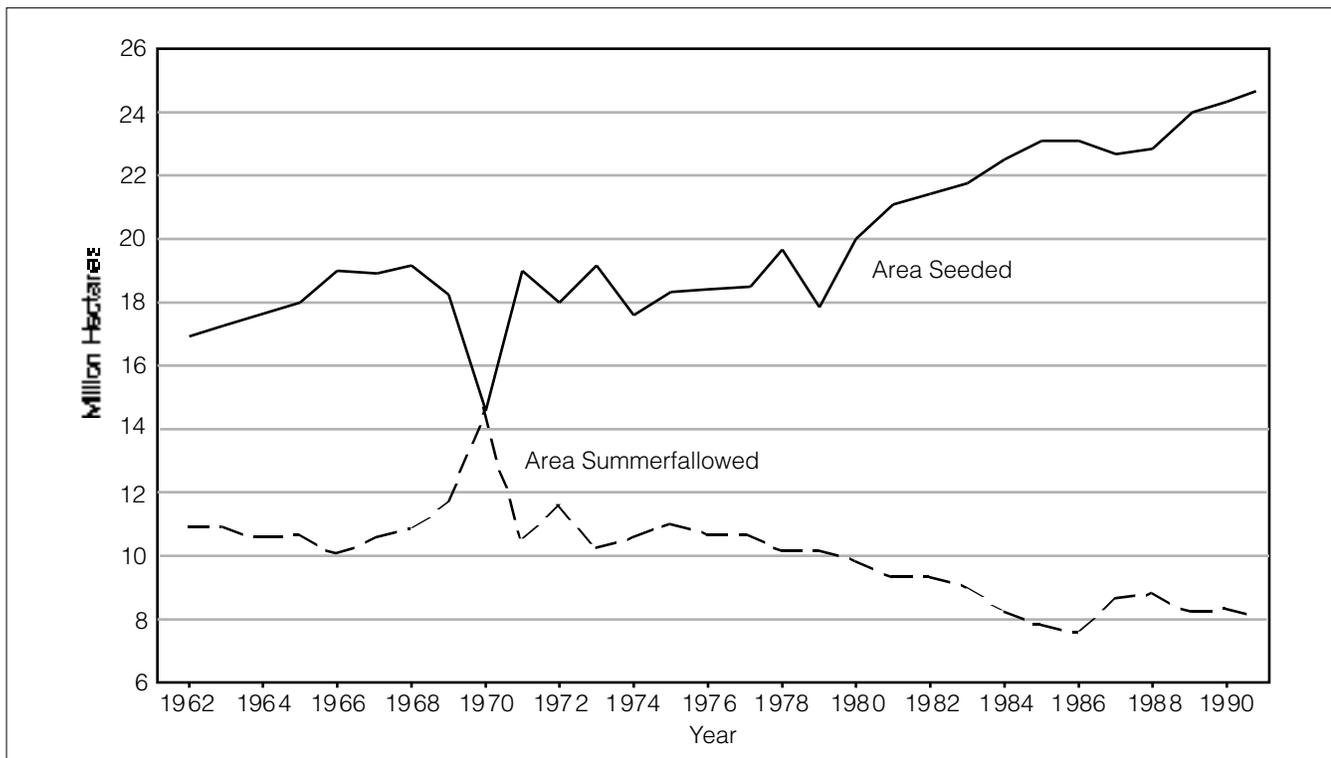
implemented to prevent an oversupply. Despite the soil conservation problems that the Prairies had recently experienced, the reduced wheat production policy did not focus on conserving the most fragile lands in the Palliser triangle. The program simply limited the wheat acreage without providing incentives for soil-conserving alternatives, such as retiring land to grasses. In response to the program, farmers merely replaced wheat with feed grains. These decisions met the most immediate needs of the day because pork exports to Europe reached their highest historical level during World War II (see Figure 1.7).

After the war, nominal and real prices for most commodities dropped as world supplies grew more rapidly than demand. Ongoing mechanization continued to reduce farm labour requirements, while the adoption of hybrid seed corn throughout the world lowered corn production costs and prices. Prices for Prairie feed grains dropped and the CWB lowered prices to remain competitive. In the case of wheat, the CWB attempted to adhere to the pricing arrangement in the international wheat agreement, but Prairie stocks began to accumulate as other countries undercut prices.

Prairie wheat production tended to outgrow sales, and with the world utilization of feed grains growing more rapidly than food grains, the Federal Task Force of the late 1960s recommended policies to divert land away from wheat production. By placing more emphasis on the rapidly expanding feed grain market, the Task Force believed the CWB could sell more barley and oats and farmers would accordingly grow less wheat. In addition, the report recommended reversing the trend towards annual increases in land cultivation by suggesting incentive programs to produce forage crops. High forage and feed grain consumption was projected if the Prairie farmers sought a larger share of the expanding beef industry.

**Figure 1.8**

*Prairie Land Utilized for Grains and Oilseeds.*



### Recent Events (1970-1992)

Immediately following the Task Force recommendations to reduce the land seeded to wheat, the Federal government offered payments for summerfallowing more land or seeding it to grasses. By 1971, the land diversion program was suspended as export opportunities improved. In effect, the land program was merely a means of managing wheat inventory. Figure 1.8 clearly shows the drop in the area seeded in 1970. During the 1970s this area continued to fluctuate between 18 and 20 million hectares. Since 1981, the area seeded has increased steadily to 23 million hectares. The 1970s represented the largest increase in the world trade of grain, while the 1980s represented a period with no growth. The irony of seeded Prairie land remaining relatively stable in the 1970s and increasing in the 1980s is rooted in agricultural and transportation policies.

In 1897, the Crow's Nest Pass Agreement between the Government of Canada and Canadian Pacific Railway stipulated a set of freight rates on grain destined for export. In 1927, the rates were extended to the Pacific Coast ports. Over time, the revenues from hauling grain fell short of the transportation costs. By the 1970s, a lack of grain transportation capital infrastructure and rolling stock limited the Prairie region's ability to ship grain to the growing export market. In spite of rising grain prices and expanding export opportunities, Prairie farmers did not increase the area producing these crops. Inventory discouraged farmers from seeding more land.

By 1980, the Federal and Provincial governments and the CWB invested in grain hopper cars to augment the shipping capacity of the railways. This was followed by the Western Grain Transportation Act which revised the statutory freight rates and transferred over \$700 million annually from the Federal government to the railways. The increased grain shipping capacity coincided with a downturn in world grain trade. In spite of declining prices, more and more land was seeded to cereal grains and oilseeds. Grain merchants exported the added production and the grain handling system shipped it. Besides the financial assistance to offset any railway shipping losses, the federal government buffered the drop in grain prices with stabilization payments and reoccurring ad hoc assistance to farmers producing cereal grains, oilseeds and pulse crops. The implicit assumption underlying the steadfast support for the grain industry was that the world grain trade would grow again and Prairie agriculture should retain the infrastructure for that time. Such policies have not only maintained the productive capacity, but have assisted in the continued upward trend of producing more cereal grains and oilseeds.

World trade in wheat was stable during the 1980s, while trade in coarse grains dropped after 1978. The demand side of world consumption of wheat is linked closely to population and income growth. World wheat consumption has tracked a long-term trend of an additional 11 million tonnes per year. Figure 1.9 shows that per capita wheat consumption grew at a compound annual rate of 1.3 percent from 76 kilograms per person in 1960 to 99 kilograms per person in 1980. During the 1980s, the annual growth rate fell to less than 1 percent. Even with no growth in per capita wheat consumption, the projected growth in population will require about 6 million tonnes more every year. Much of the population growth is projected to occur in regions where wheat production is low, suggesting the potential for an increasing world trade relative to total use.

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*The 1970s represented the largest increase in the world trade of grain, while the 1980s represented a period with no growth.*

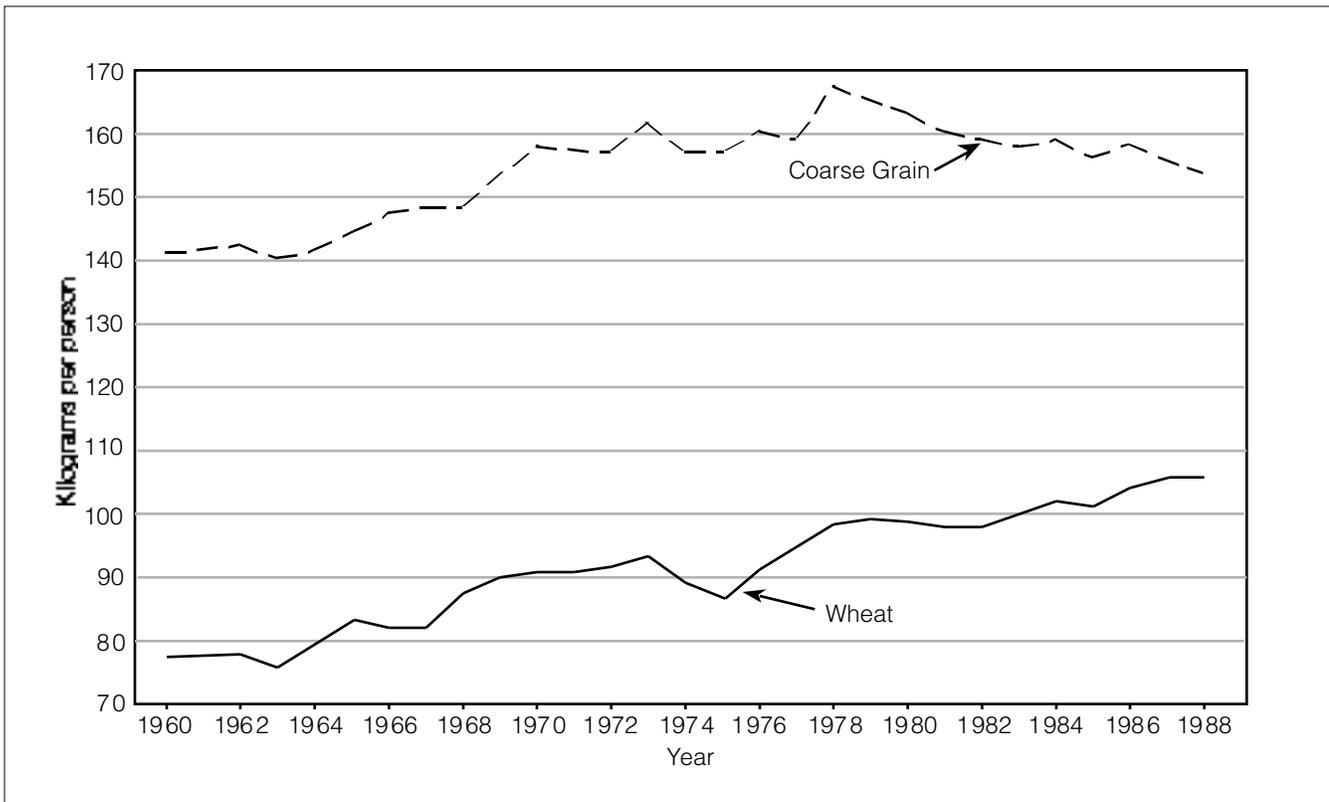
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*The Western Grain Transportation Act revised the statutory freight rates and transferred over \$700 million annually from the Federal government to the railways.*

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**Figure 1.9**

*World per Capita Consumption of Wheat and Coarse Grain, 1960-1988.*

Wheat consumption is less sensitive to a nation's income than coarse grains. Coarse grains are utilized by livestock. Since meat and dairy products are more of a luxury food than bread and pasta, substantial growth in coarse grain utilization will occur primarily as a result of more income. Figure 1.9 shows that world per capita coarse grain consumption increased from 140 kilograms per person in 1960 to 166 kilograms per person in 1978. Since 1978, per capita coarse grain consumption dropped to the point where current consumption has returned to the 1970 level.

Growth and decline of per capita consumption coincide closely with the rise and fall of economic growth in the less developed economies. Between 1965 and 1980, income in the developing countries grew by 6 percent annually, but this annual growth fell to 3.5 percent over the next 8 years. Coinciding with the growth in income was an exploding level of foreign debt, which grew from \$60 billion in 1970 to \$430 billion in 1980. With more funds required for debt repayment and slower income growth in the 1980s, the money available to upgrade diets in the developing nations diminished. Subsequently, world per capita consumption of coarse grain dropped.

The developed economies in Europe, North America and Asia also experienced a recession in the early 1980s, but the reduced level of income had minimal effect upon the consumption of feed grains in these areas. Similarly, as the developed economies increased their income every year between 1983 and 1990, this growth also had a minor effect upon world meat and dairy product consumption.

Prairie exports of wheat and coarse grain are also dependent upon world grain yields. Annual average world grain yields rose 3 percent in the 1960s, 2.6 percent in the 1970s

and just over 2 percent in the 1980s. Unless inputs are increased, or crop yield research raises productivity, the slower growth in yields will place increased reliance upon areas such as the Prairies. World population growth is projected to range between 1.2 and 1.7 percent over the next 50 years. If just the rate at which crop yields have grown is maintained, this suggests that the higher world population will consume all the increase with little improvement in diet.

The recent decade of a reduced or stagnant level of world grain trade is largely demand induced. If the economic circumstances that many developing nations found themselves in during the 1980s are permanent rather than temporary, the expanding trade opportunities of the 1970s will not likely return. Debt, high interest rates and recessionary conditions, however, are not permanent. Whereas the developing nations may not return to the growth experienced in the 1960s and 1970s, the conditions of the 1980s will not likely be perpetuated.

### **Future Demand for Prairie Agriculture and Sustainability**

Two scenarios are advanced for consideration. Under the first, it is conceived that importing nations will become more self-sufficient in domestic food consumption. The circumstances underpinning this phenomenon could be a greater growth in domestic crop and livestock production or a slower growth or even a drop in dietary living standards. Alternatively, a world with a higher growth in incomes, especially in the developing economies and the former centrally planned economies, will, in all likelihood, result in increased reliance on imports of grains, oilseeds and livestock products. The Prairie's capability of supplying a portion of the growing import needs will depend on issues of sustainability.

A stable or slow growth export market implies reduced economic opportunities unless the Prairies are able to capture a larger share of the world grain and livestock trade. A larger share can only be justified in an economic setting where the export revenues are sufficient to pay market-related costs of production, processing and distribution, and any associated environmental costs. Export earnings in the 1980s have fallen well short of meeting the market costs, even without including the environmental costs. A pending policy change in the trading regulations for the nations signing the General Agreement of Tariffs and Trade (GATT) would require agricultural exports to be less reliant on government subsidies.

In a no growth setting, the only way that Prairie agriculture could expand its share of the world grain trade in a post-GATT agreement would involve a protracted reduction in sales by Europe and the United States. Levels of government support for the grain industry are higher in Europe than in North America, while Australia and Argentina have the lowest subsidies. The latter two exporters are more likely than Canada to increase their share of a post-GATT world market. Whether the Prairies maintains or reduces its share of the world market, neither scenario will necessarily become the norm.

A trade setting with reduced regulatory barriers and subsidies will result in higher prices to exporting nations. But in some Prairie areas the increased market revenue will not equal the drop in government support. Without financial support to ease the transition, environmental damages are likely to occur in places where it is necessary to switch from a grain and oilseeds based economy to a more mixed farming system that includes grains,

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*Assistance to support environmental or conservation programs that achieve a more sustainable agricultural system is legitimate as long as the payments do not more than offset farmers' income losses.*

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*Conservation decisions are more difficult if more jobs and income are given up for a balanced ecosystem.*

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forages and ruminants. In some cases, the switch may be back to a more natural ecosystem. Personal savings, buildings, equipment and natural resources will be depleted in a bid to maintain the family farm. Working papers leading up to the GATT negotiations recommend that government support for structural adjustment should not contravene trading rules. Furthermore, assistance to support environmental or conservation programs that achieve a more sustainable agricultural system is legitimate as long as the payments do not more than offset farmers' income losses. Similarly, government expenditures related to research, extension and education would be exempt. Therefore, a world food market with little growth and fewer trade barriers and subsidies does not diminish the need for public involvement. In fact, only the nature of the support changes.

A world with increasing levels of international trade in the context of reduced trade barriers and agricultural subsidies presents a more challenging economic setting for sustaining Prairie agriculture. Rising export prices will likely more than offset reduced subsidy levels for most commodities. However, a change in the relative prices is likely to alter the comparative advantage between crops and livestock in some regions of the Prairies. With greater economic incentives to expand agricultural output, the opportunity cost of environmental regulations increases. Government programs which pay farmers to adopt conservation measures will be more expensive if it means sacrificing immediate market opportunities. Conservation decisions are more difficult if more jobs and income are given up for a balanced ecosystem. Science, with the objective of expanding agricultural output within the limits of the ecosystem, presents the primary opportunity to achieve both more food and a stable ecosystem. Farmers will be more inclined to adopt alternative farming systems and governments will be more willing to pursue conservation objectives if short-term losses are lower.

Scientific applications have successfully increased agricultural productivity and lowered food costs. In the past, agricultural science has focused upon raising crop yields and reducing year-to-year variability, along with improving animal health through nutrition and disease prevention. In a world with a growing demand for food, the challenge is to continue to do the same, but with minimal environmental side effects.

The purpose of this document is to demonstrate that the scientific community understands the ecological limits of Prairie agriculture and is capable of incorporating this knowledge into the way we produce crops and livestock. The chapters that follow discuss the critical limits for sustainable agriculture. They are presented from the perspective of Prairie climate, soils, energy, water, air and biology. In addition, the health of the consumer is examined from the perspective of food safety and nutrition.

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## 2. WEATHER AND CLIMATE RESOURCES FOR PRAIRIE AGRICULTURE

Weather and climate are both important factors that affect agricultural production. While the two terms are often used synonymously, there is an important distinction between them. Climate is the long-term weather pattern for an area and encompasses highs and lows as well as seasonal and year to year variations. Weather is a much shorter phenomenon representing the atmospheric conditions at a particular time and place.

While weather and climate can be important in all aspects of the agri-food system, including production, processing, and marketing, their main influence is on production. The potentials and limitations of agricultural production are influenced by a number of other factors. These include genetic potential of the organism to produce the commodity, other environmental conditions (such as competition with other organisms and pest and soil conditions) and inputs (for disease and pest control and for nutrient supply). Each factor places restrictions on production. For example, genetic constitution imposes a limit on the amount produced by a particular organism. This limit is not exceeded regardless of how favourable environmental and input conditions may be. In the same vein, there is a limit to the amount that can be produced under a given set of weather and climate conditions which cannot be exceeded after a certain level of inputs. Thus, besides determining potential for production, weather and climate have an important influence in defining the optimum level of inputs into the agricultural production management system.

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### Weather Limitations

#### Temperature

The climate of most of Manitoba is considered extreme continental, and that of Saskatchewan and Alberta is considered continental. Both of these climatic regions have a mean monthly temperature for the coldest month of less than 2 °C, a mean temperature for the warmest month in the range 10 to 20 °C, and an average of less than 50 millimetres of precipitation in the wettest month. The seasonal range for temperature is 20 to 36 °C for the continental climate, while the upper limit for the extreme continental is greater than 48 °C.

The mean annual temperature on the Prairies is lower than that of most other food producing regions of the world (Table 2.1), as a result of a lower average temperature during the coldest month. The average temperature of the warmest month (which includes the growing season) is not substantially lower than that at many other locations, excluding the tropical regions.

An important agroclimatic characteristic of a region is the duration of the frost free period. This is because the freezing point of water, 0 °C, defines the lower limit for survival of most plants during the period of active growth. The suitability of a region for producing a particular crop can be determined by comparing the number of days required to reach maturity to the frost free period of the area. On the Prairies, less than one-third of the year is free of frost! This is substantially less than that in other parts of southern Canada, as well as those parts of the United States and Europe which produce similar agricultural commodities. Some hardy species are able to tolerate temperatures slightly below freezing, e.g. - 2 to -5 °C, during the active part of their lifecycle. Perennials can tolerate temperatures of -20 °C and lower in the dormant (winter) phase of their lifecycle.

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*The mean annual temperature on the Prairies is lower than that of most other food producing regions of the world.*

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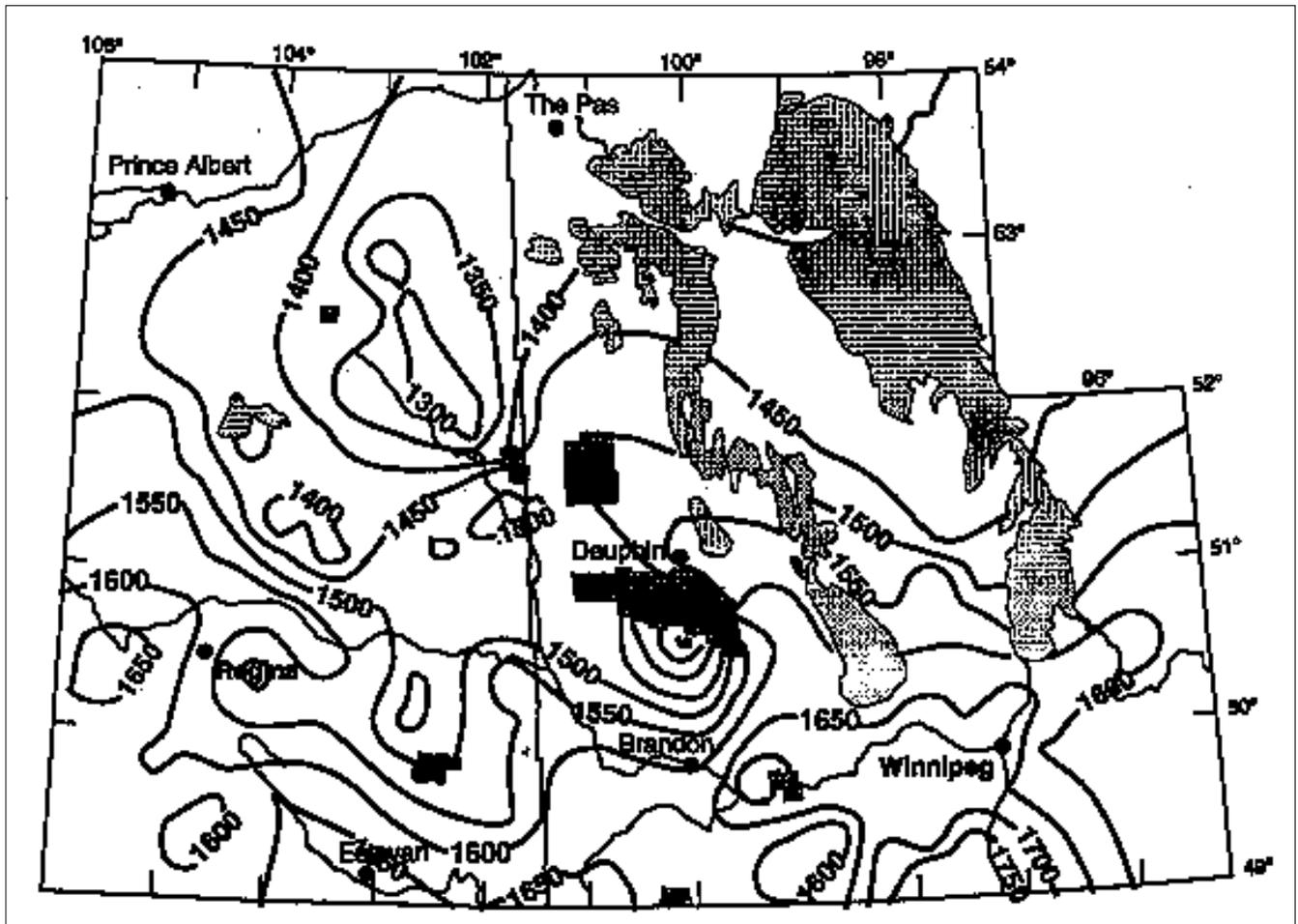
	Mean Annual Temp. (°C)	Mean Temp. Coldest Month	Mean Temp. Warmest Month	Frost Free Period (days)	Degree days > 5°C	Mean Annual Precip. (mm)
<b>Prairie Cities</b>						
Winnipeg	2.3	-18.3	19.7	121	1785	535
Regina	2.1	-17.3	18.9	109	1677	398
Saskatoon	0.1	-17.3	19.1	117	1620	353
Lethbridge	5.4	-9.4	18.8	124	1776	424
Edmonton	1.4	-16.3	16.1	105	1328	459
<b>Other Areas of Canada</b>						
Vancouver	9.8	2.4	17.4	216	1994	1068
Toronto	7.5	-6.3	20.7	149	2127	752
Montreal	6.5	-9.9	21.2	157	2113	941
Halifax	6.0	-5.9	18.1	155	1694	1396
<b>Other Areas of the World</b>						
Omaha, U.S.A.	10.3	-5.0	25.0	189	-	736
Denver, U.S.A.	8.1	-1.0	21.0	150	-	357
Rio de Janeiro, Brazil	23.2	22.0	24.0	-	-	1027
Buenos Aires, Arg.	16.1	10.0	23.0	-	-	1027
Kiev, Ukr.	6.8	-4.0	21.0	165	-	615
Lyon, Fr.	12.8	2.1	21.0	-	-	827

<sup>1</sup> Dashes (-) indicate that no data could be obtained.

**Table 2.1**

*Comparison of Climate Characteristics of Several Locations on the Prairies with Other Parts of Canada and the World.<sup>1</sup>*

The temperature required to allow for a reasonable rate of the chemical and biological reactions responsible for growth is called the threshold temperature, and is, on average for most plants, in excess of 5 °C. One of the simplest ways to quantify the amount of heat useful for plant growth and development is to average the maximum and minimum temperatures for a day and from this subtract the threshold temperature. This gives the degree day or heat unit accumulation for that day. These may be calculated for every day from planting to maturity and summed to determine a degree day requirement for a particular species. This might be in the order of 1,200 degree days above 5 °C for wheat. Using weather station data accumulated over a number of years, one can calculate an average growing season degree day accumulation for an area. Figure 2.1 provides such an example for Southern Manitoba and Southeastern Saskatchewan. Comparing the degree day requirement of a species with this average will give some indication of the potential for growing that species in that region.



**Figure 2.1**

*Average Accumulated Number of Growing Degree Days above 5°C, for Southern Manitoba and Southeastern Saskatchewan (centre line denotes provincial border with Saskatchewan to the left and Manitoba to the right).*

Degree day accumulation is substantially lower on the Prairies than on the West Coast or central Canada. Thus, the kind of agriculture that can be practiced on the Prairies is much more restricted than that in other regions.

While crops have no choice but to assume the temperature of their environment, animals control their body temperature. The further environmental temperature is from the ideal range, the more effort the animal has to exert to keep its body temperature constant. As a consequence, the animal's productivity is decreased. The effect of temperature on the productivity of animal agriculture will be discussed in more detail in a later section.

### Precipitation

Average annual precipitation in the agricultural regions of the Prairies varies from about 500 millimetres in eastern and northern regions to about 300 millimetres in those southern regions centred on the Alberta-Saskatchewan border. The relatively low mean annual precipitation is considerably less than that in other parts of Canada and the world (see Table 2.1).

The most important characteristic of Prairie precipitation is that it produces a water deficit situation, i.e. much more water could be evaporated from natural and agricultural

surfaces than is available from precipitation. Of the precipitation that falls on the Prairies, 20-25 percent is snow, 40 percent is rainfall during the growing season for wheat, and 35-40 percent is rainfall outside of the growing season.

About two-thirds of the water used by wheat is from rain that falls during the growing season, the remainder comes from soil moisture stored outside the growing season.

Another important characteristic of Prairie precipitation is the extreme variation, both spatially within a season or year and from year to year. This has important implications for Prairie agriculture and will receive detailed attention in the following sections.

### Wind

High winds are an important constituent of Prairie weather and climate. Mean annual wind speed in many Prairie locations is 18-21 kilometres per hour, while in Vancouver it is 12 kilometres per hour, and in Montreal and Toronto it is about 16 kilometres per hour.

As wind greatly influences the evaporation of water, much of the dryness of the Prairie climate can be attributed to wind. In combination with precipitation patterns and evaporation conditions, wind determines the amount of soil erosion and resulting land degradation that occurs. This issue will be dealt with in some detail in the chapter dealing with land.

In animal agriculture, wind is most important to animals not housed in winter since it influences the amount of heat that is lost from the animal. As will be discussed later, this has a major influence on animal productivity.

## Requirements for Crop Production

The two most important weather elements that affect plant biology are temperature and precipitation. In certain instances, other weather elements may also be important, as will be discussed in later sections.

### Temperature Requirements

Many of the thermal requirements for crop production have been outlined above. Requirements for frost free period of many crops are listed in Table 2.2. The significance of these data is illustrated when considering frost statistics for the Prairies (Table 2.3). While most of the crops listed have a growing season requirement which falls within the available time, crops such as sunflowers and corn require more days to reach maturity and therefore can be grown in only a few locations on the Prairies.

A better measure of the potential for crop production is useful heat, i.e., degree day accumulation such as that in Figure 2.1. As mentioned earlier, wheat requires 1,200 degree days above 5 °C. Figure 2.1 shows that this requirement is met over all of the eastern Prairies.

Calculation of degree days is a first approximation of the amount of useful heat in an environment. Research has led to the development of more complex equations which more accurately describe the way in which plants respond to temperature. In some cases, there has been an effort to determine the combined effect of day length and temperature

	Wheat	Oats	Barley	Flax	Canola	Sunflowers	Corn	Navy Beans	Buckwheat
No. of Days	90-100	85-88	60-90	85-100	92-102	120-130	110-120	90-100	80-90

on plant growth and development. The effect of day length is particularly important on the Prairies because of the large variation in latitude within the agricultural region. For example, the longest days in the Peace River region of British Columbia can be just over 17 hours compared to just over 16 hours at the Western Canada-United States border. Many crops, such as wheat and corn, respond quite differently in the two environments.

Maps showing the thermal resources for plant agriculture (i.e., frost free periods, heat units) are available in publications such as the Agroclimatic Atlas of Canada. More detailed maps are available on a provincial or regional scale. These maps can be used to define the maximum level of production, as determined by weather and climate, which might be sustained in these regions.

*Temperature Variation and Extreme Events*

One of the most difficult factors in assessing agricultural potential on the Prairies is the year to year variation in weather. Agricultural potential is assessed mainly by using average values of weather characteristics. There is a great danger in doing this because average weather conditions do not necessarily produce average yields. For example, yields can be decreased by both low and very high precipitation. Thus, the highest yields are obtained when rainfall is average or slightly above average.

As indicated above, the growing season for many crops is defined by the last frost in spring and the first frost in autumn. For many locations on the Prairies, the last spring frost occurs, on average, in late May or early June, while the average date of the first autumn frost is early to mid-September (see Table 2.3). The average frost free period, i.e., the length of time between the last spring and first autumn frost, varies between about 90 and 125 days, with more northerly and higher elevation locations having the lower values.

The variability of frost characteristics is described by the standard deviations in Table 2.3. An approximate definition of the term standard deviation is that two-thirds of the time

**Table 2.2**

*Number of Days Required for Some Crops to Grow to Maturity.*

**Table 2.3**

*Frost Statistics for Several Prairie Cities.*

	Last Spring Frost		First Autumn Frost		Frost Free Period	
	Mean	Standard Deviation (days)	Mean (days)	Standard Deviation (days)	Mean	Standard Deviation (days)
Lethbridge	May 21	7.4	Sept. 15	10.4	121	14.8
Edmonton	May 13	10.4	Sept. 18	11.9	129	17.8
Regina	May 28	13.3	Sept. 8	15.5	102.9	19.5
Swift Current	May 20	14.8	Sept. 15	10.4	117	14.8

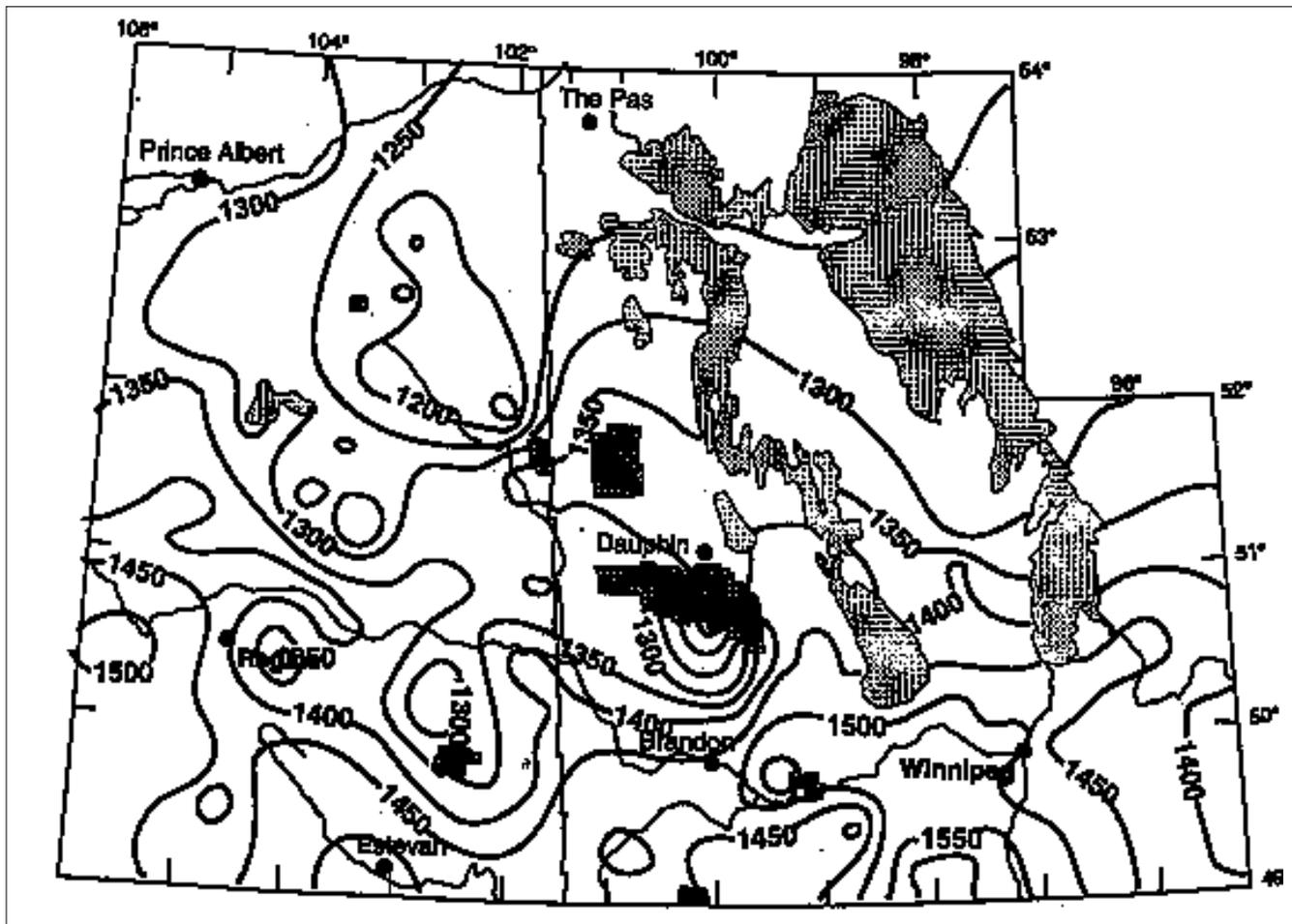
the actual value will occur within one standard deviation of the average. For example, on average the last spring frost in Regina occurs on May 28; two-thirds of the time it will occur between (May 28 -13.3 =) May 15 and (May 28 +13.3 =) June 10, a range of 26 days. Also, one year in six, the last spring frost will occur before May 15 and one year in six after June 10. Thus, while averages of frost statistics may leave the impression that the Prairie climate is quite favourable for agricultural production, the large standard deviations mean that the risks are quite high.

**Figure 2.2**

*Minimum Accumulation of Growing Degree Days above 5°C at a 10 Percent Risk, for Southern Manitoba and Southeastern Saskatchewan (centre line denotes provincial border with Saskatchewan to the left and Manitoba to the right.)*

Natural year to year variation in temperature leads to year to year variation in useful heat, i.e., growing season degree day accumulations. Thus, it is important to consider not only the average value (Figure 2.1), but also the probability distribution of this weather characteristic. With this, one can calculate the degree day accumulation associated with a given level of risk. For example, at 10 percent risk this would be the lowest degree day accumulation which would occur one year in ten. From Figure 2.2, degree day accumulations at this risk level are about 150 less than the averages shown in Figure 2.1. It is this 10 percent (or some other appropriate level) risk map, and not the average, which should be used in deciding whether a certain crop should be grown in a given area.

While risk maps are helpful in agricultural production, extreme events are virtually impossible to prepare for. In the case of frost, an extreme event was the frost of August 27,



1982. This affected a large area across the Prairies, and caused losses in terms of both yield and quality of the Prairie wheat crop. This event had only a 3 percent probability of occurrence, but had a devastating effect on Prairie wheat farmers.

Abnormally high temperatures in the summers of 1988 and 1989 have led some to speculate that the climatic warming predicted by meteorologists has already arrived. The climatic record does not always support such speculation, as illustrated by comparing values of degree day above 5°C accumulations during the 1980s. It turns out that while 1988 and 1989 were record high years, with degree day accumulations in excess of 1900, 1985 was in fact the lowest of the preceding 50 years, with a degree day accumulation of only 1428. Many crops which usually having no difficulty reaching maturity on the Prairies were lost due to insufficient heat in 1985.

### Water Requirements

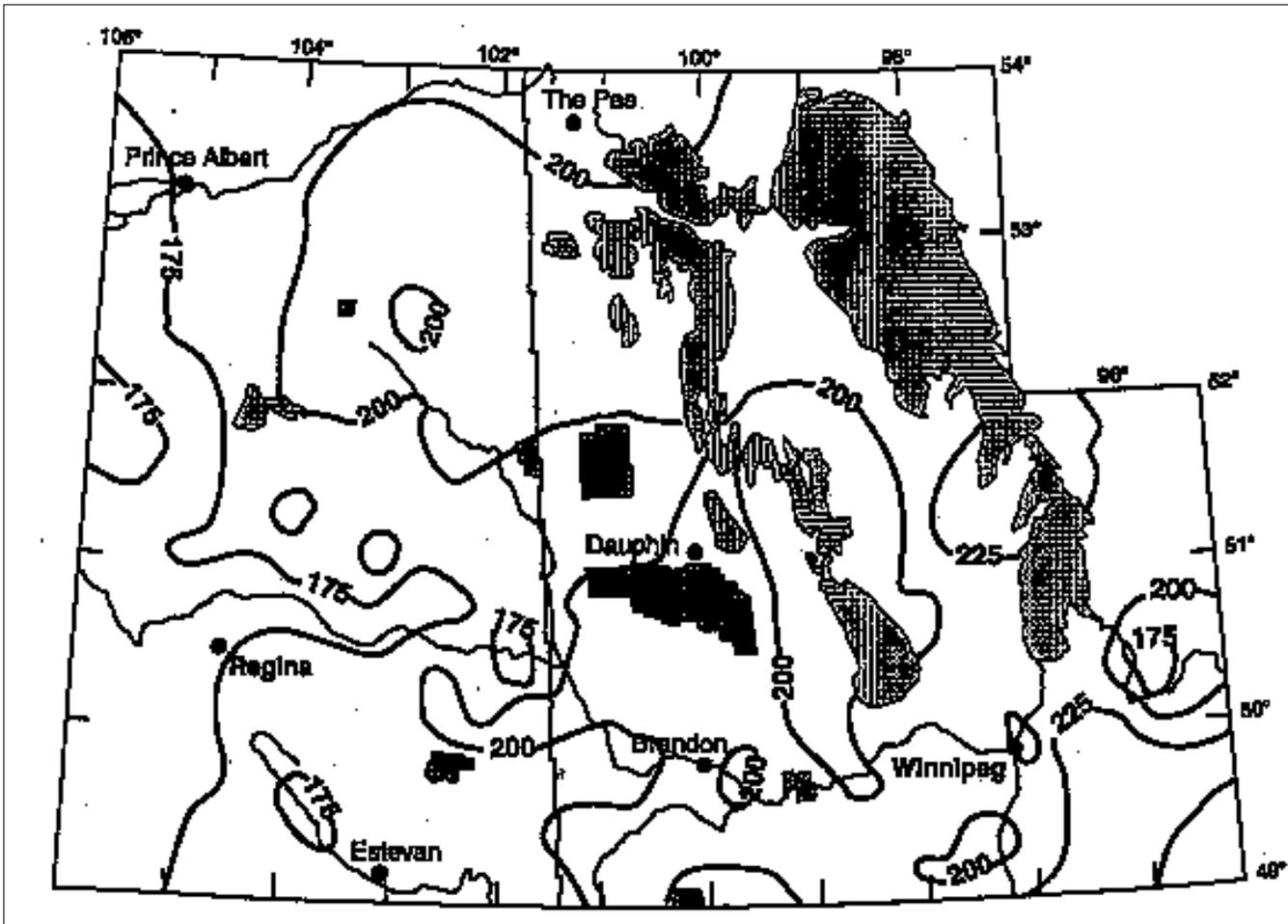
Droughts, such as the one that occurred in 1988, illustrate the importance of water in agricultural production. The amount of water considered ideal for agricultural production is not commonly understood. Quantifying this amount requires considering some basic principles.

The capacity of the atmosphere to evaporate water from the earth's surface is determined by weather conditions, such as intensity of solar radiation, temperature, relative humidity and wind. This atmospheric demand is met if the evaporating surface is well supplied with water, e.g., the surface of a lake. This demand is also met by a vegetative surface which completely covers the ground and is well supplied with water. Thus, a perennial forage crop such as alfalfa, which completely covers the ground with actively growing vegetation for virtually the entire growing season, is capable of using water at a rate equal to atmospheric demand. On the Prairies, growing season atmospheric demand and, therefore, the demand by forage crops, ranges from 500 millimetres in the cooler northern locations to about 700 millimetres in the hotter southern regions.

Since potential water use is proportional to green leaf area, the capacity of a crop like wheat to use water is less than atmospheric demand. The leaf area of wheat is non-existent at planting, increases to its maximum at flowering, then as the crop matures becomes inactive and ceases to require water. Water demand by wheat on the Prairies varies with year and location, but is generally in the range of 280 to 350 millimetres per year. By comparison, growing season precipitation averages 150 to 225 millimetres (Figure 2.3), a shortfall of about 100 millimetres compensated for by soil moisture stored outside the growing season or, alternatively, irrigation. Because the shortfall is only partly supplemented, Prairie wheat yields are usually limited by lack of moisture.

#### *Precipitation Variation and Extreme Events*

Figure 2.3 can be used to illustrate the magnitude of year to year variability in rain that falls during the growing season of wheat in the Eastern Prairies. From Figure 2.3, the average growing season rainfall in most of Manitoba is in the order of 200 millimetres. (Note that this is approximately two-thirds of the water requirement for wheat). As one moves west into Southeastern Saskatchewan, average growing season precipitation decreases to 175 millimetres, while for Northeastern Saskatchewan it is 200 millimetres.



**Figure 2.3**

*Average Accumulated Growing Season Precipitation (millimetres) for Wheat, for Southern Manitoba and Southeastern Saskatchewan (centre line denotes provincial border with Saskatchewan to the left and Manitoba to the right).*

Risk maps that show the 25 percent risk of dry conditions for rainfall during the growing season of wheat (i.e., over the long term, one year in four will have this much growing season precipitation or less) have values that are approximately 50 millimetres lower than the average values. Note that this difference is greater than the spatial variability of the average values. Similarly, risk maps that show the 25 percent risk of wet years have values that are approximately 50 millimetres higher than those for the average.

