LANDS DIRECTORATE

DIRECTION GÉNÉRALE DES TERRES

# DEGRADATION OF CANADA'S PRAIRIE AGRICULTURAL LANDS:

# A GUIDE TO LITERATURE

# AND ANNOTATED BIBLIOGRAPHY

WORKING PAPER No. 37



Environment Canada

Environnement Canada

Canada

# DEGRADATION OF CANADA'S PRAIRIE AGRICULTURAL LANDS:

# A GUIDE TO LITERATURE

# AND ANNOTATED BIBLIOGRAPHY

Paul D. Bircham
and
Hélène C. Bruneau

March, 1985

A report of the Land-Use Policy and Research Branch.



Lands Directorate
Environmental Conservation Service
Environment Canada

Working Paper No. 37

Aussi disponible en français sous le titre:

La dégradation des terres agricoles de la Prairie canadienne:
Guide des publications et bibliographie annotée

Minister of Supply and Services 1985
Cat No. En 73-4/37E
ISBN 0-662-13797-3

## ABSTRACT

The agricultural land base of Canada's Prairies is critical to meeting national economic and employment goals. Much has been written about the state and prospects of agricultural land on the Prairies by land resource specialists. It is the intent of this report to provide an introductory overview of the issues, and to act as a reference tool. It will aid the Federal Government in the implementation of the Federal Policy on Land Use (Government of Canada, 1981), as well as in other federal land resource committments--notably, the Federal Land Management Principle. It should also be of use to farmers, concerned citizens, administrators, and other decision-makers. The report explores the basic sources, as well as a representative sample of the recent work of specialists, on agricultural land degradation on the Prairies.

Part I of this report outlines substantial basic information about, and the concerns of scientists related to, stresses threatening the likelihood of sustained production from this key agricultural land resource. Part II contains annotated listings for the 71 books, reports, and articles surveyed specifically for this publication. Thus, the report serves as a guide to more extensive and detailed information on the many aspects of Prairie agricultural land degradation.

## RÉSUMÉ

Le territoire agricole des Prairies canadiennes est essentiel à la réalisation des objectifs économiques et à la création d'emplois au niveau national. Les spécialistes de la ressource "terre" ont écrit beaucoup sur l'état et l'avenir des terres agricoles des Prairies. Ce rapport vise à donner un aperçu global des préoccupations en la matière, de même qu'être utilisé comme ouvrage de référence. Le rapport assistera le gouvernement fédéral dans la mise en oeuvre de la Politique fédérale sur l'utilisation des terres (Gouvernement du Canada, 1981), ainsi que de d'autres principes énoncés relativement aux ressources terrestres dont, entre autres le Principe de gestion des terres fédérales. Ce document devrait aussi être utile aux agriculteurs, citoyens intéressés, administrateurs ainsi que politiciens et gestionnaires. L'étude examine les principales sources d'informations de même qu'un échantillon représentif des plus récents ouvrages scientifiques.

La première partie décrit les grandes lignes des principales oeuvres d'information ainsi que les préoccupations des scientifiques au sujet des contraintes qui menaçent le rendement soutenu des terres agricoles des Prairies. Le seconde partie contient une bibliographie annotée sur 71 livres, rapports et articles échantillonnés. Somme toute, ce rapport constitue un recueil d'information très détaillé sur une variété d'aspects traitant de la dégradation des terres dans les Prairies.

## ACKNOWLEDGEMENTS

Preparation of this report has required the services and co-operation of many others. Reviews of a draft version of this report were generously provided by the following:

- Dr. John W.B. Stewart, Director; Dr. H.P.W. Rostad; and Dr. D.W. Anderson, Saskatchewan Institute of Pedology, Saskatoon.
- Gary Carlson, Co-ordinator of Soil Conservation Awareness; and Malcolm Black, Soil Erosion and Fertility Specialist, Prairie Farm Rehabilitation Administration, Agriculture Canada, Regina.
- Dr. D.R. Coote, Land Resource Research Institute, Agriculture Canada, Ottawa.
- David Gierman (Canada Land Use Monitoring Program), Arthur Petch (Land Planning Analysis Division), and Edward W. Manning (Chief, Land Use Analysis), Lands Directorate, Environment Canada, Ottawa.

The contribution of each is gratefully acknowledged. Errors of fact or ommission, however, remain the responsibility of the authors.

The preparation of the maps and figures was ably carried out by the Drafting Division, Environmental Conservation Service, especially Mark Allen. Carole Aubin-Lalonde and C. Whittaker Associates provided fine word processing assistance for which we are also grateful. Debora Moncada and others in the Lands Directorate assisted in final production of this document.

# TABLE OF CONTENTS

## LIST OF TABLES



## LIST OF FIGURES

## 1.0 INTRODUCTION

As a nation, Canada is committed to substantially increasing its food production and exports. The Agri-Food Strategy of Agriculture Canada (1981) calls for a two-thirds increase in agricultural production by the year 2000. Canadian Wheat Board targets for grain exports for 1990 total 36,000,000 tonnes. This target is 20% above 1984 levels, which already have recently expanded considerably. These increases have been and must continue to be produced by the intensified use of currently utilized land, since there is little quality land left for expansion. Further, most new land in Canada, capable of commercial agricultural production, is on the northern fringes of the area currently in agricultural use on the Prairies (Figure 1.1). This land is climatically fragile and less productive than most of the rest of the Prairies. Thus the Prairies, which already produce the vast majority of Canada's grain, and which constitute the only net food-exporting region in the nation, will inevitably be called upon to provide the greatest part of any expansion in Canadian agricultural production.