Droughts are the precipitation extreme events which have the greatest impact on agriculture. While many people remember 1988 as the most severe drought year on the Prairies, climatic records show that 1961 was the grand-daddy of Prairie droughts. A comparison of growing season precipitation for 1961 versus 1988 for three Prairie locations is as follows: Winnipeg - 88 versus 164 millimetres; Brandon - 90 versus 175 millimetres; and Regina - 85 versus 102 millimetres. In all three locations the growing season precipitation of both years was less than half the long-term average value (see Table 2.1 for the mean annual precipitation for Winnipeg and Regina).

Precipitation on the Prairies is extremely variable spatially, particularly in drought years. For example, the 1980 growing season precipitation for Winnipeg and Regina was 80 and 108 millimetres, respectively, while at Brandon it was 146 millimetres.

At the other extreme, there are also times when excess precipitation severely limits production. Such was the case in 1974 when very heavy spring rainfall delayed seeding operations by 3 to 4 weeks over most of the Prairies. This delay, combined with a subsequently dry summer, resulted in low levels of production.

Extreme events in growing season precipitation occur with a certain amount of regularity over time. In addition, local situations may be quite different than the regional average. Both these facts need to be considered when developing a strategy for sustainable agriculture.

### **Wind**

Although there is little quantitative knowledge of the effects of wind on agriculture, a number of qualitative comments can be made. For example, wind is important in determining the atmospheric demand for water from plant surfaces. Thus, a location such as Lethbridge, with an average annual wind velocity of 20.4 kilometres per hour, would have a higher atmospheric demand than another location which has a similar climate but a lower wind velocity. The higher demand would increase the water stress on crops and result in lower production.

Wind, especially in combination with rain, may cause crops to lodge, resulting in poorer crop yield and quality. Wind can also destroy crop seedlings, forcing farmers to replant crops. The soil erosion produced by wind is a major source of soil degradation on the Prairies. This problem will be discussed in some detail in Chapter 4.

## **Requirements for Animal Production**

Animal production necessitates the provision of adequate nutrients, a suitable climate (temperature and photoperiod) and freedom from health disorders. Traditional domestic animals have a remarkable ability to survive the wide extremes in the Prairie climate, but outside of a specific narrow range of conditions will likely not produce maximum performance or production profitability. Extremes in temperature are the climatic factors which most strongly affect animal production on the Prairies. Prairie winds can magnify these effects. Water restrictions can usually be alleviated by on-farm supply management.

### **Temperature Requirements**

The range of still air temperatures in which a particular animal can survive is called its Zone of Survival, bordered by the Cold Zone and the Hot Zone. Within the Zone of Survival is a narrower range called the Thermal Neutral Zone, which is the maximum temperature for animal comfort and performance. The use of nutrients and level of productivity become inefficient and potentially negative outside the Thermal Neutral Zone.

For any animal maintained at Cold Zone temperatures, reductions in production efficiency can occur and are the result of many factors. Animals kept at their Cold Zone temperature experience a rise in resting metabolic rate (the amount of energy required to maintain the animal, for example, from shivering). This high rate reduces the growth/production yield from a given feed input. Since Prairie beef cattle are traditionally housed outdoors, there are many occasions when these animals are exposed to Cold Zone

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*Extreme events in growing season precipitation occur with a certain amount of regularity over time.*

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*The soil erosion produced by wind is a major source of soil degradation on the Prairies.*

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temperatures. Within the winter temperature ranges characteristic of the Prairies, 20 to 30 percent more feed may be required to maintain ruminants.

The feed energy used to support the increase in metabolic rate will not support the production of, for example, meat, fat and milk. In extreme cases, if the majority of consumed feed energy merely maintains the animal, then some of the costly feed ingredients (protein and vitamins) may be wasted because the product for which they are required will not be produced. Protein content of feed, therefore, can be reduced during cold weather with no deleterious effect.

In most species, the animal's increased *ad libitum* intake in a chronic cold environment does not match the increased feed energy requirement. As a result, such productivity as growth or milk production will be further reduced.

Prolonged exposure of ruminants to Cold Zone temperatures will reduce production and fibre digestion as the rate of passage of the feed through the rumen increases.

In hot environments the opposite occurs, with animals reducing intake in order to decrease body heat production and thereby lessening their thermal imbalance. The effect of this is reduced intake can be cushioned by ensuring that feed is available during the cooler part of the day. Severe heat stress conditions, however, are rare on the Prairies.

When housed outdoors on the Prairies, most domestic animals will be exposed to production impairing climatic conditions for an economically important proportion of the time. It has been found most efficient to provide an indoor heated environment for species like poultry and swine which are in their Cold Zone for much of the time. The neonates of all domestic animals are particularly cold intolerant, having a much narrower Zone of Survival. Some degree of shelter is required to avoid frost-bite and death of new-born animals.

Besides the direct effect on feed energy requirements, temperature influences many other physiological functions. These influences are manifested mainly in the animal's reproductive capabilities and responses to other stress factors. Extremes in either heat or cold, like other stresses, cause impaired reproduction function in both the male and female. The warm summer temperatures of the Canadian Prairies have been shown to significantly reduce swine and cattle fertility, although the decrease is much less than that seen in more equatorial regions. If winter breeding of swine is desired, heated facilities are absolutely necessary.

Reproduction is influenced by photoperiod as well as temperature. Many species are seasonal breeders in that either a decrease or increase in the number of daylight hours causes the animal to cycle. This must be considered when introducing new breeds or species into a particular geographical location.

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*Animals under climatic stress will also be more susceptible to infectious agents, since stress impairs the immune system.*

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A better understanding of the effects of temperature and other climatic factors on animal reproduction could lead to management strategies which would maximize reproductive performance on the Prairies.

Animals under climatic stress will also be more susceptible to infectious agents, since stress impairs the immune system. Infectious agents, parasites and insects thrive under certain climatic conditions. However, Prairie animal production is only minimally affected by these factors because of the cold, dry climate.

Some of the long-term effects of exposure to Cold Zone temperatures do not occur in ungulates native to cold regions. Presumably, a natural selection process towards more energy conserving mechanisms has occurred, the thermal insulation provided by the hair coat having improved. This insulation reduces the lower limit of the Thermal Neutral Zone and therefore reduces the number of days that an animal will be subject to Cold Zone temperatures.

**Wind**

Wind affects animal productivity in two ways. First, heat loss by convection from all surfaces is increased. Second, the hair coat of the animal is disrupted and thus the thermal insulation is reduced and heat loss is further increased. To account for the effect of wind, it is common to refer to values of Equivalent Still Air Temperature (ESAT). For example, in terms of rate of heat loss from an animal or the effect of weather on animal productivity, a temperature of -10 °C with a 30 kilometre per hour wind has an ESAT of -20 °C. The temperature demarcating the upper limit of the Cold Zone (and the lower limit of the Thermal Neutral Zone) is called the Lower Critical Temperature (LCT), the temperature below which animal productivity will be reduced. Table 2.4 lists the LCT for a variety of domestic species. Values are given in ESAT and also in an example with a wind speed of 30 kilometres per hour.

**Table 2.4**

*Lower Critical Temperatures of Some Agricultural Animals.*

	Lower Critical Temperature (ESAT, °C)	Lower Critical Temperature with 30 km/hr wind (°C)
Beef cow (dry, pregnant)	-19	-7
Feedlot steer	-35	-16
Calf (at birth)	9	16
Sow (lactating)	2	10
Grower pig (100 kg)	14	19
Piglet (2 kg)	31	NA
Layer chicken	18	23
Chick	34	NA

ESAT - Equivalent still air temperature; NA - not available.

**Climate Issues for Sustainable Agriculture**

**Climate Variability and Risk Reduction**

One of the objectives of sustainable agriculture must be to minimize either the variations in production, or the economic effects of the variations. Climate variability is considered by some to be the most important contributor to short-term variability of crop yield. The effect of climate variability on Prairie agriculture is illustrated by data on crop losses due to various weather conditions (Table 2.5). What is particularly striking in the table is the year to year variation in losses due to a particular adverse weather condition. Thus, the losses due to frost were over \$10 million in 1982 and 1985, and practically negligible in

1983 and 1984. Other climatic conditions, such as wind, drought, hail and excessive heat have also proven quite costly.

Climate Condition	1982	1983	1984	1985
Frost	\$ 11,667,953	\$ 212,542	\$ 278,320	\$ 10,281,932
Excess Moisture	1,095,840	2,842,831	1,591,708	5,946,983
Wind	123,790	753,466	1,494,607	5,319,024
Drought	1,631,286	5,343,864	10,573,866	2,508,534
Hail	992,503	855,815	1,153,102	412,462
Heat	7,030	4,152,090	1,002,932	-
All Causes	\$ 16,712,673	\$ 15,096,410	\$ 17,482,451	\$ 26,611,068

**Table 2.5**

*Value of Crop Losses in Manitoba due to Adverse Weather, 1982-1985 (these numbers do not include losses due to hail spot damage or unseeded acreage).*

Another striking feature of the data in Table 2.5 is that crop losses from drought can occur in the same year as crop losses from excess moisture. Thus, as far as agriculture is concerned, it is a gross oversimplification to talk about the Prairies being either wet or dry in any one year. These differences in moisture conditions could occur in two different parts of the Prairies or in the same area all within the same year. In other words, Prairie agricultural production is affected by the weather's spatial and temporal variability.

In the following sections we will briefly consider how we might alleviate the effects of climate on variability in production.

### Technology

Stabilizing agricultural production might be achieved by using species which are less sensitive to the stress conditions created by climate variation. Thus, plant breeding programs which try to produce such species would contribute significantly to sustainable agriculture. Substantive yield increases would result in parts of the Prairies through greater water use efficiency. Such efficiency could be reached by increasing the storage of water from snowmelt, early planting, preventing runoff and evaporation during field operations, and other improved agronomic practices.

Mechanization has assisted in decreasing the effects of climate variability. The advent of large machinery on the Prairies has meant that many crops which might not have been seeded or harvested half a century ago now add to overall production. Grain drying technology has alleviated the problems of grain harvested at high moisture levels. While mechanization has assisted in conditions such as climate variability, it has created its own set of problems which will be discussed in later chapters (e.g. dependence on fossil fuels, soil compaction, large unsheltered fields). In order to contribute to an agricultural system which, from an overall context, is sustainable, these problems will have to be considered and accounted for in future developments.

Another form of technology which can assist in dealing with weather risk factors is through crop modeling. Crop growth models make use of our knowledge of weather elements, soil properties, and crop characteristics and requirements to give a mathematical description of crop growth.

*As far as agriculture is concerned, it is a gross oversimplification to talk about the Prairies being either wet or dry in any one year.*

One such model uses four production levels which are determined by environmental factors, these levels and their conditions being: water and nutrients are never limiting; water is limiting at least some of the time; water or nitrogen is limiting, as well as weather at times; and availability of nutrients is the main limitation.

Since 80 percent of Prairie wheat is exported, it is useful for the Canadian Wheat Board to have reliable estimates of the amount of grain that will be harvested and available for sale each year. The Prairie Wheat Yield Simulation Model (PWYSM) was developed to simulate wheat growth in the computer while the crop is actually growing in the field. The model makes use of precipitation, temperature (including accumulated heat units) and crop water use information to estimate growth. When the PWYSM estimates yields from a regional mean drought index, the forecasted yields correspond well with actual yields. PWYSM does a better job than previous wheat-weather models because it incorporates reasonable but simple physiological concepts.

Weather variability also influences the producers' ability to conduct field operations. Models using weather data have been developed to determine the days when soil moisture status is low enough to permit field operations. Table 2.6 shows days available for harvest and post-harvest operations at various locations on the Prairies. Using Swift Current as an example, the data may be interpreted as follows: in 50 percent of the years, 30 days - the maximum - are available for field operations; in 30 percent of the years, 28.8 days or less will be available; while in 10 percent of the years, only 17.5 days or less will be available. The data show that for locations like Edmonton and Winnipeg, one year out of ten will be marginal in terms of adequate time to conduct fall field operations.

Similar probabilities for spring workdays, i.e., relating to planting operations, are also available. Like the above, they show that weather variability creates real risks to the producers' ability to plant crops. These risks must be considered when assessing the sustainability of Prairie agriculture.

*For locations like Edmonton and Winnipeg, one year out of ten will be marginal in terms of adequate time to conduct fall field operations.*

**Table 2.6**

*Number of Fall Field Workdays Available (maximum = 30) on Heavy Prairie Soils, August 21 - September 20, at Three Risk Levels (% Risk indicates the percent of years these fall field workdays would be available).*

% Risk	Lethbridge	Edmonton	Swift Current	Regina	Winnipeg
50	30	30	30	30	30
30	29.9	27.4	28.8	30	22.4
10	20.9	14.8	17.5	20.3	11.6

*Weather and Climate Information and Forecasting*

Basic information on climate is available in publications such as the Agroclimatic Atlas of Canada. In recent years, a number of projects characterizing the climate of all or parts of the Prairie region have been completed (for example see Dzikowski and Heywood, 1990, in the Reading List). These publications consist of maps and tables of characteristics which have particular meaning to agriculture, e.g., degree day maps which can be used to assess the potential for production of a particular crop. No doubt continued effort in this area will contribute significantly to the development of a sustainable agriculture on the Prairies.

The science of weather forecasting is continually making progress and agriculture will no doubt benefit from this progress. Apparently, 6 to 10 day forecasts are on the horizon which will greatly assist producers in short-term planning.

Weather forecasts assist the producer in making decisions such as when to apply herbicides, or if grain should be harvested moist. However, even with an accurate forecast a response is not always feasible, such as when large farm size precludes any response or a late spring frost occurs after crops are already in.

Another source of information useful to the agricultural industry is agrometeorological advisories, prepared by the Atmospheric Environment Service. The advisories are issued weekly and give information on weather in the growing season to date, i.e., a summary of the cumulative effect of the weather in the current growing season up to the present time. The kind of information given might include an estimate of the stage of development of wheat and, given normal weather in the remainder of the growing season, an estimate of date of maturity. This kind of information assists various sectors of the agricultural industry in short-term planning.

#### *Crop Insurance*

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*Crop insurance is insurance against crop failure, with bad weather being the basic cause of such failure.*

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Crop insurance is insurance against crop failure, with bad weather being the basic cause of such failure. The degree of coverage for a particular crop is usually based on the average yields obtained over the previous 15 to 25 years for the particular area.

In recent years, certain criticisms have been levelled at crop insurance. The long term average yield is calculated by including even those crops produced under poor management and at a time when technology was less advanced. Many producers feel that using this criterion as the insurable level is too restrictive. They believe that they can produce much more than the historical average most of the time, and thus, there is very little reason for them to take out crop insurance. Clearly, this situation warrants investigation and it may be that crop models, such as those described earlier, may have an important role to play in these investigations.

#### **Global Warming**

A change in the climate of a region will affect both the amount of agricultural production and the nature of the production system or systems that are sustainable. Although any type of climate change may be important, global warming is often perceived to have the greatest potential to affect agriculture in the Canadian Prairie region.

#### *Human-Induced Climate Change*

Global climate warming and cooling, which basically mean an increase and decrease in the earth's average temperature respectively, are not new phenomena and have followed a cyclical pattern for millions of years. It is thought that these cycles have been caused by natural events. In recent years, however, many scientists have come to believe that human activities (e.g., the burning of fossil fuels and extensive deforestation) may be changing these natural cycles of warming and cooling. These activities have increased the atmospheric concentrations of gases such as carbon dioxide (CO<sub>2</sub>), chlorofluorocarbons (CFCs), methane, nitrous oxide and ozone. Collectively, these gases are referred to as

greenhouse gases, and the global warming effect that they are hypothesized to cause is called the greenhouse effect.

The greenhouse effect gets its name from the way in which these gases act in the atmosphere (i.e., like the glass in a greenhouse). Short-wave radiation emitted by the sun is able to penetrate through the earth's atmosphere and reach the surface. Some of this radiation is absorbed by the earth and converted into heat energy and some is reflected back. As the earth's surface warms, it also emits radiation back up into the atmosphere. This radiation has a longer wavelength and a portion of it is absorbed and reflected back to the earth by many of the gases present in the atmosphere, thus limiting energy loss from the earth. An increase in the atmospheric content of these gases should increase the ability of the atmosphere to trap more energy and slowly raise the temperature of the globe.

While agriculture will be greatly affected if significant global warming occurs, modern agricultural activities also contribute to the greenhouse effect. Large quantities of fossil fuels are consumed by modern agricultural machinery. The spread of the agricultural landbase has resulted in the natural vegetation being replaced by production of seasonal crops, reducing the amount of foliage that is able to consume CO<sub>2</sub>. Increased production of domestic livestock has been hypothesized to significantly increase atmospheric concentrations of methane.

Human-induced climate warming is such a recent phenomenon that it is difficult for researchers to distinguish between temperature changes due to natural climate fluctuations and those due to human activities. Most current evidence is based on recent measurements of atmospheric greenhouse gases and the known historical relationships between these gases and temperature. Historical atmospheric levels of CO<sub>2</sub>, the most important of the greenhouse gases in terms of atmospheric concentration, may be obtained from polar ice. From these measurements it has been estimated that since the Industrial Revolution (in the mid 1800s) CO<sub>2</sub> levels have increased by approximately 25 percent and have increased by 10 percent over the last three decades. If this trend continues, CO<sub>2</sub> levels will have doubled from pre-industrial revolution levels to 600 parts per million (ppm) by the year 2050.

It is generally accepted that human activities are increasing the quantities of greenhouse gases in the atmosphere and that these gases have an effect on the global climate. However, since the exact relationship between an increase in radiative heat and temperature change is not known with certainty, there is significant disagreement and debate concerning the exact magnitude and nature of climate change that can be expected.

Weather models have been used to predict temperature and precipitation changes resulting from the greenhouse effect. Results from most models indicate that if CO<sub>2</sub> concentrations double to 600 ppm, annual global temperatures will increase by between 1.5 and 4.5°C. However, this warming trend is not evenly distributed either geographically or temporally. A greater degree of warming is expected at the poles and during the winter months. Canada, because of its northerly geographical location, will likely experience a more significant temperature change than countries like Brazil which are close to the equator. In general, most models predict that precipitation will increase on the Canadian Prairies under a doubled CO<sub>2</sub> scenario, with the greatest increase

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observed in northern areas. However, the models differ with respect to the temporal distribution of precipitation.

*Climate Warming and Prairie Agricultural Sustainability*

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*The effects of a temperature increase on crop production are dependent upon the corresponding change in precipitation.*

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If the predicted climate changes occur, they will affect the Prairie agroclimate and have an impact upon current agricultural practices and the types of agricultural production systems that will be sustainable. An increase in temperature will increase the heat available and the growing season length. However, the effects of a temperature increase on crop production are dependent upon the corresponding change in precipitation. At higher temperatures, crops require more water to develop because evaporation of soil moisture increases as does the plant's transpiration rate. If insufficient moisture is available, crops could suffer from water and heat stress, which will adversely affect yields or even lead to total crop failure.

Crops produced in the region may change dramatically. This may involve the migration of crops such as corn, soybeans and sorghum from the south (i.e., from the United States). Given the general degree of climate change predicted for the region, some current Prairie crops may become less economically viable. Research may be required in order to develop new varieties that will be economically competitive. At present it is not known how significant these changes will be in terms of the types of crop production systems that will be sustainable in a warmer climate.

The timing of important agricultural activities (e.g., seeding) is dependent upon temperature and moisture conditions. Thus, another result of climate change may be radical changes in management practices.

Livestock production may also be affected by climatic warming. Climate warming may not have any direct impact on production systems that involve the use of controlled environments (e.g., hogs, poultry). However, a warming trend will affect the costs of maintaining the controlled environment. In particular, heating costs may be reduced in winter, while costs of maintaining a cool environment may be increased in the summer, depending upon the degree and pattern of warming. Feed intake, feed conversion efficiency, and milk production levels are all affected by the environment in which the animals are maintained. The effect of climate warming on these factors, and the types of livestock production systems that would be sustainable, are not known at the present time.

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*If the average temperature in the Prairie region increases, the area of land that is economically viable for agricultural production in the Prairies will expand northward.*

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If the average temperature in the Prairie region increases, the area of land that is economically viable for agricultural production in the Prairies will expand northward due to increased heat accumulation and growing season length. Factors other than climate (e.g., soil quality) will limit agricultural production in these areas. However, there is likely a significant amount of land in the Prairie provinces that is presently prevented from becoming agriculturally productive by adverse climate conditions (see Land chapter).

The described effects of average temperature increases may not be uniform across all of the Prairie provinces. This imbalance has implications for the types of agricultural production systems that may be sustainable within different regions of the Prairies. Crop and livestock production may be affected in different ways.

Global climate change will affect agricultural practices in all areas of the world. Some indications of the general impacts of global warming in different geographical regions are available. However, the net winners and losers from climate change cannot be predicted with any degree of certainty.

In general, northern latitude regions such as Canada, Northern Europe and the northern areas of the former Soviet Union are predicted to benefit, as crop production in these countries is presently restricted by a low accumulation of heat, insufficient rainfall and a short growing season. Global warming is expected to increase temperature and precipitation and lengthen the growing season in these regions.

Conversely, crop production in the midlatitudes (e.g., the United States, Western Europe and Southeast Asia) is expected to be adversely affected by climate change. Precipitation is not expected to increase to the same degree as in the northern latitudes, which may result in increased crop moisture stress and consequently reduced crop yields. The effects of climate change on countries close to the equator are likely to be small because the change in climate predicted for this area is negligible.

The effects of global warming on agricultural production in other regions of the world may also affect the types of production systems that are sustainable in the Prairies. The northward shift in comparative advantage in production for many agricultural commodities that might occur could affect commodity prices and supply. If these shifts are significant, the economic incentives for Prairie farmers may change in terms of the types of agricultural commodities that are produced and the production systems that are used. However, little is known about the types of changes that are likely to occur and the magnitude of these changes.

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*The net winners and losers from climate change cannot be predicted with any degree of certainty.*

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### 3. BIOLOGICAL CONSIDERATIONS AND AGRICULTURAL SUSTAINABILITY

The biological resources upon which agriculture is most dependent are the wild and domestic plants and animals and the soil microorganisms. The sustainability of agriculture is dependent on how effectively and efficiently these resources are used and maintained. The biological resources currently available, coupled with unprecedented possibilities to manipulate life forms through “biotechnology” in its broadest sense, will enable the current level of agricultural production to be maintained and, if properly managed, will permit a significant increase in crop and livestock output without jeopardizing environmental quality.

With the world population expected to reach 8 billion by 2010 and mounting by over 100 million per year, the demand for food will also continue to rise. If agricultural producers are supported by adequate levels research, they will continue to utilize their ingenuity, resourcefulness and efficiency to produce Canada's traditional share of the world's food supply. Adequate incentives are obvious precursors to such sustained production, and these will only be achieved through a return to a more normal marketplace influenced less by government intervention and more by the dictates of supply and demand.

#### Limitations to Biological Processes

Climate is the major determinant in crop growth on the Canadian Prairies, and to a large extent determines the scale and type of livestock enterprises. The major field crops are spring sown annuals that mature in about 100 days. Forage crops are largely perennials in which breeding and management for winter survival are as important as maximizing annual productivity.

The major climatic limitations affecting Prairie agriculture were outlined in the previous chapter. This section discusses the limitations to the biological processes that affect Prairie agriculture, taking into account climatic and other environmental limitations and human responses to such limitations.

#### Crop Adaptation

The crops grown in the Prairie provinces were originally dictated by climatic constraints. As production increased beyond the producers' personal needs and Canada's local needs, export markets became the central force driving production. Often, this factor outweighed our approach to production and research.

Some 15 field crops (grains, oilseeds and pulses) and even fewer forage crops occupy over 95 percent of the cropped area of Western Canada. The horticultural industry, while of economic significance, occupies a very small percentage of the arable area. With the exception of canola, these 15 crops have been the mainstay of production since the beginning of settlement in Western Canada. They are reasonably well adapted to the overall environment and have changed little since their introduction. Yield increases have been primarily the result of improved management (fertilizer, water-conserving tillage systems) and pest control (pesticides). Yield improvements due to inherent greater yielding ability of new cultivars is minimal. While cultivars have changed over time, research has emphasized maintaining yield through improved disease resistance and to improve quality, particularly in wheat, malting barley and canola. Yield losses due to diseases are still unacceptably high, largely because of a lack of plant pathology support in

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many of the breeding programs. Continuous cropping and limited options for crop rotations have increased losses from pathogens that occur both in the soil and on crop residues.

### Livestock Adaptation

Only half a dozen domesticated animal and bird species are of major economic significance in Western Canada, namely beef and dairy cattle, swine, horses, chickens and turkeys. However, there are other domestic and native species well adapted to Western Canada and which could make more efficient use of the resources available. The limitations to utilizing such species is primarily lack of both consumer acceptance and the infrastructures required to domestically raise and market these species.

### Pests

Agricultural ecosystems are very predictable, particularly on the Prairies, where large numbers of each species are maintained together and relatively few species of plants and animals are raised in any one year and from year to year. Host species are therefore relatively easy to find, as they reoccur with a high degree of predictability from year to year. Plant and animal pathogens and insect pests have come to utilize agricultural plants and animals as a food resource. In contrast, weeds generally are not associated with particular crops, but rather are linked with specific agronomic practices. For this reason, the same species of weeds typically occur in all Prairie crops, but the pathogens and insect pests differ from crop to crop.

The biology of many pests is not sufficiently well understood, which places limitations on control methods and in predicting the consequences of changes in production practices. The high adaptability of many pest species places further limitations on our ability to control them. For example, short generation cycles, characteristic of insects and diseases, mean that a particular pest species can develop resistance to a pesticide fairly quickly. Weed species are often better suited to our environmental conditions than agricultural species and thus can outcompete them. Many pest species detrimental to crop and animal species have been introduced as contaminants of seed grain or feeds, or simply happen along. Because these species do not have natural predators here, they are difficult to control and can cause large economic losses.

For economic reasons and because of the lack of understanding of the biology of many pest species, pesticides are the easiest way to control them. The generalist nature of these pesticides, however, has produced concerns regarding their impact on nontarget organisms, including wild and domestic animals, birds and fish, as well as humans and beneficial insects and microorganisms.

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## Background on the Nature of the Biological Limits

### Crop Production

#### *Desired Characteristics and Crop Selection*

While many new crops, ranging from grain amaranths to yucca, are under superficial evaluation, it is unlikely that another Cinderella crop will suddenly stimulate the industry

as did rapeseed (alias canola) nearly 40 years ago. There are niche markets that could be exploited, but we must learn from past experiences with crops such as triticale and fababeans that successful introduction of new crops must be supported by the same level of research as the traditional crops, coupled with aggressive market development and salesmanship. All three of the above-mentioned crops have proven potential but failed to become well-established for a multitude of reasons.

Traditionally, plant breeders have been faced with two conflicting goals. On the one hand, they attempt to generate new varieties, but on the other hand, the end users of crop varieties, the farmer and processor, demand that the crops grown be uniform and stable. Uniformity ensures that there is very little variation among plants in a field, while stability ensures that properties of a particular variety will not vary from year-to-year and field-to-field. Both characteristics are important to the producer for convenience of management (such as for spraying and harvest) and for insurance against failures. Also, quality requirements have been extended beyond nutritional or palatability factors to encompass aesthetic components, such as loaf volume in bread and clarity of beer.

Since the introduction of hybrid corn in the 1930s, hybrid varieties have been of immense value in meeting the criteria of stability and uniformity. Hybrid varieties of canola, sunflower, corn, sorghum and many horticultural crops are currently being developed. While the development of hybrids for cereals such as wheat, barley, oats and rye has proven more difficult, methods are being developed.

This undue emphasis on crop uniformity, varietal stability, and the aesthetic components of quality has, however, placed limitations on our ability to substantially increase potential yield through plant breeding. Stability and uniformity can be undermined when a plant breeder wishes to improve a single trait, such as disease resistance, in an otherwise well-adapted cultivar.

#### *Crop Characteristics and the Genetic Base*

The genetic resource must be envisioned at two levels. The phenotype is a high-level concept encompassing those traits that can be seen or measured. The underlying genes which act in concert to create the phenotype are referred to as the genotype. Thus, the genetic resource can be quantified in terms of either phenotypic diversity, the range of different traits present in the population, or in terms of the different forms of genes, referred to as alleles, and their frequencies of occurrence in the population.

The plant genetic resource is renewable in the sense that sexual crosses recombine genes present in the population and can be used to develop varieties possessing desirable traits. In the past, genetic manipulations have been through such indirect methods as sexual crosses, induced random mutations using chemicals or radiation, or introduction of wild relatives of domestic crops.

The common technique in sexual crossing is to identify the desirable new trait in another cultivar or even closely-related species, referred to as the donor, and to cross the donor to the adapted cultivar. The offspring will have many different combinations of genes from both parents. The genetic background of the adapted cultivar is then reconstructed with the addition of the desirable new trait, accomplished over six or more generations of repeated backcrossings to the adapted cultivar. The difficulty in repeated backcrossing lies

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in selecting those individual plants in each generation which have the desired new trait and yet retain as much of the background genes from the adapted variety as possible.

In the last decade, methodologies have been developed for transforming, or inserting specific genes into many crop plant species, resulting in so-called transgenic plants. Transgenic plants have been produced for such important crops as alfalfa, flax, corn, potato, rapeseed, sorghum and white clover. So far, most cereals have proven intractable to transformation attempts. Inserting specific genes into a plant is a much quicker, more accurate, and thus less costly way of producing a desired trait. Transgenic plant technology also greatly expands the plant breeder's access to the genetic resource. Plant transformation makes it possible to insert genes from other plants, fungi, bacterial, or animal sources.

The greatest potentials for genetic improvement of Prairie crops lie in combining some of the traditional selection techniques with new technologies, and in conventional plant breeding for transfer of specific genes from one species or organism to another. One of the problems of genetic manipulation is that the science is still in its infancy. Little is known about the basic mechanisms of gene regulation and expression in plants and the interrelationships between gene expression and physiological processes and biochemical pathways.

### **Livestock Production**

To meet the market's desire for new products and the environmental need for reduced inputs, production systems will need to evolve. This evolution will depend in large part on our ability to engineer animals to better fit our environment and to better utilize animals that are already adapted to our environment.

#### *Desired Characteristics and Species Selection*

While several species of domesticated animals and birds are adaptable to Western Canada's environment, the ones of major economic significance, as mentioned already, include only beef and dairy cattle, swine, horses, chickens and turkeys. Many others, including sheep, goats, rabbits, bison, llama, ducks, geese, pheasants, ostriches and numerous wild species, are being produced to meet niche markets or for non-agricultural purposes. Few appear likely to be major participants in an expanded meat, egg or dairy industry.

Consumer preferences influence both the type and characteristics of products available in the marketplace. The issues of cholesterol content, caloric value and fat content, and a range of safety concerns have influenced plant products but more so animal products. This concern has led to demands for organically grown, green or natural products that are free of hormones, antibiotics, pesticides and preservatives. This demand has been somewhat unconsciously connected with the so-called environmentally friendly product concept leading to an unwarranted buyer beware attitude and perhaps an overreaction by producers and processors.

Consumer preferences have influenced the livestock industry in a variety of ways. They have resulted in feeding programs for leaner beef, high protein milk and leaner carcasses with more rapid growth in hogs and poultry. These programs are based on high nutrient

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*Consumer preferences have influenced the livestock industry in a variety of ways.*

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density rations that require greater use of grains relative to forages and result in more frequent health problems in livestock.

There is also unfounded resistance in the marketplace to the use of intact males for meat production, which results in animal castration (an animal welfare issue), the use of implants with synthetic male hormones for rapid growth (food safety issue), and longer feeding periods and reduced feed efficiency. Male dairy calves, a by-product of the dairy industry, are not utilized to their full potential because of fears that the meat will be discounted in the marketplace even though it is leaner.

Broilers are the major source of poultry meat in the Canadian diet, although greater processing flexibility and resource use may be achieved with turkeys. The introduction of alternate species, such as rabbits, wild ruminants, pheasants, quail and ostrich, is hampered by Federal “road blocks” concerning their slaughter and processing. With no available guidelines, Federal inspectors are unwilling to approve small scale premises or new processing techniques.

#### *Livestock Characteristics and the Genetic Base*

The genetic improvement of Prairie livestock populations has been accomplished by selective breeding for traits considered of economic importance. This process depends on natural genetic variation and the selection of preferred gene combinations, the identity and function of which is unknown except for their visible expression. As with plant improvement, the potential for genetic improvement of livestock lies in a combination of traditional techniques with new technologies. Lack of knowledge on the basic mechanisms of gene regulation and expression and the interrelated influence of biochemical and physiological pathways is a limitation for both crop and livestock improvement.

While genetic improvement, coupled with management, has produced leaner beef, high conversion rates in hogs and broiler chickens, and doubled the production of individual dairy cow milk, little improvement has been achieved in the reproductive efficiency of either cattle or swine. Current knowledge and technology, if effectively used, would permit 15 percent increases in calving rates, an increase from 15 piglets per year per sow to 20 to 22 and lambs per ewe from 1.5 per year to 2 every 8 months. There is also tremendous opportunity for reducing costs of production with poultry by improving breeder efficiency.

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#### **Pest Populations**

##### *Pest Management*

With the exception of internal pests of livestock, which are the province of the veterinarian, pest management most frequently involves pesticides, biological control, cultural methods, or pest-resistant plants or animals.

**Pesticides** — Pesticides have made an enormous contribution to agricultural productivity in the last 40 years. Unlike most other control measures, they can be used at short notice to control unexpected pest outbreaks. Insecticides have been used on the Prairies since 1919 when arsenic baits were first used for grasshoppers. Patterns of insecticide use on

the Prairies range from regular applications to protect vegetable crops and cattle, to occasional applications for sporadic outbreaks of crop insects and for insects in grain stores. Fungicides have been widely used to control seed and soil-borne fungal pathogens, and have more recently become common for controlling specific diseases in some high value crops.

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*Yield increases from the early 1960s to 1980 were due primarily to herbicides, and secondarily to improved cultivars and fertilization.*

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Herbicides have been used on the Prairies as the primary means of controlling weeds since the early 1950s. Herbicides have replaced tillage for weed control to a large extent, significantly reducing summerfallow and intensive spring tillage in some areas. Studies on long-term wheat rotation at Lethbridge, Alberta, indicate that yield increases from the early 1960s to 1980 were due primarily to herbicides, and secondarily to improved cultivars and fertilization. Not only have herbicides been effective in reducing competition from weeds, but by eliminating the need for a late spring tillage for weed control have permitted earlier seeding, providing for more efficient water use and earlier, improved harvesting conditions.

Pesticides, however, have two major difficulties. Pest populations can develop resistance to them, and they can affect nontarget organisms. The process of natural selection is responsible for the development of pest resistance to pesticides and for the development of strains of pests which can overcome the resistance bred into agricultural plants and animals. If pest populations contain a small proportion that can survive a specific pest control method, and if the same control method is applied repeatedly, then the resistant proportion will increase to the point that effectiveness of the control method is reduced significantly .

Worldwide, resistance to insecticides is now evident in at least 500 species of insects. One example on the Eastern Prairies is that of horn flies, which developed resistance to synthetic pyrethroids only a few years from the time of widespread adoption of cattle ear tags impregnated with the insecticide. Insect pests of the Prairies, however, have generally not developed resistance as rapidly as in many areas, probably because fewer generations of insects occur in the short Prairie growing season, and because many Prairie insect pests do not receive repetitive insecticide applications.

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*Because of the widespread use of herbicides in Prairie agriculture, herbicide resistance is of major concern and may require significant changes in weed control practices.*

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Resistance to herbicides is now known for at least 116 weed species worldwide. Herbicide resistant weeds have only recently been reported on the Prairies, but are now known for green foxtail, wild oats, kochia, chickweed and wild mustard. Because of the widespread use of herbicides in Prairie agriculture, herbicide resistance is of major concern and may require significant changes in weed control practices. Resistance to fungicides is also documented, but because of their limited use is not currently a problem here.

**Biological control** — Biological control involves the use of living organisms to control pests. One form of biological control, the inoculative method, involves a single release of a biological control agent which becomes established and permanently controls the pest. When permanent establishment is not possible it may be feasible to release biological control agents at regular intervals. An alternative approach is to encourage increases in population of natural enemies of pests.

The inoculative method has met with considerable success in control of some insect pests of greenhouses and of fruit and forest pests, but effective biological control of insect pests of Prairie agriculture has been elusive. Introduced parasites of plant bugs and of canola-infesting flea beetles have not become effective control agents. The introduced seven-

spotted lady beetle eats pea and grain aphids and has become established in the Prairies, but it is not yet clear whether it will provide adequate control. The inoculative method has also been tried for control of weeds. Release of insect biological control agents has reduced the rate of spread of some weeds in Prairie pastures but is not likely to be useful on cropland.

In biological control of plant pathogens, antagonistic micro-organisms are introduced which may outcompete or kill the pathogen, induce the host plant to defend against the pathogen more vigorously, or promote better plant growth so that the effects of the pathogen are masked. These antagonistic interactions have been demonstrated experimentally and are the subject of intense research, notably with respect to take-all disease of cereal crops. However, there is currently no commercial application of this technique.

**Cultural control** — Examples of cultural control for crop pests include cultivation, crop rotation, maintenance of crop vigour, separation of new plantings from existing pest infested crops and eradication of weeds which harbour insect pests or pathogens. Cultural control of livestock pests includes quarantining infected animals to prevent spread of infectious diseases, management of manure in feedlots to minimize animal contact with pathogenic microorganisms and reduce breeding of nuisance and biting flies, and selection of pastures which are distant from sources of biting flies. Cultural controls were widely used for pest control in the first half of the century, but with the advent of effective pesticides many of these practices have been neglected.

Breeding programs have been developed to make varieties of animals or plants resistant to diseases or to insect pests. The most important of these to Prairie agriculture is breeding wheat with resistance to stem and leaf rust. This program has provided protection from rust diseases, with no additional cost to farmers and without hazard to the environment. Because new strains of rust may evolve which can overcome the previous resistance, the breeding program must continue to develop new varieties with novel mechanisms of resistance.

Crops or livestock which are resistant to insects have not been widely used on the Prairies, partly because effective insecticides are available for most insects. Also, insect resistant crops or livestock frequently produce less yield or a lower quality product. For example, cattle tolerant of severe biting fly attacks produce meat which is unattractive to consumers. The primary example of a Prairie crop showing insect resistance is that of some wheat varieties resistant to the wheat stem sawfly. This breeding program was pursued because there were no satisfactory insecticidal controls. Nevertheless, the resistant varieties are inferior to the susceptible wheats and so resistant wheat is grown only when there is a threat of significant loss from the sawfly. A breeding program is currently underway to develop varieties of canola which are resistant to flea beetles.

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## Issues

### Biotechnology and Genetic Limits

Biotechnology can be used to make more efficient use of the resources available to us, thereby increasing the profitability and world competitiveness of Prairie agriculture and ensuring its sustainability. Biotechnology, however, should be regarded simply as another

tool in the plant and animal improvement arsenal, and agricultural research institutions must ensure that research conducted under the biotechnology label does indeed serve a distinct purpose or objective and does not simply produce an assortment of isolated end results. The efficiency and effectiveness of biotechnology is the degree to which technology and research can be used to produce safe, nutritious food and feed, in a manner which is economically productive to producers and imposes the least damage on the environment.

#### *Plant Technology*

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*Recent advances in biotechnology, if adopted widely by plant breeders, can greatly simplify many of the operations of plant breeding.*

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Classical plant breeding, through indirect manipulation of the genetic resource, relies upon screening hundreds of thousands of offspring for plants with favourable phenotypes. Recent advances in biotechnology, if adopted widely by plant breeders, can greatly simplify many of the operations of plant breeding and the backcross/selection cycle in particular.

The most important tool from the plant breeder's point of view is the molecular marker. Molecular markers enable the breeder to identify specific portions of a chromosome and link it with a desirable trait. The ability to identify this marker makes it possible to determine which offspring from a cross carries that particular trait. If used routinely, molecular markers can accelerate the process of plant breeding by decreasing 1) the number of generations of backcrosses needed in making inbred varieties, 2) the number of individual plants that must be screened in each generation and 3) the cost of screening for desired traits.

Although transgenic plant technology holds great potential for crop improvement, its application to complex problems such as increasing photosynthetic efficiency, nitrogen fixation or cold tolerance awaits a better understanding of the complex nature of these characteristics. In the short-term, the benefits of genetic engineering will be seen in applications in which a single gene is modified or added. Examples would include the introduction of genes for resistance to herbicides in canola and flax or for the production of male-sterile plants which are potentially very useful in the production of hybrid varieties.

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*The benefits of recent advances in plant biotechnology will be greatly diminished if monopolized by the private sector.*

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The benefits of recent advances in plant biotechnology will be greatly diminished if monopolized by the private sector. For example, because each new molecular marker obtained in a species improves the usefulness of the larger chromosomal map, the efforts of both public and private sectors will best be served by cooperative mapping programs involving open exchange of markers by academic, governmental and industrial plant breeders. Such programs are now conducted by, and should remain in the hands of, public plant breeders.

#### *Plant Nutrition*

More efficient use of nutrients for crop production can be attained through proper soil management and through the study and manipulation of soil microorganisms and their metabolic processes.

One suggested mechanism for enhancing fertilizer use efficiency is to inhibit the activity of populations of microorganisms which convert  $\text{NH}_4$  fertilizers into forms of nitrogen

that are readily lost from the soil-plant system. Although not a substitute for good fertilizer management, inhibitors would provide flexibility in the management alternatives available to producers. Numerous compounds have been proposed as inhibitors, in particular, ones which inhibit urease activity or nitrification. These compounds have been marketed in other countries, particularly Japan, Germany, and the United States and there is considerable interest in marketing them in Western Canada.

The use of inhibitors, however, has not been universally accepted because of a lack of consistency in their ability to improve yield and fertilizer efficiency and because of possible adverse effects. Not all plants will adequately metabolize forms of nitrogen made available through inhibitors, plus the effect of inhibitors on the physiology of the plant is not well understood. In addition, inhibitors have been shown to adversely affect the mineral nutrient content of the plant and may also be phytotoxic.

An alternative to inhibitors is to enhance indigenous soil populations, thus exploiting those metabolic activities most beneficial for increasing fertilizer efficiency. The populations of microorganisms most beneficial to crops are those which associate themselves with plant roots, either in a symbiotic relationship or in an associative or semi-symbiotic relationship. The free-living organisms in the plant rhizosphere are one such example. Other examples include: the *Rhizobium* bacteria, which forms a symbiotic relationship with legumes, thereby reducing atmospheric nitrogen to a form usable by plants; the mycorrhizal fungi, which will form symbiotic relationships with crops and assist the plant in nutrient uptake and translocation; and the free-living organisms from the rhizosphere such as *Penicillium bilaii*, which will utilize nutrients exuded from the roots and in return will make phosphorus more available for plant uptake. Microbial consortiums, such as a fungal/bacterial consortium, could enhance residue degradation and thereby increase the nitrogen content of the soil.

### *Animal Technology*

Future sustainable agricultural systems for animals must produce food, biomedical products and fibre for human consumption; they must endure over time; and they must be adaptable and flexible enough to accommodate evolution in production systems. Production systems will continue to be governed by economic and biological efficiencies and by market demands for quantity, quality and product form. If producers hope to maximize lean meat production, minimize egg cholesterol, control milk composition, formulate foods from meat, milk and dairy constituents, and conserve soil and water, production systems with modified animal genotypes that link product demand with the resource base will be required.

Initially, techniques in genetic delivery and screening have the greatest potential to increase the food production efficiency of animals and poultry. Multiple ovulation, embryo transfer, cloning and artificial insemination can accelerate the incorporation of desirable genetic material from superior males and females into the greater population. A number of these techniques are used routinely in dairy herd management but are almost nonexistent at the commercial level in beef, swine, sheep and poultry operations.