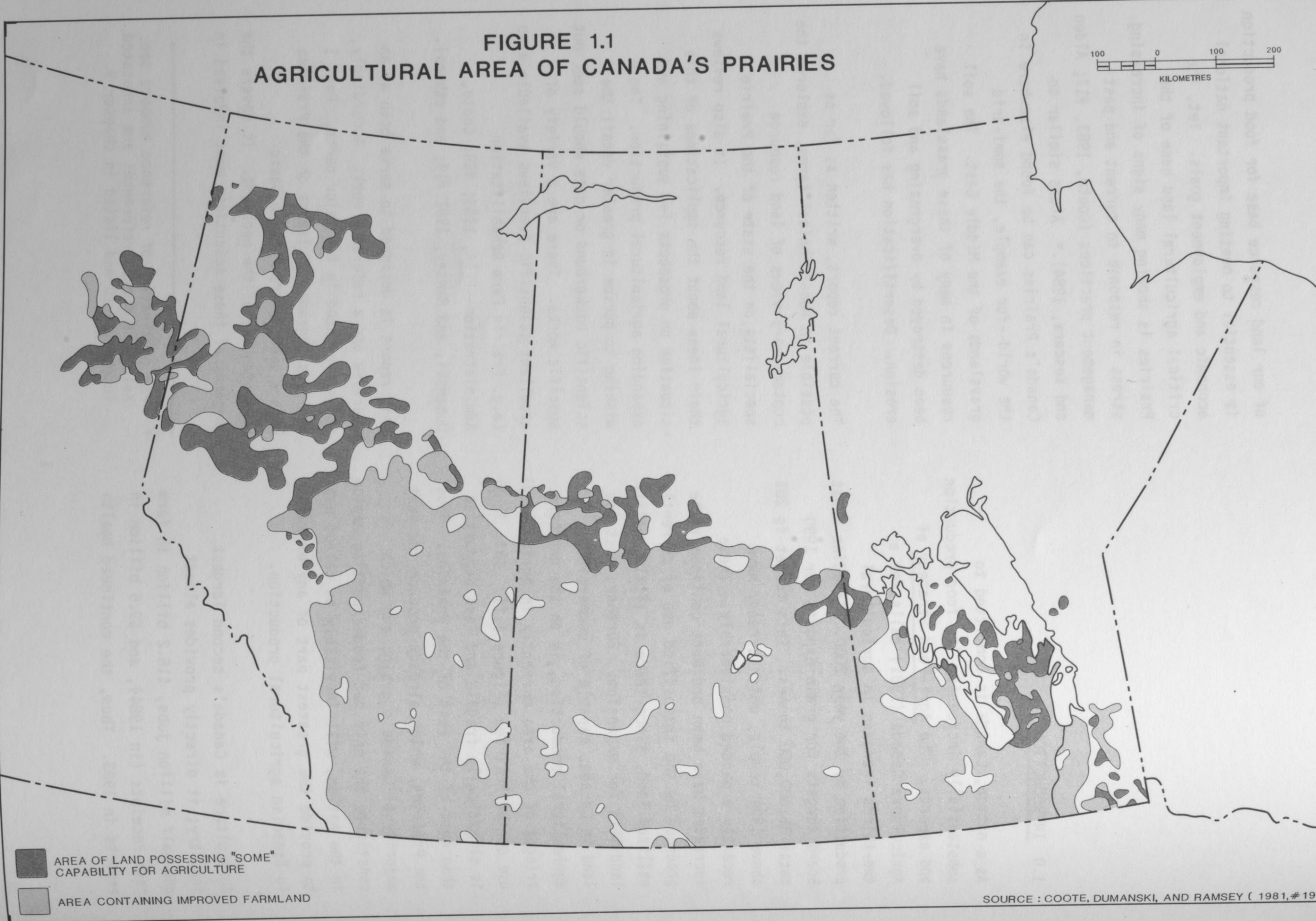
Agriculture is Canada's second largest industry; it directly provides almost one-half million jobs, $18.2 billion in farm cash receipts (in 1984), and $9.5 billion in exports in 1983. Thus, the continued health of our land resource base for food production is essential to meeting important national economic and employment goals. Yet, the critical agricultural land base of the Prairies is showing many signs of increasing stress in response to current and past management practices (Coote, 1983, #17; Alden and Vescera, 1984).* Areas similar to Canada's Prairies can be found elsewhere in the world--for example, the semi-arid grasslands of the Middle East. The soil resources in many of these grasslands have been destroyed by overgrazing and soil erosion. Desertification has followed.

The current report, written as far as possible in non-technical terms, explores the contemporary views of land resource specialists on the state of the Prairie agricultural land resource. It also reviews their ideas about the implications of this situation on prospects for sustaining and expanding agricultural production. Those wishing to pursue in greater detail the scientific background or data should seek out specific works. There are a variety of excellent scientific overviews available also (e.g. Prairie Farm Rehabilitation Administration--PFRA, 1983, #58; Coote, Dumanski, and Ramsey, 1981 #19; and others).

This report is designed to serve both as an overview and a reference work. Accordingly, it is presented in two major parts. Part I outlines degradation issues on the Prairies with a view to providing a basic understanding of the problems. It covers the concerns of those scientists most involved in

* For explanation of reference numbers see below. Numbered references are annotated in chapter 10 and listed in chapter 9.

## FIGURE 1.1
## AGRICULTURAL AREA OF CANADA'S PRAIRIES




SOURCE : COOTE, DUMANSKI, AND RAMSEY ( 1981, #19 ).

issues of land degradation there. Part II contains annotated listings of the 71 books, reports, and articles surveyed specifically for this report. Each annotation contains an outline of the item, plus an overview of its major findings. That these 71 items are not exhaustive is well illustrated by the many other references cited in Part I.

Part I begins by discussing in turn the different types of soil degradation on the Prairies (in three classes as defined by Coote, 1983, #17):

1) Loss of soil materials (Chapter 2), including :
   - erosion both by water and wind.
   - loss of organic material.
   - loss of organic soils.

2) Chemical deterioration (Chapter 3), including :
   - salinization.
   - acidification.
   - contamination.

3) Physical deterioration (Chapter 4), including :
   - compaction.
   - mixing and disturbance.

These three chapters describe in turn the physical processes involved in each type of degradation. The discussions then provide for each type a review of the information about the location, extent, and trends, along with a review of the major human causes and influences on the Prairies. An outline of the consequences, in terms of both socio-economic and environmental impacts, concludes each section.