Procedures need to be developed to screen genetic material at both the macro and micro levels. Currently, identification of superior animals takes anywhere from several months to 8 years depending upon the animal and production trait being selected. Selective

screening of the young animal, embryo or even sperm or ova would reduce the time required for expression of genetic improvement. Traits such as animal behaviour for specific management systems, disease and longevity are not currently being considered for selection due to insufficient knowledge on how to effectively screen for them.

In the longer term, gene transfer shows great promise for animal production in Canada. Currently, the technology of gene transfer in farm animals is limited to the introduction of single cloned genes into the genome. Casein genes have been isolated and cloned with the potential to improve cheese texture and heat stability of milk. The search is continuing for a mastitis resistant gene, and milk composition can be altered by introducing new milk protein genes. In chickens, a single gene responsible for 30 percent of the variation in fat content of broilers has been identified. Commercial application of these genes depends on a better knowledge of their control mechanisms.

One of the areas where gene transfer is likely to have a major impact is in the manipulation of metabolic pathways. Sheep wool and body growth has been enhanced by the effect of introduced genes on biochemical pathways. Extending this technique to interspecies gene transfer, it is reasonable to expect that monogastric metabolism might be altered to make efficient use of forage; or that the digestive systems of grazing species might be altered to allow them to utilize more browse; or that the basal metabolism of domestic species might be lowered to withstand colder temperatures; or that fertile hybrids between wild and domestic species might be realized.

Disease resistance may be enhanced in many species by gene transfer. Examples of such possibilities include transferring genes responsible for disease resistance or disease tolerance from indigenous breeds to new breeds, or inserting a transgene to incorporate an insecticidal agent into the skin.

The processing industry is expected to play a larger role in influencing consumer preferences. Larger carcass size, a sustainable practice since it reduces the resource use per unit of lean meat production, will become acceptable if the industry moves away from primal cuts and greater use is made of restructured meat products. Tremendous potentials exist for introduction of synthetic fats such as sucrose polyesters, which give meat the same tenderness and juiciness as fat but provide no calories because they are indigestible by humans.

#### *Feed Efficiency*

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*A new possibility for enhancing feed efficiency in ruminants is manipulation of the rumen microbial population.*

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Characterization of the physical and chemical constituents in plants, especially the carbohydrate fraction, is critical for future improvements in voluntary intake and digestibility by livestock. This will influence our ability to formulate feed rations, predict productivity and establish optimum stocking rates. A new possibility for enhancing feed efficiency in ruminants is manipulation of the rumen microbial population. The technology exists to depopulate the rumen, to store microbial preparations for reinoculation into the rumen and to introduce new genes into existing microbes. Application of this technology will not proceed until an alternative improved microbial system(s) can be identified and microbes or genetic material complimentary to this alternative system(s) can be identified or developed.

Bioprocessing for synthesis of complex molecules, such as vitamins, amino acids and enzymes, offers innovative opportunities to expand use of existing feeds, creation of new feeds and development of feeds from industrial waste treatment. For example, fungi used to purify sulphite liquor, a waste from paper production, have an added benefit if they can be harvested for animal feed. Current practices of the feed industry, such as formulating diets to maximize production and over-formulation, are viewed to be unsustainable due to inefficient feed use and excessive waste output. Development of “designer enzymes” to deal with specific feed problems and a changing attitude of formulating for an optimum production level would go a long way in reversing some of the current inefficiencies.

### *Research Priorities*

The objectives of biotechnology can only be achieved through considerable research efforts. To realize the potential of genetic improvement we need extensive information about the basic mechanisms of gene regulation and expression and the interrelated influence of biochemical and physiological pathways. Gene transfer is only successful if the new gene functions properly in the recipient and is successfully transferred to its offspring. Transgenesis can increase genetic variation but can also introduce new deleterious effects within the genome.

The demands of the consumer for a particular product often generate research activities that have short-term goals but do not contribute to a basic understanding of the plant and animal system. Such an understanding would ultimately bring about more precise regulating of end products to meet market demands.

Regulatory guidelines governing release of transgenic plants are needed. Properly formulated, this legislation could decrease the time and costs of using transgenic crop plants by eliminating the need for extensive case-by-case reviews of proposed releases. Research should be the foundation for the formation of such regulatory guidelines. While early fears about recombinant DNA were greatly overstated, major emphasis must be placed on the evaluation of the ecological effects of transgenic plant technology. It could draw upon expertise from ecologists, plant pathologists with experience in biological control, and molecular biologists. Methods for biological containment of transgenic constructs should also be developed.

The majority of transgenic plant experiments performed in research laboratories up to now have utilized tobacco, since it is the easiest plant to transform. While such experiments may have less risk of failure, the practical application of gene transfer technology will not occur unless funding agencies, despite whatever difficulties may be involved, apply this technology across the range of agronomically important crop species.

Funding may limit the development of genetic engineering. To attract investment there must be a reasonable opportunity for profit. The lack of basic knowledge on gene regulation, the need for basic scientific research, the relatively long development and testing period (5 to 15 years) and the uncertainty in making useful transgenic stock in the first attempt are all factors which will make investors cautious.

With respect to plant nutrition and enhancing indigenous soil populations, attempts at inoculations in the field, with the exception of *Rhizobium*, have not proved reliable in

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*The demands of the consumer for a particular product often generate research activities that have short-term goals but do not contribute to a basic understanding of the plant and animal system.*

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the past, mainly because the complexity of the natural soil biological populations has not been unravelled. The targets for inoculation research should include: recognition/binding to hosts/soil particles, host/inoculant genetics, phenotypic/genotypic elevation of useful gene products, physiology/fermentation technology of inoculants, product formulation/toxicology and soil types and conditions. All appropriate new biotechnology should be harnessed into optimizing crop productivity by soil management with minimal environmental damage and conservation of the soil resource.

Some specific research needs for animal products include the development of an accurate, quick and economical means of measuring live animal and carcass fat; identification of cellular and molecular mechanisms that control partitioning of protein and fat; potential mechanisms for control of fatty acid content of eggs, milk and meat; and probiotic strategies to minimize or eliminate low level continuous antibiotic use in animal feeding. Along with the research there will have to be continued unbiased information flow to the consumer relative to the safety and quality of animal products.

## Pesticides

### *Pesticide Resistance*

Pests evolve most rapidly when confronted with a single selection pressure which is repeated. Thus, a population subjected to widely differing pesticides develops resistance more slowly than one in which pesticides with the same mode of action are always used. Although there are a large number of pesticides, many of them have almost identical modes of action. Techniques to conserve our pesticides in the face of developing resistance are to rotate different modes of action among pesticides and to use pesticides only when absolutely necessary. Thus, pesticides should not be persistent, and should be applied only when warranted by pest populations.

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*Research into the basic physiology and population biology of pests is urgently needed.*

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In order to meet the challenge of resistance, research into the basic physiology and population biology of pests is urgently needed. Unnecessary control measures that accelerate the development of resistance should be reduced. These should include research to develop economic thresholds, education of farmers in the use of thresholds, and education of consumers to accept inconsequential pest related blemishes to products so that grading standards can be altered.

### *Alternatives to Pesticides*

Although pesticides are considered a necessary tool for Prairie agriculture, there are other tools available and being developed.

**Pest Resistant Species** — Current biotechniques that make it possible to incorporate into plants a toxin characteristic of an existing control agent, for example *Bacillus thuringiensis*, enable the plant to resist insect predators. Such resistance is usually based on a single gene. However, evolution will occur whenever the pest contacts the plant, and the result of the evolution will be the loss of both the plant resistance and the biopesticide. While multiple gene resistance requires longer term research and breeding programs, it is a more desirable approach. Another approach is to use a number of single gene resistant plants together to produce a crop which has diverse resistance mechanisms, but which is morphologically and agronomically identical.

**Biological Control** — While complications exist, effective biological control of many pests on the Prairies can be achieved. Before control agents can be released there must be extensive testing to ensure the agent will not attack crop plants. In addition, biological control agents introduced to the Prairies face a climate that may be harsh enough to impede their establishment. Furthermore, the inoculative method depends upon establishing a permanent relationship between the population of the pest and the control agent. This is difficult to achieve since many of the insect pests are migratory and are only on the Prairies during the summer.

Progress has been made in developing biological control through application of biopesticides consisting of pathogens or the toxins they produce. The private sector is working on this and some companies are using molecular biological techniques to develop agents effective against different target pests. Different types of *Bacillus thuringiensis* and their toxins can kill cutworms and other caterpillars and the larvae of blackflies, mosquitoes and some beetles. So far, these applications have not always been as effective or as inexpensive as the insecticides, but they are desirable because they have less effect on non-target organisms. The use of pathogens of weeds as bioherbicides is being actively researched in North America and elsewhere. Round-leaved mallow, a weed primarily of waste places, is likely to be the first to be controlled by a bioherbicide in Canada. If fermentation and formulation technology can be perfected, biopesticides may become as effective and cheap as synthetic chemical pesticides.

To achieve maximum effect from biological control a sustained research effort is required into the biology of both the pest and its potential control agents.

**Integrated Pest Management (IPM)** — Increased diversity of control measures can be achieved by integrated pest management in which reliance on a single pest control method is replaced by combinations of control methods. Research is needed to develop integrated pest management schemes for the Prairies and a comprehensive extension and education program is necessary to ensure adoption by the agricultural industry.

#### *Pesticide Regulation and Registration*

Hazards to humans, wildlife and the environment have led to withdrawal of some pesticides and to increasingly stringent registration requirements. Satisfying these requirements is also becoming increasingly expensive. Unless potential Canadian sales justify the cost of registration, new pesticides are not registered in Canada and so there is a dwindling supply of new pesticides to replace those which are no longer available. Pesticides will be necessary for the foreseeable future and it is important that the most effective and safe compounds be available. However, market forces are a major determinant of pesticide availability and these are unlikely to ensure that the array of pesticides available in the future will provide the best protection while minimizing detrimental effects. Thus, Canadian agriculture faces a future in which a far from ideal array of pesticides will be available, and where more desirable pesticides will be available to competitors in countries where regulations are less stringent or pesticide markets are larger. The Federal government needs to institute ways of regulating pesticides that ensure that safe, effective compounds are available for use in sustainable agricultural production. Inducements may be required to register desirable compounds where market forces are insufficient to ensure their availability.

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*Pesticides will be necessary for the foreseeable future and it is important that the most effective and safe compounds be available.*

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### Animal Welfare

The impact of animal health and welfare issues on sustainability centres around ethics and economics. Farmers have typically been concerned and knowledgeable about animal well-being and responsible stewardship. However, in response to escalating economic pressures to improve production efficiency, new technologies are being applied. But concerns have arisen that the production systems associated with these technologies may be compromising the normal behavioral and physiological processes of animals, often in ways not readily apparent.

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*A major issue of animal health and welfare concerns the intensive housing of large numbers of animals (factory farming).*

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The major issues of animal health and welfare concern the intensive housing of large numbers of animals (factory farming) and the drive to increase animal production efficiency. The imposition of biotechnologies, such as transgenic animals, growth promoters, and repartitioning agents, stimulates many questions of ethics and welfare regarding metabolic diseases, biologic limits to exogenous intervention, and new animals which may have unique, as yet undefined needs and requirements.

More than ever before, farmers are voicing concerns about farm animal welfare, and are objecting to many intensive housing systems and to real or perceived animal manipulation with exogenous compounds. While some of these concerns are founded more on misplaced sentiments than true knowledge of animal needs, consumer influence can greatly affect animal agriculture. Yet consumers still want relatively inexpensive food sources. Meanwhile, there are some very real animal welfare problems and concerns that can negatively impact on agriculture's sustainability.

The industry is hampered by a lack of objective methods to measure animal well-being. In spite of a large number of experiments, relatively little progress has been made in animal welfare science. Rather than developing complex criteria which accurately evaluates the whole animal environment, we tend to focus primarily on a single behavioral or physiological trait. Life-sustaining and health-sustaining needs are fairly well established. But the comfort-sustaining needs — those that when thwarted result in behavioral aberrations, ill-health, and compromised development or reproduction — are the most difficult to delineate and are where our knowledge is limited. A clear understanding in this area is essential to avoid well-meaning but misdirected guidelines and developments for housing and maintaining animals.

Headway is being made in defining animal distress and its causes, symptoms and solutions. However, much more emphasis and research on this area and its application is required. Alternate housing that affords the animal the opportunity to meet its various investigatory, social, and comfort needs, while being economically competitive and maintaining suitable production efficiency, requires sound scientific evaluation. Some of the more extensive systems, though initially appealing to welfarists, can present different welfare concerns, such as potential exposure to predation, ectoparasites and airborne pathogens, decreased environmental control, as well as different nutrient requirements and waste handling problems. These potential problems must be carefully scrutinized before such systems can be recommended.

Educating the general public, producers and their advisors about animal behaviour, care and well-being will nurture understanding and help assure sound management practices and preventative maintenance. In order to uphold sustainable production systems,

guidelines for care and handling of animals must be based on scientific knowledge, practical experience and biology-based, rather than technology-driven, strategies. Research must be carried out on animal needs and preferences, objective measures of well-being and distress, optimal housing designs that remain economically feasible, and use of probiotics and prevention of disease rather than extensive antibiotic use. Ethical issues of biotechnologies need to be addressed both philosophically and scientifically.

### Diversity

Expansion and specialization has occurred in Prairie agriculture in response to various government policies, market trends and technological innovations. These trends have led to a decline of diversity in agricultural systems and ecosystems, a loss now being blamed for some of the current farm financial problems and environmental concerns.

While technology has in some cases contributed to the decline in the diversity and condition of the ecosystem, in other cases it has helped to restore it. Technological fixes, however, have their limits. In addition, biotechnology is dependent on a diverse gene pool supply, which can be ensured only if there is a sufficient supply of natural habitats. A more stable agricultural ecosystem would involve an increase in diversity within an area and, over time, a return to more balanced soil-plant-animal relationships. This process will require, in some cases, relocation of animal and crop production within close proximity of each other, the introduction of perennial crops, introduction of new animal and cropping options that are conducive to our climatic conditions, and careful land management. Consideration should also be given to setting aside native plant species and wildlife habitats.

### Crop Species

Environmentally acceptable increases in crop production will result from further exploitation of the diversity already available in the traditional crops. Positive effects could be gained from greater utilization, where possible, of fall sown crops (including fall rye and winter wheat), perennials (such as alfalfa and various grasses) and shrubs or trees. Production could be increased because of the inherent yield advantage of the winter cereals through better competition with weeds and more effective use of spring moisture. In addition, the risks of soil erosion would be reduced, while the effective use of marginal land would be improved. Probably the greatest potential gains can be realized by developing fall-sown rye and wheat for widespread use on the Prairies. Fall-sown oilseeds, canola in particular, warrant further research emphasis.

Ideally, the diversification of agriculture can be accomplished by broadening the range of crops used for food. But this practice is difficult owing to the barriers of consumer preference, food processing technology, adaptation of cultural practices and the need for development of crop varieties that are suitable for large-scale cultivation and consumption. Examples of food crops which have potential for larger-scale production include beans, chickpeas, quinoa and amaranth. Cultivation of native species of wild rice may also be appropriate in some areas.

Marginal agricultural land is often extensively drained in an attempt to establish traditional cropping systems. Perennial grasses, however, are tolerant to poor drainage and

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*Ideally, the diversification of agriculture can be accomplished by broadening the range of crops used for food.*

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flooding, allow production on this marginal land and also provide continuous cover to prevent erosion. Many turfgrass species, like creeping bentgrass, survive well on marginal land while producing a high-value seed crop.

The diversity of Prairie agriculture can also be improved by increasing the use of alternative species for feed. For example, Poplar has been suggested as a feed for ruminants, while lathyrus is being developed as a feed for swine. Lupins have also been suggested as a protein supplement for livestock. Production of new legume species may provide annual plow-down crops which have nominal establishment costs. An example of one such legume is the North African annual medics, which produces a large amount of seed. Non-dormant alfalfa cultivars provide a more expensive source of nitrogen, but high-value hay production should offset their higher seed costs.

A diversification of forage crop production would include use of species native to the tall grass prairie. These species not only provide essential nesting cover for waterfowl but also contribute to genetic diversity of the community. Increased use of these species will also provide researchers the opportunity to evaluate how they best fit into animal production systems.

#### *Livestock Species*

There are many native species, such as bison, elk, moose and deer, that could be utilized in multiple-grazing systems under extensively managed rangelands. In addition to greater exploitation of the feed supply, these species have greater cold resistance than cattle and, under favourable circumstances, higher reproduction rates. From the meat production standpoint, these species have superior muscle distribution, hence a higher percentage of high-priced cuts of meat.

Over 75 percent of the potential agricultural land, including the Aspen Parkland and the Boreal Mixed wooded areas, is prime habitat for indigenous species and would provide conservation through utilization. Grazing systems in Canada and the United States that employ native species in natural habitats can increase production by up to a 45 percent over systems that employ only cattle. Mixed grazing strategies that include both cattle and native ungulates can increase grazing capacity 35 percent over cattle alone. The native species have another major advantage, namely, the ability to forage and maintain themselves for 12 months of the year with little or no feed supplement.

Other species, including sheep, goats and rabbits, differ from cattle in terms of plant preferences under grazing conditions, ability to degrade or transform toxins, resistance to pests and ability to bridge between high feed availability periods. Given that a market for alternate meats can be established, the potential for these species should also be evaluated under the context of sustainable production.

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*Natural ecosystems must be preserved or restored wherever possible as a means of preserving the vast genetic resource that they represent.*

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#### *Natural Ecosystems*

Natural ecosystems must be preserved or restored wherever possible as a means of preserving the vast genetic resource that they represent. The ability of species of an ecological community to adapt to environmental changes (e.g., climatological changes) is dependent on the underlying genetic diversity of that community. Additionally, as transgenic plant technology becomes more sophisticated in coming decades, wild species

will serve as a resource base of genes for genetic engineering of disease resistance, photosynthesis, nitrogen fixation, winter hardiness and many other traits. While we have referred to the gene pool as a renewable resource, it is only such to the extent that the diversity of that gene pool is preserved through the preservation of natural habitat for wildlife.

One of the applications of the natural ecology to agriculture is the encouragement of wild buffer zones bordering cultivated lands. Such buffer zones serve to separate fields biologically, slowing the spread of plant pathogenic fungi and bacteria. Additionally, buffers can serve as habitat for insectivorous birds.

The diversity of the gene pool in wild and domestic plant populations is an irreplaceable resource that must be conserved through preservation and re-establishment of wild communities, maintenance of germ plasm by plant breeders and diversification of the species and varieties used in agriculture.

#### *Institutional Linkages*

Municipal taxation and land assessment systems have also promoted cultivation of marginal lands. Because all land is taxed, although at varying rates, farmers have had an incentive to regain income from fragile and marginal lands. As farmers have shifted from mixed farming operations to specialized crop production, they have lost the benefit from uncultivated marginal lands that may once have provided income through cattle grazing. The Land Rehabilitation Act allows municipalities to grant taxation relief on uncultivated land. But municipalities have been reluctant to consider the measure, since it would shift taxation to the more productive land rather than lose the revenue. Recent shifts in transfer payments from the Federal and Provincial governments have increased the revenue requirement of municipalities.

Unequal government subsidies to certain sectors of the agricultural industry have also contributed to shifts in production of certain commodities. For example, the rail transportation subsidy available for grains, oilseeds and pulse crops has raised the value of these crops for export. The increased cost to Prairie industries using these crop inputs has in turn reduced the diversity of the agricultural economy and ecosystem. Another grain and oilseed specific program was introduced in 1991.

The Gross Revenue Insurance Plan (GRIP) is revenue insurance on annual crops and these contracts have allowed farmers to maintain the specialization in the eligible crops. Without the guaranteed income levels, farmers would have diversified their cropping program. Guaranteed income levels are provided on a seeded acreage basis, again promoting crop production on marginal lands and discouraging animal production. In addition, some crops are given more protection than others, further reducing farm diversity to include only the crops that provide the best revenue guarantee.

Factors such as the location of slaughtering and processing facilities have also influenced the distribution of animal production on the Prairies. The recently completed Cargill beef processing plant in High River, Alberta, can process over one-half of the beef produced on the Prairies. This means that much of the beef finishing will take place in Southern Alberta. The location and size of this processing plant was not determined by the ecosystem's ability to produce cattle in this region but rather by financial incentives

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*Guaranteed income levels are provided on a seeded acreage basis, again promoting crop production on marginal lands and discouraging animal production.*

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provided by the provincial government and the proximity to emerging Pacific Rim markets.

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## 4. LAND

Agricultural land constitutes the most important natural resource in the Prairie Region of Canada. It is the source of much of our food and, as a result of the export of grains, oilseeds and animal products, is an important source of domestic wealth and foreign exchange. The loss of our agricultural land resource, the deterioration of the soil, and the impact that these have on our crop production potential, are major causes of concern to farmers, rural communities and the urban public in Western Canada.

Public support for sustainable agriculture will put greater pressure on governments to ensure that the agricultural land base and environment are maintained and that the food we eat is safe and of high quality. Use of land on the Prairies for agricultural purposes has been directed by domestic and foreign food requirements, government policies, and scientific and technological innovations. These will all continue to be important in the future. The challenge is to steer them in the direction that will ensure sustainability of our land resource and integrity of our environment.

### Land Limitations

#### Quantity of Agricultural Land

##### *Area of Land Suitable for Agriculture*

The Prairie (see Figure 1.1 in Introductory chapter) has a combined land area of 113 million hectares. The area of land where soils and climate are suitable for arable agriculture is 47 million hectares, or about 41.5 percent (Table 4.1). Of this 47 million hectares, approximately 38 million hectares is under cultivation, leaving an estimated 9 million hectares that have not been developed for crop production. Although up to 7.6 million hectares of this uncultivated, or 'unimproved' land could support the production of cereal grains, it is not well suited for this purpose.

##### *Competing Uses*

Much of the Prairie's prime agricultural area is privately held by farmers and ranchers so that competing uses, such as habitat for wildlife, become a by-product of an agriculturally dominated landscape. Thousands of acres of wildlife habitat have disappeared on the Prairies as a result of agricultural expansion.

**Table 4.1**

*Land in Soil Capability Classes One to Four as Related to Improved Land in Farms (million hectares).*

	Millions of Hectares		
	Total Area Class 1 to 4	Improved Land	Unimproved Land Class 1 to 4
Alberta	18.03	12.91	5.12
Saskatchewan	21.60	20.26	1.34
Manitoba	8.00	5.40	2.60
Total Prairie Region	47.63	38.57	9.06
Canada	71.39	45.60	25.79

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*For the last decade, public and private interests have advocated the development of multiple land use management techniques as a means of achieving sustainable development.*

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*The indigenous quality of land can be increased or decreased by agricultural practices and amendments.*

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For the last decade, public and private interests have advocated the development of multiple land use management techniques as a means of achieving sustainable development. The focus of much of this effort is protection and enhancement of wetlands and wildlife habitat in the more humid parkland belt, where wetlands constitute 25 to 50 percent of the land surface. Since much of this land has severe limitations for arable cropping, such efforts should not have significant negative impacts on agricultural production on the Prairies.

Unlike Eastern Canada, competing uses for land on the Prairies, such as for forestry or for urban development, do not pose a serious threat to the physical base for arable crop production. In the West, most of the loss of prime agricultural land to urban areas is offset by the reclamation of abandoned farmsteads, school grounds and small rural towns associated with rural depopulation. In the future, agroforestry could compete with crop production in areas sensitive to degradation and in areas set aside for wildlife habitat.

### Quality of Agricultural Land

Agricultural land must possess certain physical, chemical and biological attributes suitable for plant growth. The best agricultural land typically has soils which are deep, well drained, with good structure, or tilth, and good water-holding capacity. These soils should have a pH near neutral, a variety of macro- and micro-organisms, and adequate quantities of essential nutrients in plant-available form. Other physical attributes, such as slope and stoniness, will also affect the suitability of soils for arable agriculture.

The indigenous quality of land can be increased or decreased by agricultural practices and amendments. Fertilizers, manures and other amendments, such as lime, can be used to correct inherent deficiencies and soil problems. However, certain physical and chemical processes occur as a result of agricultural use, and can cause deterioration in land quality, thereby limiting sustainability.

Declines in soil organic matter content below critical levels limit yield and sustainability. Erosion of topsoil by wind and water is one of the most serious factors affecting soil quality and long-term agricultural sustainability. Desirable soil structure (soil tilth) is essential to provide aeration and soil conditions favourable for root growth. Soil quality and productivity cannot be sustained unless essential plant nutrients, removed from soils by harvest of grain and forage crops, are replaced. Acidification is a form of soil degradation which can result in toxic concentrations of aluminum and/or manganese in soil solutions, thereby decreasing yields of forage, grain and oilseed crops. Acid soils also reduce the ability of perennial and annual legumes to fix atmospheric nitrogen.

Both the nonagricultural and the agricultural sector can affect land and water quality, with organic and inorganic pollutants, resulting in contamination of soils and water, and thus food and feed.

## Background

### Area

The 47 million hectares of agricultural lands in the Prairie provinces make up one of the most extensive agricultural regions in the world. Soils of this region occur in concentric

zones emanating outward from a warm, dry prairie core centred in Southwestern Saskatchewan and Southeastern Alberta toward the more moist, cooler boreal forest region of the north (Figure 4.1). The natural vegetation in the driest areas, where Brown soils predominate, was short-grass prairie. Dark Brown soils occur in the slightly moister area surrounding the Brown soil region. Black Chernozemic soils occur in the more moist, subhumid northern grasslands and adjacent aspen parkland, where approximately 25 to 50 percent of the land surface is wetlands. Dark Gray and Gray Luvisols that were formed under mixed deciduous and coniferous forests occur in the northern agricultural region.

**Figure 4.1**

*Major Soil Great Groups of the Prairie Provinces.*



Figure 4.1  
Map

*Soil Characteristics/Weather/Plant Interface*

Soil development in the Plains Region of Canada has been influenced by climate, parent material, near-surface drainage and groundwater conditions. Glacial lake sediments, in the form of silts, clays and sands, are the most widespread parent materials for soils on the Plains. Ground and hummocky moraine form the next most common soil parent material. Unlike lake sediments, these glacial till materials contain variable amounts of coarse material.

Of the total land area suitable for arable agriculture, approximately 70 percent consists of Chernozemic soils. Other soils (the remaining 30 percent of the region's arable land base)

used for field crop production are Solonetzic soils in the south, Solodic soils in the Peace River area and Gray Luvisolic soils along the northern agricultural fringe.

Soil and climate are the principal determinants of the production potential of plants. In spite of technological achievement, soil and environmental conditions control the type of management and conservation practices that optimize production and sustainability.

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*By reducing input costs in this manner, farmers can maintain acceptable levels of profitability in the short-term, but often at the expense of soil quality.*

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Spring wheat, barley, canola, flax and oats are the dominant field crops grown in the Prairie region. Significant areas are also summerfallowed. The proportions of wheat and summerfallow are highest in the driest and warmest areas in the south and decrease regularly to the north where the area sown to oilseeds, oats, barley and tame hay is greater. The percentage of land seeded to pasture is generally similar in all zones except on Gray Luvisols where it is dramatically higher. Such land use adjustments to agroecological realities account for much of the physical and economic evolution in cropping patterns in the region. The tendency towards lower operating expenses in the drier south, particularly the use of fertilizer inputs, reflects the more unreliable crop response to such inputs in these areas due to more unreliable precipitation during the growing season. By reducing input costs in this manner, farmers can maintain acceptable levels of profitability in the short-term, but often at the expense of soil quality.

Year to year variations in crop production are directly related to the soil-water regime. Seasonal distribution of water within the soil profile is a complex interaction of many variables related to precipitation events and available solar energy, crop requirements for heat and moisture, the soil's ability to hold and transmit water, and production management systems affecting water use efficiency (cropping systems, use of pesticides and fertilizers).

In most zones of the Prairie region, there is high probability that at some time during the growing season there will be sufficient water stress to affect yields (see Climate Chapter). The probability of extreme water stress ranges from nearly no risk in the northern and eastern regions to high risk (greater than 60 percent) in the south-central region.

Summerfallowing as a method to reduce risk in low rainfall areas. It is most effective in the Dark Brown Chernozemic zone, the southern portion of the Black Chernozemic zone and northern portion of the Brown Chernozemic zone. Summerfallow potentially can increase the amount of water stored in loamy soils by approximately 30-36 millimetres. Typically, the contribution of summerfallow to soil water is about 44 millimetres in the driest zone and about 18 millimetres in the north. In many cases, the extra water conserved on clay soils in wetter zones can be detrimental for early seeding.

Cereal crop yields vary the most in the Brown soil zone in Saskatchewan and lowest in the Black soil zone in Alberta. However, differences between zones are not as great as expected because of the greater use of summerfallow in the Brown soil zone.

In recent decades, improved soil and crop management practices have enabled farmers to increase total crop production by 1.5 to 2.5 percent annually. Technological innovations and achievements in agricultural research have overcome barriers imposed by climate and the landscape (i.e. risk of erosion, drainage and stoniness characteristics), as well as soil chemical, physical and mineralogical deficiencies.

*Past Trends and Current Usage*

Early husbandry methods on the Prairies required farm families to focus on self-sufficiency. Priority was given to securing homesteads on farmable land with a good supply of water, wildlife and fuel wood. With the mechanization of agriculture, greater dependence on purchased farm supplies developed and the perceived values of wood, water, and wildlife declined. Woodlands, wetlands, and consequently wildlife habitat were cleared and converted to cropland. As a result, only minimal remnants of the original flora and fauna now remain in many areas of the Prairies. Some species have been lost; many are listed as endangered. About 50 percent of the original Prairie wetlands have been converted to agricultural land.

Since Confederation, strategies to develop the well-being of Canadians have radically changed the use and condition of the Prairies. Government policies established the pattern and pace of changes regarding use of land resources. The orderly division of the Prairies into a square mile land survey allowed for the systematic allocation of lands to settlers. Within 50 years, from 1870 to 1920, farmsteads dotted the Prairies on most sections of land from Winnipeg to the Rockies.

Land ownership rights were guaranteed by the Crown but the Crown retained the rights to free-standing water and wildlife inhabiting the deeded land. To maximize economic returns, the farmer's best option was to cultivate from fence to fence, as there were more disincentives than incentives to preserve wetlands and wildlife habitat. Common rights held by the Crown continued to be lost due to the farmer's interest in maximizing profits on privately held land.

Transportation policies, from those affecting railways and the confederation of the provinces to the current argument on rationalization of rail services, all exploit the Prairie resources for the well-being of Canadians and people abroad without considering the costs of loss of common property.

*Potential for Agricultural Expansion*

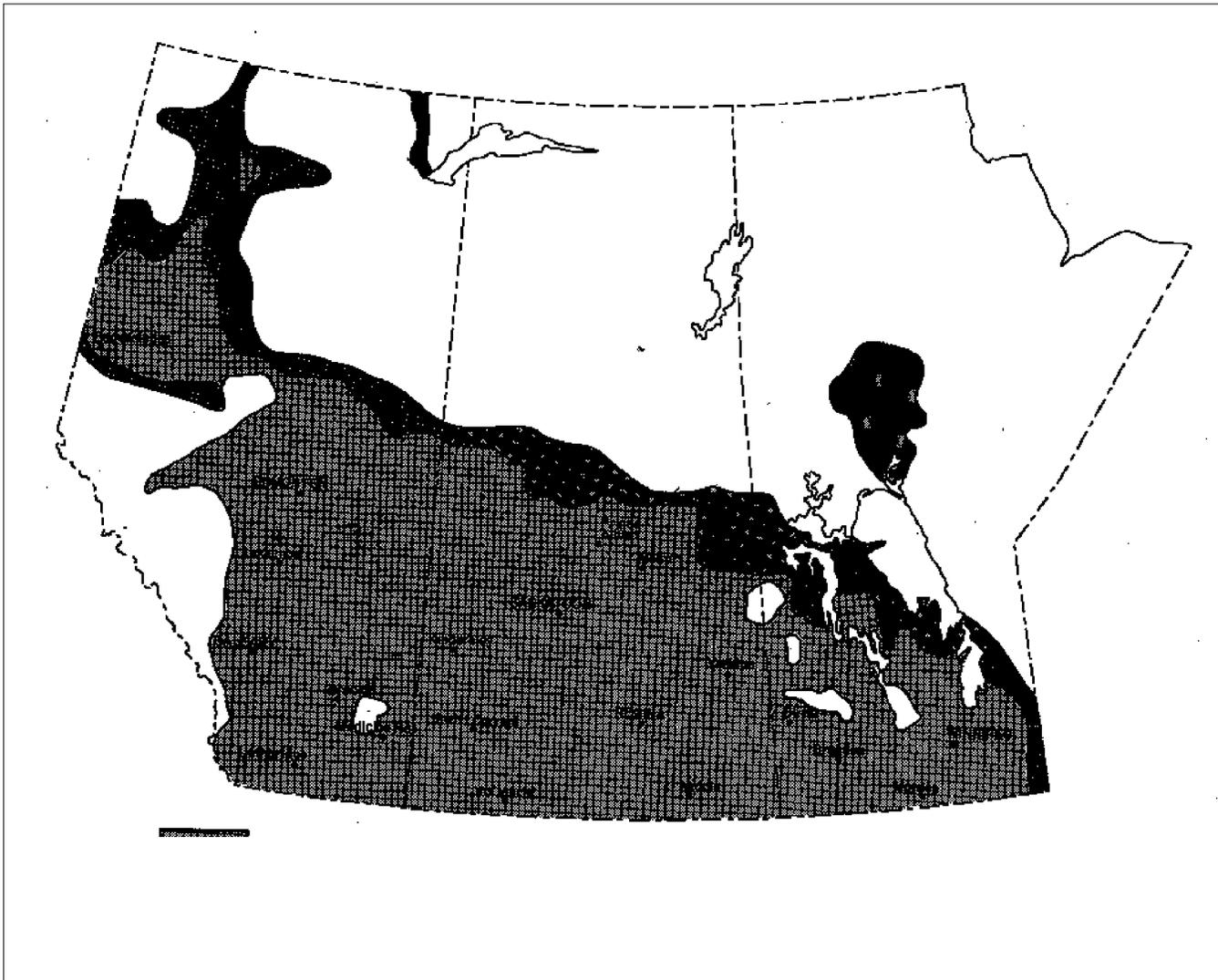
Three major unfarmed areas potentially capable of being brought into production include the Chernozemic Dark Gray and Gray Luvisols of the Peace River district of Alberta (approximately 9.6 million hectares); the Chernozemic Dark Gray Luvisols (2.9 million hectares) and organic soils (3.0 million hectares) of the Manitoba Lowlands; and to a lesser degree, the Gray Luvisols, sandy Brunisols and Gleysols of the Northern Forest Reserve and Saskatchewan River Delta of Saskatchewan (3.0 million hectares; Figure 4.2). Most of this undeveloped land would be suited for the production of forages for grazing. Obstacles to realizing even a fraction of this physical potential include the high costs of ameliorating landscape and soil limitations, uncertain markets, and the increasing influence of a population concerned with environmental quality and the preservation of natural lands as waterfowl and wildlife habitat.

In addition to the 32 million hectares of Chernozemic soils suitable for cultivation, there are about 2 million hectares of Solonetzic, Regosolic and Gleysolic soils on the Prairies suitable for producing crops. In addition there are about 20 million hectares of Solonetzic, Regosolic and Gleysolic soils that are poorly suited for cultivation in their native state and would require major inputs for sustainable crop production.

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*To maximize economic returns, the farmer's best option was to cultivate from fence to fence, as there were more disincentives than incentives to preserve wetlands and wildlife habitat.*

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**Figure 4.2**

*Potential Agricultural  
Lands of the Prairie  
Provinces.*

Notwithstanding current financial and environmental difficulties being experienced by Prairie farmers, further advances in long-term agricultural production will probably be achieved through better utilization of land already in production. To maximize sustainability, cropping systems must be better matched to inherent production environments of the area.

Agriculture in the Black Chernozemic zone has not yet reached its agronomic or economic potential. Some intensification of agriculture could be undertaken in these regions by reducing summerfallowing in the more humid regions. Conversely, some areas, particularly in the Brown Chernozemic and Gray Luvisolic zones, should be utilized at lower intensity levels than at present, or removed from cultivation. In all areas of the Prairies, there is considerable potential for improved land management (e.g., more balanced soil-water management in relation to crop needs and improved fertilizer and crop residue management). Recent research findings suggest that production in some areas can be almost doubled with improved water management practices.

**Loss of Soil Organic Matter**

Soil organic matter (SOM) refers to all of the organic materials present in the soil, and includes plant roots and other plant residues, along with recently added, partially decomposed organic material and more completely decomposed or humidified material. Soil organic matter increases granulation (aggregation) of soils, resulting in desirable soil structures; reduces the plasticity and cohesion of wet soils, resulting in increased ease of tillage; and increases the water holding capacity of soils, which is of significance in very coarse textured soils. Soil organic matter also acts as an absorber and exchanger of plant available nutrients by increasing the cation exchange capacity of soils. Large portions of total nitrogen, phosphorus, and sulphur are held in organic forms.

In the native state, soil is in equilibrium with its environment, and the organic matter content of the soil is in a “steady state”. Under intensive agriculture, the system’s equilibrium is disrupted, with the outputs from the system exceeding the inputs to the system, resulting in a decrease in the SOM content. Frequent fallowing and intensive, sometimes excessive tillage has accelerated the decrease of SOM, while causing soil losses through erosion.

Cultivation has also affected the quality of SOM. The active fraction (responsible for releasing nutrients) has declined more than the humidified (more stable) fraction. However, the active fraction of the SOM can be replenished relatively quickly, while the humidified fraction is more difficult to recover once it has been lost.

Upon decomposition of the SOM, nitrogen and other nutrients are mineralized and made available for plant uptake. However, after initial breaking of the soil, mineralized nitrogen will greatly exceed crop requirements and large amounts become susceptible to losses, either by leaching or denitrification (gaseous forms). After years of cultivation and continuous decomposition of SOM, the amounts of nutrients released begin to decline. There is evidence that in some Prairie soils the losses of potentially mineralizable nitrogen, that is the soil’s nitrogen-supplying power, are even greater than the losses of gross SOM. Continued decreased soil organic matter levels, such as occurs with summerfallowing, will result in lower and lower amounts of mineralizable nitrogen.

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*Frequent fallowing and intensive, sometimes excessive, tillage has accelerated the decrease of soil organic matter, while causing soil losses through erosion.*

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**Table 4.2**

*Estimated Losses of Organic Matter from the A Horizon, by Soil Zone and Provinces of the Canadian Prairies.*

Zone	Percent Loss			Weighted Average
	Alberta	Saskatchewan	Manitoba	
Brown	38	43	NA	41
Dark Brown	42	45	NA	44
Black	47	50	51	49
Dark Gray	40	44	44	42
Gray Luvisolic	35	41	34	36
Weighted Average	42	46	49	45

By contrast, continuous cropping, the addition of nitrogen fertilizers and use of forages can aid in maintaining SOM levels and mineralizable nitrogen.

The SOM content of soils in the Prairies has been decreasing at an alarming rate since the inception of agriculture some 80 to 100 years ago. It is estimated that from 36 to 49 percent of the SOM content originally present in Prairie soils has been lost solely due to the effect of cultivation (Table 4.2).

The period of greatest SOM decline is over. Rates of SOM loss in the Brown and Dark Brown zones have slowed, in part due to improved farming practices. The SOM can be maintained or increased in soils if erosion is eliminated and recommended levels of fertilizer are used to maximize crop growth. Long-term crop rotation studies at Lethbridge, Alberta have shown that the use of continuous cropping, together with fertilizer, have resulted in SOM levels similar to those before cultivation; however, the quality of the SOM may not be the same. Losses of SOM in the Black soil zone have generally been greater than in drier areas of the Prairies, mainly because there was more SOM to begin with and because SOM is in a more readily available form. The period of greatest SOM decline is also over in the Black soil zone, although between 1960 and the mid-1980's SOM in Manitoba has declined, on average, 0.5 percent. Maintaining the SOM levels of the Black soil zone can also be accomplished with appropriate crop and land management practices. In the Gray and Dark Gray soil zones, pre-cultivation SOM levels were variable, and in some cases SOM levels have increased since cultivation. Increasing SOM levels in this zone is a high priority, especially for improving soil structure.

### **Erosion**

Soil erosion is a process of detachment and transport of soil material by running water, wind or gravitational creep. The process is natural (geological), is of universal occurrence, and has been occurring throughout history. Accelerated erosion is excessive soil removal and is caused by human alterations to the nature and density of native vegetation. When erosion occurs, the uppermost soil layer, the fertile and valuable topsoil, is affected. Selective sorting of soil particles takes place during the erosion process. The finer particles such as silt and clay or small aggregates of silt, clay and organic matter are readily transported, leaving the coarser, less important particles behind.

Wind erosion occurs from strong winds during dry conditions on lands with little-to-no surface cover and with soil aggregates less than 1 millimetre in size. It is a serious problem on soils that are summerfallowed and on cropped fields in the spring before seedling establishment.

Water erosion occurs on soils with varying degrees of slope when rainfall amounts exceed the water infiltration rate. The impact of the raindrops breaks down the aggregates and clods into finer silt and clay particles. These "fines" move downslope with the runoff water. The greatest damage is usually done in spring when the soil is thawed only at the surface and snowmelt is rapid. Some areas also experience erosion during intense summer storms.

Organic matter is one of the most important constituents lost during erosion of topsoil. Topsoil has the capacity to accept, hold and transmit rainfall slowly to the underlying

horizons. When some of the surface constituents are removed by erosion, the infiltration is reduced and greater amounts of water run off, carrying additional topsoil with it.

During high runoff, considerable sediment may be transported to the drainage network of the farm, leading to siltation of ditches, waterways and storage reservoirs and reducing their capacity. Water quality may also be affected by the excess runoff from eroded soils to the surrounding water bodies. The addition of organic matter and suspended soil containing considerable nutrients, and possibly pesticides, results in a decrease in water quality.

Soil erosion results mainly from mismanagement of soils and inappropriate land use. Summerfallowing and cultivation practices, particularly intensive tillage, increase the risk of erosion. The soil is left loose with minimal residue, particularly when fall tillage is used to incorporate herbicides and fertilizers. Removal of crop residues, such as by burning, also leaves land unprotected and subject to erosion. Lack of shelterbelts and windbreaks (including standing stubble) allows winds to pass with maximum velocity over cultivated land. The land remains exposed during the winter and often remains bare of snow, thus increasing the risk of wind erosion. Similarly, the land remains exposed during spring.

Inappropriate land use also results in erosion. Fragile lands (for example, coarse textured land or steep slopes) are often used for annual cropping without proper tillage and crop rotational practices. Land is commonly used for production of cereal crops when the appropriate use would be to retain it in native habitat or seed it to perennial forages.

For Prairie land affected by moderate and severe erosion, water erosion has been estimated to occur on 4.64 million hectares (12 percent of the improved land), and wind erosion on 6.31 million hectares (16.4 percent of the improved land; Table 4.3).

**Table 4.3**

*Prairie Region Land Damaged by Moderate to Severe Erosion Caused by Water and Wind.*

Agent	Hectares Damaged (millions)	Percent of Improved Land	Estimated Income Loss (\$ millions)
Water	4.64	12.0	155 to 197
Wind	6.31	16.4	213 to 271

In 1989 and 1990, a series of maps entitled Soil Landscapes of Canada were prepared for each province by the Land Resource Research Centre, Ottawa, at a scale of 1:1 million. Additional interpretive maps and legends were prepared for wind erosion risk and water erosion risk. These maps show the long-term risk of erosion on bare, unprotected soils; the proportion of land that is cultivated, and therefore, likely to be at risk; and the effectiveness of current management in protecting the soil from erosion.