The present review purposely focusses only on the types of degradation mentioned earlier. No attempt has been made to deal with the various processes of urbanization, urban-type land uses, and urban influence. While these processes and phenomena may also destroy and reduce potential for productivity of the agricultural land resource, urbanization is essentially a land allocation issue. For recent review and bibliographic coverage of these influences, the reader is referred to The Influence of Exurbanite Settlement on Rural Areas: A Review of the Literature (McRae, 1980), Land and the Automobile: A Selected Bibliography (Simpson-Lewis and McKechnie, 1981), various parts of Stress on Land in Canada (Simpson-Lewis, McKechnie, and Neimanis, 1983), The City's Countryside (Bryant, Russwurm, and McLellan, 1982), The Rural-Urban Fringe--Canadian Perspectives (Beesley and Russwurm, 1981), or "The Impact of Non-Farm Development on Agriculture: A Synthesis" (Bryant and Russwurm, 1979).

Chapter 5 reviews the range of technical or farm-level responses on the Prairies which have been either recommended or evaluated in the surveyed literature. Government actions, including those now underway and those recommended (or even warned against), are discussed in Chapter 6. A "road map" to the overview is included (Table 1.1) to assist the reader with only specific interests. Chapter 7 concludes the information overview with a brief summary comment on the significance of the information reviewed herein.

The literature is prominently cited throughout this report in order to provide the reader with the best possible access to the further information needed to answer whatever questions he may have. References which contain a number, (e.g. Batie, 1983, # 3), refer to those included in the annotated bibliography listed in Chaper 9. All other sources are fully referenced in Chapter 8.

TABLE 1.1:

A "ROAD MAP" TO THE GUIDE

| Aspects of Land Degradation / Types of Land Degradation | Loss of Soil Materials | | | | Chemical Deterioration | | | Physical Deterioration | |
|---|---|---|---|---|---|---|---|---|---|
| | Water Erosion | Wind Erosion | Loss of Organic Materials/ | Loss of Organic Soils | Salinization | Acidification | Contamination | Compaction | Mixing and Disturbance |
| Physical Processes | 2.1.1 | 2.1.3 | 2.2.1 | 2.3 | 3.1.1, 3.1.5 | 3.2.1 | 3.3 | 4.1 | 4.2.1 |
| Location, Extent, and Trends | 2.1.2 | 2.1.4 | 2.2.2 | 2.3 | 3.1.2, 3.1.5 | 3.2.2 | 3.3 | 4.1 | 4.2.2 |
| Causes | 2.1.5 | 2.1.5 | 2.2.1 | 2.3 | 3.1.3 | 3.2.1 | 3.3 | 4.1 | 4.2.1 |
| Consequences | 2.1.6 | 2.1.6 | 2.2.1 | 2.3 | 3.1.4 | 3.2.3 | 3.3 | 4.1 | 4.2.1 |
| Solutions | 5.1 | 5.1 | 5.2 | 5.2 | 5.3 | 5.4 | 5.5 | 5.6 | 5.7 |
| Government Role | CHAPTER 6 | | | | CHAPTER 6 | | | CHAPTER 6 | |

The matrix shown in Table 1.2 was utilized to ensure the choice of a representative sample of literature. It is reproduced here to assist further the reader to find sources of particular interest. The matrix illustrates which reports deal with each aspect of each type of degradation discussed. Potential solutions and government's role in each degradation problem are also covered. Key reports in each cell of the matrix and those specifically used in Part I of this guide are underlined in the matrix. It is hoped that this notation will increase the usefulness of the report.

Degradation is increasingly becoming the focus of scientific research because of its agreed importance, economically and environmentally. New material on the subject of land degadation is emerging very rapidly; the authors are aware of major overview reports underway from both the Science Council of Canada and the Canadian Environmental Advisory Council. Where specific new or forthcoming research is known, they are also reported.

It should also be recognized that, throughout this report, many of the conclusions of authors cited may not be universally accepted; indeed some remain controversial. The comprehensive study of "land degradation" remains in its infancy; clear, well documented findings are often lacking. Some studies contain or represent assumptions or interpretations that are not well accepted or tested, or are first approximations. For example, the recent overview by Anderson et al. (1984) cites far different costs for salinization on the Prairies than the earlier PFRA (1983, #58) report. They may also be in papers published in journals or books which are not subject to stringent review by scientific peers prior to publication. In all these cases, the reader should be cautious in interpreting such findings until substantive proof is available. The reader's attention has been drawn to these differences of opinion, wherever possible. More research on the subject of interest will thus sometimes be necessary. In this regard, the matrix can be most useful in finding alternative or additional sources to persue.

## TABLE 1.2:

## A GUIDE TO THE LITERATURE SURVEYED

| Aspects of Degradation \ Types of Land Degradation | Loss of Soil Materials | | | | Chemical Deterioration | | | Physical Deterioration | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Water Erosion | Wind Erosion | Loss of Organic Materials/ Fertility | Loss of Organic Soils | Salinization | Acidification | Contamination | Compaction | Mixing and Disturbance | Additional/ General |
| Physical Processes | 17, 58, 19, 11, 15, 18, 3, 59, 14. | | 17, 19, 11, 46, 15, 1, 13, 49, 36, 62, 5, 48, 59, 14. | 17, 19, 50. | 17, 31, 67, 8, 33, 19, 11, 15, 66, 57, 59, 38, 14, 32. | 17, 19, 34, 46, 14, 68. | 17, 19, 14, 68. | 9, 17, 19, 14. | 17, 19, 14, 68. | --- |
| Location, Extent, Trends | 17, 19, 18, 58, 11, 15, 22, 69, 36, 3, 28, 41, 59, 61, 14, 24. | | 17, 19, 11, 62, 48, 13, 69, 36, 52, 46, 15, 5, 9, 58, 59, 61, 14, 24. | 17, 19, 50, 46, 14. | 17, 67, 58, 8, 19, 11, 46, 31, 15, 22, 69, 66, 57, 7, 52, 59, 38, 61, 14, 24. | 19, 56, 34, 58, 30, 14, 68, 17, 46. | 46, 19, 68, 14. | 22, 14, 17, 19. | 32, 68, 14, 17, 19. | 22, 20, 69, 21. |
| Causes (Human) | 11, 40, 58, 3, 60, 15, 55, 42, 18, 69, 64, 63, 36, 21, 28, 9, 6, 35, 41, 22, 30, 61, 54, 37, 48, 39. | | 17, 11, 13, 48, 58, 5, 62, 43, 19, 10, 54, 46, 60, 15, 55, 42, 40, 69, 64, 63, 49, 36, 52, 62, 21, 9, 6, 61, 16, 35, 58, 59, 30, 53, 6, 14, 24. | 17, 50, 19. | 17, 32, 67, 46, 60, 15, 31, 55, 22, 40, 69, 64, 63, 66, 57, 7, 52, 21, 6, 35, 58, 23, 59, 30, 38, 53, 61, 14, 24, 43. | 46, 34, 58, 68, 56, 30, 14, 19. | 46, 68. | 19, 10. | 32. | 29, 63, 70, 2, 47. |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Physical Consequences | 17, 20, 58, 1, 43, 19, 10, 11, 46, 60, 45, 18, 69, 36, 3, 28, 9, 6, 41, 59, 61, 14, 24, 39, 22, 69. | 11, 17, 19, 48, 58, 5, 62, 13, 69, 49, 36, 9, 6, 58, 28, 61, 14, 62, 24, 10, 4, 60. | 17, 19, 46, 50, 14. | 67, 58, 24, 17, 19, 11, 46, 60, 31, 22, 69, 66, 57, 6, 59, 38, 23, 61, 24, 8. | 46, 56, 17, 19, 34, 58, 14. | 46, 17, 19, 14, 68. | 40, 9, 22, 48. | 32, 17, 19, 14. | 15, 70, 16. |
| Socio-Economic Consequences | 17, 58, 1, 42, 20, 69, 3, 28, 37, 14, 18. | 17, 5, 42, 20, 69, 48, 58, 14, 16. | --- | 67, 14, 58, 16, 17, 69, 66, 38. | 56, 14, 58. | 17, 14. | 22, 9, 14, 17, 19. | 17, 14. | 15, 55, 45, 42, 16, 69, 26, 47, 70, 24. |
| Solutions | 40, 20, 3, 28, 6, 36, 69, 51, 65, 58, 11, 22, 64, 49, 36, 21, 35, 30, 53, 57, 46, 66, 7, 48, 17, 19, 13, 39, 43, 25, 10, 46, 60, 39, 55, 45, 1, 69, 63, 41, 59, 61, 14, 24. | 35, 50, 40, 36, 48, 13, 20, 54, 11, 22, 13, 69, 63, 49, 9, 6, 65, 58, 44, 53, 16, 62, 49, 70, 65, 39, 64, 60, 55, 11, 35, 57, 7, 59, 47, 41, 43, 10, 46, 51, 64, 21, 5, 30, 61, 14, 24, 17, 19. | 17. | 43, 51, 31, 66, 34, 38, 53, 36, 40, 11, 54, 55, 63, 57, 7, 52, 67, 6, 35, 30, 16, 62, 29, 21, 39, 70, 11, 46, 60, 22, 69, 64, 21, 5, 65, 59, 23, 61, 14, 24, 70, 3, 39, 8. | 34, 58, 17, 10, 56, 30, 14, 68, 46. | 46, 68, 19. | 22, 9, 17, 10, 69, 64, 60. | 32. | 22, 69, 47, 70, 44. |

## PART I

### 2.0 LOSS OF SOIL MATERIALS

Soil is degraded by the loss of soil materials through four major processes (after Coote, 1983, #17):

1) Erosion of soil by water (discussed in section 2.1).

2) Erosion of soil by wind (2.1).

3) Loss of soil organic matter through a variety of practices and processes (2.2).

4) Subsidence and erosion of organic or peat soils (2.3).

### 2.1 Erosion by Water and Wind

#### 2.1.1 Processes--Water Erosion

Water erosion is generally initiated when soil particles are disrupted by the splash of raindrops (PFRA, 1983, #58). When the capacity of the soil to absorb the water is exceeded, soil movement begins by a thin layer of water--sheet erosion. When the water is channelized, it becomes rill erosion. Gully erosion is an advanced stage, in which tiny rills eventually become deep channels reaching into the subsoil. Soil deposits form at the base of slopes (first coarse particles, then progressively finer ones) or appear as sediments in adjoining water bodies.

Run-off from snow melt and rainfall erodes all soils, even well-vegetated, untilled land. The extent of water erosion is influenced by the following factors (Coote, 1983, #17; Prairie Farm Rehabilitation Administration--PFRA, 1983, #58):

1) Soil susceptibility, which is determined by the following:
   - -- particle size distribution or soil texture.
   - -- organic matter content
   - -- soil permeability or ability to hold or transport water.
   - -- degree of aggregation of primary soil particles into compound particles.
   - -- structural stability.

2) Intensity of rain and/or run-off.

3) Degree, length, and configuration of slope.

4) Presence of frozen soil layers, which decrease the ability of the soil to hold water.

5) Presence of vegetation cover or residue.

#### 2.1.2 Location, Extent, and Trends--Water Erosion

Coote, Dumanski, and Ramsey (1981, #19) have indicated that (when cropping practices are taken into account) the vast majority of the Prairie grainlands are subject to a "moderate relative risk" of water erosion. Their relative risk assessment is based on expected annual flow of water to streams, maximum one-hour rainfall in a ten year period, and surface soil texture. Generally, water erosion is the result of infrequent, severe rainstorms. Sheet erosion of knolls and rilling and gullying near road culverts are evidenced throughout the Prairies (Coote, 1983, #17; Coote, 1984, #18). Rain falls most intensely in the southern portion of the region. There, Stewart (1985b) notes that erosion has often removed the soil to a depth at which the less-fertile subsoil is exposed or brought up by tillage. Steeper-sloping parts of the landscape, notably the Turtle, Pembina, Duck, and Riding mountain areas, the Tiger Hills, and the Red River Valley (all in southern Manitoba) exhibit the most extensive soil erosion.*

In higher moisture areas, notably the foothills of Alberta, the Peace River area, the Grey Luvisol soil zone,** and the southern Manitoba floodplain. Annual rainfall and snowmelt runoff are the main factors. In the Peace, the combination of fine-textured soils, the deeply-incised nature of drainage, extensive summerfallow, and little use of control measures leads to a high degree of concern over water erosion. Similar conditions are found in the lower foothills of Alberta and east-central Saskatchewan (Prince Albert to Yorkton).