The economic cost of soil erosion on Prairie agriculture is difficult to determine exactly, since no detailed figures are available for the area of land with soil damage, the quantity of soil lost, or the costs associated with siltation of waterways and reservoirs. However, recent estimates of annual on-farm economic impact in the Prairie region range from \$155 to \$197 million due to water erosion and \$213 to \$271 million due to wind erosion (see Table 4.3). The annual economic impact of soil erosion, in general, is

estimated at \$370 million, and unless soil management and land use practices improve, is expected to increase by about \$5 million each year.

It has been estimated that loss of 1 centimetre of topsoil reduces wheat yields by 40 kilograms per hectare. The total annual soil loss to erosion on the Prairies, therefore, extrapolates to a yearly reduction of 71,600 tonnes of wheat. While this amount may not seem substantial, soil losses due to erosion are cumulative, since the rate of soil formation does not keep pace with erosion. Prairie soils have been farmed for an average of 75 years, therefore, the loss of potential production is equivalent to 4.65 million tonnes of wheat annually. This is 13.7 percent of the total crop production averaged between 1969-1978.

The loss of this potential production has been offset to some extent by the use of improved technology, principally the use of fertilizer. In areas where moderate to severe soil erosion has occurred, it is estimated that the yield recovery will probably be limited to approximately 85 percent of potential yields.

### **Soil Structural Degradation and Compaction**

Soil structure refers to the aggregation of primary soil particles into compound units. The size, shape and stability of aggregates influence the porosity of soil. Porosity is essential to provide aeration, water movement, water storage and channels for root penetration. Desirable agricultural soils possess structures where aggregates are arranged to provide a complex of macro- and micropores. An excess of macropores may cause loss of water and nutrients through rapid drainage. An excess of micropores may cause slow infiltration of water resulting in excessive wetness at the surface. This wetness may also trap soil colloids and increase bulk density.

Soil aggregate formation results from interaction among mineral particles, organic matter and the soil solution. Soil organisms acting on the organic material provide most of the “cementing” agents that hold aggregates together and influence stability. Deterioration in soil structure makes the soil more susceptible to erosion, slows infiltration rates, impedes seedling emergence and root penetration, and makes the soil susceptible to compaction by machinery. Some practices have contributed to undesirable degradation of soil structures.

The crops grown on the Prairies have different life cycles, rooting systems and crop residues compared to the native grasses they replaced. Exudate from the decomposition of these residues differ in quality and quantity from the original grasses, and may result in weakening of structures. Under cropping systems that include frequent fallow, there is a reduction in the amount of crop residue produced and “cementing” agents released when residues decompose, thereby weakening soil structures. Excess fallow and tillage generally results in a breakdown of soil structures due to abrasion, and often exposes soil to erosive forces which themselves degrade desirable structures. Tillage can also increase the oxidation of organic residues and hasten the rate of reduction of “cementing” agents. Farm machinery has increased in size and weight which can cause compaction, particularly when soils are wet. Some machines, however, have tires designed to reduce weight per unit area.

Soils with granular structures conducive to field crop production include the grassland soils (Brown, Dark Brown, Black and Dark Gray Chernozems) developed on medium to fine textured parent materials. Weakly-aggregated, platy structures of forest soils (Luvisols) are unstable and break down easily. When unprotected from rainfall and

ponding of water, platy and granular structures can form crusts upon drying. Crusting can have a detrimental effect on plant emergence and cause severe yield reductions, particularly of small-seed crops such as alfalfa and canola.

Undesirable structures include large and massive clays often associated with salt-affected (Solonchic) soils and some Chernozems. About 0.8 percent of the land area of the Prairies are classified as Solonchic soils characterized by leached surface (Ae) horizons and massive, dense subsurface (Bnt) horizons that resist water infiltration and root penetration. Solonchic soils also have a high clay content in the subsoil that swells when wet and cracks deeply when dry. Cracking causes loss of subsurface moisture by evaporation, and roots can be pruned by the separation of the massive structures. Solonchic structures are naturally occurring. Research work for improvement includes degradation of the peds by drainage, physically breaking them by deep tillage, and/or the addition of chemicals (such as gypsum or elemental sulphur). Structureless soils (sands) also occur. Sands and weakly structured (platy) soils are highly susceptible to erosion.

### **Salinization**

All soil solutions contain soluble salts. A critical concentration of ions must be present in the soil solution for proper plant nutrition. However, salts greatly in excess of plant needs are detrimental to plant growth. The level at which soluble salts in the soil interfere with plant growth is described as salinity and will vary with plant type. Salinity is essentially a water problem. Soluble salts are transported out of or into the root zone by the movement of water. Downward flow of infiltration water leaches salt down below the root zone. Upward flow of capillary water from the water table can bring salts into the root zone.

Within the Prairie ecosystem, there are two sources of salinization - artesian and saline seeps. The majority of strongly saline areas are closely associated with groundwater discharge from confined and semi-confined glacial outwash and bedrock aquifers. Therefore, it is likely that any change in salinity will be a function of the controlling mechanisms, such as long-term precipitation, rather than of agricultural land management.

Induced salinity is that which has developed as a direct result of land use practices. Practices which raise local water tables to within 1.5 metres of the soil surface are most likely to promote the processes of soil salinization. Some examples of these practices include the use of unlined irrigation and drainage canals, continuous cultivation (summerfallow) of moist areas adjacent to wetlands, inadequate cleaning and drainage of wetlands, and restrictions or alterations of natural waterways. The end result of these practices is the enhancement of seepage processes and capillary water flow to the soil surface with the consequent deposition and accumulation of soluble salts.

The presence of soil salinity has a deleterious effect on crop yield and biomass. In addition, the level and distribution of salinity reduces management options such as choice of crops and tillage practices. The adverse effects of moderate salinity on crop growth are clearly visible, and yield reductions of 50 percent of normal can occur.

Salinity is also a major factor in determining the physical quality of soil. Saline soils containing high concentrations of sodium salts (saline-sodic soils) typically have poor physical structure due to the dispersive effects of sodium on soil particles. Large tracts of

solonchic soils on the Prairies also derive their poor physical characteristics from the presence of excessive sodium and/or magnesium salts. The poor structural properties of both saline-sodic and solonchic soils hinders the preparation of seed beds, as well as the penetration and proliferation of plant roots.

The most recent assessment indicates that the total extent of moderate salinity affecting agriculture in the Prairie ecosystem is about 1.3 million hectares. This area includes 0.3 million hectares in Manitoba, 0.6 million hectares in Saskatchewan, and 0.4 million hectares in Alberta. At lower levels of salinity the extent will be significantly larger.

The most common occurrences of induced salinity is that related to irrigation practices, such as flood irrigation with inadequate drainage. It is currently estimated that 100,000 hectares of land in southern Alberta and 20,000 hectares in Saskatchewan are affected by irrigation related salinity. To date no irrigation induced salinity has been reported in Manitoba.

Land use practices which maintain water tables well below the root zone will control and often reduce the accumulation of salts in the soil. These practices include the use of deep-rooted perennial forages such as alfalfa, tillage practices which minimize the disturbance of the soil surface, salt-tolerant plant species in the salt affected area, and pipelines and linings in drainage and/or irrigation canals.

### Loss of Soil Fertility

Soil fertility refers to the capacity of the soil to provide plants with the nutrients necessary for growth. Nutrients may be in forms readily absorbed by plants (available nutrients) or, more commonly, they may be bound in minerals, organic matter, and other soil particles in forms which cannot be absorbed (unavailable nutrients). Soil fertility is greatly influenced by the balance of nutrients between their available and unavailable forms and by the rate of their conversion from one form to the other. The balance of nutrients between the two forms is influenced by the amount of the nutrient, the physical and chemical nature of the soil, and the abundance of soil organisms.

Plant available nutrients enter soil through a variety of sources, for example weathering of minerals, decomposition of plant and animal residues, deposition from precipitation, conversion (fixation) of atmospheric gases, and application of soil amendments (fertilizers, manures, lime). Losses or output of nutrients from soil also occur in a variety of ways, for example absorption by plants and their subsequent removal, conversion to gases and loss to the atmosphere, leaching into groundwater, runoff in surface waters and losses through wind erosion.

Loss of soil fertility is mainly the result of removal of nutrients by crops but also the result of many of the same practices which contribute to soil erosion and loss of soil organic matter. Summerfallow results in a temporary increase in soluble nitrogen (primarily nitrate) which can be absorbed by plant roots, but in the long-term causes a decrease in total nitrogen content of the soil. Summerfallow can also result in leaching or volatilization of soil nutrients. Burning of residues leads to loss of nutrients and organic matter.

Soil nutrients critical for agricultural production include nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg), copper (Cu), zinc (Zn), iron

(Fe), manganese (Mn), chlorine (Cl), boron (B) and molybdenum (Mo). A deficiency in any one of the above elements limits yield. When cultivation of the Prairies first began, many soil nutrients were in relatively high concentrations, particularly in soils developed under grassland (Chernozemic soils). Other soils, such as those formed under forests (Luvisols), or in areas with high precipitation rates, may have had relatively low levels of soil nutrients. Prairie soils supplied relatively adequate amounts of nutrients (mainly N, P and S) for crop growth for several decades after cultivation. Nutrients were supplied from the rapid decomposition of soil organic matter. Nutrient supply to crops, however, declined rapidly as soil organic matter levels dropped. Fertilizer use became a necessity to maintain and/or increase yields, either because the soil did not contain adequate levels, even when first cultivated, and/or the nutrients were exhausted by such factors as crop removal or erosion.

*The conversion of organic N to plant available N occurred at about 70 to 80 kilograms per hectare per year over the first 20 years of cultivation on the Prairies. By 1980, the value had decreased to 30 to 50 kilograms per hectare per year.*

Years	Nitrogen <sup>1</sup>			Phosphorus <sup>2</sup>		
	Removed	Added	Added/ Removed (%)	Removed	Added	Added/ Removed (%)
1883-1953	14.43	0.07	0.5	2.50	0.12	4.6
1954-64	4.90	0.24	4.9	0.84	0.22	2.6
1965-71	4.36	0.89	20.5	0.77	0.41	53.9
1972-78	4.98	2.17	43.5	0.86	0.78	91.4
1979-89	9.69	8.11	83.8	1.65	1.92	116.5

<sup>1</sup>N content of wheat and rye, 2.2%; oats and barley, 1.8%; flax, 4.0%; rape, 3.5%.  
<sup>2</sup>P content of cereals, 0.35%; oilseed crops, 0.60.

It has been estimated that the conversion of organic N to plant available N occurred at about 70 to 80 kilograms per hectare per year over the first 20 years of cultivation on the Prairies. By 1980, the value had decreased to 30 to 50 kilograms per hectare per year. In recent decades, however, organic matter decline has been offset to a certain degree by use of nitrogen fertilizers.

Prairie soils are deficient in P available for plant growth. Use of P fertilizers is necessary to meet crop demands for P (Table 4.4). One-third to one-half of soil P may be in an organic form. Long term studies suggest that under cultivation organic P levels decline, but the impact of this decline on long term soil fertility is unknown.

Total soil K in Prairie soils is high, but the levels of available K are largely dependent on soil texture and rates of precipitation. Lighter soils (higher sand content) in the wetter

**Table 4.4**

*Estimates of Total Nitrogen and Phosphorus Removed in Grain of Wheat, Barley, Oats, Rye, Flax, and Canola and Applied as Commercial Fertilizer (millions of tonnes of elemental N or P).*

areas of the Prairies tend to be deficient in K while soils with higher clay content and in drier areas tend to maintain high levels of soluble K.

Sulphur deficiencies, which are most prevalent in sandy and well-drained soils, have occurred in recent years in some crops grown on the Prairies. Sulphur deficiencies are most prevalent in sandy and well-drained soils. Sulphur is similar to nitrogen in that it tends to be bound in organic matter and is made available to plants through the action of microorganisms (mineralization). Hence, the decline in soil organic matter may lead to declines in sulphur concentrations. An exception to this generalization is Prairie soils which are naturally high in gypsum (calcium sulphate).

Mineralization of organic matter and weathering of minerals contribute “trace” elements (micronutrients) necessary for plant growth. In general, micronutrients are not limiting to plant growth on the Prairies. Certain micronutrients may, however, be deficient in specific areas. For example, Cu can be deficient on some highly organic (peat) soils and acid soils and manganese may be deficient on poorly drained, alkaline clay and organic soils. Once identified, these deficiencies can be ameliorated with soil amendments.

### Acidification

Acidification of soil refers to a complex set of processes resulting in a depletion of basic cations (Ca, Mg) from the soil and an increase in the acidic cations (hydrogen, aluminum). Soil pH describes the extent of acidity in soils. For agricultural purposes, soils with pH less than 5.5 are undesirable and require corrective measures and management, while soils with pH 5.5 to 6.5 are potentially acid, those with pH 6.5 to 7.5 are most conducive for farming and those with pH greater than 7.5 are alkaline. Thus, from the point of view of crop production, soils which have pH less than 6.5 merit special attention.

The greatest human-constructed cause of acidification is the use of large applications of ammonium sources (nitrogen fertilizer), elemental sulphur and some phosphate fertilizers. Though rapid and large-scale acidification due to fertilizer use is uncommon, since all soils possess a natural ability to resist changes in their pH, a slow and slight drop in the soil pH should be expected as a consequence of fertilizer use. Other causes of net acidification of soils are plant uptake of base cations in exchange for H released. This occurs naturally to the extent that the reduction in the pool of exchangeable bases may not be replaced by the weathering of minerals. Acidic deposition by industrial emission can also cause significant lowering of soil pH. The sensitivity of soil to acidification is governed by inherent soil characteristics and the management systems imposed. The least sensitive soils are those which have both a high pH and a high cation exchange capacity and which contain carbonates.

Plant growth on acid soils is usually retarded because aluminum (Al) and/or Mn concentrations increase to toxic levels; the toxicity increases with decreases in pH. Legumes do not fix atmospheric N well under acid conditions due to toxicities and lack of Ca. Metals such as Cd and Pb are more soluble under acid conditions and thus can be more readily taken up by plants, affecting crop quality.

The current area of land in the Prairie provinces considered to be acidic (pH less than 5.5) is 2.1 million hectares. In addition, an estimated 10.5 million hectares are in the

potentially acidic (pH 5.5 to 6.5) range. Most of this area lies in Saskatchewan, Alberta and the Peace River region of British Columbia. Manitoba has less than 5,000 hectares of acid agricultural soils.

Acidification of soils is expected to increase with continued farming practices, and soils presently considered to be potentially acidic could become acidic. The pH of weakly buffered soil can be reduced by about one and a half pH units over 10 to 15 years with an annual application of about 112 kilograms per hectare of ammonium sulphate.

### **Concentration of Agricultural Chemicals and Contaminants**

The soil is a medium for a variety of fertilizer nutrients and pesticides. Soils are also recipients of metals and other contaminants as a result of industrial and other emissions, use of various soil amendments and disposal of various wastes on agricultural land.

**Metals** — Some metals are essential to plant growth, e.g., Cu, Fe, Zn. These metals exist naturally in soils at concentrations which depend on the nature of the parent material from which the soil was derived. The mobility of metals and their availability to plants depends on their chemical form. The form in soil solution will be influenced by hydrogen ion activity (approximated by soil pH), oxidation-reduction reactions, and the degree of association of the metals with other substances in the soil. Where metals exceed beneficial concentrations in soil or where they have no nutritional value, they are of concern as pollutants.

Metals such as Cd, Cr, Pb, Ni, Zn and Cu may be added to soils as contaminants in phosphorus fertilizers, in urban wastes such as sewage sludges, in industrial and automobile emissions, in incineration of materials, and in the use of fossil fuels. Increases in metal concentration in crops decreases crop quality.

The extent of contamination of Prairie soils with metals is unknown. In general, soils near highways and in urban areas contain higher levels of Cd and Pb than rural soils. Contamination of soils is of importance with respect to the resulting metal content of crops. Generally, levels of metals in crops is believed to be below acceptable levels with the possible exception of Cd.

**Pesticides** — Pesticides (insecticides, herbicides, fungicides, acaricides, rodenticides) are largely organic chemical substances. By far, the most commonly used pesticides on the Canadian Prairies are herbicides. Whether such pesticides persist in the environment depends on their volatility, degradation rates, partition coefficients in air and water, and strength of their adsorption to soil. Herbicide residues remaining in the soil beyond one growing season may represent a benefit in terms of long-term weed control, but also may pose restrictions on crop rotations where phytotoxic residues persist. Such long-lived residues may also be transported to aquatic systems in surface runoff or may be leached through the soil profile to contaminate ground water.

Insecticide use on the Canadian Prairies is associated with crop protection, livestock protection, stored product protection, forest protection and urban insect control. Contamination of the land base itself through insecticide use in agriculture is most affected by their use to control flea beetles on oilseeds and the Colorado potato beetle on potatoes. Presently, Carbofuran is presently the most widely-used insecticide. Carbofuran degrades in soil over the period of one growing season, but sufficient quantities are used

on the Prairies on potatoes and oilseed crops to provide the potential for groundwater contamination to occur.

Herbicides account for 80 percent of all pesticide sales in Western Canada. In 1990, 95 percent of land planted to wheat, barley, canola and flax was treated with one or more herbicides. Herbicides incorporated onto soil before seeding must remain in the soil in an active form for a sufficiently long period to kill germinating weeds. Depending on the persistence of the herbicide molecule, and the environmental conditions in the soil (moisture, temperature), these herbicides may remain in the soil for 1 month to 2 or more years. They do not pose a threat through drift to nontarget areas since they are applied at the beginning of the growing season; however, depending on the properties of individual compounds and of the soils themselves, they may be sufficiently mobile in some soils to contaminate groundwater.

The use of post-emergent herbicides allows the farmer to evaluate the weed problem before the herbicide is applied. Most, but not all, of these herbicides have very low activity or have a short-term persistence in the soil; however, the greatest danger is with nontarget drift. Each year, herbicide spray and vapour drift cause damage to surrounding vegetation (also see the Air chapter).

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Runoff is believed to be a major route of pesticide loss from agricultural land, particularly of residues sorbed to soil particles and subsequently desorbed at various rates when contaminated soil enters surface water. The participation of soil and dissolved organic matter in this sorption and transport of contaminants is just beginning to receive research attention.

The contamination of surface and groundwaters with pesticides may lead to toxicological effects for fisheries, wildlife, irrigated agricultural crops, as well as humans through contaminated drinking water. It may also interfere with the use of the water resource for industrial purposes.

The extent of contamination of Prairie surface waters with pesticides has received very little monitoring attention. cursory studies on rivers and streams have shown trace levels of herbicides such as 2,4-D and related phenoxy acid herbicides. However, these residues have been lower than those which can normally be quantified with any analytical confidence (less than 0.01 microgram per litre). The presence of trace levels of pesticide residues indicates the potential for future problems. Measures should be taken now to avoid severe problems. Reducing the runoff and erosion in treated agricultural fields, for example, could prevent the situation from worsening.

**Nutrients** — The addition of nitrogen fertilizers is essential to the maintenance of soil fertility on the Prairies. The use of nitrogen fertilizer at rates in excess of crop requirements, however, increases soil nitrate-nitrogen levels. Many stubble fields are high in nitrate-nitrogen, do not require fertilizer nitrogen for 1 or 2 years, and (particularly on coarse textured soils) pose a high risk of contaminating groundwaters with nitrate-nitrogen.

During summerfallow, mineralization of organic matter releases nutrients such as N. Mineralized nitrogen is present mainly in the nitrate form and moves with soil water. Many studies have shown that large quantities of nitrate-nitrogen occur below the rooting depth of annual crops in soils frequently fallowed.

Contamination of groundwaters with nitrate-nitrogen can also occur from livestock operations. Nutrients, particularly those containing N and P, are often present at high concentrations in groundwaters below confined animal units. Application of manures at rates which provide greater amounts of N than needed to meet crop requirements also causes nitrate-nitrogen to accumulate in soils and poses a risk to groundwater contamination. The extent of contamination of groundwater with nitrate-nitrogen by agricultural activities is unknown.

Contamination of groundwaters with phosphorus is not likely. However, erosion of soils containing commercial fertilizer, animal manures and indigenous sources of P results in increased P contamination of surface waters. The extent of P contamination of surface waters as a result of agricultural activities is also not well documented (see Water Chapter). Feedlots and farmsteads adjacent to rivers and streams have been known to cause pollution of these waters. Phosphate contamination of surface waters leads to excessive plant growth, eutrophication and loss of recreational potential. The death of excessive plant growth causes oxygen depletion of the water resulting in fish mortality and gross destruction of aquatic habitat.

**Other Contaminants** — Other soil contaminants which must be considered include petroleum wastes, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polychlorinated biphenylenes (PCBPs), polychlorinated diphenyl ethers (PCDPE), and many other organic industrial contaminants. Such contaminants are widespread in soils and sediments and concentrate in fatty tissue of agricultural animals and fish. Other organisms are similarly affected. Contamination of meat, fish and dairy products with these pollutants may prevent their acceptability for the commercial market.

## Land Use and Sustainable Agriculture

Sustainable agriculture depends on maintaining or improving the productive agrarian land. Land use practices that include managing the soil in a way that maintains productivity while upholding environmental and food quality are required.

### Appropriate Management Practices

The productive capacity of the soil must be maintained to ensure sustainable food production. Land degradative processes which cause irreversible damage to the soil and long-term loss of productivity must be minimized or eliminated. Thus, improved agricultural practices must be used to reduce and prevent such soil degradative processes as erosion, salinization, compaction and loss of desirable soil structures, nutrient depletion, organic matter losses and acidification.

In particular, rates of soil erosion must be controlled to maintain soil productivity and environmental quality. On most lands, the rate can be reduced to levels required for sustainable agricultural production. Much of the information needed to implement such a sustainable system is known. Losses of from 2.5 to 12.5 tonnes of soil per hectare per year is considered acceptable, depending on soil type, since these loss rates are about equal to rates of topsoil formation.

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Certain agricultural practices can have a negative impact on surface or groundwater quality, or on food quality. In order to achieve sustainability, the agricultural and food industry must continue to use and adopt practices which do not impair food and environmental quality.

#### *Tillage and Other Practices*

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*Minimum to zero tillage practices, would virtually eliminate erosion on the land suitable for arable agriculture.*

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*Some form of conservation tillage is possible on all Prairie lands.*

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**Reducing Tillage** — Tillage practices have a profound effect on erosion, soil organic matter decomposition rate and soil structure. Reducing frequency of tillage or eliminating tillage favours sustainability. Adopting minimum to zero tillage practices, which has been shown to be feasible in the Canadian Prairies, would virtually eliminate erosion on the land suitable for arable agriculture.

A vegetative cover is extremely effective in reducing soil loss by erosion. This cover is maintained by reduced tillage, continuous cropping practices, cover crops, and maintenance of surface residue. The land cover reduces the beating action of the rain and reduces the detachment of soil. Some form of conservation tillage is possible on all Prairie lands. Zero and minimum tillage systems, however, may increase reliance on use of herbicides to control weeds, although the actual amount used may decrease.

**Summerfallow** — Summerfallow should be practiced only in the drier areas of the Canadian Prairies, when lack of water has made the risk of crop failure high and the stored soil moisture is insufficient for cropping. Summerfallowing is unnecessary in the Black and Gray soil zones, with any benefits being mainly due to the mineralization of organic nitrogen (conversion of nitrogen to a form which plants can absorb; i.e. a fertilization effect) and weed control. Summerfallow can be reduced by snow and residue management, proper use of fertilizer amendments, and perennials instead of annual crops in some drier regions. The risk of crop failure needs to be assessed prior to each crop year using information on stored soil water, rainfall frequency and quantity. Cropping on stubble land should be encouraged, even in the drier areas when stored soil water is higher than average and risk of crop failure due to drought is less than average. Use of models, as will be described later, should be used to predict the need for summerfallow.

In many instances, summerfallow causes nitrate-nitrogen to accumulate in soils at depths below rooting depth of many annual crops, posing a risk to contamination of groundwater. If summerfallow was only practiced in the arid parts of the Prairies, where it is essential for storing water, the risk of nitrate-nitrogen leaching by rainfall would be very low. Moreover, if summerfallow even in the arid areas was conducted only in years of low stored soil water and practiced only on land of the soil type loam or a heavier texture, risk of leaching would be further reduced. By developing amendments to reduce bacterial activity during the summerfallow period, it may also be possible to retard the mineralization of N (production of nitrate-nitrogen). Chem-fallow, (no or little tillage) could be used to prevent erosion and enhance water storage.

**Other Cropping Practices** — Crop residues should be returned to the soil to maintain soil organic matter levels and desirable soil structures. Burning of residues can be avoided by using effective residue choppers and spreaders on combines. Retaining residues on the land may initially require additional fertilizer applications, as the soil organisms will tend to immobilize nutrients.

Shelterbelts planted perpendicular to prevailing winds reduce the wind velocity near the ground, which minimizes erosion during dry conditions and strong winds. The shelterbelts also trap snow during the winter months, protecting the soil surface and contributing to the moisture supply in the spring.

Strip cropping, as used for wind erosion control, consists of a regular arrangement of erosion-resistant and erosion-susceptible crops or fallow strips running at right angles to the direction of the prevailing winds. Erosion is reduced mainly because the less erodible strips trap eroding particles and thus curtail the momentum of the erosion process.

Contour tillage is one of the simplest forms of water erosion control in areas with long gentle slopes of between 3 to 8 percent. On steeper slopes the ridge cannot retain the runoff during heavy rainfall events. In areas with significant uneven topography, such as in a till plain, this practice is not practical.

Grassed waterways have been used for decades to prevent further erosion along flow paths in undulating and hummocky topography. In steeper terrain, drop structures are used to dissipate the velocity of water in the waterways and prevent water erosion.

**Use of Models** — Models and prediction equations have been developed for predicting the relative annual soil loss due to wind and water erosion in various geographic locations. These models are based on site characteristics and are used for determining whether summerfallow is needed (Flex-Crop Model). Modeling has been used as a tool for conservation planning, and in comparing conservation practices. Various models have been used to identify moderate to high risk areas, and to analyze the effectiveness of current management practices in protecting the soil from erosion.

The Universal Soil Loss Equation (USLE) for sheet and rill erosion and the Wind Erosion Equation (WEQ) are the empirically-based methods most widely used for predicting soil erosion and making interpretations for conservation planning. The conceptual basis for the two equations is that erosion is a function of the erosivity of climate, inherent soil erodibility, topography, and human activities.

Process-based erosion prediction technology is being developed in the U.S. to replace the USLE and WEQ. These are referred to as the Water Erosion Prediction Project (WEPP) and the Wind Erosion Prediction System (WEPS). The models are intended to be more event responsive and attempt to predict the soil loss when a water or wind erosive event, or a sequence of events, take place. Applications of the products from the water and wind erosion prediction projects will begin to be used in local Soil Conservation Society (SCS) offices in the mid-1990s.

Related research work on water and wind erosion is presently being conducted at various locations across the Prairies. The data will be used to test the applicability of the WEPP and WEPS models once they become available for SCS use. Studies on modeling, such as described above, must be continued to provide the means of assessing the long-term impact of particular practices on soil loss and productivity. Practices which result in high soil loss could then be eliminated. There is also a need for continued diligence regarding topsoil loss. Monitoring of soil loss must be undertaken to ensure that practices which have been adopted (for example, as a result of predictions from models) are in fact having the desired effect in terms of attaining sustainability.

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**Farming by Soil Unit** — Soils in farm fields are seldom uniform. They vary in topography, fertility and physical properties. Since variation within fields is usually large, different management practices would have to be employed in various parts of a field. However, fields are generally farmed in the same manner for convenience and practices employed may favour sustainability in one part of the field but not in other parts. For example, despite a risk of runoff barnyard manures are applied in parts of the field with steep slopes. To obtain sustainability, farming must be based on the inherent properties of the soil or land base. This practice requires an intimate knowledge of the physical and chemical properties of soils within a field, and how soil quality would be affected by different management systems. Some of the information and equipment needed for farming by soil unit is available. However, much more soil information and other technologies have yet to be obtained to make farming by soil units a reality.

**Drainage and Irrigation** — Drainage and irrigation practices have been implemented singly, or in tandem, to facilitate crop production in areas with excess seasonal surface water and areas with large seasonal moisture deficits. Once initiated, however, the infrastructure for both must be maintained to ensure sustainable crop production. For example, surface drainage of the fine textured soils in the Red River Valley is a necessity for the production of annual crops and forages. Irrigation, on the other hand, has increased the yield and diversity of crops grown in the drier regions of Southwestern Saskatchewan and Southern Alberta. Production in both regions could not be sustained if the infrastructures for drainage and irrigation were not maintained.

Subsurface drainage has been used to lower water tables in areas susceptible to salinization under both dryland and irrigation farming systems. To a more limited extent, it's also been used to drain isolated shallow water bodies such as sloughs.

The lack of sufficient quantity and quality of both groundwater and surface water on the Prairies, combined with significant annual moisture deficits, is a major constraint to sustained crop production in a major portion of the Prairie provinces. If agricultural production is to be increased, or if the risk of current production levels are to be reduced, it is crucial that more efficient methods of water management be developed. More efficient methods of precipitation utilization and surface water distribution, as well as improved techniques for irrigation, will be required in the future if existing production areas are to be maintained and new areas brought into production. (See Water chapter for further discussion of irrigation water).

#### *Nutrient Inputs and Other Amendments*

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*The criteria for sustainability do not dictate against, or include, the use of inorganic or organic amendments.*

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The productive capacity of the land can be maintained by the application of either organic or inorganic amendments or both. The criteria for sustainability do not dictate against, or include, the use of inorganic or organic amendments.

**Nutrients** — Soil nutrients need not be returned to pre-cultivation levels to make crop production sustainable. However, it is highly desirable, if not necessary, that these components be maintained at present levels, and in many soil types increased. Sustainable fertility of the soil depends on a continuous ensured supply of fertilizers, continued investigation into alternative nutrient sources, effective and efficient use of nutrient sources, and an understanding of the effect of these nutrients on the environment.

The credo for sustaining soil fertility is to return the nutrients which are removed by a cropping practice. There is an inexhaustible supply of N in the atmosphere. Industrial production of nitrogen fertilizers can continue as long as there is a reliable supply of energy. With respect to alternative N sources, greater use of annual, biennial, and perennial legumes as green manures would reduce the requirements for nitrogen fertilizers. Greater use of forage legumes requires an increase in livestock population to utilize the forage and help cycle nutrients within a farm operation. A greater dependence on legumes to provide N will require increased use of phosphorus fertilizer, since legumes have relatively high P requirements. Notably, the use of perennial legumes (e.g., alfalfa) in rotations in the arid and semi-arid regions depletes soil of water to depths of 250 to 300 centimetres and thus is not recommended for such areas.

The greatest limitation to sustaining soil fertility is replacement of P removed by cropping. Phosphorus is mined from calcium phosphate reserves, which are a finite resource. Use of biological resources, such as soil bacteria and fungi, may help us utilize P more efficiently, but at present there is no apparent solution to this inevitable problem of a finite resource. In the future, it will be necessary to recycle our dwindling supplies of phosphate and use P resources (crop residue, animal manure, sewage effluent and sludges, phosphorus fertilizers) more efficiently.

Effective use of barnyard manures, sewage sludges and other urban wastes as nutrient sources must be encouraged. However, metal additions to soils via amendments and fertilizers will have to be regulated (i.e., life-time loading limits established for particular soils). To prevent accumulation of metals in soils, more emphasis should be put on removing metals from urban wastes and fertilizers prior to application on land, and the contamination of carbon wastes with metal should be prevented. When manure is disposed of on agricultural land, risk of contamination of groundwaters with nitrate-nitrogen can be reduced to acceptable levels by application at appropriate rates and only to soils with a low risk of leaching.

Another goal to achieving sustainable soil fertility includes maximizing plant use of added nutrients. Use of excessive amounts of fertilizers is not only a waste of resources but can impact negatively on water and food quality (e.g., nitrates in groundwater). To avoid adding excessive amounts of fertilizer, the amounts supplied by the soil must be determined. Soil tests have been developed for this purpose. However, nutrient content in a field is seldom uniform. The technology to apply these soil tests efficiently must be further developed. Increasing the efficiency of crop use of fertilizer nutrients can be achieved by applying nutrients as close as possible to the time it is taken up by the plant. Improvements in equipment design and performance are needed to efficiently handle and apply fertilizers in spring in a single operation. Sustainable fertility is essentially dependent on addition of soil amendments and fertilizers. The limitations to applying such amendments are ones of energy and economics.

**Other Amendments** — Additional amendments are and will be required to correct problems such as soil acidity and poor soil structure. Use of natural products, such as quicklime, limestone, marl and shells, and byproducts such as slag are an effective way to neutralize soil acidity. Furthermore, liming materials are relatively pure and easy to use, therefore reducing the risks of contamination of the soil and precluding the need for expensive technological advances. Nevertheless, the amount of lime used in Alberta and

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Saskatchewan is much less than would be warranted, mainly because of the costs involved. A large initial expenditure of between \$200 to \$400 per hectare is required. The effects usually last for more than 10 years. Further maintenance cost is about \$10 per hectare per year. Assistance programs will be required to encourage the use of lime to maintain soil productivity.

While potentially acidic soils should be farmed, liming programs should also be developed and implemented to prevent acidification. Management of intensively farmed land should consider data not only on pH and fertilizer requirements, but should also have measurements of cation exchange capacity (CEC), base saturation, and liming requirements, especially on potentially acidic soils.

Rate of soil acidification can be reduced by selecting and applying fertilizers and other amendments in a manner which reduces the acidity normally produced. For example, nitrogen fertilizers vary in potential to acidify soils. If nitrification of added fertilizers is reduced prior to crop uptake, the acidity produced decreases. Nitrification can be reduced by applying nitrogen fertilizers in bands, and by the use of nitrification inhibitors.

#### *Crop Diversity*

Crop diversity and yield on the Canadian Prairies is limited due to weather events and climate. Climate in some parts of the Prairies is suitable only for grassland. However, in the less arid areas (e.g., Black soil zone) a variety of cereals, oilseed, pulse and forage crops can be grown.

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*The long-term productivity of many soils on the Prairies is not limited by the simple rotation of cereals with oilseeds.*

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Growing a variety of crops is not necessarily a requirement for sustainable agriculture. The long-term productivity of many soils on the Prairies is not limited by the simple rotation of cereals with oilseeds. Research has shown that soil productivity for a monocropping system can be maintained by proper use of soil amendments such as inorganic fertilizers and animal manures.

A monocropping system, however, will be plagued by crop diseases (especially in wetter areas) and may be less efficient in using nutrient resources than a multicropping system. The mechanisms behind the positive effect of crop rotation on soil fertility are not always clear. Research has shown that in some instances only about 50 percent of the positive effect on yield of crops following a legume crop can be attributed to increased nitrogen supply. Rotating crops may result in a greater diversity in the soil microorganisms that make soil nutrients more available to plants. Including mycorrhizae-promoting crops in the rotation can ensure maintenance of spores and hyphae in the soil for mycorrhizal infection of crops. Infection of mycorrhizae crops with mycorrhizal has a positive effect on the P and minor element nutrition of these crops.

Perennial forages (grass and grass-legume), when grown for forage or green manure, have a beneficial effect on soil fertility, soil organic matter levels and soil structure. Roots often contribute more to soil organic matter than do above ground parts. Thus, crops with a higher root:shoot ratio, such as perennials, could be included in the rotation to maintain soil organic matter levels.

Planting of grasses and deep-rooted perennial forages to utilize water in the soil (preventing upward capillary rise of water) in discharge areas, as well as in strategic recharge areas, can also be used to prevent salinization. Crop species and cultivars differ in

their abilities to grow in saline soils. Crop selection is thus a means available to sustain production on these soils.

Roots of perennial forage crops normally penetrate the soil profile to a greater depth than roots of annual crops and, therefore, can be used to recapture nitrate-nitrogen that has leached below rooting depth of some annual crops. The use of perennial legumes and other forage crops can, however, also pose a risk to contamination of groundwaters with nitrate-nitrogen once the crop is plowed down.

Crop species and cultivars vary in their tolerances to toxicities of Al and/or Mg encountered in acid soils. Plant breeders should concentrate on selection of cultivars with tolerances to these toxicities. It should be recognized, however, that plants which tolerate Al and/or Mg toxicities and grow well on acid soils may in fact absorb higher than normal amounts of heavy metals from the soil.

Crop species also vary in potential to acidify soils. Legume crops generally acidify soils to a greater degree or greater rate than nonlegume crops. Thus, the impact of legume crops on resulting soil pH and lime requirements needs to be considered for sustainability. (See the Biological Considerations chapter for further discussion on crop diversity).

#### *Pest Management*

Pesticides vary in their properties, causing them to interact with pests, non-target organisms and the environment in different ways. The strategy towards a sustainable, environmentally sound system should include using those pesticides which degrade quickly and do not accumulate in food chains.

The mobility of pesticides in soils is a function of the degree of interaction (adsorption-desorption) between soil and the pesticide, which is a function of the properties of the soil and pesticide. It is possible, if the properties of the soil and pesticide are known, to predict the degree of interaction between soil and pesticide and risk of groundwater contamination.

The impact of pesticides on environmental quality and non-target organisms can be reduced by decreasing the amount of pesticide used, which is accomplished by applying the pesticide at the time of optimal lethal effects on the pest (i.e., by spraying weeds and insects at the most vulnerable time, and at the time when most pests have already emerged). Reductions in pesticide usage will be linked to research to establish threshold limits and on knowledge of the life history, physiology and biology of the target species. Other opportunities to reduce the pesticide load and off-target contaminants will result from continued improvements in application technology.

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#### *Research and Regulation Requirements*

This section outlines some of the research and regulation requirements regarding those management practices which will ensure the sustainability of the land resource. Such requirements centre on the effective and efficient use of the land and other resources used for agricultural production.

Although much is known about the effects of tillage and crop residue management on soil quality, efforts must be continued to provide additional information on the effects of

these practices on yield and economic viability as well as on soil quality. Models need to be developed and/or adopted to predict soil quality parameters as a function of soil use and management, in order that a sustainable system be developed for particular soils and regions.

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Acceptable rates of soil loss in relation to the quality of surface waters are unknown. In order to maintain environmental quality, soil loss may have to be reduced to levels much lower than those considered acceptable for maintaining soil productivity. Research can provide information on impacts of soil from agricultural lands on aquatic systems.

Management recommendations should be developed to improve the use and efficiency of the soil and water resources of the Prairies for both agricultural and non-agricultural uses. Further information on the dynamics of the hydrologic system in soil landscapes will assist in this process.

Continued assessment of the risks involved under varying moisture conditions will lead to improved recommendations on cropping and summerfallow frequency.

Technologies to quickly map nutrient composition in a field and equipment to adjust fertilizer rates consistent with nutrient variations in a field will advance the potential of farming by soil unit. Equipment has been developed to alter rates at time of application. However, instrumentation to measure nutrient content *in situ* has not yet been developed to the extent that it could be effectively used. A means of quickly assessing the nitrate-nitrogen content of soils to depths of 60 to 120 centimetres and spatial distribution of nitrate-nitrogen in fields is of particular importance.

Maximizing the efficiency of fertilizer use could also include: the use of plant growth-promoting microorganisms in the rhizosphere; selection of plant cultivars and species with roots of high absorptive capacity to effectively use nutrients from fertilizer bands; manipulation of the fertilizer band geometry and chemistry to decrease fixation and promote root proliferation; and preventing loss of nutrients from soils.

The probability of a leaching event under different soil, cropping, tillage, fertilization and weather conditions can be assessed by developing appropriate models. Fertilizer and cropping practices found to have an unacceptably high risk of a leaching event would have to be discontinued or altered. Also, nitrogen fertilizer application to soils of a high risk of a leaching event would have to be restricted.

Other technological innovations to reduce potential of leaching of nitrogen fertilizers include altering the form and method of N application. Nitrogen in the ammonium form leaches slowly in comparison to other forms of N, even on sandy soils. Thus, applying N in the ammonium form and maintaining it in this form as long as possible would reduce movement of N in the soil. The rate of change of ammonium nitrogen to nitrate-nitrogen in soils can be retarded, for example, by banding of the fertilizer, application of fertilizers with chemical (urease and nitrification) inhibitors, or coating of fertilizer granules with various types of coatings. Further evaluation of these technologies will provide an understanding of their impact on yield and environmental and soil quality.

Information on nutrient release from barnyard manures, sewage sludges and other urban wastes is required to maximize efficiency of use. The impact of use of sewage sludges and other urban wastes on food quality and safety must also be thoroughly investigated prior

to their widespread use. It is also necessary to know the fate and bioavailability of metals in order to assess their impact on food quality.

Further understanding of the factors responsible for good soil structures (e.g., types of soil organic matter, microbial products) can make it possible to alter the soil biomass by the use of various amendments. Binding agents that promote aggregation (carbonates of Ca and Mg and residues from microbial activity) could be used. The use of polymers or binding agents in sandy soils may become viable. The use of lime may improve structure of soils low in Ca and Mg. Gypsum is used in the reclamation of solonchic soils. At present, large quantities of organic materials considered to be wastes are placed in landfills and/or are incinerated. Safe, effective methods of composting and applying these materials to agricultural soils are necessary.

With regard to disposal of manure on agricultural lands, regulations have to be established for method, rates and frequency of application as well as land area required prior to establishment of the animal unit. Studies on mineralization of various constituents from manures, and the fate of these in the soil are required to establish effective and fair regulations. Regulations regarding location of animal units also need to consider prevention of surface water contamination.

The basis for positive effects of crop diversification on fertility and crop yields needs to be better understood. Research is required to more fully exploit the beneficial effects of crop rotations. A more integrated research approach is required to gain further understanding of the relationships between, for example, soils and crops and microbials.

Studies on the release of N from soils following perennial and annual legumes and other forage crops will provide information on risk of contamination of groundwaters with N and methods of efficiently using the N released for subsequent crop growth.

The impact of pesticides on nontarget organisms and on surface and groundwater quality has to be well within acceptable limits and in many cases even undetectable. Studies are needed on pathways by which pesticides enter the environment, the impact these pesticides have on nontarget organisms, and methods of preventing damage to the environment.

### **Appropriate Land Use**

Land use must be consistent with the attributes of the soil, with management systems tailored to sustained productivity. Land presently used for arable agriculture, but subjected or sensitive to degradation will have to be removed from arable agriculture to less intense uses such as forage production and wildlife habitat. Development of new lands will need to take into consideration not only suitability for use in agriculture, but the desire and need to preserve wetlands and wildlife habitat.

### *Institutional Innovations*

Institutional structures have been developed to support agriculturally dominated land use on the Prairies. The sectoral and disciplinary structure of law, government, universities, and private organizations that developed to support the agricultural industry have resulted in entrenched single-interest cells of people within which structure and resources are carefully protected by each group.

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Agricultural policies have tended to disregard land use practices and the environment. Existing farm policies tend to favour expansion of cropland regardless of the land capability or suitability, and provide no incentive to maintain wetlands, wildlife habitat, or less intensive uses. The policies also tend to favour today's soil management systems (cropping and tillage practices), such that a farmer who alters a practice in favour of the environment risks losing income. As a result of existing policies, marginal land is being used for crop production and more crop specialization and monoculture is practiced. Programs such as crop insurance, input subsidies, agricultural land improvement subsidies (funds for land drainage), drought aid programs, and income stabilization programs tend to affect land use and management. Some of these programs encourage specialization, with the consequence that farmers do not search for alternate crops and/or approaches to farming to reduce risk or increase income.