Poor management of irrigation return flows and of unused irrigation water has resulted in erosion of gullies and channel banks in southern Alberta and Saskatchewan (Coote, Dumanski, and Ramsey, 1981, #19). Some irrigated fields have also experienced erosion due to poor water application practices.

The quantity of water erosion varies dramatically based on location, soil type, crop rotation, and other factors. PFRA (1983, #58) has estimated that total soil loss is 117 million tonnes per year.* This is equivalent to a reduced total crop of 30,500 thousand tonnes wheat (each succeeding year).

In general, the current trends to reduction of summerfallow area, more frequent stubble cropping, and minimum tillage are expected to reduce water erosion risks somewhat. On the other hand, increases in the area of corn and soybean crops on finely-textured soils in southern Manitoba may partially offset this overall improvement. Water erosion is known to be increasing in the Peace River area due to extensive land clearing (Coote, 1983, #17).

### 2.1.3 Processes--Wind Erosion

The process of wind erosion has been described in the following stages (PFRA, 1983, #58):

1) Detachment--through frost, wetting, rain, mechanical abrasion, or windborne particles.
2) Movement--in response to turbulent airflow, usually above 25 to 50 kilometres per hour; the finest particles are most easily eroded.
3) Transportation--fine particles in (air) suspension; coarser particles by a jumping motion (saltation); large particles, up to a millimeter in diameter, are pushed or rolled by the saltating particles.

---

* For these and all other place names in the report, see Figure 2.1.

** Luvisols are well- to imperfectly-drained mineral soils associated with forests in mild to cold climates. A rough schematic of generalized soil zones is illustrated in Figure 2.2.

* One metric tonne equals 2,205 pounds or 1.1 short tons.

## FIGURE 2.1
## KEY PLACES FOR THE GUIDE

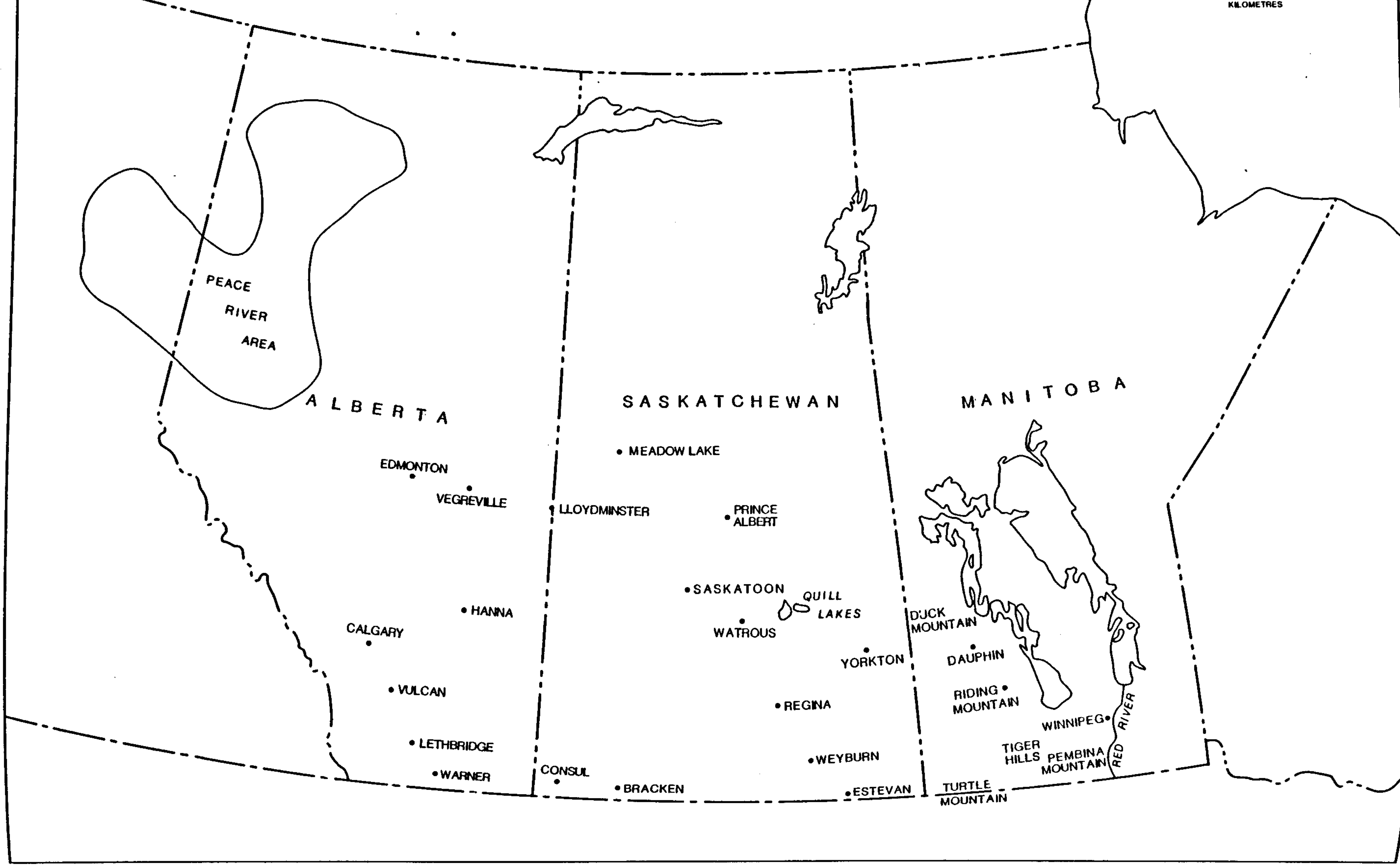
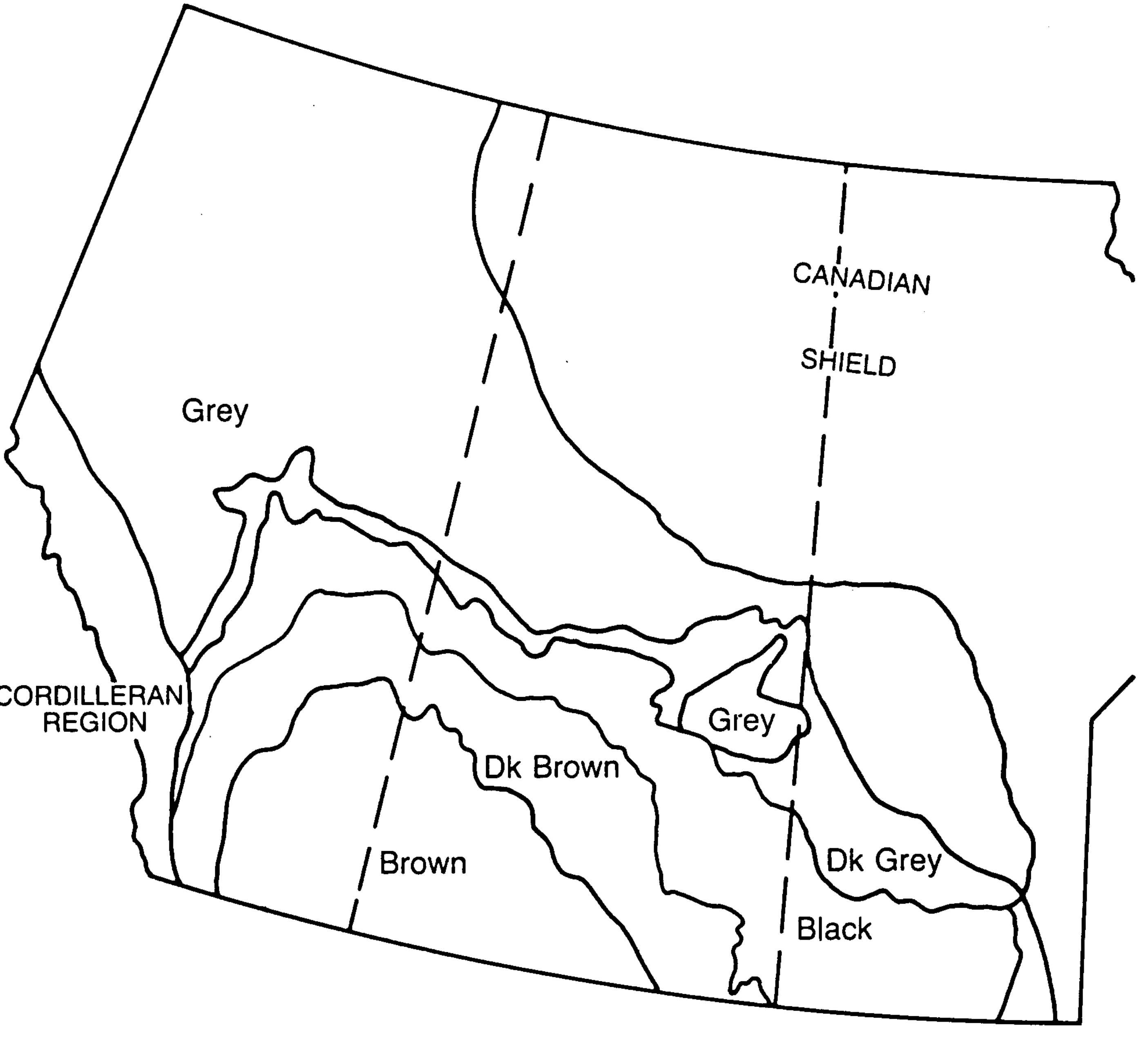


**FIGURE 2.2:**
**GENERALIZED SCHEMATIC OF SOIL ZONES**



4) Deposition--by rain or reduced wind velocity, coarse particles first; fine particles may be carried many miles.

The amount of wind erosion depends on several factors (PFRA, 1983, #58; Coote, 1983, #17):

1) Wind velocity and turbulence--on the Prairies, winds are widespread and steady in March to May when the soil is often the least protected.
2) Topography--knolls, for example, are subject to greater wind erosion.
3) Vegetation--crops, crop residue, and windbreaks reduce wind speed at the surface depending on quantity, height, orientation, and texture; therefore these protect the soil. Also, the width between wind barriers (i.e. the unprotected fieldwidth) influences the occurrence of erosion.
4) Soil aggregation--both finer- and coarser-textured soils are more subject to wind erosion.
5) Moisture--holds soil particles together.
6) Surface roughness--determines the wind drag at the surface.

### 2.1.4 Location, Extent and Trends--Wind Erosion

South-eastern Alberta and south-western and south-central Saskatchewan (an area known as Palliser's Triangle) are at high risk to wind erosion (Coote, 1983, #17; PFRA, 1983, #58; Toogood, 1977.) This risk assessment is based on the maximum one-hour wind speed in a ten-year period, soil moisture, and surface soil texture. Palliser's Triangle is the single most susceptible area to wind erosion in Canada. Coote, Dumanski, and Ramsey (1981, #19) also note that extensive additional areas at moderate risk to wind erosion are found in south-eastern Manitoba, south-western Saskatchewan, and the remainder of southern Alberta. High wind velocities, dry soils, and the Chinook winds in winter have entirely stripped some areas of their topsoil.

The worst occurrences of wind erosion were in the Dust Bowl of the 1920s and 1930s, when up to 2.4 million hectares were affected.* In 1960, Johnson (1961) estimated that erosion had severely eroded 1.0 million hectares in this area, almost all by wind. An additional 2.7 million hectares have been less severely-eroded. Over 800,000 hectares are being rehabilitated under the Prairie Farm Rehabilitation Administration's (PFRA) Community Pasture Program. A further one million hectares of severely-eroded and one and one-half million hectares of slightly- to moderately-eroded land are found throughout the Red River Valley of Manitoba (both wind and water-eroded). Excessively tilled Black Chernozemic soils, soils in the Peace River area, and organic soils in Manitoba are also subject to wind erosion risk.** Winter winds also threaten irrigated lands in row crops near Lethbridge, Alberta. PFRA (1983, #58) estimates place wind erosion losses on the Prairies at 160 million tonnes of topsoil per year. This is equivalent to the loss of an additional 41,400 tonnes of wheat (8% of Prairie crop production) each year.