Several programs and policies, however, have emerged or are emerging which will alter present land uses, cropping systems and tillage practices. Programs offered by public agencies (such as the Prairie Farm Rehabilitation Administration's Permanent Cover Program), or private agencies (such as Ducks Unlimited's Prairie Care), will result in preservation of wetlands, wildlife habitat and reallocation of erosion-prone cultivated land to more permanent cover.

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*Taxation policies may have to be altered and other incentives offered if society wants to protect wetlands and wildlife habitat.*

Thus, at present, Canada has policies which favour present land use and programs to alter land use. However, most of these policies have not been evaluated with respect to the criteria necessary for sustainability. Economic and regulatory policies and research and education programs will have to be evaluated in terms of their effect on the sustainability of agricultural production. The impact of policies or programs on economic viability of the farm, productivity of the land resource, food quality and safety and protection of the environment will have to be assessed prior to implementation of the program or policy. Incentives that favour land use which are inconsistent with the attributes of the landscape will have to be discontinued. Income stabilization programs will have to be based less on a particular commodity than at present. Taxation policies may have to be altered and other incentives offered if society wants to protect wetlands and wildlife habitat. Multiple and complimentary land use is possible if appropriate programs and policies are adopted.

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*Balancing social values, biophysical capability and material needs will be central to sustainable agriculture strategies.*

A voluntary response by society to sustainability issues is preferable to regulation. Ensuring that the agricultural sector is informed on issues that pertain to sustainable agricultural production may best bring about this response.

There will be a need for regulatory programs in instances where educational programs have not resulted in voluntary change. Undesirable practices (such as stubble burning and contamination of groundwaters by excessive fertilization and manuring) will need to be prevented and regulations may be required to steer practices in a particular direction (e.g., frequent soil testing to prevent overfertilization with N and potential for groundwater contamination). Regulations will have to be established for land use and minimum acceptable standards set for water, soil and air quality. Consumers, producers and the scientific community will need to collaborate and cooperate in establishing standards.

Multi-purpose, multi-interest interdisciplinary institutions are needed to address sustainable agriculture. Balancing social values, biophysical capability and material needs will be central to sustainable agriculture strategies. The agroecosystems approach

proposed in the "Growing Together" document of the Federal and Provincial Ministers of Agriculture provides a framework for developing a sustainable agriculture strategy.

Support for local farm/community land use and management institutions will be essential to developing broad support for sustainable agriculture and ecological resources. Each day, farmers face the challenge of balancing family and community well-being with agricultural production and landscape maintenance decisions. The involvement of the managers of the land will be central to any strategies concerning land use and management.

Interrelationships between production systems and ecosystems are poorly defined. Future research and education strategies will need to redirect resources to develop a better understanding of the interrelationships between land use and ecological stock.

### *Technological Innovations*

The Prairie ecosystem responds to land use and agricultural practices in that the equilibrium between soil, water and vegetation shifts according to changes induced in any or all of the components. Sustainability depends upon knowing what impact land use and other practices have on this equilibrium. Additional information is required on properties of the land base and ecological communities, and how these properties and communities respond to various land uses and stress.

Much of the Prairie lands have been examined and the various soils mapped or delineated according to various physical, chemical and biological properties. Land capability maps have also been prepared as a guide for land use and management practices. This information must be used as a fundamental base for determining appropriate land use. The desire of society to maintain wetlands, wildlife habitat and ecological communities must also be considered in land use. Some of this information has yet to be obtained, particularly when details within a landscape unit are required. Also, information is needed (through models for example) to determine the impact or stresses placed on a land unit due to a particular land use. Database development must be continued. Methodology (computer programs) to access and utilize the basic information has to be further developed. Progress towards achieving a good soil (land) information system and application for various uses has been slow.

As noted previously, the land base in the Prairies has been rated for agricultural capability with Class 1 being the most favourable for agricultural use. The capability class of land can be used to foster or encourage various types of land uses. For example, lands of Classes of 1 to 3 are highly suitable for arable agriculture and should be retained as such. Minor areas would be available for wildlife habitat and other alternative uses. The land, however, could be managed in a manner consistent with provision of wildlife habitat to a greater extent than at present, through, for example, zero-tillage or fall-planted crops to provide nesting grounds for waterfowl. The lower Classes of land (4 to 5) are more conducive to multiple use. Wetlands or steep slopes, for example, could be maintained as wildlife habitat and ecological communities. Lands not suited to arable agriculture (Class 6) could be used as range or pasture land, with the emphasis being placed on the preservation of wetlands and wildlife habitat. Development of low classes of land for agriculture is costly, and may have undesirable effects on environmental and food quality.

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## 5. ENERGY FOR SUSTAINABLE AGRICULTURE

Prior to the early nineteenth century, food production was energized by the instantaneous flow of solar energy. The only other energy inputs were human and animal effort and the almost incidental input of plant and animal residues. Primitive or subsistence farmers were able to feed their small families but few or no others. By the middle ages, through advances in farming techniques, agricultural producers were able to feed themselves and an ever increasing urban population. Society remained predominately rural, with 80 percent or more of the economically active population engaged in agriculture.

If human societies had remained as hunter/gatherers, it is estimated that the total world population would have increased to only about 10 million people because of limited food supplies. But with evolving agricultural technology, total world population slowly increased to about 1.5 billion by 1900.

Since the advent of the industrial age, energy input to food production systems has increased to enable a modern farmer in a developed country to produce the equivalent of enough food for as many as 90 people. In Canada, less than 5 percent of the total population is engaged in primary agriculture. World population has increased to about 5 billion because of reliable food supplies, produced largely by the widespread use of additional energy in food production systems. The added energy, usually termed cultural or support energy, and referred to as an energy subsidy, has been almost entirely obtained, directly or indirectly, from two fossil fuels - petroleum oil and natural gas.

There is now concern that with continued depletion of fossil fuel reserves, agriculture will not be able to sustain or increase food production at the level necessary to support growing world populations. There is also concern that emissions from the burning of fossil fuels must be controlled to protect the environment.

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### Major Premises on the Limits

The coming energy dilemma of relatively inexpensive, yet dwindling, petroleum fuels is the most serious economic and environmental threat facing the Western world and its high standard of living. Except for overpopulation problems, the coming fossil fuel energy scarcity is the most serious threat for most of the world. There are, however, reasons to be optimistic about the availability of traditional fossil fuels as energy supplies for agriculture for the foreseeable future. Also, practical alternative fuels will become increasingly available and competitive with remaining fossil fuels and will eventually replace them.

The energy supply problem has an economic and an environmental dimension, both of which are very complex. Conservation of energy is a good approach to the energy problem and will require new ways of thinking about technology. Conservation methods need not be overly sophisticated to be effective in reducing emissions and extending oil, coal and gas reserves.

### Sources and Uses of Energy in Prairie Agriculture

#### Availability

Energy use for agricultural production increased rapidly across Canada after World War II. Energy consumption was promoted by plentiful, relatively cheap, domestic energy

supplies from oil and natural gas deposits found mainly in Alberta. Canadians became the highest annual energy users per capita in the world. There are numerous factors that have contributed to this high energy use, including Canada's cold climate, long transportation distances, aluminum smelting, cement manufacturing, petrochemical production and other energy intensive industrial enterprises.

Fossil fuels, in the form of petroleum oil, natural gas and coal, supply approximately 88 percent of global commercial energy, with the balance supplied by nuclear fission (5 percent), hydroelectric power (3 percent) and other minor renewable energy contributors. The main commercial energy sources, the fossil fuels, are depletable and nonrenewable and production of energy from these sources will not be sustainable. Hydroelectric energy can be considered renewable, but hydroelectric power sites do have environmental impacts.

Throughout most of the twentieth century, increases in supplies of petroleum fuels have comfortably kept pace with demand. There have been periodic shortages and times of rising prices, but proven reserves for the world currently stand at an all time high of 1,000 billion barrels (1 barrel = 42 US gallons = 0.159 cubic metres). Proven reserves of petroleum oil are defined as the amount of petroleum oil that is recoverable under current economic and technical operating conditions. The amount of the ultimately recoverable petroleum oil may be six times the proven reserves. Of the remaining proven petroleum reserves, approximately 75 percent are in countries of the Middle East.

In 1979, Canada's energy supply was dominated by fossil fuel resources in the form of oil. Energy from oil alone accounted for about 55 percent of energy use. Other sources of energy were natural gas, coal, and electricity generated by water power or nuclear reactors. Efforts in conservation and more efficient use of energy have led to less growth in energy demand than had been predicted in the 1970s. Due to shifts in the sources of energy, by 1987 only 39 percent of the total energy used was supplied by oil. More energy is now supplied by natural gas, coal and electricity.

The change in energy supply sources was caused by the perceived smaller reserves of oil, as compared to natural gas and coal. Proven reserves of petroleum oil in Canada stand at about a 10 year supply, based on current production rates, while there are about 21 years of gas reserves. It should be noted that new discoveries and rising oil prices tend to increase the proven reserves. These estimates of proven reserves appear to be alarming, and indicate that alternative sources of energy should be seriously considered. Predicting exactly when Canada's oil, gas and coal resources will be exhausted is not really possible. Fortunately for Canada, there are several energy options to conventional fossil fuels. Continued energy conservation, the adoption of more efficient technology and the development of solar energy processes and of the tar sands are just a few of the options.

### *Regional Supplies*

Alberta, British Columbia and Saskatchewan are the only areas in Canada where primary energy production significantly exceeds local energy demand at this time. This situation could change as the Beaufort Sea and off-shore Maritime oil and gas discoveries come into production. Canada has been forced to import light crude oil because Alberta's production of light crude oil has been falling at about 5 percent per year. Alberta produces about 80 percent of Canada's oil and about 70 percent of its total energy produced.

Canada remains a net oil exporter overall because of heavy oil exports. Exports of natural gas will continue for the foreseeable future.

#### *Allocation Procedures Between Users*

There are no allocation procedures or regulations to ensure the supply of energy, in the form of fuel and fertilizer, for the production of food. Formerly, energy for agriculture and food processing use has had an A classification, meaning that energy was critical to the health, welfare and security of the citizens of Canada. This classification gave agriculture and food processing a high priority for energy supplies, but not as high as the priority of energy for space heating.

Agricultural production, using only about 4 percent of the total energy used in Canada, makes little demand on the energy supply system overall. On-farm energy use includes direct and indirect energy inputs. These energy inputs are variously applied to the production of crops and animals or animal products.

Regional demands for energy for agriculture are higher than the 4 percent national average. But these demands are seasonal, as there is not much demand from agriculture during the winter when energy demands for space heating peak. In the event of temporary import supply interruptions, because of foreign political unrest, there should be no major problems in diverting energy to agricultural use in the short run.

#### **Agricultural Share of Usage**

In Canada, the distribution of energy usage is roughly 23 percent for domestic home use, 28 percent for industrial use, 24 percent for transportation use, and 25 percent for the generation of electricity. Energy used in the food supply system is only about 18 percent of the total, with 4 percent used in farm production, 5 percent used in food processing, 4 percent used in food transportation, and 5 percent used in food preparation.

Regional predominance of agricultural production activity, to the exclusion of other industrial activity, can lead to agricultural energy usage that is often relatively higher than the average values. For example, the Prairie region uses 57 percent of the energy used in Canadian agricultural production. Of the total energy used on the Prairies, 41 percent is used for agricultural production. As noted above, only 4 percent of the total energy use for all of Canada is used in agricultural production.

The direct energy inputs used for agricultural production are in the form of gasoline, diesel fuel, electricity, and space heating fuels, including natural gas where available. Direct fuel use in farm production can be as high as 50 percent of total farm energy use, or about 2 percent of the total energy used in Canada. There is considerable variation on individual farms in the percentage of total farm energy use represented by direct fuel use.

The indirect energy inputs consist of fertilizers, seed, pesticides and the energy embodied in the manufacture and supply of machinery. In addition to the concerns about the supply of the energy embodied in these inputs, one might also be concerned about the supply of the basic resources needed to manufacture the inputs, that is the iron and steel for machinery, the raw materials for the pesticides, and the N, P and K for fertilizers. We live in a finite system where either energy supply limits or raw material supply limits will define some sustainable scope to human activities.

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While overall energy supplies are important, the discussion in this section is concerned mainly with the supply of energy for on-farm use, that is, gasoline and diesel fuel or fuel for mobile equipment. Liquid fossil fuels are used in engines for mobile equipment because of their characteristic high energy content per unit mass (43 to 45 megajoules per kilogram)<sup>2</sup>, their ability to vaporize at least partially at low temperatures, their ignition and burning properties when mixed with air, and their relative ease and safety in handling, storing and transporting. Fuels for industrial use can be solid, liquid or gaseous, but for mobile equipment and transportation use liquid fuels are better suited.

#### *Crop Production Energy Demand and Efficiency of Use*

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*For crop production, nitrogen fertilizer would account for about 25 percent of the total energy, liquid fuels about 30 percent and machinery about 25 percent.*

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*The energy input in the form of pesticides is relatively low, typically less than 5 percent of the total energy subsidy.*

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The conventional energy inputs for grain production on the Prairies were mentioned above. Other energy inputs that might also be considered include irrigation, drying, labour and transportation. All of these inputs can be expressed in energy equivalents and, as already explained, can be direct energy input or indirect energy input.

A typical energy subsidy or input for dryland farming production of cereal grains on the Prairies would be about 7,000 megajoules per hectare. Mixed farming operations tend to have subsidies of about 8,000 megajoules per hectare. It would not be unusual for individual farms to have energy demands more than twice the values above. For crop production, nitrogen fertilizer would account for about 25 percent of the total energy, liquid fuels about 30 percent and machinery about 25 percent. Other fertilizers, pesticides, heating fuels and electricity account for the remaining 20 percent of energy subsidy inputs to crop production. There is a great deal of variation in these percentages. For example, if no nitrogen fertilizer is used, then the other percentages are proportionally higher.

The energy input in the form of pesticides is relatively low, typically less than 5 percent of the total energy subsidy. The energy equivalent for the manufacture and use of most pesticides is relatively low, so that considerations of pesticide energy consumption probably are not significant to sustainable agriculture.

Fossil fuels are currently the predominant energy sources for energy subsidies. Natural gas is the major feed stock for nitrogen fertilizer manufacture and is important in machinery, pesticide and electricity production. Except for the liquid fuels for mobile field operations, alternative sources of energy are relatively adoptable to many manufacturing processes.

The output from a grain crop is the clean grain that can be used or sold and can be thought of in terms of energy output. The remaining above ground biomass (phytomass) yield and the roots are usually not included in the economic or energy output, although in some cases the straw could have economic or energy value. In some situations, it may be desirable to measure the output in terms of actual food energy delivered to a consumer, where the energy costs of food production, food processing, food transportation and food preparation are also accounted for.

Output-input energy ratios can be calculated for various crops and production systems. A typical ratio for Prairie grain production, in terms of dry grain yield, could be 4:1. In other words, four times as much energy was harvested compared to the input energy that

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<sup>2</sup> Joules are used to express units of energy. A megajoule (MJ) is one million joules.

was supplied in growing the crop. Solar energy inputs are excluded in calculating the output/input ratios.

Energy output-input ratios are not always favourable and can be misleading. For example, many fruit and vegetable crops have output-input energy ratios of less than one. A primitive hunter-gatherer could possibly obtain 15 times as much energy as the energy expended in hunting or gathering but there could be days of no success in the hunt. A low-input traditional farming system could have a ratio of 12:1 compared to a high-input system ratio of 6:1, but in terms of output per unit area the high-input system would be producing almost 2.5 times as much food energy. There is also the intangible consideration of reduction in human drudgery through the use of high-input mechanized systems. In terms of cost per unit of energy output from human labour compared to fossil-fuelled machine output, equivalency can only be had if human labour is valued near zero or fossil fuels at about 400 times the present price.

Prairie grain production systems are relatively energy efficient when compared to other cropping systems. Overall energy input comparisons are difficult to make since it is not always clear that the comparisons are on an equal basis. For instance, crop drying is not an integral part of Prairie grain production but only employed in years of adverse weather, whereas in U.S. corn production drying is often an integrated component of the production system. The same comment can be made concerning corn or rice production that relies heavily on irrigation inputs. In spite of these reservations about comparing systems, it is possible to state that Prairie grain production energy inputs are relatively low compared to 30,000 megajoules per hectare for corn production, 50,000 megajoules per hectare for rice production, or 60,000 megajoules per hectare for potato production.

More accurate energy input comparisons are possible when individual production operations are compared. For example, reduced tillage or minimum tillage systems are used widely on the Prairies and compare very favourably, in terms of energy input, to conventional moldboard plowing tillage systems still used throughout much of the U.S. corn belt. The common minimum tillage systems used on the Prairies use less than 50 percent of the energy input in a moldboard plowing tillage system. No-till or zero-till systems, including the energy input for chemical weed control, would use less than 20 percent of the energy used in a moldboard plowing system. The machinery component of energy input to crop production ranges from about 10 to 25 percent of the total.

#### *Livestock Production Energy Demand and Efficiency of Use*

When considering the human food supply, more people can be fed per unit area of arable land if the land supported crops rather than animals. However, vast areas of nonarable land cannot produce cultivated crops but can sustain animals, especially ruminants, that can convert grass into highly nutritious food for human consumption. Grassland grazers collect dispersed nutrients and concentrate them, thereby reducing the bulk of food that humans must eat to get adequate dietary needs. People tend to like animal products, want them in preference to a steady diet of a single staple food and are willing to pay for them. Some animal products, such as wool, are important because there is no completely satisfactory substitute.

The energy inputs to mixed farming operations, where grain and hay support beef or pork production, tend to be higher than for grain crops alone. A typical value for the input

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energy to animal production is 8,000 megajoules per hectare but could range up to 16,000 megajoules per hectare. Animal production from mixed farming serves as a vehicle to market the crops produced.

In cases where animals are produced in relative confinement because of a limited land base, or because of climatic reasons, it is not possible to determine energy subsidies on a per unit of land use basis. Energy input demands are given, rather, in terms of energy per unit of gain or in terms of energy per unit of live weight at the point of slaughter. Using the latter basis, beef production is the most energy intensive, requiring about 100 megajoules per kilogram for production from a combination of feedlot feeding and grazing. The value includes the energy cost of feed and any energy subsidies. Pork can be produced for about 50 megajoules per kilogram, broiler chicken for about 30 megajoules per kilogram, eggs for about 50 megajoules per kilogram, while milk production is the least energy intensive at about 8 megajoules per kilogram.

In most animal production systems, management and feed costs are of greater concern than the type of system, likely because of the inherently low efficiencies of converting animal feed into human food. Current standards for the efficiency of conversion are 0.12 energy units of human food for 1 unit of animal feed energy for swine and poultry and 0.06 energy units of human food for 1 unit of animal feed energy for ruminant animals. Milk and eggs can be produced with average conversion efficiencies slightly higher than the value for swine and poultry. The values for swine and ruminants have shown slight declines over recent years while the value for poultry has been increasing over the same period. Conversion efficiencies tend to be independent of the production system — confined or unconfined — given equal management skills.

Conversion efficiencies are temperature dependent, with each animal having an optimum temperature range (see Climate chapter). Ambient temperatures above or below the optimum will result in lower conversion efficiencies. The cold winter temperatures of the Prairies result in lower conversion efficiencies, but summer heat in southern areas may, in fact, be more devastating to efficient animal production than moderately cold temperatures.

### **Processing, Transportation and Preparation**

As noted previously, the food chain uses about 18 percent of the total energy used in Canada. The processing, transportation and final preparation components account for 5 percent, 4 percent and 5 percent of the total, respectively.

Obviously, foods that are eaten raw, requiring no processing or preparation involving cooking, and are eaten close to the point of production require less energy. Apples fit the above description to a point but a steady diet of apples is not possible and the energy cost of production is high at about 100,000 megajoules per hectare, far exceeding wheat at about 6,000 megajoules per hectare.

Energy efficiency should be compared over the whole food chain. To illustrate the reason for this point consider wheat and milk. Wheat can be produced at the farm gate with an energy out-energy in ratio of about 4:1, while milk can be produced with an energy ratio of about 1:0.65. At the point of consumption as bread and milk the ratios are 1:0.50 and 1:0.60, respectively. Milk can be delivered to the point of consumption much more efficiently than wheat because wheat requires milling and baking prior to consumption.

## Issues

Two lessons that should have been learned over the past 20 years with respect to energy are to expect unexpected events and to be very careful of trend analyses based on extrapolating past trends. The present concerns for environmental pollution and global warming may dictate future energy use. Thus, the use of cleaner burning fuels with reduced emissions may be required even though there are supplies of conventional fuels available at competitive prices.

The continued availability of relatively inexpensive fossil fuels, which are depletable and nonrenewable, delays the development of suitable alternative or renewable fuels. Continued improvements in energy use efficiency in agriculture will be one method of conserving energy. Developing appropriate practical renewable energy sources and technologies is another method of conserving fossil fuels for use as liquid fuels.

Any rapid substitution of high density energy resources (fossil fuels) by low density renewable energy resources (crop residues) is illusory without the collapse of urban societies. A return to solar powered farming systems of the early 1900s would result in a halving of the world's population. New ways of using fossil fuels will extend their use for many, many years. Clean combustion and emission reduction will be necessary to ensure that there is minimal environmental impact. Synthetic fuels from tar sands and oil shales, coal gasification and liquefaction are future methods of using the vast reserves of the remaining fossil fuels.

It has been estimated that there may be 20 million tonnes of recoverable crop residue per year across the Prairies. The recoverable crop residues would contain about 3.5 times as much energy as is currently used in crop production on the Prairies. In some areas of the Prairies the agronomic demands for recycling the crop residues into the soil would preclude diversion to energy uses. Nevertheless, crop residues from crop production do represent a source of energy, and practical technology to use this resource should be developed without delay.

### Conservation Through Improved Efficiency

In a sense, energy conservation can be thought of as a new energy resource. It is very cost-effective, risk free, technologically possible, environmentally benign, has quick results, and is relatively easy to put in place. Concerted efforts in energy conservation have reduced actual oil demand below predicted demand in almost every year since the oil supply "shock" of 1973. Most energy consuming operations can be reduced by at least 25 percent by adopting the most efficient technology currently available, and energy consuming operations in the future have the potential of a further 25 percent reduction in energy use. In fact, oil demand in Canada, the United States and Western Europe has been falling 2 to 4 percent per year in recent years.

#### *Crop Production*

Conservation tillage or reduced tillage systems offer an opportunity for reduced energy inputs to crop production. Not all crops or soil conditions are suitable for adopting reduced tillage systems. An added bonus for reduced tillage systems is the reduction of soil erosion.

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Reduced tillage systems can reduce tillage energy input by up to 43 percent, while no-till systems can reduce tillage energy input by up to 85 percent. The energy cost of the required herbicides used in no-till and reduced tillage systems is not really significant. Future tillage research may be able to bring about even greater energy reductions compared to conventional tillage systems. The smaller and therefore less costly machinery associated with reduced tillage systems represents a reduction in indirect energy inputs.

Other practices that will contribute to overall crop production efficiency include the use of legumes, deep banding of fertilizers for better fertilizer utilization, use of optimum fertilizer application rates, reduction of summerfallow, and if possible the adoption of winter crops. The use of legumes in the cropping rotation can reduce or eliminate the use of nitrogen fertilizer, thereby saving almost 50 percent of the support energy.

Research in biotechnology holds the promises of incorporating nitrogen fixation mechanisms into nonlegume crops such as wheat and of improved yields for the same inputs as currently used. Development of these technologies offer significant savings in energy inputs, since both direct and indirect energy inputs are reduced. The usual efficiency of solar energy capture in photosynthesis is less than 1 percent. If biotechnology research could possibly result in doubling, the effect on food production would be incredible.

#### *Livestock Production*

There appears to be great potential for improving the efficiency of livestock production, especially in the area of ruminants where cellulosic material can be digested. Research led to a greater than 50 percent improvement in metabolic efficiency for broiler chicken production from 1950 to 1975. Modern biotechnology methods may lead to a similar improvement in beef and pork production. Of course, the use of hormones must be safe and acceptable by the informed public.

#### *Processing, Transportation and Preparation*

The potential for improving energy use efficiencies in processing, transportation and food preparation is immense. Twenty-five to 50 percent improvements are immediately available just by adopting the latest technology in these areas. But advanced research indicates that reductions in energy use from current levels could be as high as 90 percent in space heating, 77 percent in transportation and 75 percent in refrigeration for processing.

#### **Analysis of Alternate Energy Sources**

The source of the only truly renewable energy for the world is the sun. In 1990, the yearly intercept of the radiative energy from the sun by the earth was 18,000 times the energy derived from global fossil fuel production. But turning an inherently diffuse radiant energy source like sunshine into the concentrated forms of energy required by modern technology is a very costly undertaking. Therefore, although sunshine is free, energy storage and energy concentration are not.

Solar energy drives the hydrological cycle from which energy can be obtained, through water wheels, hydroelectric power, tidal power, wave power, and ocean currents. Energy

from these resources may be renewable but, in most cases, there is some impact on the environment and on the local ecology through, for example, flooding, silting, shoreline changes and erosion, and invasion of wildlife habitat. If all of the above sources were fully exploited, with due consideration and preservation of the environment, the total potential energy from these sources would be less than 10 percent of world energy needs. For the most part, practical hydroelectric sites on the Prairies have already been developed. Any future developments would most likely be very costly.

In Canada's moderately cold climate, the economics for solar energy use in space heating and water heating are not very satisfactory. Solar energy can also be tapped through wind energy and photovoltaic cells. While the contribution of energy from these sources can be very important locally, there is a lack of energy density and there is the problem of intermittent availability. The direct use of solar energy will likely contribute about 10 percent of the world's energy needs within the next 20 years if sufficient capital is made available.

Solar energy is the natural energy source for the photosynthetic reaction where green plants fix carbon from carbon dioxide in the air to form carbohydrates in the form of biomass or phytomass. The solar energy is stored in the form of chemical energy that is released when the biomass is burned. Dry biomass, except for high oil content materials, has an energy content of about 18 megajoules per kilogram. Biomass materials with high oil content could contain up to 29 megajoules per kilogram. Fossil fuels represent stored solar energy that was accumulated and transformed over very long periods of time. The amount of moisture that is present in the phytomass and the efficiency of the combustion process and equipment will determine the amount of recoverable energy.

Yearly biomass production stores approximately 10 times more energy than is used globally each year. It should be obvious that fuels derived from biomass are renewable if they are consumed at a rate equal to the rate of biomass fixation and that the fixation-combustion process recycles carbon dioxide so that there is no net gain of carbon dioxide in the atmosphere. Biomass is by nature rather dispersed and cannot be used directly to power internal combustion engines. Nevertheless, biomass sources of energy are likely to be increasingly utilized.

Generally, the same amount of gasoline or diesel fuel is required to satisfy the demands of mobile farm equipment and in the manufacturing of fertilizer. Energy for the manufacture of fertilizer is supplied largely by natural gas. Energy from biomass sources is not a direct or convenient substitute for liquid fuels for mobile equipment or for the energy needed in the production of fertilizer.

From an environmental quality viewpoint, the cleanest energy would be electricity derived from an economical renewable source where the products of combustion, if any, would be recyclable. There are several suitable candidates to energize such an ideal system, but economics, portability and storability are all factors to be considered. For example, a liquid fuel would be desirable for long range land and sea transportation and for air transportation.

While energy from nuclear fission will be debated for some time to come, it is expected to be used in increasing amounts. This energy is not renewable since cheap high-grade uranium ore is depletable. Breeder reactors may be developed to solve the problem of

uranium supply but the radioactive waste products of the fission process create a problem for safe disposal. There have been hidden subsidies in many nuclear powered electricity generating facilities and, therefore, the economics of nuclear power are also in question.

Nuclear fusion has the potential to supply inexpensive energy from a relatively clean process. The practical use of fusion energy, if possible at all, is many years in the future, and the required research will be very costly. The fusion process, however, holds great promise for solving the world's energy supply problems once and for all. The virtually unlimited energy available from the fusion process could lead to the widespread use of hydrogen as a fuel. Hydrogen would have some not insurmountable handling difficulties but it can have very high energy density and has only water as an emission product of combustion.

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*Natural gas is very clean burning with the lowest output of carbon dioxide per unit of energy produced.*

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*Most forms of renewable energy cannot compete economically with crude oil costing \$20 to \$25 a barrel.*

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The three energy options closest to being practical substitutes for gasoline and diesel fuels in the near future are neat (nearly pure) methanol, compressed natural gas (CNG) or liquid natural gas (LNG), and electric powered vehicles. Natural gas is very clean burning with the lowest output of carbon dioxide per unit of energy produced. Electric powered tractors are not an option yet since storage battery energy densities are too low and fuel cells also have energy densities too low to be practical for tractor use. It is interesting to note that methanol fuelled diesel engines are already being tested. The motivation for producing these engines is not lack of diesel fuel supplies but standards for emission control.

Methanol (and ethanol) can be produced from biomass materials and can be low-polluting fuels for transportation use. The energy content for methanol and ethanol is 20 megajoules per kilogram and 27 megajoules per kilogram, respectively. Ethanol does serve as an octane improver and as an oxygen carrier but costs three to four times as much as gasoline on an energy-content basis. The cheapest source of methanol is from natural gas. Methanol serves as a liquid energy carrier to move natural gas to market. Most forms of renewable energy cannot compete economically with crude oil costing \$20 to \$25 a barrel. There are significant energy costs in the production of methanol and ethanol.

Geothermal energy is considered a renewable resource by some experts, while others consider the resource nonrenewable. Even with the full use of exploitable sites, it is unlikely that more than 1 percent of the world's energy needs can be provided by this energy source.

Since the first oil supply shock of 1973, energy conservation, rather than renewable energy or alternate energy, has emerged as the main new energy resource. This conservation has contradicted many of the dire predictions of the 1970s. There are no cheaper alternative or renewable fuels available to agricultural production than current fossil fuels. It now seems that there will be substantial quantities of oil and natural gas available until late into the twenty-first century.

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## 6. WATER

### Water as a Limiting Factor in Prairie Agriculture

Water is one of the main limiting factors for life in the Prairie ecosystem. As noted in the discussion on climate in Chapter Two, the generally low levels of precipitation on the Prairies has a significant impact on agriculture.

#### Moisture Supply

The low level of precipitation on the Prairies is reflected in the fact that, for much of the Prairie region, the combined potential evaporation and transpiration by crops (evapotranspiration) exceeds the average annual precipitation from rainfall and snow. As shown in the Climate Chapter, water is also limiting due to the high variability in the spatial and temporal distribution of the precipitation that falls on the Prairies. Twenty to 30 percent of all precipitation in the region is from snowfall, which falls in varying amounts across the Prairies. Snowmelt from the eastern slopes of the Rocky Mountains provides 60 percent of all the annual flow for rivers and groundwater recharge in the three Prairie provinces.

Agriculture also contributes to water being a limiting factor on the Prairies. Water use by agriculture is consumptive, that is, water use by crops precludes the use of that water for other activities (municipal, industrial, recreational and wildlife uses).

#### Water Quality

Another way that water is a limiting factor on the Prairies is due to insufficient water quality. The discussion in the Land chapter of the impacts of the high saline water tables that underlie some areas of the Prairies is an example of a water quality issue. This type of problem puts added pressure on use of water supplies for agriculture in two ways: first, groundwater in these areas cannot be used to supplement precipitation; and second, it is important that water that enters the soil from above ground be maintained at levels that will prevent the saline water table from moving up into the root zone.

Agriculture, itself, may adversely affect water quality by contributing to runoff of materials such as soil sediment, manure, chemical fertilizers and pesticides.

#### Redistribution of Water

The limiting nature of precipitation and thus water in Prairie agriculture has made the issue of water redistribution, through drainage, storage and transfer, an important factor to both farmers and policymakers in the area. Water redistribution can be accomplished through on-farm techniques for capturing precipitation before it runs off (and to increase the efficiency of the use of precipitation captured) and for drainage of water in undesirable locations (potholes within fields), intrabasin transfers (moving water around within the Prairie agricultural region), and interbasin transfers (using the abundance of water north of the Prairie region for agriculture in the Prairies). These techniques not only reduce the water scarcity caused by low average precipitation, but decrease the impacts of the variability of that precipitation. However, these benefits do not come without costs. The costs of redistribution are both economic and environmental in nature and need to be carefully analyzed before any of these techniques are put into place.

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*Snowmelt from the eastern slopes of the Rocky Mountains provides 60 percent of all the annual flow for rivers and groundwater recharge in the three Prairie provinces.*

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## Background

### Water Shortfalls

#### *Climate/Water/Plant Relationships*

Sources of water loss from crop production are evaporation, transpiration, runoff or redistribution on the field, and deep percolation (often overlooked). For cereal crops, approximately 10 centimetres of available soil water (in the 120 centimetres rooting zone) are required before any grain yield is produced.

Since potential evapotranspiration (PE) exceeds precipitation in the entire region, water conservation and efficiency of water use are critical to sustained food production in all areas of the Prairies. Variability in water availability is greater between areas of the Prairies than between years within an area. This spatial variability is illustrated in Table 2.1 of the Climate Chapter, as well as in long-term crop insurance records which indicate that, on average, drought accounts for 80 percent of the claims in Saskatchewan, compared to 50 percent of the claims in Manitoba. Therefore, there is a different urgency regarding on-farm water management practices between drier and wetter areas.

Crop water use efficiency (WUE) — the efficiency of the plants to create dry matter given the total amount of water used during the growing season — ranges widely for all crops grown on the Prairies (Table 6.1). As shown in the table, winter wheat is often more efficient in using water than spring wheat. In many instances, WUE is influenced more by prevailing weather conditions than by crop type. WUE for canola (a drought sensitive crop) is typically much lower in Brown and Dark Brown soil zones than in wetter areas. Crop WUE has increased over the past 40 years due to fertilization and improved cultivars and methods of pest control. The efficiency with which water is converted into biomass is also an important factor for soil conservation, a high priority in all areas of the Prairies.

**Table 6.1**

*Water Use Efficiency for Prairie Crops.*

Crop	Range of Water Use Efficiency (WUE) (kg/ha/mm ET) <sup>1</sup>
Spring wheat (for seeds only)	4.5 - 12.7
Winter wheat (for seeds only)	6.8 - 18.8
Barley (for seeds only)	6.8 - 19.0
Canola (for seeds only)	4.0 - 11.0
Alfalfa (all above ground biomass)	10.0 - 35.0
<sup>1</sup> ET - evapotranspiration	

#### *Location and Time*

In the Brown and Dark Brown soil zones, a major priority is to store and recover enough precipitation to grow next year's crop. In these areas, 30 to 40 percent of crop yield can be

attributed directly to the level of available soil water in spring and there is often insufficient soil moisture recharge over winter to recrop. One method for increasing available soil moisture is through summerfallow, where the land is left bare for 13 to 21 months, with most of the water recharge occurring in the first year. Summerfallow, however, is an inefficient method of accumulating and storing water, since 70 to 80 percent of the precipitation received during the fallow year is lost through evaporation, runoff, blowing snow or deep drainage. Furthermore, high evaporation rates can cause movement of salts to the upper soil layers. Nevertheless, the additional 3 to 4 centimetres of water stored by this method can be critical for crop production in the Brown or Dark Brown soil zones (Table 6.2). Approximately 40 percent of the arable land in these soil zones is summerfallowed each year. While extensive research has shown that chemical summerfallow (herbicides instead of tillage to control weeds) only increases water conservation from 0 to 2.5 centimetres over conventional summerfallow, it is most useful for reducing soil erosion during the fallow year. The greatest advantage of chemical fallow, with respect to water conservation, is that most of the stored water is in the surface soil layers; this additional water may be critical for crop emergence in a dry spring.

**Table 6.2**

*Differences in Spring Soil Water Content Between Fields that Had Been Fallowed and Those Cropped in the Previous Year (cm ± standard deviation).*

Soil Zone	1971-77 <sup>1</sup>	1982-88 <sup>2</sup>
Brown	4.5 ± 4.5	4.3 ± 1.6
Dark Brown	3.5 ± 3.3	4.0 ± 2.8
Black	1.8 ± 4.5	0.3 ± 2.5
Gray	0.3 ± 2.0	N/A

<sup>1</sup> Agriculture Canada, Agrometeorology Section.  
<sup>2</sup> University of Saskatchewan, Soil Science Department.

The Black and Gray soil zones suffer from both water shortages and excesses. While spring conditions in most areas are wet, they're followed by water shortages by mid-summer. Due to sufficient recharge from fall rains and snowmelt, summerfallow is not as prevalent in these soil zones (storage efficiency of fallow year precipitation less than 10%; see Table 6.2). However, snow trapping and soil moisture conservation are still high priorities, especially since there is little reliance on summerfallow for water conservation. Due to higher air humidity, efficiency of water use by crops is often higher than in the Brown and Dark Brown soil zones, although other factors such as weeds and diseases may limit WUE in these areas. The long-term water use efficiency (crop production per unit of water lost to the atmosphere over a number of years) is much higher in the Black and Gray soil zones, mainly because of the lower frequency of summerfallow (i.e., more of the precipitation is cycled through the crop, less is lost through evaporation). Cycling more of the available water through the crop also reduces soil salinization (see Land Chapter). Perennial forages, such as alfalfa, are sometimes included in rotation with annual crops and, because of different moisture conditions than those in the Brown and Dark Brown soil zones, only sometimes cause water shortages in subsequent crops.

While summerfallow is not usually necessary for water conservation in the Black and Gray soil zones, it is still practised in some areas (usually Southwestern Manitoba and Northeastern Saskatchewan). In some years it is required for water conservation because of high variability of soil water content. This is shown in Table 6.2 by the high standard deviations for over winter water conservation in the Black soil zone.

#### *Livestock Requirements*

Water shortages on the farm are important not only to crops, but also to livestock. Trapping and storing sufficient water for livestock, especially range cattle, is important. The most severe water shortages occur in Southwestern Saskatchewan and Southeastern Alberta, as far north as the Hanna/Kindersley area. Sloughs and dugouts are recharged by snowmelt or by pumping. Presently, most dugouts are designed to withstand only two consecutive years of no snow recharge. During a drought, water for cattle may have to be transported by truck. Approximately 2,500 farms in the Prairie region receive their water via pipelines. Much of the water development for livestock has been coordinated by the Prairie Farm Rehabilitation Administration.

#### **Redistribution of Water**

As stated earlier, one way of circumventing water as a limitation to Prairie agriculture is to distribute water from those areas where it is in abundance to those areas where water is short. While the previous section has discussed to some extent the current state of on-farm techniques for redistribution of water through time, an important aspect of redistribution transfer has not been discussed. In terms of agriculture, the transfer of water is tied up with irrigation and drainage developments and animal water supply issues.

#### *Agricultural Water Use and Irrigation Developments on the Prairies*

Agriculture is the largest user of the surface waters (lakes, rivers, flowages, etc.) in the Prairie provinces, as shown in Table 6.3. While the quantities of water withdrawals given in the table are for both surface and groundwater, the figures in the table can be taken as essentially surface water withdrawals because of the relatively little use of groundwater in the Prairies (approximately 2% of current total use). The high level of withdrawals by agriculture relative to other uses reflects the importance of agriculture in the Prairie economy and the small human population levels in these provinces.

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*The Prairie provinces withdraw more surface water in agriculture than all the other provinces combined.*

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The Prairie provinces withdraw more surface water in agriculture than all the other provinces combined. While it appears from the table that withdrawals for thermal power generation are nearly as large as that for agriculture, the impact of the withdrawals for power generation may be considerably less. If the consumption of water by sector, as reflected in the bottom of Table 6.3 for total Canadian water use, is correct, then the major use of surface water on the Prairies is also the most consumptive use, and this water is generally unavailable for other uses.<sup>3</sup>

<sup>3</sup> Consumptive use in a strict sense includes evapotranspiration losses, groundwater recharge, animal sewerage, and water contained in the bodies of plants and animals. Although water that is evapotranspired or used for groundwater recharge is not strictly consumed because it enters the hydrologic cycle, its loss to the prairies may be real for longer periods of time in the case of groundwater, or to the region itself for the other uses, because the reprecipitation of the water may not occur in the Prairie region.

Region	Agriculture	Mineral Extraction	Manufacturing	Thermal	Municipal	Total
Atlantic Provinces	12	86	640	1,837	307	2,882
Quebec	82	107	2,319	308	1,369	4,185
Ontario	148	124	4,414	14,930	1,450	2,066
Prairie Provinces	2,338	197	382	1,846	579	5,342
British Columbia	545	134	2,182	360	558	3,779
All Canada						
Intake	3,125	648	9,937	19,281	4,263	37,254
Recirculation	-	2,792	10,747	1,868	-	15,407
Gross Use <sup>1</sup>	3,125	3,440	20,684	21,149	4,263	52,661
Discharge	713	470	9,443	19,113	3,623	33,362
Consumption <sup>2</sup>	2,412	178	494	168	640	3,892

<sup>1</sup>Intake plus recirculation.  
<sup>2</sup> Intake minus discharge.

Agricultural water is used mainly for irrigation and livestock, with irrigation using about 88 percent of the water withdrawn. This could have important implications for irrigation water users as well as livestock producers, if, in the future, there is increasing competition for surface waters.

In the Brown and Dark Brown soil zones, intensive and non-intensive irrigation is practised on approximately 1 million hectares, with the main source of irrigation water being surface water. Current efficiency of irrigation water use ranges from 25 to 70 percent. The main irrigation crops in this region are cereal grains.

Irrigation is practised in localized areas within the Black and Gray soil zones. Irrigation water in these areas is derived mainly from aquifers. An example of a very significant aquifer used for irrigation is the Carberry aquifer in Manitoba. Other sources of irrigation water are local runoff (trapped by dams). The main irrigation crops in this region are potatoes, alfalfa and vegetable crops.

Water shortages for livestock occur in the southern and western areas of all of the above soil zones. Small dams are also used to store local water for livestock.

The droughts of the mid to late 1980s have stimulated interest in expansion of the irrigated acreage and livestock water supplies on the Prairies. This increased interest is reflected in the various projects being done in Central and Eastern Saskatchewan (Lucky Lake, Blackstrap and Rafferty-Alameda), and the Pembina Valley project that is under study in Manitoba. While activity has concentrated on these intrabasin redistributions of water, there is also interest in interbasin transfers as a solution to water shortages. This interest focuses on water flowing north above the agricultural region of the Prairies. This water is viewed by some as a lost resource. While these interbasin transfers of water are very much still in the think-tank realm of ideas, their persistence is important to note.

**Table 6.3**

*Water Intake by Regions and Water Use in Canada, 1981 (million cubic metres per year).*

*Extensive drainage has occurred in all areas of the Prairies, with an estimated 40 percent of the original wetlands in the Prairie region having been drained.*

#### *Environmental Considerations*

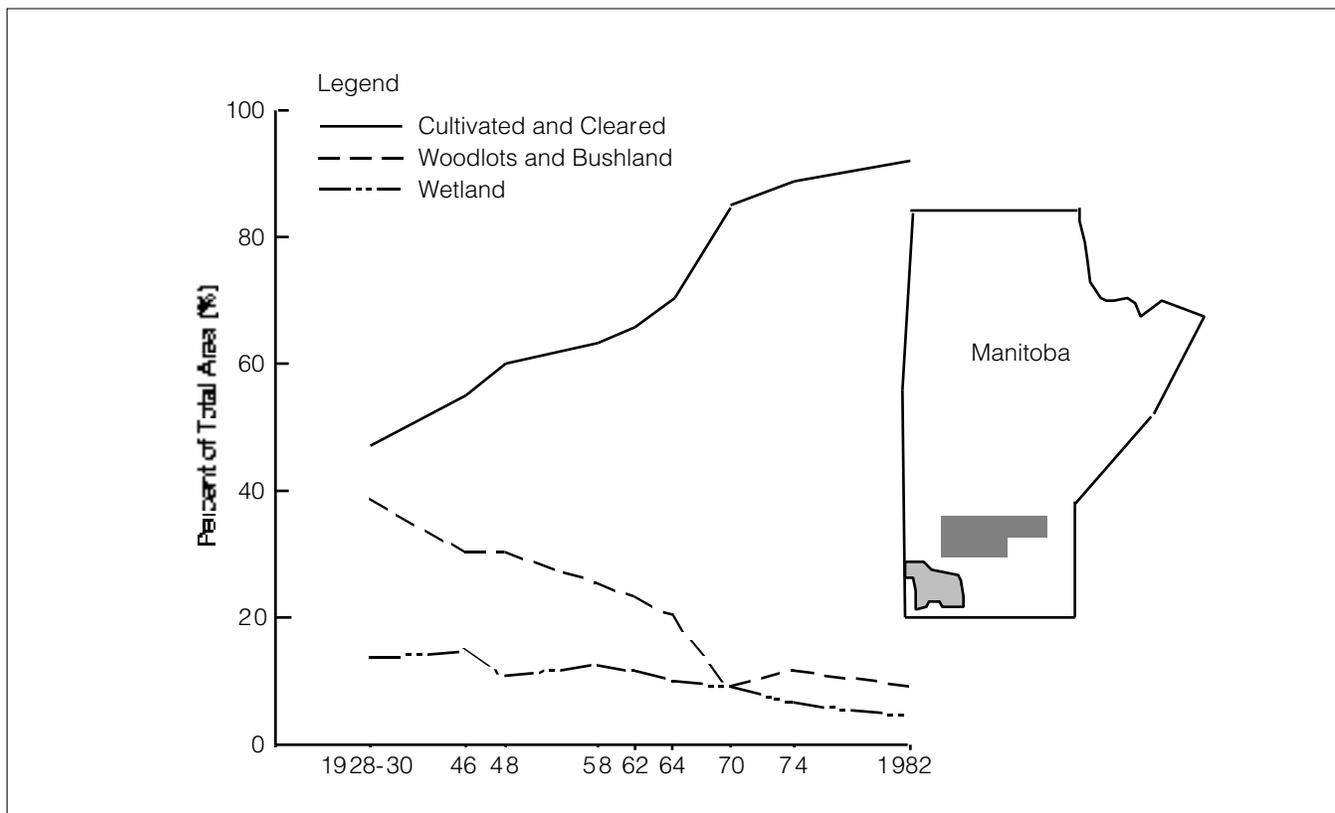
Attempts to redistribute water through space and time can have serious environmental consequences. Some of these consequences reflect problems that are common to poorly managed irrigation systems, such as increased salinity of soil and return waters. This increased salinity is not unique to the Prairies but is important because of the resulting losses to both agriculture and affected ecosystems.

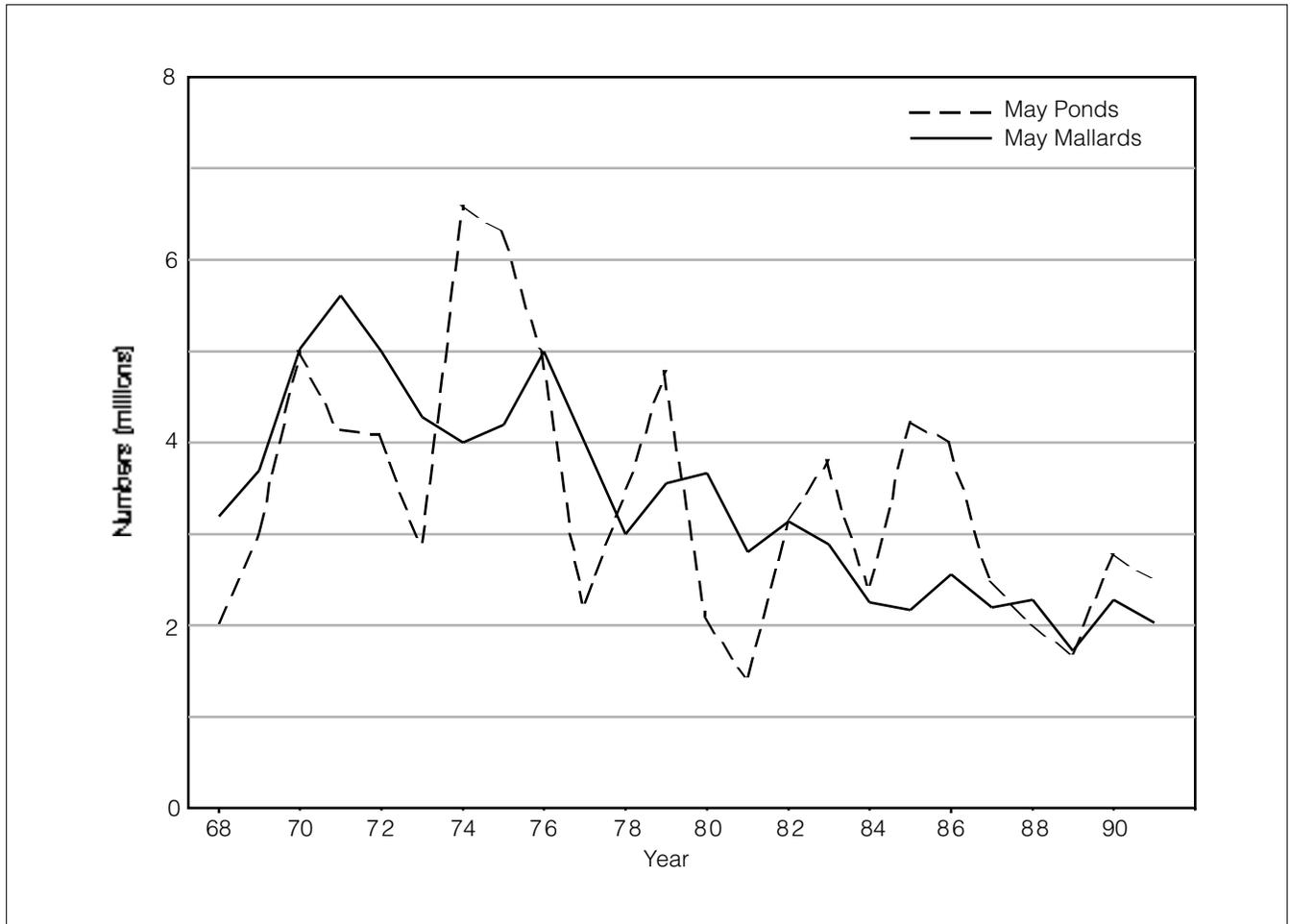
The consequences of both intrabasin and interbasin transfers can be quite severe from an environmental point of view. Intrabasin diversions can eliminate species or introduce new ones, an example being the introduction of the black bullhead into Lake Manitoba as a result of the floodway diversion at Portage la Prairie. Interbasin transfers can have even greater environmental impacts. The known impacts of the reversal of rivers in the former Soviet Union and the problems of California's central canal demonstrate the magnitude of the ecological destruction. Examples closer to home include the Churchill River Diversion, which has caused the Northern Indian Lake to shrink to half its original size, with resulting habitat loss for fisheries and other wildlife. Problems don't end at the basin losing the water, as greater flows, scouring of stream beds, shoreline erosion, and higher silt and trash loads have also occurred.

#### **Figure 6.1**

*Land Use Changes in the Minnedosa District (1928-1982).*

Extensive drainage has occurred in all areas of the Prairies, with an estimated 40 percent of the original wetlands in the Prairie region having been drained. The impact of drainage (and bush clearing) in the Minnedosa area of agricultural Manitoba is shown in Figure 6.1. Since the Black and Gray soil zones are the most productive waterfowl nesting areas in the





Prairies, drainage in these zones is particularly damaging to nesting waterfowl. Figure 6.2 illustrates that the number of May ponds on the southern Prairies has shown a downward trend from 1968 to 1991. The coinciding population decline in May mallards indicates the relationship between May ponds and ducks. The number of ponds occurring on the Prairies in May is a factor of agricultural practices and weather patterns. Waterfowl are dependent not only on the wetland basins in an area but also on the quantity and quality of habitat surrounding the basins.

**Figure 6.2**

*Estimates of May Ponds and Mallards in Southern Prairie Canada, 1968-1991.*

#### *Economic Dimensions*

The redistribution of water can be extremely expensive. Not only do large public expenditures need to be made for dams and diversions, but additional expenditures are also necessary for other infrastructure investments if irrigation is to be a major use of the water. Economists and other concerned professionals note that these huge public outlays for redistribution projects may not be a prudent investment. In other words, the public could undertake better investments with its limited funds than agricultural irrigation.

In order to assess the returns to a public investment an evaluation of the costs and benefits of that investment is required. In the case of irrigation, the main benefits of the project will mainly be increased and more stable income to farmers. Other potential

benefits may accrue from the construction of the project because materials and labour used in the project are currently either under-employed or unemployed. Further benefits may occur from increased economic activity in the area surrounding the project. This latter benefit will only occur if the increased economic activity would not have occurred in any way with or without some alternative public investment.

The costs of the projects are what are known as the opportunity costs of the materials, labour, loss of the ability to put water to other uses, and use of public investment elsewhere. In the case of materials and labour, the opportunity costs are reflected by the market prices of these inputs. In the case of loss of ability to use water and public investment elsewhere, determination of the opportunity costs is much more difficult because one can't easily measure the value of such costs. Water scarcity, coupled with the consumptive nature of agricultural water use, makes water unavailable for municipal use, industrial use, hydroelectric power generation, recreation and wildlife habitat. Water may be more valuable in these alternative uses. Similarly, public funds are limited. If they are used for irrigation projects they are unavailable for other uses, even within agriculture, that might have greater merit. Only by tallying up the benefits of an irrigation project and subtracting off the opportunity costs can efficiency of public investment be assessed. Past analyses of agricultural irrigation projects have shown that irrigation projects are not always efficient. A discussion of these past analyses will appear later in this chapter.

#### *Institutional Dimensions*

Many institutions have a direct impact on water quantity and quality in the Prairies. These fall into three broad categories: Federal agencies (Environment Canada, Canada Department of Fisheries and Oceans, and the Prairie Farm Rehabilitation Administration); provincial agencies and commissions (Manitoba Clean Environment Commission, Manitoba Environment, Manitoba Natural Resources, Saskatchewan Environment and Public Safety, Saskatchewan Water and Alberta Environment); and private and quasi-private bodies (Manitoba Hydro, Saskatchewan Power Corporation, Alberta Hydro and Ducks Unlimited). The various roles these institutions play with regard to water include assessment and review (Manitoba Clean Environment Commission), regulatory (Environment Canada, Canada Department of Fisheries and Oceans, Manitoba Environment, Saskatchewan Environment and Alberta Environment), and resource use (Prairie Farm Rehabilitation Administration, Manitoba Natural Resources, Saskatchewan Water, Manitoba Hydro, Saskatchewan Power Corporation, Alberta Hydro and Ducks Unlimited).

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*While regulations to reduce indiscriminate drainage have recently been introduced, enforcement of these regulations is difficult.*

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Drainage of Prairie potholes is a perfect example of how institutions can affect agriculture and water availability. As stated earlier, extensive drainage has occurred in all areas of the Prairies. Drainage of Prairie wetlands has been supported by PFRA as well as the Provincial and Municipal governments. While regulations to reduce indiscriminate drainage have recently been introduced, enforcement of these regulations is difficult. This difficulty exists in part because all land is taxed, although at varying rates, creating a disincentive for leaving wetlands intact.

There is one other institution unique to water in the Prairies. That institution is the Prairie Province Water Board (PPWB). The PPWB is a joint Provincial and Federal government agency, with representation from all three Prairie provinces. Its main

mandate is to oversee the allocation of water from those rivers flowing from one province in the Prairie region to another. It also provides a forum where other institutions that have an impact on water (such as those mentioned earlier) can interact with each other.

## **Water Quality and Uses**

### *Recreation and Municipal Demands*

The trends in Canada of greater urbanization, coupled with higher family incomes (due in many cases to dual income households), has resulted in new demands on water. These result in higher water demands for municipal and industrial use, and for power generation. Water demands for these activities are still small in the Prairies, as shown by Table 6.3, but growing, as shown by concerns in Winnipeg that the current aqueduct supplying water to the city is not sufficiently large to meet growing municipal demand. Similarly, much of the concerns regarding water shortages in the Pembina basin of Manitoba revolve around municipal and industrial supplies and their inability to cope with growth.

The trends in urbanization and affluence also result in higher demand for outdoor water-based recreation. Studies in both the U.S. and Canada have shown that the value placed on outdoor water recreation is quite high. Unlike agriculture, increased demands for water by municipalities, industry, and power generation are not as competitive with recreation. This is the result of these demands being less consumptive than agriculture, as shown in the bottom of Table 6.3.

### *Agricultural Quality Requirements*

Agriculture requires different levels of water quality depending on whether the water is for drinking water for livestock or for crops. Drinking water for livestock has nearly the same water quality needs as drinking water for humans.

Water for crops must have low salt content and the absence of heavy metals and other toxic substances. But it can have higher levels of sediments, P, N, other organic matter, and bacterial levels than for most other uses. Because of its tolerance for these higher levels, there is the possibility of using treated effluent from municipalities to irrigate crops. This tolerance is of course subject to the absence of toxins and heavy metals.

### *Point and Nonpoint Residuals from Agriculture*

Agriculture is a contributor of both point and nonpoint source pollution to water. Examples of point pollution sources in agriculture are effluent from processing plants for agricultural products, confinement livestock operations, and feedlot runoff. The pollutants from these point sources are mainly phosphorus, nitrogen and organic material. The latter can increase oxygen demand in a water body, while phosphorus and nitrogen increase the potential for algae blooms that harm aquatic ecosystems by also depleting oxygen supplies. Furthermore, phosphorus and nitrogen can have toxic effects when present in drinking water of humans, livestock or wildlife, or in the habitat of aquatic species. As seen in Figure 6.3, phosphorus is found in large concentrations in the Prairies. These concentrations are associated with heavily populated cities and municipalities and areas with high concentrations of livestock operations. While there is

**Figure 6.3**

*Phosphorus in  
Canadian River Basins,  
(1980-1982).*

insufficient information to fully associate the role of agriculture with problems of high phosphorus and nitrogen in surface and groundwater on the Prairies, analysis of similar problems elsewhere in Canada and the U.S. indicate that agriculture may be a major contributor.

Agriculture is also a contributor to nonpoint source pollution to water. As stated earlier in this chapter, these contributions take the form of sediment, phosphorus, nitrogen and pesticides. While high sediment levels are a problem, this condition is somewhat of a natural state for rivers and lakes in the Prairies. This is reflected in place names like Winnipeg, which roughly translates to the meaning of “muddy waters”.

Phosphorus, nitrogen and pesticides may reach surface waters via runoff or by attachment to sediments carried in the runoff. As will be shown in the Air Chapter that follows, nitrogen and pesticides may also be deposited in surface water via aerosols. These latter two contaminants may also be deposited in groundwater. Pesticides such as 2,4-D have already been detected in surface waters throughout the Prairies. But as is the case with phosphorus and nitrogen, there is insufficient data to gauge the magnitude of the problem. However, experiences in the U.S. with groundwater contamination from pesticides indicate that without continued monitoring a serious problem may go undetected.

*Manipulation of snow cover offers the greatest potential for increasing the water availability for dryland crops.*

### Issues Impacting Sustainability

The above discussion of water shortfalls, water redistribution and water quality and uses presented issues that will have a major impact on agricultural sustainability. The remainder of this chapter will focus on two main issues that could have the greatest effect on sustainability—on-farm water management and competing uses for water.

#### On-Farm Water Management

As discussed earlier, 20 to 30 percent of the annual precipitation on the Prairies is in the form of snow that is unevenly distributed throughout the Prairies (Table 6.4). Even with the uneven distribution of snow, manipulation of snow cover offers the greatest potential for increasing the water availability for dryland crops (it is estimated that snow management could make an additional three centimetres of water available to the next

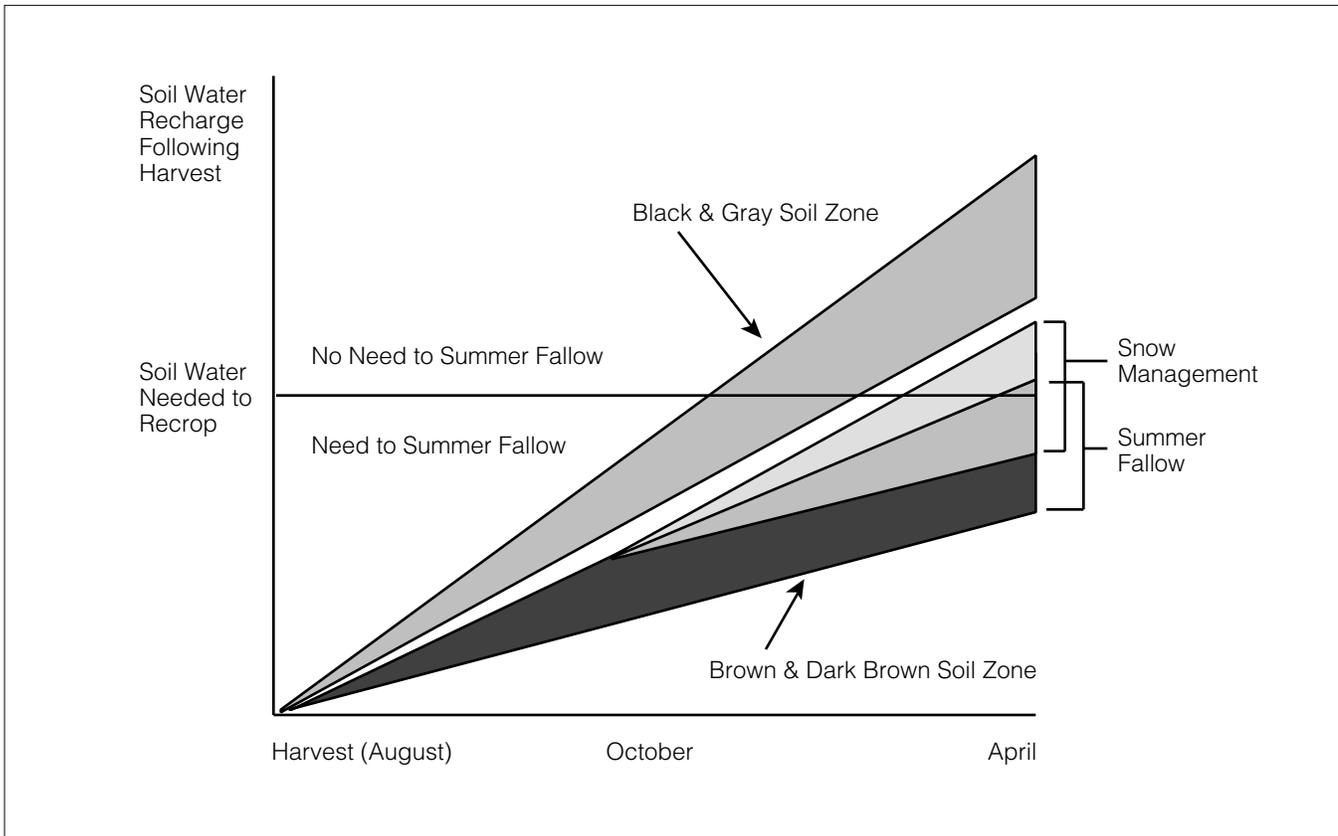
**Table 6.4**

*Water Equivalents of Mean Snowfall (1951-1980) for Various Prairie Locations.*

Location	Water Equivalent (mm)
Alberta	
Calgary	152.2
Edmonton	137.9
Lethbridge	163.5
Red Deer	130.1
Saskatchewan	
Regina	115.7
Saskatoon	113.1
Swift Current	129.0
Yorkton	138.2
Manitoba	
Arborg	126.5
Boissevain	117.0
Brandon	116.9
Dauphin	149.1
Emerson	103.2
Winnipeg	125.5

Note: Approximately 50% of the precipitation from snowfall is lost by sublimation.

crop). Figure 6.4 illustrates the soil moisture recharge from harvest to spring for the Black and Gray Soil Zones and the Brown and Dark Brown Soil Zones. Without snow management, Brown and Dark Brown soils often do not have enough water to recrop in the spring and require summerfallow. Snow management can, in many years, eliminate the need for summerfallow. Figure 6.4 also illustrates the variability in soil moisture that can occur in the two soil zones, even with snow management.



**Figure 6.4**

*Typical Soil Water Recharge Following Annual Crop Harvest.*

*The combination of snow management, conservation tillage and winter crops allows for a further increase in WUE and a reduction in summerfallow.*

The use of snow management techniques such as alternate stubble heights, tall stubble strips, and vegetative barriers is increasing on Prairie farms. Snow trapping is often less on pastures than on crop fields, since pastures of the Prairies are largely overgrazed and often provide little standing vegetation to trap snow. Recent research in Manitoba (University of Manitoba; Agriculture Canada) has shown that use of rotational grazing and the appropriate animal stocking rate increases the over-winter soil water recharge.

Water efficient cropping systems such as minimum or zero tillage also increase water storage and WUE (Table 6.5). Fall-seeded crops such as winter rye and winter wheat have a higher WUE than spring-seeded crops (40 percent higher; Table 6.1). The combination of snow management, conservation tillage and winter crops allows for a further increase in WUE and a reduction in summerfallow. Such a crop production system has not been widely adopted, however, mainly because of genetic limitations of current winter wheat cultivars and market restraints of fall rye. Including perennial crops, such as alfalfa, can increase the rotational WUE. Also, the use of herbicides to terminate perennial forage

stands, rather than fall-tillage, increases over-winter soil water recharge and WUE, and thus reduces reliance on fallowing the year after the forage stand is terminated.

Tillage System	Indian Head 1987-1989	Waldron 1987-1989	Tadmore 1987-1989
Soil Water, cm to 120 cm Depth			
Zero	42	28	16
Minimum	40	27	17
Conventional	39	25	13
Grain Yield (kg/ha-1)			
Zero	1,940	1,852	876
Minimum	1,943	1,671	995
Conventional	1,438	1,765	891

Note: Approximately 50% of the precipitation from snowfall is lost by sublimation.

Herbicides instead of tillage to control weeds allows for greater WUE, as shown in Table 6.6. This table shows that additional moisture from standing stubble versus fall tillage (i.e., better snow management) is of limited value without weed control and crop fertilization. This fact illustrates that snow management, or any water conserving farming practice, does not stand alone but must be thought of as part of a whole cropping system which includes weed control and fertilization. With the discovery of herbicide resistant weeds, however, the success of substituting chemical weed control (herbicides) for mechanical control (tillage) is not assured. As previously stated, while chemical summerfallow holds little promise for increasing available water over conventional (tilled) summerfallow, it is very important for control of soil erosion during the fallow year.

Summerfallow is often, but not always, necessary for producing annual crops such as cereals and pulses in the Brown and Dark Brown soil zones. Successful stubble cropping requires about 5.0 to 7.5 centimetres of available water at seeding, adequate fertilization and effective weed control. Predictive models can assist farmers in determining whether to summerfallow or to seed a crop that year. Existing models use inputs such as level of available soil water in spring, value of the crop to be seeded, level of soil nutrients, costs of nutrients, and probability of growing season precipitation in the area. This approach is referred to as “flexible-cropping”. Use of these flex-cropping systems could easily eliminate roughly 20 percent of summerfallow on the Prairies. In order for these systems to be effective, improvements will be required in 1) measurement of on-farm soil water levels, 2) farmer training in computer use, and 3) understanding of precipitation probabilities (see the Land chapter for further discussion of summerfallowing and modelling). Rotation WUE in the Brown and Dark Brown soil zones could be increased by including summerfallow substitute green manure crops such as Indian Head lentils (which fix some nitrogen but do not use copious amounts of water).

**Table 6.5**

*Total Spring Soil Water and Yield of Spring Wheat Under Three Tillage Systems at Three Locations in Eastern Saskatchewan.*

*With the discovery of herbicide resistant weeds, however, the success of substituting chemical weed control (herbicides) for mechanical control (tillage) is not assured.*

Treatment	Stubble Treatment		Additional Yield due to Stubble Treatment
	Fall Tillage	Standing Stubble	
No Herbicide, No Fertilizer	910	970	60
Herbicide, No Fertilizer	1,290	1,400	110
No Herbicide, Fertilizer	1,240	1,310	70
Herbicide, Fertilizer	1,670	1,930	260

**Table 6.6**

*Influence of Herbicide, Fertilizer, and Stubble Treatments on Yield (kg/ha) of Continuous Wheat Rotation over a Seven-Year Period (1983-89) at Scott, Saskatchewan.*

*As the Prairie provinces attempt to diversify their economies away from the heavy dependence on agriculture, water will become a limiting factor for other sectors of the economy.*

Irrigation efficiency can be improved. Efficiency is affected by how water is applied to the crop, and the quantity and timing of that application. Efficiencies of various irrigation systems are as follows: contour ditches - 24 percent; border ditches - 55 percent; furrow irrigation - 60 percent; side roll sprinkler - 70 percent; centre pivot sprinkler - 75 percent; trickle system - 85 percent. Prevailing conditions during irrigation also influence WUE. In a Saskatchewan study, losses of 46 percent were observed when centre pivot irrigation was used on a windy day.

### Competing Uses

Water availability and quality are the major challenges that must be overcome if agriculture on the Prairies is to be sustainable. The success of agriculture to meet such challenges will require the industry to deal with two factors. First, the existence of an affluent, faster growing, and larger nonfarm Canadian population. The existence of this nonfarm population, both inside and outside the Prairie provinces, means that there are fewer Canadians directly tied to farm production and that their preferences regarding economic and environmental issues likely differ from those of farmers. Second, as the Prairie provinces attempt to diversify their economies away from the heavy dependence on agriculture, water will become a limiting factor for other sectors of the economy. Agriculture will therefore face greater competition for scarce water resources. These factors taken together mean that a sustainable agricultural system for the Prairies will need to be more environmentally friendly and justifiable, on economic grounds, as a good place for public investment.

As stated earlier, some farmers and agricultural policy-makers look to intra- and interbasin water transfers, coupled with irrigation, as an alternative solution to on-farm management practices to solving the problem of water scarcity. The difficulty with this solution is that it is often uneconomical from a public investment point of view because such water use is highly consumptive and therefore competes with other water uses. Differing views as to the efficacy of these projects exist because the price paid for water is lower than the cost of supply.

The economic feasibility of various irrigation projects is assessed by their return on the investment where the costs exceed the benefits. The inefficiency of some of these projects in Central Saskatchewan is shown in Table 6.7. This table shows that if the irrigation water is used for grain production, two of the four irrigation expansion projects have

benefits that are less than the associated costs of the project. Even where expansion for grain provides positive net returns, the projects are suspect because some of the secondary benefits are suspect. While all the projects have positive benefits for livestock and a more aggressive crop scenario (use of higher value crops, such as vegetables), these scenarios are not likely to happen. It is not clear that expansion of livestock is more efficient through investment in wetland agriculture or dryland agriculture. Furthermore, as seen in Figure 6.5, use of irrigated cropland in Alberta, where there is a much longer history of more extensive irrigation, is predominately for grains, oilseeds, hay and other fodder. Very little irrigated land is used for potatoes or other specialty crops, a result of the subsidized price farmers pay for water. If farmers were charged the full cost of irrigation water, their enthusiasm for intra- and interbasin transfers would decline.

*If farmers were charged the full cost of irrigation water, their enthusiasm for intra- and interbasin transfers would decline.*

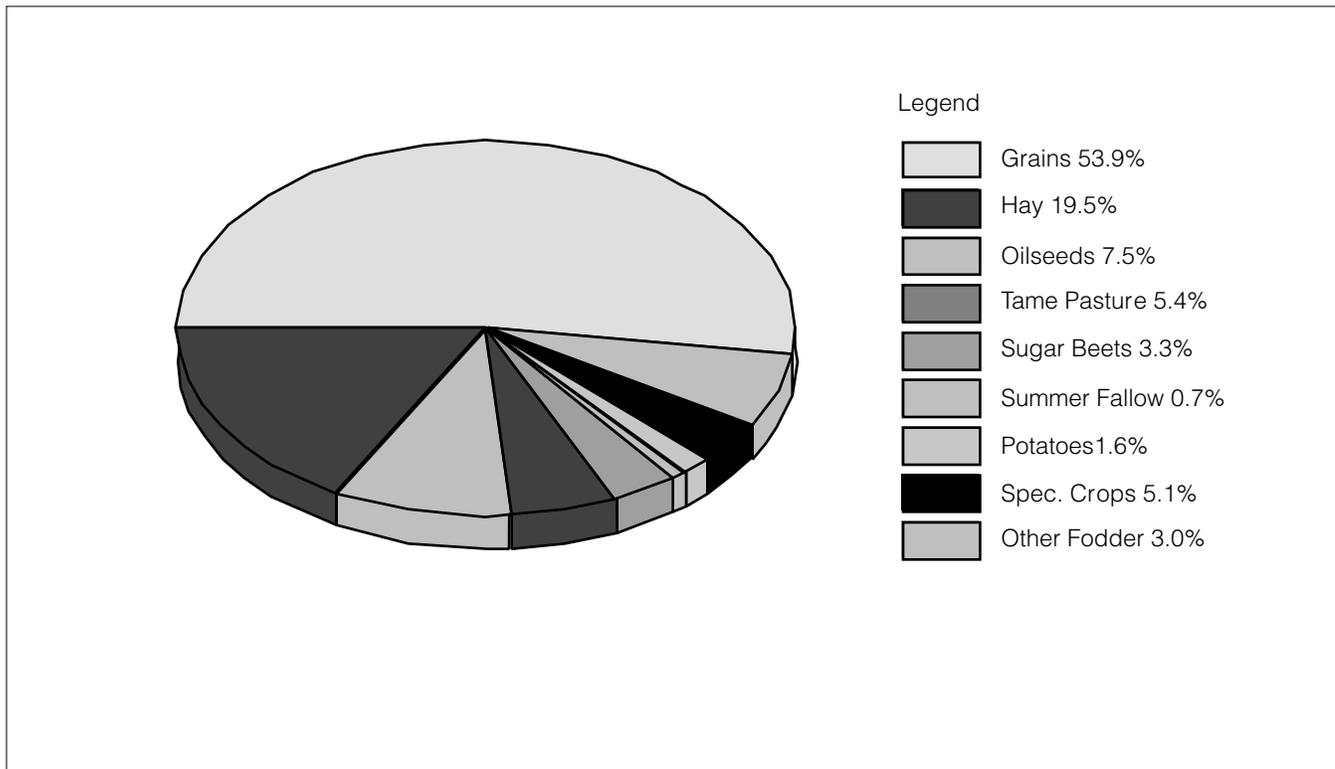
Project	Scenario		
	Grain	Livestock	Aggressive <sup>1</sup>
	Benefit/Cost Ratio		
Lucky Lake	.8	1.4	2.2
West Side	1.5	2.6	4.5
Blackstrap	1.3	2.2	3.5
Riverhurst Reg	.6	1.0	1.6
All Projects	.9	1.4	2.3
	Net Present Values (Benefits-Costs) (\$ million)		
Lucky Lake	-5	11	35
West Side	32	98	212
Blackstrap	2	6	13
Riverhurst Reg	-73	8	130
All Projects	-44	123	390

<sup>1</sup> Refers to aggressive crop scenario, involving higher value crops such as vegetables.

Agriculture also competes with other water uses via its point and nonpoint pollution. As recreation and environmental preferences become stronger in the Canadian population, tolerance of the negative impacts of agricultural pollution will come under increased pressure. Point source contaminants can be controlled by better effluent treatment in the agricultural processing industry and restrictions on the location of confinement livestock operations. Nonpoint source agricultural pollution will be much harder to control. It should be noted that many of the techniques for improved on-farm water management would result in some reduction in nonpoint source pollution.

A few institutional changes would work considerably towards assuring the sustainability of Prairie agriculture vis-a-vis other competing water uses. First, property taxes on agricultural wetlands should be eliminated. This change, when coupled with regulations on drainage of wetlands (even if enforcement is weak) and cash incentives arranged by

**Table 6.7**  
*Economic Feasibility of Irrigation Projects in Central Saskatchewan Under Three Prospective Development Scenarios.*



**Figure 6.5**

*Irrigated Cropland in Alberta, 1984.*

organizations like Ducks Unlimited, would help lessen the conflict between wildlife habitat and agriculture in the water area. Second, a better tie within the pollution control regulations between manure production by livestock and the ability to apply manure to the land at levels that will not result in phosphorus and nitrogen pollution. Finally, full-cost pricing of water to agriculture. This would make initiatives like interbasin transfers of water less appealing to agricultural interests and would provide monetary incentives for farmers in water-short areas to practice better on-farm water management. These are examples of technological and institutional solutions to agriculture's water problems.

### A Final Word

There are several areas where further research is necessary if water issues surrounding agricultural sustainability are to be solved. First, we need to continue development of assessments regarding the agronomic and economic viability of snow management and other on-farm water management techniques. Second, more data collection and analysis are necessary to determine the seriousness of problems of nitrogen, phosphorus and pesticides in water of the Prairie region. Finally, there is need for information regarding the economic value of recreation and wildlife habitat in the Prairie region.

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## 7. AIR

Air and water are the two prime components that support higher forms of life. Air provides both the carbon dioxide for photosynthesis by plants and the oxygen for animal and plant respiration. Under normal unconfined environmental conditions, neither carbon dioxide nor oxygen concentrations are of major concern to the sustainability of agriculture. Under confined agricultural systems for plants (e.g., greenhouses), animals (e.g. swine barns) and food storage structures (e.g., potato storages or grain bins), both carbon dioxide and oxygen levels may be of concern, but both are manageable through proper engineering design. Neither gas represents a major limitation to the sustainability of agriculture.

Agriculture is both a source and a receiver of environmental contaminants transported through air. Some of these contaminants are relatively global in nature, such as acid rain, pesticides, ozone, nitrogen oxides and methane, while others may be more regional, such as dust, feathers, odours, and ammonia. Still others, including many of the above, may be more of a problem due to their release into confined environments. In the past, some of these contaminants have been of concern but have not likely had a significant impact on the overall sustainability of agriculture. Table 7.1 provides a brief summary of the main contaminants that are associated with agriculture and transported by air, with a general classification of their potential significance to agriculture. These contaminants have various effects on agricultural crops and animals, humans and the general environment. While some of these contaminants and their effects represent potential limitations to the sustainability of Prairie agriculture, in many cases we have the ability to control the effects through proper management.

**Table 7.1**

*Significance of Contaminants Associated with Agriculture and Transported by Air.*

	External Environment		Confined Environment	
	Past	Future	Past	Future
Solids:				
particulates	+	+	+	++
dander	-	-	-	+
feathers	-	+	+	+
soil	++	++	-	-
pollen	-	-	-	-
bacteria	-	+	+	++
virus	-	-	+	++
spores	-	-	+	++
Liquids:				
aerosols (containing pathogens)	-	-	+	++
Gases:				
pesticides (anything sprayed)	+	++	-	+
gases (CH <sub>4</sub> , H <sub>2</sub> S, NOX, NH <sub>3</sub> )	+	+	+	+
odours	+	++	+	+
- not of major concern	+ some negative impact		++ significant negative impact	

## Air Quality — Limiting and Nonlimiting Factors

**Plants** — The air carries many types of contaminants that may have a deleterious effect on plant growth and development and on the quality of the plant products. Acid rain and ozone from large industrial emissions, lead along highway transport corridors, and particulates deposited on the surface of leaves can all result in significant reductions in the rate of photosynthesis by plants and thus reductions in productivity. Other compounds transported by air, such as herbicides, may result in complete destruction of the plant or may leave a residue as a contaminant in the final product. In general, the major air pollutants that affect plant growth in some areas of the country, such as ozone and acid rain are so far not of major concern for Prairie agriculture. In specific instances, particulates (e.g., airborne soil, particulates from straw or peat burning or dust from barn exhaust fans) may coat leaves and lead to significant reductions in photosynthesis and plant growth. Pesticide drift may also have a local negative impact on a specific crop. However, as both of these types of problems are local in nature, and since there are management options which can reduce or eliminate the problem, neither of these types of problems will likely have a significant effect on the sustainability of agriculture.

**Animals** — Contaminants in ambient air are generally not at a level that will have a major impact on non-confined animals. For confined animals, there are two general problems. First, low levels of oxygen, high levels of carbon dioxide, high levels of hydrogen sulphide or ammonia, viable and non-viable particulate levels, and high concentrations of pathogens can all exist in barn air at levels that can have both short- and long-term effects on animal health and welfare. It is these short and long term health effects and their consequent effect on animal productivity, and thus economic viability, that are of concern. The design and proper management of ventilation systems for confined livestock buildings can reduce the problem. Second, if the general public decides that animals should not have to live in what the public perceives to be an environment having an unacceptable level of air quality, they may ask that regulations be developed to ensure animal health and welfare. Such regulations and controls could have a significant impact on the sustainability of agriculture.

**Humans** — Contaminants in confined livestock buildings present major potential concerns with regard to workplace health and safety. The major gases of concern in barn air are hydrogen sulphide, ammonia and methane. All three of these gases can be controlled with proper management and should not affect the sustainability of Prairie agriculture. Particulates can reach levels that can cause severe eye irritation and respiratory problems, and airborne pathogens can lead to a variety of worker health problems. If regulations are developed that set very high standards for barn air quality for the protection of worker health, the resulting cost may have a significant impact on the economic viability of the confined livestock industry. The air in tractor and truck cabs associated with pesticide application may also be of poor quality.

The other major interaction between humans and air results from the transport of odours and dust from livestock buildings, feedlots, manure lagoons, and during and after the land spreading of manure. Although these contaminants do not represent a health hazard in the normal sense of the word, they do represent a nuisance and as such can have an effect on whether livestock operations are allowed to expand or where new operations may be allowed to be built.

**General Environment** — There are three areas that should be mentioned with regard to air, agriculture and the environment. First, the concentration of methane gas in the atmosphere is increasing. As was described in the Climate chapter, there is concern that any activity that results in an increase in the release of methane may be contributing to global warming (i.e., the greenhouse effect). There are many agricultural activities that can have an effect on global methane production. Drainage of wetlands and aeration of the soil will both reduce the production of methane from natural ecosystems. Ruminant animals produce methane gas as they digest feeds. Methane gas may also be produced during the anaerobic breakdown of animal manures. Carbon dioxide and methane reportedly account for 49 and 18 percent of the global warming effects, respectively. But whereas it has been predicted that it will take from preindustrial times to up to the year 2050 for the carbon dioxide concentration in the atmosphere to double, the methane concentration is currently increasing by 1 percent per year. Since methane also traps 25 times as much energy per molecule as carbon dioxide, methane could be the principal greenhouse gas within 50 years. It is estimated that the 1,300 million cattle in the world release about 50 million tonnes of methane per year to the atmosphere through eructation. An additional 28 million tonnes are released during the anaerobic decomposition of manures in storage. It is estimated that the livestock in the three Prairie provinces contribute about 1.5 percent of the methane generated by domestic animals worldwide. There are ways to reduce methane production and emission from manures in storage. It may also be possible to reduce methane production during ruminant fermentation through choice of feeds, genetic selection and manipulation of the microbes in the rumen. Such methods will, however, require extensive research.

Whether agricultural practices result in a net increase or decrease in overall concentration of methane in the environment is still open to question. Even the relative importance of methane as a contributor to global warming and whether global warming is indeed occurring are both open to debate. If the warming trend is real and methane is a significant contributor, as has been proposed by some people, even the contribution made by Prairie livestock may have an impact on the long-term sustainability of the livestock industry (see Climate chapter for further discussion of global warming).

The second area of concern is the general movement of pesticide residues throughout the biosphere. Many of the older pesticides are persistent and although they exist and are transported through the air at very low concentrations, they find their way into every part of the environment. Several of these compounds have had major adverse impacts on the environment. The long term effects some of these new compounds will have on ecosystems to which they were never meant to be exposed is in question.

The third area of concern is the transport of airborne particulates. The main agricultural sources are: soil and manure airborne particulates produced by wind erosion; straw, stubble and peat burning; and dust and feathers from the exhaust air of confined livestock facilities. Along with these particulates, agriculture is also a receiver of particulates from other sources, such as forest fires, industrial stack gases, cars and trucks, coal-fired power generators and soil erosion from landfill sites. Although particulates coating the surface of leaves can reduce the rate of photosynthesis, and under certain climatic conditions high particulate levels may develop in air, (which can result in traffic accidents and health problems), such cases do not represent a real problem to the sustainability of agriculture.

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*It is estimated that the livestock in the three Prairie provinces contribute about 1.5 percent of the methane generated by domestic animals worldwide.*

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*At this time, there are very few enforceable regulations that can be used to reduce the level of airborne particulates resulting from agricultural enterprises.*

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The real concern to agriculture occurs when airborne particulates land on someone else's car, or clothes drying on the line, or interfere with a barbecue out on the patio. The particulates are perceived to be a nuisance and in response, the neighbours use common law as it relates to nuisance and attempt to have the problem resolved by the courts.

At this time, there are very few enforceable regulations that can be used to reduce the level of airborne particulates resulting from agricultural enterprises. Those practices that do add particulates and that can be readily identified, such as straw and peat burning, can be reduced or controlled based on changes in management practices. Although some of these changes may result in some increased costs to the farmer (e.g., tillage of straw instead of burning), concerns related to airborne particulates resulting from agricultural activities will not, at this time, have a significant impact on the sustainability of agriculture.

## Background

### Pesticide Transport

#### *Extent and Nature of Pesticide Transport*

During application, pesticides can be volatilized to yield vapour residues, or, alternatively, they can be incorporated into fine droplets forming an aerosol of pesticide solution. In either case, drift of this material off-target represents both an economic loss to the farmer/applicator and a potential detriment to the neighbouring farmer/gardener, shelter belt, forest or prairie. In addition, pesticide losses may occur after application due to volatilization of residues from treated soil or foliage, given sufficiently high temperatures and air movement.

Once pesticide residues are airborne, their deposition will be determined by the nature of atmospheric movements and precipitation. The residues may be degraded by sunlight to some extent. They may also fall to earth as part of a raindrop, or become adsorbed to particulate matter which in turn falls to earth or is carried there as part of a raindrop, hailstone or snowflake.

Uptake of organic environmental contaminants, including pesticides, by vegetation is a major source of food chain bioaccumulation and an important route of exposure for humans and animals. Residues of widely used compounds have been found to accumulate in grain crops, natural vegetation, conifer needles, tree bark, and moss and lichens. Vegetation is thus likely to play a significant role in the environmental fate of these compounds. Plants can also be used to monitor atmospheric concentrations of such contaminants.

Pesticides with substantial vapour pressures are the most likely to become volatilized during application. Such pesticides as 2,4-D ester formulations are the most common offenders in this regard. Indeed, any phenoxy herbicide ester formulation may behave the same way. Hence, such formulations are improved by the use of long chain alcohols as the substituent group in the ester, thereby increasing the molecular weight of the product and lowering the vapour pressure. Other volatile pesticides of major importance on the Prairies include trifluralin and relatives and EPTC.

Pesticides applied in such a way as to enable the formation of fine aerosols will also be lost to the atmosphere during application. Any pesticide applied in a liquid carrier can become an offender.

Transport of airborne pesticide residues will be magnified if the application nozzles are higher than the minimum required above the crop/soil surface, or if the nozzles are operated under excessive pressure or flow rate.

Airborne pesticide residues that impinge on the Prairie area may also originate from third world countries in which such pesticides are used and lost to the atmosphere. In this case, the worst offenders are the organochlorine insecticides such as DDT (dichlorodiphenyltrichloroethane) and its relatives, cyclodienes such as heptachlor and toxaphene, and the chlorinated cyclohexanes such as lindane. Deposition is most serious in the Arctic regions and has the greatest impact on Arctic mammals and the human inhabitants who use Arctic mammals and fish as major food sources.