---

* One hectare equals 2.47 acres.

** Chernozems are well- to imperfectly-drained mineral soils of good structure. They develop in areas of cool to cold, and subhumid to subarid continental climates, typically on grasslands or in the grassland-forest transition. Black and Brown Chernozems constitute the most productive and extensive soil on the Prairies.

Recent complacency about wind erosion risks has led to abandonment of many erosion control practices adopted after the Dust Bowl (Bennett, 1982). Strip cropping for example is less frequently used now. Where they are used, strips are now generally wider than previously to accomodate modern machinery. These changes come at the expense of their erosion-resisting capabilities. In addition, more land has been put at risk by recent improvements in markets for wheat and rapeseed and uncertainty in the beef industry. Together, these changes have encouraged field crops, as opposed to forage production. Some marginal lands previously under permanent grass have now been put in crops. Coote, Dumanski, and Ramsey (1981, #19) attribute the increasing frequency of dust storms on the southern Prairies to these changes. On the other hand, the current trend to increased adoption of conservation tillage and reduced summerfallow (in Alberta and Manitoba) may tend to reduce the wind erosion risks there. For the future, climatic change is a major unknown quantity. Drier conditions would likely influence wind erosion, as well as encourage increased summerfallow usage and its consequences.

#### 2.1.5 Causes

Erosion, by both water and wind, is often made more likely by certain farm management practices on the Prairies (PFRA, 1983, #58; Campbell and Biederbeck, 1980, #11; Lindwall and Dubetz, 1984, #40):

1) Intensive tillage (the major cause)--reduces resistance to erosion through soil organic matter loss. Fall tillage to incorporate fall-applied fertilizers and pre-emergent herbicides and to prepare the soil for early spring seeding is a significant cause of these losses (Kirkland and Austenson, 1978).

2) Overworked summerfallow (8 or 9 tillages per cycle)--causes the destruction of trash cover and loosened soil. Summerfallow is very extensively used on Canada's Prairies, especially in Saskatchewan (Table 2.1).

TABLE 2.1:

AGRICULTURAL LAND USE, PRAIRIES, 1981 (HECTARES)

| LAND USE | TOTAL | MANITOBA | SASKATCHEWAN | ALBERTA |
|---|---|---|---|---|
| Cropped Land | 24,603,013 | 4,420,466 (18.0%) | 11,741,121 (47.5%) | 8,441,427 (34.3%) |
| Fallow (% Fallow of cropped and fallow) | 9,508,493 (27.9%) | 598,351 (11.9%) | 6,704,611 (36.3%) | 2,205,516 20.7%) |
| Improved | 37,714,142 | 5,504,101 | 19,684,286 | 12,525,756 |
| Unimproved | 14,958,572 | 2,111,996 | 6,263,778 | 6,583,198 |

SOURCE: Statistics Canada (1982).

3) Larger machinery--tends to scalp knolls and encourage fast operation, which pulverizes soil, as well as contributes to increased field and vegetative strip widths.

4) Special crops--tend to leave insufficient residues (e.g. hardy row crops).

5) Use of marginal land sensitive to erosion--to increase crop production.

6) Baling and burning of straw (Biederbeck et al., 1980).

According to Batie (1983, #3), conservation is often discouraged by the following factors:

1) Forgone income associated with adoption of wise soil management.

2) Cost of fertilizers and herbicides.

3) Farmers' failures to see the need.

4) Lack of a land ethic.

5) Lack of confidence in current conservation measures.

6) Desire for clean fields and straight rows.

7) Expectations that the land (even if heavily eroded) will continue to increase in value.

8) Leasing arrangements for land which provide no incentive for soil conservation practices.

### 2.1.6 Consequences

Erosion re-distributes soil particles and transports or removes primarily the necessary organic matter and fine mineral fractions (Coote, 1983, #17; PFRA, 1983, #58; Anderson and Gregorich, 1984, #1). The resulting topsoil losses and changes may result in the following:

1) Reduced soil water-holding capacity.
2) Retarded root development.
3) Degraded soil structure.
4) Difficult seedbed preparation.
5) Uneven and locally-reduced crop growth.

6) Reduced yields through lower soil productivity and mechanical crop damage.

Gully development from water erosion of susceptible soils may make farming of adjoining fields difficult or uneconomic. Silt may block drainage ditches or fill in downstream reservoirs. Water erosion also causes sedimentation and chemical pollution of streams and lakes (Crosson, 1981, #20). Siltation may reduce light penetration, reducing aquatic productivity, and interfering with fish spawning and egg survival. Attached pesticide residues and nutrients (e.g. phosphorous) may degrade water quality for aquatic life and humans and increase aquatic productivity (i.e. eutrophication). Dust from wind erosion causes temporary air pollution and discomfort and respiratory ailments.

PFRA (1983, #58) has estimated that fertilizer inputs to replace lost production due to water and wind erosion on the Prairies cost $101 million and $138 million respectively each year (at 1982 prices). Additional costs of $54 million and $75 million respectively per annum represent forgone yield--these cannot be recovered. The costs, which total $368 million, grow by $5.6 million each year. PFRA considers these estimates to be conservative, since they do not include the cost of increased power requirements, damage to growing crops, loss of cropland, etc.. Others have questioned PFRA's estimates, however, because of assumptions in the soil loss equation which are based on conditions on the US Great Plains (e.g. Stewart, 1985a; Kachanowski and de Jong, in press).

Erosion impacts and costs occur even though Leskiw and Bentley (1983, p. 12) have noted that:

> Soil scientists, and superior farmers, now know that technically soil deterioration by erosion is largely unnecessary and therefore inexcusable.

## 2.2 Loss of Organic Materials and Fertility

### 2.2.1 Processes, Causes, and Consequences

Loss of soil organic matter begins with clearing and tillage of the land. Increased activation of soil microbiological action reduces the soil's organic matter (Coote, 1983, #17). This results in depletion of the most easily decomposed "organic fractions" and the release of mineral nutrients, mainly nitrogen, for crop uptake or leaching. Overgrazing, burning, erosion, and intensive cropping of irrigated soils may also encourage organic matter loss (Coote, Dumanski, and Ramsey, 1981, #19).