### *Regulations*

Current legislation and regulations governing pesticide registration is the responsibility of the Government of Canada through Agriculture and Agri-food Canada in conjunction with Canada Department of Fisheries and Oceans, Environment Canada, and Health Canada. Provincial legislation and regulations can increase the stringency of this control. On-farm pesticide use is the responsibility of the farmer, but follows recommendations issued by the provincial Departments of Agriculture in conjunction with university and private sector expertise.

Residues permitted in air come under the jurisdiction of provincial environmental agencies. Dealing with problems associated with such residues would, of necessity, involve provincial agricultural departments.

### **Confined Environment Air Quality**

There has been concern in recent years that the atmosphere in livestock and poultry facilities may have a deleterious effect on the health of animals and humans. When industrial agriculture introduced intensive livestock housing in Europe in the 1950s and North America in the 1960s, it separated animal production from the land base. Previously, most farms produced the majority of their feed on their own land and the manure produced by the animals was put back on the land. Nutrients that left the farm as marketed livestock were replaced with off-farm purchases of fertilizer. The concentrating of livestock in feedlots and buildings required that feed be brought to the animals. Feed purchased off-farm increased the amount of nutrient entering the farm nutrient pool and removed the natural on-farm recycling and management balance of nutrients.

### *Extent and Nature of Concerns*

The technology that evolved and permitted the confinement of large numbers of livestock in buildings and on feedlots has led to the concentration of large quantities of manure that must be managed if both air and water quality problems are to be avoided. In addition, barn air quality must be maintained at acceptable levels if animal and worker health and welfare are to be maintained. If stocking densities and ventilation rates are not

properly managed, oxygen levels may drop to unacceptable levels and airborne contaminants, including gases (such as ammonia and hydrogen sulphide), dust and pathogens, may rise to unacceptable levels. When threshold concentrations of specific contaminants are exceeded, direct and immediate effects on animal and worker health can occur. Problems that are more of a chronic nature can occur when animals and workers are exposed for extended periods of time to contaminants at below threshold levels. For humans, the problem may also be a function of the workers age. Young workers may possess the capability of clearing their lungs of particulates and thus reduce their chances of disease, whereas older workers may no longer have that capacity and may be more susceptible to disease. Water vapour respired by the animals or released from urine and faeces may also have an effect on the ventilation rate and can interact with other airborne contaminants.

**Dust** — The dust in livestock buildings is almost entirely organic and originates from feed, skin, feathers, bedding and faeces. Both the concentration of particles and the size distribution of the particles can have a major impact on their effect on animal and worker health. There is also evidence that the majority of viable viruses and bacteria transported in air are associated with airborne particulates. Viable fungal spores, however, can readily exist in the isolated state. Particulates can be classified according to size as respirable or nonrespirable. As a first approximation for humans, particles greater than 10 micrometres are deposited in the nasal passages, those of 5-10 micrometres are deposited in the upper respiratory tract and those less than 5 micrometres are deposited in the lungs themselves. Similar particle size distributions and depositions are found for swine and poultry. It is the respirable particles which penetrate the lungs (particles less than 5 micrometres) that represent the greatest potential health problem. The extent of the problem will depend on the site of deposition, the retention time, the number and nature of the particles, and the species of the receiver.

Dust levels are a function of animal species, stocking density, feed type, ventilation rate, and animal activity. There appears to be no significant relationship between temperature, relative humidity and dust level for swine barns. Dust levels are significantly lower at high summer ventilation rates (15 to 60 air changes per hour) when compared to winter rates (two to eight air changes per hour). In one study, recirculation of air within the building through plastic ducts did not affect dust levels. In the same study, the addition of fat to the feed did not reduce airborne dust, but other reports have shown a decrease. In another study, dust levels were shown to vary two- to three-fold over time even at similar ventilation rates and stocking densities. The explanation appears to be that animal activity is the overwhelming factor in generating airborne dust levels.

**Gases** — The major gases of concern in barn air are ammonia, hydrogen sulphide and methane. Hydrogen sulphide is produced during the anaerobic decomposition of manure in storage and is slowly released into the environment. Significant quantities can be released during the agitation of manure, and if adequate ventilation rates are not used lethal levels can result. Ammonia is released very rapidly from fresh poultry manure and from stored livestock manure. The gas can cause severe eye irritation and respiratory problems. The addition of bedding can absorb urine and reduce the release of ammonia but can also increase problems related to dust and production of pathogens. Methane, as mentioned previously, is produced during the anaerobic decomposition of manure and by ruminants during the fermentation process. Methane can increase to explosive levels in

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*The major gases of concern in barn air are ammonia, hydrogen sulphide and methane.*

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barns. But this again is a management problem and should not be of major concern if proper management practices and ventilation systems are used.

**Pathogens** — The concentration and particle size distribution of dust particles plays an important role in their transport and on their impact on animal and worker health. Most pathogens are associated with particulates greater than 5 micrometres in size, and filters are available that can render air sufficiently free of pathogens to meet worker safety standards. Unfortunately, no air filtration systems exist for workers that are acceptable in terms of both particulate removal efficiency and worker comfort. Unless the workers will wear the systems on a regular basis, they are of little value.

**Pesticides** — Many pesticides are used in association with livestock, both in confined and unconfined environments. When handled properly, they are not considered to represent a major concern to animal or worker health as it relates to the sustainability of agriculture. A recent concern has been expressed with regard to the quality of air in tractor cabs during the application of pesticides. The information is conflicting, but again it is a problem that can be addressed by proper design and management.

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*Unfortunately, no air filtration systems exist for workers that are acceptable in terms of both particulate removal efficiency and worker comfort.*

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*Institutional Aspects*

Government provides virtually all of the controls, regulations, research and information dissemination related to agriculture/air interactions. Most of the regulations, controls and extension are provincial-based. The funding for research is split between the Federal and Provincial governments, with the majority of federal funds coming through the Natural Sciences and Engineering Research Council (NSERC) system, and with each province having its own system of support. The following institutions all have a part to play in decisions related to agriculture/air problems:

<b>Provincial</b>	<b>Federal</b>
Departments of Environment	Environment Canada
University Research	Energy Mines and Resources
Departments of Agriculture	NSERC
Regional Planners	Agriculture Canada
Workplace Health and Safety	
Provincial Environmental Commissions	
Departments of Health and Welfare	

**Livestock Waste Management**

*Extent and Nature of Effect on Ambient Air Quality*

Complaints and conflicts involving livestock operations in the Prairie provinces have increased substantially over the past few years. Major public outcries have been raised over proposals for setting up operations in new areas. Intensive livestock operations can have an impact on the environment, and regulatory agencies are responding to the perceived

concerns of the citizens. The reasons for the increase in the number of complaints include larger operations, poor public relations by producers, development on small land bases, ineffective development procedures, fragmentation of agricultural land and an overall increase in public sensitivity. In many cases, these complaints are based on subjective rather than objective judgements.

The major concerns related to land use planning are the nuisances created by dust, odours, flies and pathogens generated from the livestock operations. Dust from poultry barns and feedlots can be a problem for neighbours. If the livestock operation has been located properly, dust and flies are usually not the main concern. Pathogen transport in bioaerosols released during the spray irrigation of manures onto land has been of concern. At this time, the transport of disease off-farms as a result of the spray irrigation of manure is not considered to be of major concern. The transport of odours to neighbours is not considered a health hazard but rather a nuisance. Manure produced by animals in feedlots may be allowed to build up over extended periods of time. During hot, dry periods, odour and dust problems may lead to farm/neighbour conflict.

#### *Institutional Aspects*

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*Only one Federal Act at the present time addresses pollution from farms.*

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Considerable confusion exists over the roles of agencies in dealing with nuisance and pollution problems on farms. In most provinces, Federal, Provincial and local governments have jurisdiction in agricultural development. The degree of involvement by each jurisdiction varies depending upon the province and the specific regulations that have been developed. Only one Federal Act at the present time addresses pollution from farms. The Fisheries Act prohibits an unauthorized deposition of any deleterious substance (one that will kill fish in 96 hours) into water frequented by fish, or water that may eventually enter water frequented by fish.

Regulations in Western Canada occur at two levels: the local municipal level and the provincial level. The primary approving agency varies with province. Local municipalities are the primary approving agencies in Alberta and Manitoba. Saskatchewan has the most rigorous process under the authority of the Saskatchewan Department of Agriculture and Food. Most provinces have guidelines to serve as a basis for manure management recommendations. These guides or “codes” are useful as a technical basis for advising local municipalities on basic standards of manure management performance on livestock farms. No regulations address the management of manure to reduce air pollution problems. In Manitoba, the Department of Environment under the Environment Act can charge and fine offenders if they “pollute”, but, at the moment, air pollution from dust or odours from agricultural operations does not fall within their jurisdiction. Under the Clean Environment Act, a proposal to build a new facility which could be classed as a “very large new operation” might require a full environmental impact study, but this is open to interpretation. The regulation of the location of livestock operations and confined livestock facilities is controlled by municipal governments under the Municipal Act. If the municipality has a Municipal Development Plan, then farmers wishing to construct new facilities or expand existing operations must apply for a building permit. Based on the size of the proposed construction, the location and the distance to the nearest neighbour or town, the municipal council can grant a conditional use. But in Manitoba, for example, there are very few guidelines for the planners to follow and each municipality is left to develop its own guidelines. The guidelines may include such factors

as separation distances (which depend on the size of the facilities), type of manure storage facility, and method of land application of the manure. If there is no municipal plan, there are really no controls and farmers are free to build and locate new facilities on their land as they wish. If it is a very large facility, they must apply to the Department of the Environment for a license for a "large operation", but this is more a registration process than a regulatory process.

#### *Control Mechanisms for Dust and Odour*

Methods that will reduce the odour intensity and quality of wastes include air filters on barn exhausts, covered concrete storage tanks, covered lagoons, soil-injection of manure, rapid cover of manure, frequency and time of manure application and odour reduction/control for manure (aeration, oligolysis, air-stripping before application). At the moment, some of these control methods are still in the experimental stage but none are considered to be "the solution" to the odour problem. Most of the systems are considered to be unreliable, ineffective or too expensive.

## Issues

### Confined Environment Air Quality

Barn air quality is of major concern with regard to animal production, health and welfare and worker health and safety. For some building designs and animal species, information is available about the expected barn air quality as to particulate levels, gases and pathogen content. In most cases, however, the information is very limited and incomplete. Even less information is available about the interactive effects of the different components of barn air quality on worker productivity and health, animal performance and animal comfort.

Research is needed to gather this information, which may be of value in minimizing airborne dust levels and the related health problems through improvements in the design and ventilation of livestock buildings and in setting stocking densities. If systems are not developed in the near future that are able to reduce airborne dust to levels that are acceptable with regard to worker and animal health, regulations may be developed and enforced that will have a major impact on livestock production.

Air filtration may be able to reduce airborne dust and pathogen concentrations to acceptable levels but the costs will be significant. There are air filtration systems that can be worn by workers, but at the moment they are considered to be a nuisance and very few farmers will wear them on a consistent basis. Until a personal air filtration system is developed that rectifies this situation, the masks will not be an acceptable solution to the problem.

In a similar manner, although there are a variety of management options available that will improve barn air quality through the reduction of hazardous gases, dust and airborne pathogens, the costs are significant. Since pathogens are associated with airborne particulates, and animal activity is the main source of airborne contamination, filtration and recycling of air in barns may not be able to reduce pathogen concentrations to levels acceptable for animal and worker health protection. If livestock production facilities do

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*Most of the systems are considered to be unreliable, ineffective or too expensive.*

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*If systems are not developed in the near future that are able to reduce airborne dust to levels that are acceptable with regard to worker and animal health, regulations may be developed and enforced that will have a major impact on livestock production.*

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not all have to install similar control systems, those with the air contaminant control may not remain competitive.

Funding for research into confined air quality is very limited. Although there are enforceable guidelines for workplace health and safety for most industries, agricultural workers do not come under those regulations. Basic information is needed to understand the problems and then set meaningful regulations or guidelines. In many cases, considerable time, effort and money will be required before the information will be available.

### Livestock Waste Management

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*It is the “nuisance” aspect created by livestock operations that is one of the major potential limitations to the sustainability of confined livestock production on the Prairies.*

It is the “nuisance” aspect created by livestock operations that is one of the major potential limitations to the sustainability of confined livestock production on the Prairies. Since such things as odour intensity and quality cannot be measured easily, and the time and duration of the odour problem is so variable, there is significant pressure on municipalities to either just ban all new confined swine and poultry intensive livestock operations and beef feedlots, or place such rigid restrictions on the operator that the farm ceases to be economically viable. This “nuisance” concern is very difficult to respond to and is potentially lethal to the development of viable long-term swine and poultry industries.

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*New legislation is being proposed to address these problems, but in many cases information on which to base decisions or formulate legislation is lacking.*

All of the following groups are part of the linkages among livestock waste management, land use planning and problems associated with regulations or planning related to odour and dust:

- Ministries of Environment
- Provincial Departments of Agriculture
- Right to farm legislation
- Municipal and town councils
- University and government research institutes
- “nuisance” law suits

Environmental legislation and its effect on agricultural development is presently in a period of transition. Provinces are just starting to address the impact of intensive livestock production on air, water and soil. New legislation is being proposed to address these problems, but in many cases information on which to base decisions or formulate legislation is lacking. During the next few years the livestock industry must become involved in promoting the use of management practices that protect animal health and welfare and worker health and safety. If workable, economically viable solutions are to be found, the industry must guide the development of legislation affecting their industry.

A reasonable set of guidelines and policies must be set out for both the location of livestock operations and for addressing dust and odour problems when they arise. Otherwise, any expansion of the industry is in for a rough ride. Each province should develop a set of management practices municipalities can use as guidelines. In some provinces, these are already in place. More research on covers for manure storages and

more economical manure injection/rapid cover systems is also required. Research on odour reduction and control should be increased until some economically acceptable solution is found to the problem. The lack of guidelines and policies acceptable to both farmers and the general public could result in the development and enforcement of controls that are not really in either party's best interests.

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*The lack of guidelines and policies acceptable to both farmers and the general public could result in the development and enforcement of controls that are not really in either party's best interests.*

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## 8. FOOD AND FEED SAFETY

Food and feed are essential for animal life. Ingestion of food, however, represents a major route by which undesirable constituents enter the body. These may be normal constituents in the food, microorganisms that are contaminants in the food, toxic metabolites produced by microorganisms that have colonized the food, toxic man-made contaminants, or feed and food additives.

While food and feeds produced in Western Canada are considered safe for human and animal consumption, the term safe is relative and the concept of safety is changing. Advances in analytical capabilities and in the science of toxicology continue to increase our knowledge of toxic food compounds, including their identification, detection, and characterization, as well as their effect on human health.

A necessary component of a sustainable agriculture system is the production of food that is highly nutritious and safe. Food should promote health, well-being and longevity, and should not contain toxic factors or nutrients that produce adverse effects, whether these be short-term acute effects, or long-term chronic effects, such as cancers, diabetes and other metabolic diseases. The actual amount of toxic compounds that ultimately are present in the food supply is influenced by guidelines established by regulatory agencies and the demand by local and foreign consumers that our food supply be free of certain contaminants. Future demands by the consumer will result in a greater emphasis on food quality, which will influence the type of food produced and the means by which it is produced.

Food safety has become an important public issue over the past few years. The North American public has expressed concern over the safety of food and the adequacy of regulatory mechanisms for ensuring that safety. Ongoing debate over issues such as fungicide residues on produce, pesticide residues on imported food, traces of dioxin in milk containers, and the potential cancer-fighting value of foods like oat bran or cruciferous vegetables indicate that these matters will gain increased prominence in coming years.

### Food and Feed Safety Standards

The safety of food and feed produced by Prairie agriculture is the responsibility of the producer, industry, government and also the consumer. The establishment and enforcement of standards and regulations is mainly the responsibility of two federal agencies, Health Canada and Agriculture Canada. The roles of these two agencies, as well as that of the provinces, are shown in Table 8.1. Health Canada sets standards for sanitation and for contaminants in food. Agriculture Canada inspects food products to ensure that standards are met, registers pesticides and plant materials, and sets standards for feeds. The high standards set by these Federal agencies are one of the reasons that Canadian agricultural products are so highly valued by other countries. Toxicants that are currently of greatest concern to scientists, regulatory agents and the consumer are pesticide residues, the use of antibiotics as feed additives, the presence of pathogenic microorganisms in the food supply and the contamination of the food and feed supply with mycotoxins.

Government Body	Direct	Indirect
	Food and Feed Safety Responsibility	Food and Feed Safety Responsibility
Health Canada	Sets standards for sanitation and contaminant in food, under the Food and Drug Act. Responsible for the testing of food for contaminant residues. Has the power to audit inspection of food processing plants by other agencies.	Only indirectly affects the level of sanitation and contaminants in feed and the agricultural production process by establishment of standards for the final product of that process. Also, has a direct impact on pesticide registration through cooperation with Agriculture Canada.
Agriculture Canada	Responsible for the inspection of all Canadian food processing plants registered with them. Their regulations for the operation of these plants specifically cite the Food and Drug Act. Responsible for the setting of standards regarding drugs and contaminants in feed.	Responsible for grain inspection and registration of plant materials. Has responsibility for the registration of pesticides but includes input from Health Canada and Environment Canada in its decisions.
Provincial Governments	Have no direct authority in the area of food and feed safety.	Have some authority regarding pesticide use within the province (could further limit the pesticides that could be used, i.e., Ontario currently does).

**Table 8.1**

*The Role of Government  
in Food Safety.*

### Synthetic Safety Hazards

#### *Pesticide Residues*

Pesticide residues are a major food safety concern for Canadian consumers, possibly because consumers are uncertain of the short- and long-term health effects of such residues, and also partly because many consumers are unaware of the vast amount of toxicological research that manufacturers undertake in support of product registration. Scientific opinion is that pesticide residues in food do not pose an important health hazard. Furthermore, concentrations of pesticide residues in food are well below regulatory limits. At present, pesticides are considered an essential tool for maintaining Canada's level and quality of food production.

#### *Antibiotics*

Production systems that keep animals in confinement housing and in large concentrations produce conditions that develop and spread disease. Antibiotics for treatment and control of animal disease have become a necessary tool for such production systems, creating a

trend to become more reliant on antibiotics for disease control and less reliant on management practices for disease prevention. Antibiotics are also used in animal feeds because they have been found to assist in animal growth efficiency.

This increased usage of antibiotics has created food safety concerns. Extensive antibiotic use can promote the development of bacterial strains that are resistant to antibiotics and may become pathogenic in humans when passed on in food.

## Natural Safety Hazards

### *Pathogenic Microorganisms*

Scientific opinion indicates that food poisoning from pathogenic microorganisms is the most serious food hazard. In contrast, the public ranks pesticide residues and pollution as the most serious food hazards. The public opinion may be due to consumers feeling they can have some control over food poisoning by using proper handling and storage procedures. There are indications, however, that the Canadian consumer seriously underestimates the risks of food poisoning. Such risks are produced by a variety of factors which work alone and in concert, and include: the large variety of food choices available to the consumer, and which originate from all over the globe; changes in the methods and technology of food processing, packaging, storage and handling; and the emergence of bacterial strains that are resistant to antibiotics.

### *Mycotoxins and Natural Pesticides*

Mycotoxins are compounds found in a wide variety of foods. They are produced by fungi (moulds) under a variety of conditions, and can cause a variety of toxic reactions to animals and humans. It has been estimated that one quarter of the world food crops are affected by mycotoxins annually and that these produce up to one third of all cancer in humans. Mycotoxins and their control impose added economic costs to crop, livestock and poultry producers, grain handlers, and food and feed processors.

Natural pesticides are toxins produced by plants for self-protection. These compounds may account for a large proportion of the human exposure to pesticides and may be important cancer-causing agents, yet very few have been tested for toxicity.

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*One quarter of the world food crops are affected by mycotoxins annually.*

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## Background

### Synthetic Toxicants

#### *Pesticide Residues*

Pesticides are a concern to some segments of the population because in addition to having desired effects on target organisms, this diverse group of agrochemicals can also have toxic effects on such nontarget organisms as wildlife, livestock and humans. Because pesticides are designed and selected for their biologic—that is, toxicologic—activity, exposure and toxicity to nontarget species are inevitable and remain significant potential problems. Pesticides are capable of disrupting virtually every major organ system. These adverse effects include altered immune function, genetic mutations, fetal malformations, embryo toxicity, reproductive failure, and an array of neurologic effects.

Hazard	Percent	
	Is a Serious Hazard <sup>1</sup>	Is the Most Serious Hazard
Food Poisoning	72	13
Pollution	69	24
Pesticides	69	26
Nutritional Problems	48	15
Natural Poisons	43	8
Additives	26	5

<sup>1</sup> Multiple responses were allowed for identifying those factors considered to be a serious hazard.

**Table 8.2**

*Attitudes of Canadians to Various Food Hazards.*

*Worries about pesticide residues top the list of food safety concerns among consumers.*

*Microbiological hazards are the most important food toxicant danger, while pesticide residues would be one of the least important.*

Furthermore, since the use of chemical pesticides has been widespread only during the past several decades, their long-term effects on human health, such as the possibility of causing cancer, are still undetermined. Not many humans have had time to develop resistance to diseases that may be associated with pesticide exposures.

Recent surveys have found that worries about pesticide residues top the list of food safety concerns among consumers. In an Agriculture Canada sponsored survey, when respondents were asked what they considered to be a serious food hazard, and when allowed multiple responses, food poisoning was the most common choice (72 percent) followed by pesticides and pollution (69 percent each; Table 8.2). When asked, however, what they believed to be the most serious food hazard, respondents ranked pesticides first (26 percent), followed closely by pollution (24 percent). Food poisoning ranked fourth at 13 percent. It was postulated that while consumers commonly considered food poisoning as a serious hazard, pesticide residues were considered the most serious hazard because their effects were not well known and consumers have no control over them. Consumers likely feel they have some control over food poisoning through proper storage and handling.

Contrary to public opinion, some members of the scientific community have expressed the opinion that microbiological hazards are the most important food toxicant danger, while pesticide residues would be one of the least important.

There is further evidence that public opinion is not always in agreement with scientific opinion and study. Although it has been shown that pesticides are toxic to animals, including humans, the evidence based on risk assessment studies would suggest that the risk of pesticide toxicity to humans is extremely low. In a recent study carried out by Health Canada, it was reported that 25 percent fewer farmers died of cancer between 1971 and 1981 compared to the general population. This lower-than-expected total held for all kinds of cancer, including those most commonly associated with farmers. The study also found no relationship between cancer rates and money spent on pesticides. These studies, although not conclusive, would suggest that a segment of the population

which is exposed to much higher concentrations of pesticides than the general public do not develop an unduly high incidence of cancer.

Furthermore, studies in the United States have shown that the concentration of pesticides in the food supply in that and other countries are well below regulatory limits, and dietary intakes are many times lower than the acceptable daily intake established by international agencies. It may be assumed that the intake of synthetic pesticides by Canadians would also be low, as pesticide concentration in our food supply is subjected to very close monitoring and regulation. These assumptions are also supported by a group of experts who, in a 1990 study by the Council for Agricultural Science and Technology (CAST), concluded "that it is reassuring to find no recognized group of toxicologists or medical experts who claim that current levels of pesticides residue in fruits and vegetables pose important health hazards to either adults or infants."

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*Concentration of pesticides in the food supply are well below regulatory limits, and dietary intakes are many times lower than the acceptable daily intake established by international agencies.*

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### *Antibiotics*

The antibiotic era that was ushered in with the discovery of penicillin has improved the level of treatment and control of animal disease. The application of inexpensive antibiotics to animal feed controlled many of the disease problems that were exacerbated by the strict confinement and intensive management of animals. As a result, the use of antibiotics has facilitated the trend toward confinement housing and greater concentration of animals in production facilities. About 9.9 million pounds of antibiotics are fed to livestock each year in the United States and proportionately smaller amounts in Canada. The widespread use of antibiotics in feed and to treat disease has reinforced a trend not to use other management techniques for disease prevention and accept the costs of antibiotic feeding and use as a routine production expense.

Feeds that contain antibiotics are widely used because in many cases they help animals use feed more efficiently. Research has demonstrated that the control of subclinical infection by feeding sub-therapeutic levels of antibiotics results in increased production and growth. It appears that antibiotic feeding also works by decreasing the total antigenic challenge to the animal's immune system. Immune systems that are stimulated for defense appear to channel nutrients to the need of the immune response and away from growth and production.

Antibiotics will always be needed, to some extent, for the clinical treatment of disease. The extensive use of antibiotics in feed and for therapy, however, has the attendant risk of promoting the selection of resistant bacterial strains that may be passed on in food, become pathogenic in humans, and resist antibiotic treatment. Research to develop new antibiotics for use only in agriculture may not resolve the concerns about resistant strains, because resistance in bacteria tends to occur for groups of bacteria. Moreover, the research, development, and Federal approval process of new antibiotics is slow and costly, and drug companies may become unwilling to take the financial risk for new antibiotic product development. It may be unwise, therefore, for animal agriculture and human medicine to assume that new antibiotics will always be developed to resolve resistance problems.

## Natural Toxicants

### *Pathogenic Microorganisms*

Current concern over the microbiological safety of food and a perceived need for improved safeguards is the result of scientific as well as social factors. Not many decades ago, the human digestive tract was considered to be a highly efficient barrier to most organisms and harmful substances, with the exception of some well-known pathogens, such as Salmonella and Shigella, and certain microbial products, such as botulism toxin and staphylococcal enterotoxin. The common symptoms of gastrointestinal distress include diarrhoea, vomiting and cramps, followed, in some cases, by disease in other parts of the body. In recent years, it has been shown that the effects of intestinal pathogens are not just immediate in terms of location and duration, but that there may also be chronic consequences of food-borne infections, such as increased incidence of arthritis.

The awareness of the chronic effects of food-borne infection has been heightened by a more strict definition of health. There is also a greater and more diverse microbial load in the food supply. The change-over in eating habits from canned foods, in which microbes have been killed, to the use of frozen foods, which may preserve microbes, has contributed to this development. The increased consumption of a wider variety of food from all parts of the globe has also had an influence. It is difficult to estimate the extent to which our new awareness of food-borne diseases is due to scientific advances, changes in food technology and distribution, a different definition of health, or changes in the virulence of microbes and in the immune status of humans. It is known, however, that these factors have affected not only the subject matter of food microbiology but have also aroused considerable public concern. As indicated in the “Pesticides” section, however, while Canadians consider food poisoning a serious health hazard, they do not consider it as serious as pesticide residues (see Table 8.2), while scientific opinion ranks it as the most serious food safety hazard.

**Table 8.3**

*Perceived Food Poisoning Experiences of Canadians.*

No data source is available in Canada or in the United States that accurately estimates the severity and distribution of food-borne diseases. While Health Canada estimates that 2 million Canadians experience food poisoning each year, the Agriculture Canada survey found that most Canadians (71 percent) felt they have never had food poisoning (Table 8.3). Furthermore, of those that believed they have had food poisoning, the majority felt

Food Poisoning Experience	Percent of Positive Responses
Have never had food poisoning	71
Have had food poisoning:	
Away from home	21
At home	5
Both away from and at home	3

they had obtained it outside of the home. According to Agriculture Canada, Canadians may seriously underestimate the risks of food poisoning.

There is also only fragmentary literature available on the costs of food poisoning. This has led to a situation whereby very diverse estimates have been made by different researchers. Cost estimates of food-borne diseases in the United States range from \$4.8 billion to \$23 billion per year. The cost estimate is not much more precise for specific diseases. For example, the estimated cost of salmonellosis ranges from \$59 million to \$846 million per year in Canada and from \$1.4 billion to \$4 billion per year in the United States. The large divergence in estimates is attributed to varying estimates of the number of unreported cases, differences in what costs are included, and methodological flaws. Nevertheless, the data does indicate that food-borne diseases cause significant economic losses in Canada.

*Salmonella* is of the greatest microbiological concern, as it is the causative organism in many cases of food poisoning. Currently, more than one-third of the reported cases of food poisoning in the U.S. are caused by *Salmonella*. The National Centre for Disease Control in the U.S. estimates that more than 40,000 cases of salmonellosis are reported each year, but because most cases go unreported it is estimated that between 400,000 and 4,000,000 cases may occur annually. For just the reported cases, about 18,000 hospitalizations and 500 deaths are associated annually with salmonellosis.

Studies in the United States by the Food Safety and Inspection Branch of the U.S. Department of Agriculture, have shown that 37 percent of the whole chickens, 12 percent of fresh pork and less than 1 percent of beef samples tested positive to *Salmonella*.

As indicated under "Antibiotics", there is concern over the emergence of bacterial strains that are resistant to antibiotics. Antibiotic-resistant *Salmonella*, for example, can spread to humans from contaminated food, which can complicate medical treatment, particularly if the *Salmonella* are resistant to several antibiotics. Many other pathogenic microorganisms may be found in the food supply, including *Shigella*, *Clostridium*, *Staphylococcus*, *Entamoeba* and *Ascaris*. Some food-borne organisms, such as parasitic protozoa, serve as hosts for unique bacterial and viral symbionts; they may also become infected with mammalian viruses. Listeriosis, (caused by *Listeria monocytogenes*) is recognized as a significant food-borne disease. Although the disease is rare, it can have a 30 percent fatality rate in both neonates and in the elderly.

An emerging problem concerns the shelf-life of refrigerated foods. In past years, bacteria that grew in refrigerated foods generally were thought to be those that result in spoilage. Consequently, the risk of extended refrigerated storage was one of spoilage rather than of illness. Now, many of the newly recognized pathogens (*Listeria*, *Compylobacter*) are capable of growth at refrigeration storage temperatures. This may pose a problem in the future, as the refrigerated shelf-life of many commodities has been extended by mild heat-processing steps, lower storage temperatures, vacuum packaging, oxygen-impermeable packaging and modified atmosphere.

Control of microbial contamination requires a three-pronged approach that combines research, regulations and consumer education. In research, *Salmonella* has been of top priority for some time in the United States but has received only limited support in Western Canada. On a more universal scale, research has been pursued in virtually all places of livestock and poultry production, slaughter and processing.

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*Currently, more than one-third of the reported cases of food poisoning in the U.S. are caused by Salmonella.*

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*Antibiotic-resistant Salmonella can spread to humans from contaminated food.*

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*Control of microbial contamination requires a three-pronged approach that combines research, regulations and consumer education.*

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*Mycotoxins*

Mycotoxins are toxic, small molecular weight compounds produced by fungi (moulds). More than 200 toxic fungal metabolites have been isolated and characterized chemically and toxicologically. Many more mycotoxins will probably be discovered and isolated in the future. About 20 general types of mycotoxins have been found to occur in a wide variety of foodstuffs at some degree of frequency. Mycotoxins can cause a variety of toxic reactions to animals and humans, including, for example, liver and kidney diseases, fetal malformations, immunosuppression and cancer.

Many factors influence mycotoxin production in food and feed and its transmission along the food chain. These include biological and environmental factors, harvesting and storage conditions, processing and distribution factors, and transfer of mycotoxins from animals to humans.

The aflatoxins are the group of mycotoxins that have received the most attention in North America and elsewhere, as they are not only one of the most potent known carcinogens, especially *aflatoxin B*, but they are also found in a wide variety of food commodities, especially corn and peanuts. Although aflatoxins are not normally detected in cereal crops grown in Canada, they pose a potential threat due to the importation of contaminated food and feed from other countries.

A second group of mycotoxins are the trichothecenes, which consists of 148 structurally related compounds. The greatest threat of trichothecenes in Western Canada is through the importation of contaminated cereal products. Recent studies would suggest, however, that these mycotoxins also occur in Western Canadian grown grains.

The individual mycotoxins of greatest concern in Western Canada, as indicated by current evidence, are *ochratoxin A* and *citrinin*. *Ochratoxin* can be readily produced under high moisture storage conditions in a wide variety of commodities, and has been detected at a rather high frequency in the blood of both swine and humans in Western Canada. It is acutely toxic to many different animals and can cause kidney and liver problems, fetal malformations, immunosuppression and cancer.

A recent report by Health Canada concluded that overall residue profiles in cereal grains, animal feeds, edible animal tissues and human blood needs to be better defined. Such data are required to estimate dietary exposure to *ochratoxin A* and to assess the need for regulatory controls or other control mechanisms. Regulatory levels of *ochratoxin A* have not been established in Canada, in contrast to many other countries. Knowledge by the public and by foreign buyers that our pork may contain a potent mycotoxin could have a negative impact on the consumption and, therefore, production of pork in Western Canada.

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*It has been estimated that one quarter of the world's food crops are affected by mycotoxins annually and that these produce up to one third of all cancer in humans.*

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Research needs to be carried out to establish the nature and extent of mycotoxin contamination, including the economic and social costs. We also need to identify the means by which the amount of mycotoxins in our food supply can be reduced and the means by which their toxic effects can be modified by dietary treatments. It has been estimated that one quarter of the world's food crops are affected by mycotoxins annually and that these produce up to one third of all cancer in humans. Mycotoxins and their control impose discernible economic costs on crops, livestock and poultry producers, grain handlers, and food and feed processors. The economic impacts of mycotoxins derive

directly from crop and livestock losses as well as regulatory programs designed to reduce risks to animal and human health. Costs to consumers may include higher product prices and increased health risks. The costs of controlling mycotoxins include research, testing, monitoring and regulatory enforcement expenses that would be incurred at all levels of production, processing and distribution by both the private and public sector.

#### *Other Natural Toxicants*

Natural pesticides are produced by plants to protect themselves against fungi, insects and animal predators. Many of these pesticides have been discovered, and every species of plant probably contains its own set of several toxins. When plants are stressed or damaged, such as during a pest attack, they may greatly increase their natural pesticide levels, occasionally to concentrations that can be acutely toxic to humans.

In contrast to the very stringent regulations to control synthetic agents in the food supply, regulations regarding permissible levels of natural toxicants are almost nonexistent. A United States toxicologist, Dr. Bruce Ames, has concluded from his research that natural pesticides account for 99.99 percent of human pesticide exposure in food, and that cancer risks from natural pesticides in food are hundreds of thousands of times greater than the hazards from synthetic pesticides.

Surprisingly few plant toxins have been tested for carcinogenicity. Among 1,052 chemicals tested in one species of animals in chronic cancer tests, only 52 were naturally occurring plant pesticides. Among these, 27 were carcinogenic. Even though only a tiny proportion of the plant toxins in our diet have been tested so far, the 27 natural pesticides that are rodent carcinogens are present at levels above 10 parts per million in many foods.

Moreover, the concentration of natural pesticides in many plants is usually 1,000 to 1,000,000-fold higher than that of synthetic pesticide residues. A great number of natural pesticides (5,000 to 10,000) are also found in the human diet. For example, the consumption of cabbage results in the ingestion of 49 natural pesticides, only two of which have been tested for carcinogenicity. Lima beans contain a completely different array of 23 natural toxins that in stressed plants range in concentration from 0.2 to 33 parts per thousand fresh weight. None of these have been tested for carcinogenicity. Many leguminous plants contain canavanine, a toxic compound similar in function to the amino acid arginine that, after being eaten by animals, is incorporated into protein in place of arginine. Alfalfa sprouts (1.5 percent canavanine dry weight) cause a lupus-like syndrome in monkeys, a condition which in humans causes defects in the immune system. The toxicity of non-food plants is well known, with plants being among the most commonly ingested poisonous substances for children under 5 years of age.

Some researchers have proposed that the human body's detoxifying mechanisms are more effective with natural than synthetic chemicals. Such a proposal is questionable, however, as defences that animals have evolved are mostly of a general type. This type of evolution might be expected in light of the fact that the number of natural chemicals that might have an effect is so large. General defences protect not only against natural but also against synthetic chemicals, making humans well-buffered against toxins. Humans, however, are not able to detoxify all compounds, probably since they have not had sufficient time to evolve specific resistance to many recently introduced plants.

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Currently, substantial resources are being invested in the production of transgenic plants (plants that have had genes transferred from a different type of plant) that will lead to the propagation of many novel food crops. Some plants, in addition to the many attractive agronomic attributes for which they are being primarily synthesized, may carry with them other constituents that are potential hazards to health if consumed regularly and in quantity. It is important that the safety and nutritional quality of new genotypes be rigorously tested before being released for public consumption. This matter is further explored in Chapter Three's discussion on biological considerations.

## Issues

### Setting of Safety Standards

#### *Safety Levels and Regulations*

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*The cost of introducing one new active ingredient into Canada is estimated at between \$30 and \$50 million, which greatly adds to the final market price.*

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Food safety standards are established and enforced by the agencies indicated in Table 8.1. Any new product that is introduced, such as a pesticide, is subjected to a thorough review by the Pesticide Directorate in collaboration with advisors from the Department of Agriculture, as well as from the Department of Health, the Department of Environment, the Department of Fisheries and Oceans, and possibly the Department of Natural Resources, Canadian Forest Service. The product is subjected to extensive scrutiny with regards to product chemistry, toxicology, metabolism, residues, environmental chemistry, environmental toxicology and efficacy. Overall, the cost of introducing one new active ingredient into Canada is estimated at between \$30 and \$50 million, which greatly adds to the final market price.

In the past, our food safety policy has focused largely on risks from short-term exposure to the microbiological pathogens or chemicals that can cause acute illness and death. The goal of toxicological assessments in this context was to find the threshold dose, the dose up to which no ill-effects can be detected, while the goal of regulation was to ensure that exposure always lay well below that threshold. In contrast, the new set of concerns emerging in recent years centres on risks from long-term exposure to synthetic organic chemicals believed to contribute to chronic health problems, such as cancers, birth defects and genetic damage. Current thinking regarding these problems assumes no threshold, as any dose, no matter how small, is presumed to enhance the risk of developing cancer or other similar health problems. Thus, regulators no longer face a problem of simply ensuring that our food supply is "safe", but must now also determine how safe that food supply should be.

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*Regulatory action increasingly relies on quantitative risk-benefit procedures, which are mandated by law for most cases involving pesticide residues on food and food additives.*

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Decisions regarding organic chemicals tend to involve large tradeoffs. Exposure to them and the risks of such exposure are typically low, while the costs of eliminating all traces are generally high. For this reason, regulatory action increasingly relies on quantitative risk-benefit procedures, which are mandated by law for most cases involving pesticide residues on food and food additives.

For several reasons, assessing these risks entails the problem of dealing with the inescapable uncertainty of chronic risk estimation. One reason is that chronic health effects have multiple causes and are mediated by a multitude of factors, only some of which are observable. Science can therefore account for only part of the observed

variations in environmental outcomes. In addition, scientific knowledge is usually limited, as our understanding of the mechanisms by which formations of cancers, fetal malformations, and genetic mutations occur is incomplete, theoretical and empirical. The linkages between exposure and long term effects are reliably detectable only in cases of extremely toxic compounds because there can be a long time lag between exposure to low concentrations and the onset of symptoms. Policies are currently aimed at preventing avoidable deaths, but due to the uncertainty involved this preventive posture delays the implementation of regulatory decisions by policy makers.

The current regulatory policies are not designed to provide a close balance between the benefits of using pesticides and the direct and indirect costs associated with their use. Furthermore, if the observation that natural pesticides are far more toxic than synthetic pesticides is correct, it may be concluded that large amounts of money are expended on the over-regulation of compounds that contribute very little to the total burden of toxins that humans are exposed to, while little or no control is exerted in the area of greatest concern.

Another concern is that the methods of determining risk in model animals, which are very expensive to conduct, cannot be extrapolated to humans with a high level of accuracy and that the regulatory policy is overly conservative. The attempt to prevent cancer by regulating low levels of synthetic chemicals using worst-case, one-in-a-million risk scenarios may not be justified. This conservatism can yield gross overestimation of health risks and will result in overly stringent and costly regulation which can impact on national productivity and competitiveness in the international economy and lead to regulatory dilemmas; i.e., biased estimates that clearly distort the pattern of regulation and will likely lead to decisions that jeopardize public health and safety. It is recommended that:

- 1) Regulatory decision-making should present risk estimates which are closer to true risks and that they should reduce dependence on overly conservative, worse-case plausible estimates. Alternatively, if the presently accepted risk levels are to be used more realistic assumptions must be made with regards to defining exposure or in the additivity of conservative assumptions made on the data set.
- 2) Risks from pollution and chemical exposure (i.e., synthetic pesticides) which appear to be of minor significance compared to risks from natural substances should be put into context to ensure that the expenditure of society's resources will do the most good in terms of reducing real risks. Excessive expenditures on the regulation of products or compounds that are of insignificant risk, coupled with complete neglect of such toxins as natural ones (which are quantitatively much more important), is of little benefit to society.
- 3) A committee comprising academics, government and industry professionals should review current regulation policies regarding both natural and synthetic environmental chemicals. It should make recommendations to the appropriate Federal legislative bodies on procedures to ensure public health is protected from environmental chemicals in a cost-effective manner. The policy should require that sound scientific principles be utilized in determining risks and that the focus should be on those chemicals that pose the most serious risk. The goal should be to promote the

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*Risks from pollution and chemical exposure (i.e., synthetic pesticides) which appear to be of minor significance compared to risks from natural substances should be put into context.*

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regulation of chemicals on the basis of a more appropriate and realistic estimate of environmental risks.

#### *Research Priorities*

Research will play a key role in the development of new approaches in the production of safe food products that are consistent with sustainable agriculture. Much of this work will be in areas of agriculture biotechnology and will be carried out in joint cooperative programs between university or government laboratories and private industry. Funding required to support basic research and infrastructure is often provided by government agencies such as the Natural Science and Engineering Research Council of Canada (NSERC) and is allocated on the basis of peer evaluation and relevancy to social and economic needs in Canada. Government policies will dictate relevancy and the need to direct research towards the improvement of the safety of food and feed. These policies should result in disease-prevention strategies that concentrate on important factors. They will affect the solution of problems imposed by the public and regulatory agencies and will therefore affect our ability to sustain agriculture.

Funds should be allocated to “policy-relevant” research aimed at establishing ways to improve current regulatory policies. Such improvements would take a number of factors into consideration, including developments in the field of toxicology, changing attitudes of the public with regards to safety of food products, and the feasibility of transferring regulatory costs directly to the compound being used. This process will require close interdisciplinary cooperation among managerial, agricultural, and environmental health scientists in government regulatory agencies, universities and private industry.

Some suggested specific areas of research include:

1. Prioritize a random testing program of the toxicity of a group of natural pesticides and pyrolysis products from cooking so that an adequate comparison be made to synthetic toxins. Studies with natural chemicals and synthetic pesticide residues should use the same standards so as to obtain meaningful assessments of relative hazards.
2. Develop and evaluate new tests and methodologies that are less expensive and more accurate for testing potentially toxic compounds, whether they be synthetic or natural toxins. For example, the development of simple in vitro screening tests that will accurately, rapidly, and reliably establish the toxicity of a given compound to humans and animals could be undertaken. These tests may involve a combination of microbial and tissue culture assays, coupled with immunobiological and other types of chemical assay.
3. Identify and quantify those constituents in food and feed that are considered to be harmful, using simplified tests. More extensive follow-up studies should be carried out once problem foods or toxins have been identified. An important aspect of this research would be to establish the mechanism by which the toxin of concern exerts its effect, which would provide a basis for reducing its toxic effect and for establishing the nature of its interaction with other toxins.

4. Develop strategies to eliminate toxins that are of significant health risks in the food supply using, for example, genetic and post-harvest treatments. Innovative and non-toxic pesticides, antimicrobials and an integrated system of pest management should be developed.

## Antibiotics

### *Antibiotic Replacement*

Alternatives to antibiotic use have been shown to be partially effective. This includes the use of specific control programs for effective mastitis control in dairy cattle, altered swine managerial programs, use of hormones to enhance natural disease defence mechanisms of animals, immunization to protect against certain diseases, the use of genetic resistance to disease, reduction of stress, and application of advanced diagnoses and technology.

In lieu of methods requiring changes to production practises, the subtherapeutic feeding of antibiotics will likely remain a simple and effective method of reducing disease loss in the swine industry. This reality is attributed to the complex etiology and the pervasiveness of disease in swine. Alternative management systems and techniques, however, can greatly reduce reliance on subtherapeutic feeding of antibiotics. Reduced confinement and the increased use of outdoor shelters and pastures are components of alternative livestock production systems that allow lowering or elimination of subtherapeutic feeding of antibiotics. Veterinary and medicine costs stemming from swine confinement production systems have been shown to be at least double those of a comparably productive pasture and hutch system. In one study, the total cost of producing 100 pounds of pork was \$40.18 for the pasture system compared to \$42.97 for the individual confinement unit system. In another example, veal calves raised in stall and pen confinement facilities have been shown to need five times the amount of antibiotics as hutch and yard calves. Using pastures and forages may improve other aspects of production, such as waste management and nutrition. Less intensive livestock production systems should also address some of the welfare needs of the animal. Preventive disease management, however, is not as simple as redesigning production systems and facilities. Similar disease conditions can develop in these situations as well.

The remedy to the human disease problem attributed to resistance generated by the use of penicillin and tetracycline in animal agriculture would be to ban the subtherapeutic use of these antibiotics in animal feeds. An alternative remedy would be to irradiate packaged meats and eggs with ionizing energy as they leave the processing lines, which would inactivate both the antibiotic-resistant and sensitive *Salmonella*, parasites, and most other disease-causing bacteria. This alternative would enable livestock producers to retain the benefits of subtherapeutic use of antibiotics.

### *Research Priorities*

The consequences of banning antibiotics in poultry, swine and rumen feeds under current management procedures needs to be explored. As well, the potential to develop new products that would ease the impact of such measures should be researched. An evaluation should be done of the feasibility of using ionizing irradiation on food products obtained from antibiotic treated animals, so as to eliminate the transfer of resistance to other microorganisms.

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*Alternative management systems and techniques can greatly reduce reliance on subtherapeutic feeding of antibiotics.*

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*Veterinary and medicine costs stemming from swine confinement production systems have been shown to be at least double those of a comparably productive pasture and hutch system.*

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In February, 1989, the Food Production and Inspection Branch of Agriculture Canada integrated *Salmonella* control activities in the poultry sector into a coordinated effort among its divisions and directorates. Control involves the following: 1) use of clean feed and the production of clean hatching eggs, primarily by fumigating feed and eggs and by educating producers on proper handling procedures; 2) use of clean rendered products; 3) use of an improved hygienic environment including use of Narmi microbial culture, which competitively reduces the effects of indigenous *Salmonella* species; 4) control measures at the processors level including use of clean poultry transportation crates, better hygienic conditions at the plant level, adding chlorine dioxide to the chilling water, and irradiating poultry products before selling to wholesalers and retailers; and 5) education of food service employers and the consumer on means of reducing the incidence of salmonellosis caused by all food, not only poultry.

While such a control program will result in reduced usage of antibiotics, it will require considerable research to assist in the development of an effective alternative. Other innovative biological controls against *Salmonella* that provide alternatives to antibiotics include probiotics (microorganisms or certain types of products that reduce the population of intestinal *Salmonella*) and the development of specific types of antibodies and vaccines against *Salmonella*.

It may be concluded that safety of food can be improved by the elimination of food-borne pathogens, that doing so is technically feasible and will be facilitated by application of known technologies and development of new ones, particularly in biology. These controls would be environmentally friendly and would result in a reduction of feed additives such as antibiotics. Increased profits would result from these changes since both the direct and indirect expenses associated with food-borne diseases would be reduced.

### Ionizing Energy

Radiation processing of food and feed entails exposing the commodity to a field of ionizing radiation (gamma rays, x-rays or electrons) for the purpose of effecting some desired benefit. The commodity absorbs energy from the radiation field and this energy, although too small in amount to raise the temperature by more than two or three degrees maximum, initiates chemical changes in the commodity.

The principal benefits of radiation processing, pertinent to the present discussion, stem from its ability to effect (i) microbial decontamination in a variety of commodities, for example, fresh meats and poultry, rendered products; and (ii) insect disinfestation. The microbial decontamination process can be tailored to meet specific requirements; for example, elimination of *Salmonella* or *Listeria* from raw meat, or the reduction of total microbial load below some specified level. Exposure of the commodity to the radiation field does not make the commodity radioactive and there are no residues of the primary treatment agent (radiation) left behind.

Microbial decontamination of fresh meats and poultry would provide similar benefits as thermal pasteurization has brought to the dairy industry. Decontamination of processed feeds used in the rearing of farm animals would allow re-cycling of rendered products without the risk of introducing pathogens into the feed distribution network. Similarly, radiation sterilization of sewage sludge would allow this material to be spread on farm land used for food production, without fear of disseminating pathogenic microorganisms.

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*Exposure of the commodity to the radiation field does not make the commodity radioactive and there are no residues of the primary treatment agent (radiation) left behind.*

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Safe recycling of waste products must be a central plank of any sustainable agricultural system.

To meet quarantine requirements, radiation processing can be used to disinfect grain and other food commodities entering international trade. With the consumer demonstrating an ever-increasing demand for a wider variety of exotic fruits and vegetables, and with the producing countries anxious to increase their exports of these exotic commodities, the volume of agricultural goods in international trade will inevitably rise. The danger of transporting unwanted agricultural pests along with the movement of foodstuffs is obvious. An effective method for elimination of the unwanted pests is crucial to allow exports to continue to develop without endangering the agricultural system of the importing countries.

The safety and wholesomeness of food processed by ionizing energy has been endorsed by all the major national and international public health agencies. Although the critics of food irradiation suggest that consumers will not buy irradiated food, the results of 38 market tests (to date) carried out in a number of different countries (including three tests in the U.S.) since the mid-1980's have indicated that consumers, if fully informed, are prepared to purchase irradiated food.

The Council for Agricultural Sciences and Technology (CAST) strongly supports the use of irradiation in the U.S. to prevent microbial and pest contamination of food and feed. On the basis of research carried out by the U.S. Department of Agriculture and the Food and Drug Administration, CAST concluded that there is no risk associated with certain uses of irradiation in food processing. In contrast, there is substantial risk in not proceeding with the authorization of its use, including illness or occasional death as a consequence of infection with disease-causing organisms or parasite infection. The use of ionizing radiation would, in part, provide an alternative to those chemicals which are currently under the most suspicion for causing health risks (e.g., antibiotics, fumigants, sprout inhibitors).

The widespread use of irradiation would be promoted through exhibits demonstrating how irradiation works and showing the merits of controlling pests and microbes by irradiation. Consumers would also be provided with accurate scientific information on food irradiation.

### Consumer Confidence

An essential component of safe food and feed within a sustainable agriculture system is consumer confidence. Whether the consumers be Canadians themselves or export customers doesn't change that fact. Consumer choices and opinion are having an ever-increasing impact on many levels of the agri-food industry from the primary producer level to industry to government. Government policies, standards and regulations in turn have an impact on production and processing management systems. Consumer concerns regarding the safety of the food supply appear to be mainly over residues of synthetic chemicals, such as pesticides, hormones and antibiotics. Consumers are receiving mixed messages regarding the short- and long-term safety of such chemicals, not only from the media but from scientific experts as well. A great deal of uncertainty has arisen among consumers, particularly in light of the incidence of such diseases as cancer in our society. If synthetic chemicals are considered essential for a sustainable agri-food system, then it is

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*It is up to the scientific community, whether in government, industry, or universities, to provide the public with the balanced information it needs.*

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important that the general public stand behind this decision. In the face of opposing consumer pressure, agricultural use of such tools could otherwise become stringently limited.

While the blame for this consumer uncertainty has been aimed at the media for providing misinformation, it is up to the scientific community, whether in government, industry, or universities, to provide the public with the balanced information it needs. Scientists must find ways of effective communication with the public, including productive use of the media.

The consumer needs to be informed on the degree of exposure to different toxins and risks associated with this exposure. As has been discussed, the problem is that often science cannot absolutely define and quantify the degree of risk. Failure to communicate these uncertainties to the public, or blanket statements that “the food is safe”, only further raises consumer suspicion and causes the public to turn to sources that attempt to quantify such risks, regardless of whether these sources are reliable.

The options already discussed in this “Issues” section will assist us in gaining the knowledge we need, and in setting the standards required to ensure a safe food supply. At the same time, we need to make use of this information and present it in a manner readily understood by the general public to ensure consumer confidence.

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## 9. BRINGING IT TOGETHER

### Introduction

Wheat has been the dominant crop on the Prairies since it was introduced over 100 years ago. Its cultivation has been sustained by the application of science and technology and favored by the creation of institutions and programs specifically devoted to maintaining Canada's position as a major exporter of grain. From the early 1900s, annual production of wheat and other grains and oilseeds has increased at approximately 2 percent per year. While in the first half century much of the gain was related to an increase in the area of cultivated land, in the last half it has resulted from genetic improvements in crop plants, mechanization, and increased use of fertilizers and pesticides. Similarly, the steady upward trends in cattle, hog and poultry production during this same period have resulted mainly from improved genetics, advances in nutritional science, improvements in animal health care products, and better design and ventilation of housing structures.

The impressive increase in output of agricultural products during the last half century has corresponded with a decrease in the number of farms in each of the three Prairie provinces and a reduction in the proportion of the workforce involved in primary production. Today many Western Canadians proudly point to the fact that, measured on individual output, our farmers rank among the most efficient in the world.

The high level of efficiency is largely the result of a combination of the skill of individual operators, strong support for agricultural research and development from both the public and private sector, and most importantly, access to relatively inexpensive sources of energy. This last factor has allowed for the large scale mechanization of tillage, seeding and harvesting operations, and the relatively low cost of crucial inputs, most notably nitrogen fertilizer.

As farm size increased, so did the level of capitalization. As a result there was a progressive need to increase farm output. This increase was achieved by intensification of individual operations, greater specialization, and increased reliance on the use of such external inputs as pesticides to boost crop yields. In some areas, fences were removed, beef production shifted into large feedlots, and so-called non-productive areas like wooded areas, native pastureland and sloughs were either cleared, ploughed or drained. All this work was in the name of improved "efficiency". Herbicides and fungicides diminished the importance of crop rotation and summerfallow as cultural means of combatting weeds and diseases. Technological innovations and changes in management practices evolved to conform to changes in the size of farm operations and to allow for ever greater "economies of scale".

Have the changes described above served us well? Are current agricultural practices affecting our capacity to profitably sustain our output of agricultural commodities and preserve our natural environment? What are the major constraints to our current systems of production? And how will science and technology contribute to the maintenance of our resource base and the diversity of the prairie landscape? These are the questions that have been addressed throughout this document. The intent of this chapter is to draw on the previous chapters in portraying the past, present and future of agriculture on the Prairies.

### Technological and Scientific Innovations

For the past 100 years, the goal of agricultural scientists in Western Canada has been to develop a system of production suited to a severe and unpredictable environment. In a sense, the approach has been combative with different, specialized agencies or units focused on narrowly-defined missions to overcome the forces of nature. Hence, the plant breeders concentrated on producing widely adapted varieties that would mature in 100 days or less, that could withstand attacks by rusts and other diseases, and that combined traits like drought tolerance, uniform maturity and excellent quality. Scientists categorized soils based on their production capability and developed recommendations for fertilizer use to optimize production, while at the same time developing management practices suited to specific soil types or conditions. Weed scientists concentrated on developing and improving recommendations for chemical weed control in field crops. Agricultural engineers developed more efficient equipment and handling systems, which contributed greatly to the timeliness of field operations and allowed for intensification of livestock production through the design of shelters to protect animals from environmental extremes. In some areas, hydrologists and engineers constructed irrigation schemes to bring water to the parched Prairie soil. Typically, the problems were immediate, with the research targeted toward clearly identifiable goals.

This purposeful march toward economic growth and risk aversion, executed with a strong disciplinary focus, resulted in dissection of agricultural problems into various components, each being the domain of a particular specialization. Hence, at universities, agriculture faculties were divided into more or less autonomous departmental units. These included, for example, departments of Animal Science, Soil Science, Plant or Crop Science, Entomology, Horticulture, Agricultural Engineering, Food Science and Agricultural Economics. At some institutions, foods and nutrition were separated completely from agricultural science. Similar, discipline-oriented units developed within Agriculture Canada where programs were focused on specific commodities. From the 1950s through to the 1990s, a strong reductionist approach prevailed, often associated with highly complex technology and sophisticated scientific procedures. This period is sometimes facetiously described as the time when scientists learned more and more about less and less.

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Despite the reductionist approach, the ingenuity, vision and determination of yesteryear's agricultural scientists, coupled with the pragmatism and resourcefulness of Prairie farmers, resulted in the transformation of the Prairies into one of the most productive agricultural regions of the world. While the scientific gains have been impressive, certain innovations and technologies permitted encroachment into areas inherently unsuited for primary production, and the adoption of practices which clearly are not sustainable. For instance, continued cultivation of some of the more fragile soils in the Brown soil zone is leading to irreversible quality changes and potential desertification. Likewise, heavy reliance on synthetic chemicals to control pests, especially weeds, has led to pest resistance. Destruction of wetlands has had disastrous consequences on waterfowl populations and in some areas has altered the hydrological cycle.

With regard to water, the projected demands by agriculture and other competing sectors, including manufacturing, urbanization, recreation and hydro development, point to inadequate supplies. Competition for water will become more severe over time. Irrigation

is one way of offsetting the risks caused by a dry climate. The limited Prairie growing season, however, narrows the range of crops which can be grown to those presently produced on dryland. Nevertheless, irrigation is the major water consumer in the Prairies. The current major subsidization of irrigation works demonstrates that this system of Prairie agriculture cannot sustain itself without government support, let alone account for any environmental losses. Water is not a free good. A user-pay approach to water pricing would result in conservation of water for existing use, and a rationalized system of allocation for longer term sustainability.

Like water, other resources will be in short supply. It is inevitable that dwindling world stocks of non-renewable resources including petroleum and rock phosphate may well be two factors which precipitate significant change in Prairie agriculture.

While primary agricultural production consumes less than 4 percent of the energy produced in Canada, and is not likely to be competitively disadvantaged in maintaining this share, the costs of energy could well increase relative to the export value of agricultural produce. This higher cost would in turn diminish the advantage that Prairie farmers have gained through large-scale mechanization of cereal and oilseed production, thereby demanding shifts into other forms of production. In the short term, higher energy costs may be offset by greater energy conservation through the use of more efficient engines, adoption of minimum or zero tillage cropping systems, and development of alternative housing structures for livestock. In the long term, higher energy costs will almost certainly reverse the trend towards larger, more-mechanized farms and the present-day use of high rates of nitrogen fertilizer with corresponding high returns.

While possibilities exist for partially substituting other forms of energy, e.g., solar energy, for petroleum products, these alternatives will not likely meet the energy demands of most modern agricultural enterprises. It is equally unlikely that biofuels will contribute substantially to the long-term energy demands of Western Canadian agriculture. While ethanol production from grains or rootcrops may help diversify production in some areas of the Prairies over the next decade and provide some short term economic advantage for producers faced with low grain prices, in the long term it makes little sense to demote valuable farmland to producing ethanol at the expense of more valuable food crops.

As indicated in Chapter 4, maintenance of fertility of Prairie soils is dependent on replenishment of nitrogen and phosphorous. Only in the last two decades have we even come close to replenishing the amounts of these nutrients removed in grain. As mentioned previously, world reserves of phosphate are finite, with current Canadian needs met by imports. While shortages are not imminent, in time the costs of phosphorous will likely increase as access to supplies declines. The production systems of the future must therefore make more efficient use of existing supplies locked up in Prairie soils, possibly through enhanced uptake by microorganisms associated with plant roots.

### **Responding to the need for change**

Whether current levels of production are maintained or increased according to the Trend Export Scenario described in Chapter 1 will be determined by two factors. The first is whether or not our production and processing capabilities can be adapted to meet export demands. The evidence presented in this document indicates that Western Canadians

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*There must therefore be a change in the method of determining the costs of new technologies (and policy decisions) to include a measure of both their direct and indirect effects on the whole of the agroecosystem.*

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*The onus to bring agricultural science together with environmental science lies equally with both agriculturalists and environmental biologists.*

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have the scientific and entrepreneurial ability to respond to changing demands. The second factor is whether the public is confident that agricultural practices of the day are consistent with the principles of sustainability. How the agri-food industry responds to public concerns will determine this level of confidence.

Production practices of the future will be judged by different criteria than those of the past. Not only must new innovations contribute to the efficiency and profitability of the agri-food industry but they must also minimize long term, irreversible effects on our natural resource base or impinge on non-agricultural land use in the region. There must therefore be a change in the method of determining the costs of new technologies (and policy decisions) to include a measure of both their direct and indirect effects on the whole of the agroecosystem. Furthermore, assigning a true worth to resources presently undervalued, such as water and biodiversity, is required.

As Canadians redefine our criteria of acceptable new practices, the scientific community must respond to the shortcomings of our present system. Both require wisdom borne from experience and a vision of the future. Developing this vision will perhaps prove most difficult, since we have no more insight into the future than our predecessors had of the present. It is unlikely that even the most long-sighted visionaries of 50 years ago could have imagined the role that organic and analytical chemistry, microelectronics, genetic engineering and biotechnology would play in today's modern agriculture.

As the limitations discussed in the previous chapters become increasingly apparent and as society's values change, the focus of agricultural research will change. The emphasis will shift from overcoming the physical constraints of production to maintaining the integrity of the resource base and ensuring that agricultural land use and production practices are consistent with the principles of sustainability. At Prairie research centres, there will be a need to blend expertise in the traditional basic and applied sciences with complementary strengths in such areas as ecology, wildlife biology, geography and resource management.

The onus to bring agricultural science together with environmental science lies equally with both agriculturalists and environmental biologists. Just as agriculturalists have often overlooked the effect of their activities on the natural environment, so too have environmental biologists ignored the greater Prairie agroecosystem, considering it to be too "disturbed" or "unnatural" to attract their interest.

This separation between agricultural scientists and biologists has been reinforced at both levels of government, where Departments of Agriculture, Departments of the Environment and Departments of Natural Resources have established distinctly separate mandates, often resulting in policies and decisions which run contrary to one another. While agriculture has undoubtedly benefited greatly from its unique and often privileged status by falling under the mandate of a separate ministry, the creation of separate institutional structures to support agricultural research has resulted in its isolation from other relevant scientific disciplines.

## Sustainability and the Future of Prairie Agriculture

With the global population expected to grow by at least 1.5 percent per year, and in keeping with Canada's position as a major exporter of food grains, the next half century will see continued production of agricultural goods on the Prairies destined primarily for the export market. However, it does not follow that either the mix of goods produced on the Prairies or the methods used to produce them will remain the same in 50 years time. Just as market forces, government policy, and technological and scientific innovations have changed the face of Prairie agriculture since 1950, so will they shape changes from now to 2050.

As indicated previously, the shape of things to come will likely be predicated by one of two possible export-based scenarios, each relating to a higher or lower world demand. The two futures are presented as illustrations for agriculture on the Prairies. Neither should be viewed as predictive since they rest upon extrapolation of historical circumstances.

The Trend Export Scenario referred to in Chapter 1 (Future Demand for Prairie Agriculture and Sustainability) corresponds to a level of annual crop production which could be projected if the trends in world grain demand return to those established between 1960 and 1980. If Canada maintains its current market share of future production, substantial capacity additions in the grain transportation, handling and storage systems will be required within 30 years. Under this Trend Scenario, annual levels of production would be as follows: cereals and oilseeds - 75 million tonnes, 50 percent higher than current levels; beef - 10 million head, 35 percent higher than current levels; and hogs - 8 million head, 100 percent higher than current levels. In contrast, a no-growth export market (No Change Scenario) will limit increases in grain production. This scenario could also result if environmental controls significantly restrict future levels of grain production in the Trend Export Scenario.

The consequences of the two scenarios vary. The level of market demand and the type of soil zone will largely determine the production potential of the Prairie ecosystem, which in turn will shape the approaches taken to improving the integrity of the region's land base.

### Gray and Black Soil Zones

Because of the relatively higher moisture conditions in the Gray and Black soil zones, cropping options are less restrictive than in the drier, more southern areas of the Prairies. Production levels of the Trend and No Change Scenarios imply continuous cropping on soils classified in the Canada Land Inventory to be I, II and III within these zones. With good management practices it is possible to include a wide range of crops, including both annuals and perennials, in extended rotations which would not only improve the condition of the soil, but diversify the landscape and reduce dependence on inorganic fertilizers and pesticides. Summerfallow could be completely eliminated, in some cases being replaced by plow-down crops such as sweet clover. Marginal lands could be restored to a more natural condition under permanent cover without sacrificing any output. Production on higher quality lands could be increased through greater intensification. The expanded levels of crop and livestock production in the Black and Gray zones will permit maintenance of the farm and rural population.

*Unlike the typical rotation of the 1970s and 1980s, the rotation of the future will include crops with different growth habits or phenologies.*

Surveys of production practices indicate that during the 1970s and 1980s many farmers followed simple rotations, typified by the example included in Table 9.1. In the future, rotations that include a wider range of crops and cultural practices will not only result in greater diversification of the landscape, but will contribute to the preservation of the resource base. By the year 2010, sequences such as the one included in the second column of Table 9.1 may be the norm. Unlike the typical rotation of the 1970s and 1980s, the rotation of the future will include crops with different growth habits or phenologies (winter cereals, perennial forages, annual cereals, grain legumes and oilseeds). Not only will the winter cereals and forages provide better ground cover, increasing moisture retention and protection against erosion, they will offer improved habitat for ground-nesting birds. As well, rotations such as these will destabilize pest and weed populations, thereby reducing the need for chemical intervention. A reduction in pesticide usage will not only allay public concerns about environmental contamination and personal safety, but will reduce the likelihood of selecting for pest resistance.

Cropping Sequence		
Year	Typical of 70's and 80's	2010
1	Wheat	Spring Wheat
2	Wheat	Polish Canola or Early Flax Variety
3	Argentine Canola or Flax	Winter Wheat
4	Barley	Perennial Forage/Alfalfa
5	Wheat	Perennial Forage/Alfalfa
6	Wheat	Perennial Forage/Alfalfa
7	Canola or Flax	Spring Wheat
8	Barley	Flax

**Table 9.1**

*Typical Rotations Now and in the Future.*

In the Black and Gray soil zones, the success of “low input” production methods is linked to the incorporation of forages in rotations and cattle in the production system. The cattle consume forages and the manure can be used as fertilizer. This activity maintains production levels while easing the reliance on chemical fertilizers and pesticides. Estimates of the number of beef cattle needed in a wholly organic system in the Black soil zone range from 30 to 200 animals per 1,000 acres of cultivated land. Regardless of whether a farmer chooses organic methods, inclusion of cattle as part of the farm operation in the more productive areas of the Prairies has merit. Cropping options are enhanced by providing an on-farm market for high quality forages including alfalfa. Incorporation of forages in crop rotations would reduce reliance on chemical inputs and, in many instances, improve soil conditions. Recycling of animal wastes will further reduce reliance on expensive synthetic fertilizers.

Although cattle represent the main ruminant on the Prairies, sheep, goats, elk and bison may be viable alternatives. These animals have proven to be more efficient than cattle in utilizing poor quality feedstuffs and are relatively easy to manage. Production of these animals could open up non-traditional markets while allowing for integrated use of marginal lands. Similarly, horses are non-ruminant herbivores that have good market potential, but unlike poultry and swine are able to utilize large quantities of forages.

Simple changes in current management practices could significantly improve wildlife habitat without causing appreciable economic losses to farmers. For example, delaying grazing on native pastures significantly improves the nesting success of waterfowl. Similarly, substitution of winter cereals seeded directly into standing stubble for spring cereals would enhance wildlife habitat and reduce losses due to predation.

### **Brown and Dark Brown Soil Zones**

Total biomass production in the Brown and Dark Brown soil zones of the Prairies is limited by moisture deficits resulting from low precipitation coupled with high evapotranspirative water losses. Cereals are the most commonly grown crops in this area, frequently sown on summerfallow. Soil erosion is a serious problem. Much of the remaining area is utilized as rangeland, with some areas being over-grazed, particularly in drought years. Mixed farm operations are limited with the majority of producers involved either in intensive grain production or cattle operations.

Compared to the Black and Gray soil zones, fewer options are available in developing a sustainable production system in the Brown and Dark Brown zones. Because of the land's fragility and its predisposition to erosion, limiting annual crop production in the driest areas would be desirable. Such lands should be reclaimed as wildlife habitat and restored to a natural short-grass prairie ecosystem. In less fragile areas where ranching is feasible, improved control of grazing would arrest the problem of soil degradation. Continuing efforts to develop forage varieties that can withstand intensive grazing pressure and have improved nutritive content (either through conventional plant breeding or through genetic engineering), will allow for maintenance of stocking rates at existing levels. Establishment of alternate pastures with spring-sown winter cereals or tame forages could assist in extending the grazing season and relieve native pastures from overgrazing. As in the Black soil zone, ruminants other than cattle may be better suited to the unimproved rangelands and short water supplies of these regions.

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*Compared to the Black and Gray soil zones, fewer options are available in developing a sustainable production system in the Brown and Dark Brown zones.*

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Under the No Change Scenario described above, there will be some diversification of crop production on the higher class soils in the Brown and Dark Brown soil zones. The introduction of new, drought tolerant crops such as canola-quality Indian mustard, and the adoption of cultural practices that promote better utilization of stored soil moisture will enhance this transition. However, the continued low returns to agriculture from the less productive soils will cause increased migration of farmers to urban areas. The economic benefits, relative to costs of land used for alternative or combined uses, will provide an incentive for land to be used for wildlife and/or recreational purposes. Farm/nonfarm conflicts generally will not be a problem due to the low population densities in these soil zones.

Under the Trend Scenario of increasing production for export, there will be increased economic incentive for farm managers to initiate soil conservation methods of crop

production, including minimum tillage, rotational grazing and crop rotations involving cereals, oilseeds, legumes such as lentils and lathyrus and perennials.

In the near future, the ongoing shift toward conservation tillage systems will continue to be the best method to arrest soil degradation resulting from excessive tillage on erosion-prone soils. Although significant gains have been made over the past decade in promoting conservation tillage, at least another decade of concerted effort will be required to see large scale changes in tillage and planting practices across the Prairies.

### Anticipatory Technology

As farmers adopt new cultural practices consistent with the tenets of sustainability, new problems will emerge. Scientists must anticipate these problems and initiate research that will avoid serious financial and environmental losses. Research must keep pace with changes in management practices to avoid setbacks that will lead to farmers becoming disillusioned with the “new” technology. For example, the conservation tillage systems that leave more crop residues on the soil surface will inevitably lead to new disease and pest problems. Is it wise to promote a technology that will almost certainly result in severe disease problems before varieties resistant to these diseases have been developed? The visionaries must be mindful that efforts to promote the adoption of new, more sustainable production systems must move forward in concert with, and not ahead of, supporting scientific research.

To develop a sustainable agri-food system, and to ensure Prairie farmers can produce crops profitably well into the future, changes on many fronts will be required. These changes must be supported by productive and imaginative research programs backed by sufficient manpower and resources to meet existing needs, as well as those which will inevitably arise in the future.

In the past 20 years, scientists have made great progress in understanding the biochemical, physiological and genetic basis of stress tolerance in plants. With continuing effort, it may well be possible to improve the cold hardiness or drought tolerance of existing crop plants to match that of native species or adapted weeds. While present options for growing fall-seeded crops are limited to winter cereals, it is not beyond the realms of possibility that other crops, such as canola, may also one day be seeded in the fall. In the long term, no other innovation would contribute as much to the development of a sustainable production system in Western Canada than a large scale shift from spring-seeded to fall-seeded crops. In this context, it is ironic that the winter wheat breeding program in Saskatchewan has recently been terminated and that the only other one remaining in the Eastern Prairies is severely underfunded.

To make agriculture sustainable, Canadians need long-term solutions. Governments and funding agencies must be willing to invest in the future. Quick fixes are not the answer. Research targeted at addressing specific problems of immediate importance, and which has continuity of funding for only 2 or 3 years, does little to promote the development of an integrated, multi-disciplinary systems approach to research. To develop sustainable production systems will require sustained research funding as well as effective vehicles for technology transfer. While it is inevitable that additional monies will be directed into environmental monitoring, these should not be at the expense of research. Monitoring will provide benchmarks but research will be the instrument of change.

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*As farmers adopt new cultural practices consistent with the tenets of sustainability, new problems will emerge.*

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*No other innovation would contribute as much to the development of a sustainable production system in Western Canada than a large scale shift from spring-seeded to fall-seeded crops.*

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*While it is inevitable that additional monies will be directed into environmental monitoring, these should not be at the expense of research. Monitoring will provide benchmarks but research will be the instrument of change.*

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## Safe, Nutritious Food

Health issues are an important priority for many Canadians, a fact manifested in their dietary choices and concern over safety of the food supply. Opinion surveys rank food safety issues high relative to other public concerns. From an agri-food system viewpoint, the challenge is to demystify some of the commonly held public beliefs about agricultural practices and food safety. Equally important is continued growth in both our knowledge about food risks, and development of the technologies and institutions required to minimize the risks to supplying safe, nutritious food. Knowledge needs to be presented in a balanced context so that the public can feel confident in our food production system and their dietary choices.

## Health and Food Choices

Food choices which provide a proper nutritional balance are a top requirement for maintenance of health. Foreseeable priorities for nutrition and the foods demanded are tied to advances in knowledge concerning diet and health. The long-term future of the agri-food system will be determined by its capacity to adapt to the food needs and preferences of the population.

Foods low in saturated fats will continue to be a long-term thrust in the food industry and will require adjustments of practices. This trend requires a major review of the strategies for the livestock industry in particular.

A long-term strategy for Prairie agri-food systems is to broaden the public's food product choices. Great changes have been made through measures such as the substitution of plant-based food oils for animal based components. While many propositions are made to alter the genetics of introduced animal species to produce meats low in saturated fats, it is paradoxical that native species of animals, such as bison, elk and deer, are difficult to introduce into the domestic market because of a broad array of institutional constraints. Attitudes towards native animal species keep them largely out of the food chain, yet it is fairly well documented that native species have many characteristics which are superior to introduced species. Native animal species can produce low fat meat products, have natural cold tolerance, utilize native plant species effectively, and are adaptable to marginal lands that are in natural conditions. In comparison to introduced species, they require lower energy inputs into the agri-food system and are more efficient to feed.

## Food Safety

The current perception of food safety issues is focused on the toxic effects of residual chemicals from synthetic pesticides and fertilizers. While there are legitimate concerns about the sources of food contamination, residual chemicals represent a very small portion of the potential for toxins to affect food safety. Indications are that toxins from natural processes, such as bacterial growth, pose more of a threat to food safety than do synthetic toxins. Normal deterioration of food by natural biological processes results in most of the cause of concern for food safety. Priorities for improving food safety are in adopting methodologies that reduce deterioration from natural processes.

Ionization or food irradiation holds great promise for improving the shelf life of processed and unprocessed food products. Promotion of accurate scientific information is required

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*While there are legitimate concerns about the sources of food contamination, residual chemicals represent a very small portion of the potential for toxins to affect food safety.*

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to ensure public acceptance of irradiation. Education about food safety will be the only sure way of setting the stage for introduction of food storage technology which reduces the risk of food contamination. The GRAS (generally regarded as safe) levels and better determination of safety standards requires both educational and technological attention.

A major opportunity for sustaining the food supply derives from improving food storage and shelf life. Improvements to food storage techniques to avoid pests and deterioration all fall within technological endeavours.

Choosing genetic materials to produce foods with lower levels of natural pesticides is one way of reducing health risks in food. However, few genotypes currently in use have been selected with this view in mind. Understandably, research has focused on the most obvious needs, such as adaptation to short, cold, growing seasons, rust and disease resistance and milling quality.

Development of alternatives to the antibiotics and hormones used in animal production represents a major challenge to the livestock industry. While regulation and testing are clearly formulated to allow animals to clear residues from their system, consumers will continue to demand animal products raised free from antibiotic and hormone feed supplements.

## Institutional Change to Enhance Sustainability

### Infrastructural Change

Prairie food systems have been in a continuing process of structural adjustment since the settlement of the West. Early years of adjustment were driven by failures of those farm systems on lands unsuitable to agriculture, drought periods that resulted in major adjustments, and the ongoing effect of technological developments which allowed fewer labour inputs and achievement of greater production. The future is also likely to produce problems, as abnormalities in climate patterns are predicted to become more severe, and market opportunities and world demand, while predicted to grow in the long term, may experience the severe variability currently existing. Given this context and given Prairie history, it is important that any policy framework provides for adaptive processes which respond to change and allow structural adjustments to take place.

Current agricultural policies seem to be largely directed at maintaining the structure of Prairie agri-food systems. While framework policies regarding areas such as transport systems and income support programs have been rationalized, the main feature of the system is to continue a structure which maintains and expands the output and export of cereals and oilseeds. Although this approach is well meant and meets short-term objectives, its long-term impact on the agricultural system and rural communities remains in question. Adopting an adaptive process that allows agri-food producers and services to adjust to emerging conditions would be a positive step. Perhaps it is time to introduce the long-discussed strategy of minimum incomes that allows primary producers to sustain family and home, but frees them from having to produce commodities on the income support stream. Not only would the bill for farm family support be reduced, the capacity for adaptations to economic opportunity would be enhanced for both present and future generations.

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*Perhaps it is time to introduce the long-discussed strategy of minimum incomes that allows primary producers to sustain family and home, but frees them from having to produce commodities on the income support stream.*

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An adaptive policy strategy would likely result in institutional strategies in which much of the marginal land used for agriculture would be set aside to other purposes. Only the better lands would be sustained in crop production. The marginal lands released would be those that involve the greatest risk in crop production, have the greatest propensity for erosion, and have the greatest potential to improve landscape diversity and protection. Structural adjustment would also likely take the form of intensification of production on better farm lands, and diversification into other crop and livestock products. With all choices for production and income derivation open to market risks, a stronger relationship between producers and processors would occur. The potential for special crop and livestock production to meet markets would be expanded. Those with unsuitable resources may well opt for a lower input form of agriculture or alternately be sustained under the minimum income strategy.

Farm income support policies that subsidize the cost of grain production and distribution raises the economic incentives for annual crop production, putting more pressure on the ecosystem. Where necessary, subsidies should be focused less on commodities and farm expenditures and more on stabilizing the agroecosystem. Markets are unable to capture the benefits of preserving a species or enhancing water quality. In these situations, environmental subsidies are justifiable. Instead of being tied to the volume of production or inputs purchased, payments should come through decoupled income support and inducements that provide environmental amenities.

In the past, the impetus for programs to set aside land has been poor grain markets or concerns about soil conservation. With the exception of the North American Waterfowl Management Plan and some modest efforts by private conservation groups, no programs have been established that place first priority on maintenance of wildlife habitat. Financial incentives have generally been used to persuade farmers to remove land from cultivation. Unfortunately, the long term success of using financial leverage to alter land use practices is open to question. Public education and demonstration of tangible environmental benefits will have to be promoted to have a lasting effect.

Much could be gained by linking an adaptive strategy to income support. In fact, the salvation of farm policy may be in adjusting it to a sustainable agroecosystem policy in which urban people can see the merit of a sustained farmer income. However, such a proposal would be difficult to realize. In every policy or structural discussion, sectoral agencies see funding as a sacred process tied to the single-purpose mandate of departments. This mindset must change.

### **Knowledge-based Agroecosystem Management**

Ecosystems are composed of biotic and abiotic elements. Agriculture involves the systematic management of organisms within the ecosystem. Sustainable agriculture implies understanding the dynamics of the ecosystem and striving to maintain an equilibrium.

Education will play a pivotal role in the development of more balanced agricultural ecosystems. Farmers must not only be informed about management practices that will decrease soil degradation and preserve wildlife habitats, but they must be convinced of the advantages both from an economic and environmental standpoint. Increased diversification within the system will mean that farmers will need to know more about

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*Educators will have to place greater emphasis on holistic approaches to agricultural and food production, incorporate courses relating to ecology and environmental science in the curriculum, espouse a philosophy consistent with the principles of sustainable agriculture, and recognize the inherent value of common property.*

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agrobiology and the various interactions between the components of the system. While the push in the 1970s and 1980s was to promote specialized farmers, the push in the future will be for adaptive generalists. Such generalists will require more indepth knowledge of crop and livestock production practices than the more specialized farmer of the past.

While there is no substitute for experience, it will become increasingly important to tomorrow's farmers to have formal training to complement their practical experience. Much of this training will entail knowing how to efficiently access important information, and to recognize the "ripple" effect of their decisions, not only within their own operation but on the agroecosystem as a whole. Much of their decision-making will be supported by the advise of agricultural consultants or extension agents who, in turn, will rely on research results incorporated into broadly based expert systems. These consultants and extension specialists, along with input suppliers, will have to be exposed to different concepts than formerly taught in traditional degree and diploma programs at agricultural colleges, community colleges and universities. Educators at these institutions will have to place greater emphasis on holistic approaches to agricultural and food production, incorporate courses relating to ecology and environmental science in the curriculum, espouse a philosophy consistent with the principles of sustainable agriculture, and recognize the inherent value of common property, which all citizens have the right to enjoy.

Most public institutions (government, university) tend to have single-purpose policy and research objectives. Yet the resources on the land lay in a complex web, each piece interacting with the next in an intricate way. Current institutions tend to apply solutions from a single-purpose viewpoint. Yet the ecosystem will also respond to these initiatives interactively. While institutional forms need change, policy makers must be cautious of those who would throw away the single interest reductionist approach to analyzing issues. New institutional forms that bring together the findings of individualists and reductionists into a cohesive whole is needed. These institutions must also directly involve the people who live on the land, since in the final analysis, sustainability is an act of husbandry to meet the needs of current and future generations.

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## SOURCES OF FIGURES AND TABLES

If the source of a figure or table is included in the “Reading List” for that chapter (those marked with \* below), then only name of the author and date is given. Otherwise the full source is provided.

### Chapter One

Figure 1.1 — Terrestrial Ecozones of Canada.

Source: *Terrestrial Ecozones of Canada*, Environment Canada, State of the Environment Directorate, 1994.

Figure 1.2 — Framework for Analysis of Sustainable Prairie Agriculture.

Compiled by author.

Figure 1.3 — Area of the Prairie Provinces in Agricultural Production, 1908-1991.

Source: Census of Canada, Agriculture (Various Issues 1908 - 1991).

Figure 1.4 — Total Number of Farms on the Prairie Provinces, 1881-1991.

Source: Census of Canada, Agriculture, (Various Issues 1881 - 1991).

Figure 1.5 — Cereal Grain and Oilseed Production on the Prairie Provinces, 1908-1988.

Source: Statistics Canada, CANSIM.

Figure 1.6 — Cattle Stocks on the Prairie Provinces, 1881-1991.

Source: Statistics Canada, CANSIM.

Figure 1.7 — Hog Numbers on the Prairie Provinces, 1881-1991.

Source: Statistics Canada, CANSIM.

Figure 1.8 — World Per Capita Consumption of Wheat and Coarse Grain, 1960-1988.

Source: United States Department of Agriculture (USDA) 1988.

### Chapter Two

Table 2.1 — Comparison of Climate Characteristics of Several Locations on the Prairies with Other Parts of Canada and the World.

Various Sources.

Table 2.2 — Number of Days Required for Some Crops to Grow to Maturity.

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Table 2.3 — Frost Statistics for Several Prairie Cities.

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Table 2.5 — Value of Crop Losses in Manitoba due to Adverse Weather, 1982-1985.  
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\*Table 2.6 — Number of Fall Field Workdays Available (maximum = 30) on Heavy Prairie Soils, August 21 - September 20, at Three Risk Levels.  
Source: Dyer, 1980.

Figure 2.1 — Average Accumulated Number of Growing Degree Days above 5°C, for Southern Manitoba and Southeastern Saskatchewan.

Source: Ash, G.B.H., *An Agroclimatic Risk Assessment of Southern Manitoba and Southeastern Saskatchewan*, Unpublished Masters of Arts Thesis, University of Manitoba, Winnipeg, Manitoba, 1991.

Figure 2.2 — Minimum Accumulation of Growing Degree Days above 5°C at a 10 Percent Risk, for Southern Manitoba and Southeastern Saskatchewan.

Source: Ash, G.B.H., *An Agroclimatic Risk Assessment of Southern Manitoba and Southeastern Saskatchewan*, Unpublished Masters of Arts Thesis, University of Manitoba, Winnipeg, Manitoba, 1991.

Figure 2.3 — Average Accumulated Growing Season Precipitation (millimetres) for Wheat, for Southern Manitoba and Southeastern Saskatchewan.

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### Chapter Three

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### Chapter Four

\*Table 4.1 — Land in Soil Capability Classes One to Four as Related to Improved Land in Farms (million hectares).

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Table 4.2 — Estimated Losses of Organic Matter from the A Horizon, by Soil Zone and Provinces of the Canadian Prairies.

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Figure 4.2 — Potential Agricultural Lands of the Prairie Provinces.  
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*Figures 4.1 and 4.2 have previously been produced by contributing authors. No permission is required for their use.*

## Chapter Five

No Figures/Tables

## Chapter Six

Table 6.1 — Water Use Efficiency for Prairie Crops.  
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Table 6.2 — Differences in Spring Soil Water Content Between Fields that Had Been Fallowed and Those Cropped in the Previous Year (cm ± standard deviation).  
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Table 6.4 — Water Equivalents of Mean Snowfall (1951-1980) for Various Prairie Locations.  
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Table 6.6 — Influence of Herbicide, Fertilizer, and Stubble Treatments on Yield (kg/ha) of a Continuous Wheat Rotation over a Seven-Year Period (1983-89) at Scott, Saskatchewan.  
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Table 6.7 — Economic Feasibility of Irrigation Projects in Central Saskatchewan Under Three Prospective Development Scenarios.

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Figure 6.1 — Land Use Changes in the Minnedosa District (1928-1982)

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Figure 6.3 — Phosphorus in Canadian River Basins, (1980 to 1982).

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Figure 6.4 — Typical Soil Water Recharge Following Annual Crop Harvest.

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Figure 6.5 — Irrigated Cropland in Alberta, 1984.

Source: Alberta Agriculture, *Agriculture Statistics Yearbook 1984*.

## Chapter Seven

Table 7.1 — Significance of Contaminants Associated with Agriculture and Transported by Air.

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## Chapter Eight

Table 8.1 — The Role of Government in Food Safety.

Source: Personal Conversations with Peter Pellaers, Head, Food and Chemical Residue Laboratory, Health Protection Branch, Health and Welfare Canada and Stan Kirkland, Program Manager, Plant Health, Food Production and Inspection Branch, Agriculture Canada.

Table 8.2 — Attitudes of Canadians to Various Food Hazards.

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Table 8.3 — Perceived Food Poisoning Experiences of Canadians.

Source: Agriculture Canada, National Safe Food Handling Study (SFHS), 1990.

## Chapter Nine

Table 9.1 — Typical Rotations Now and in the Future.

The **International Institute for Sustainable Development (IISD)** is a private non-profit corporation established and supported by the governments of Canada and Manitoba. Its mandate is to promote sustainable development in decision making — within government, business and the daily lives of individuals. Its scope is international, in recognition of the fact that local, national and global development issues are interconnected and impact upon each other.