The "present cropping system," generally emphasizing summerfallow and intensive tillage, has the following range of impacts relevant to soil organic materials and fertility (McGill et al., 1981, #48; PFRA, 1983, #58; Campbell and Biederbeck, 1980, #11):

1) Reduction in the capacity of organic matter to provide plant-available nitrogen (mineralization rate). Both actual mineralization and potentially mineralizeable nitrogen have declined (Campbell, Paul, and McGill, 1976, #13).

2) Decreased availability, and thus decreased uptake, of native soil nitrogen for crops.

3) Increased fertilizer requirements to maintain yields (Beaton, 1980, #5).

4) Loss of available nitrogen through leaching to below the root zone (Rennie, Racz, and McBeath, 1976, #62), denitrification (losses of nitrogenous gases to the air), and erosion (thus water pollution). Rennie (1983) estimates $16 billion worth of nitrogen has been lost in Saskatchewan alone since settlement.

5) Reduction in soil aggregate stability and tilth (Allison, 1973).

6) Reduced soil moisture storage, because of lack of water infiltration due largely to a lack of surface residues and poorer soil structure.

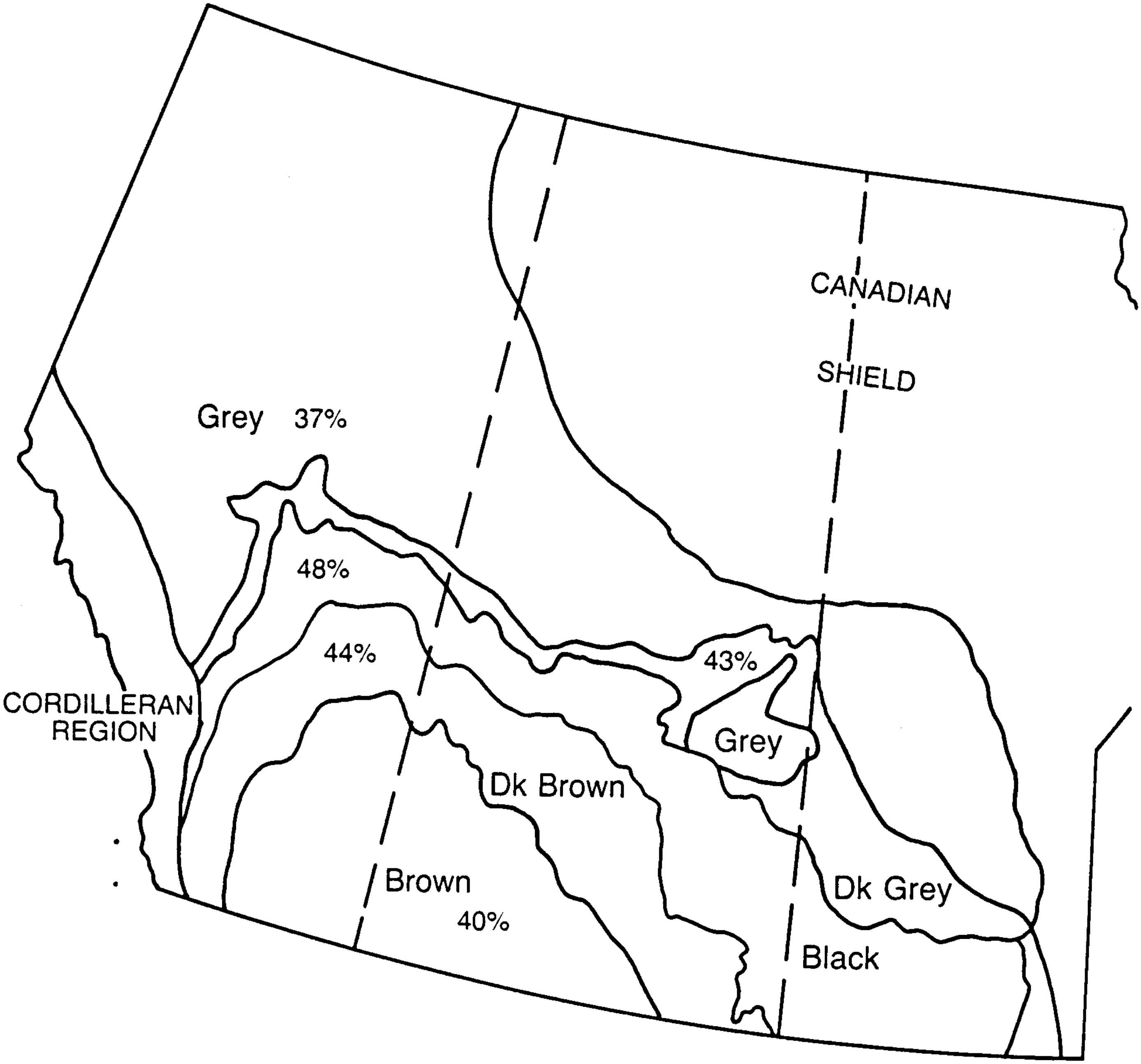
7) Loss of the ameliorating effects of organic matter on aluminium toxicity in acidic soils.

Crop systems which remove most plant material are destructive of soil organic matter content. Conversely, conservation (reduced) tillage systems tend to maintain organic matter levels.

### 2.2.2 Location, Extent, and Trends

Prairie soils have lost about 45% of their original levels of organic matter since cultivation began--in all, about 700 million tonnes (McGill et al., 1981, #48). This has already had a major adverse effect on the soil nitrogen level and perhaps also on sulphur and micro-nutrients (Rennie, Racz, and McBeath, 1976, #62). Proportional losses of carbon from the "A" or uppermost horizon appear to have been highest in Manitoba (50%) and in the Black Chernozem soil zone (51%) and lowest in Alberta (42%) and in the Grey Luvisol soils (37%; see Figure 2.3). Coote, Dumanski, and Ramsey's (1981, #19) map of soil organic matter loss risk shows that most of Saskatchewan's cropland and much of southeastern Alberta's are at high risk. Most of the Prairies, including the Peace

## FIGURE 2.3:
## SOIL ORGANIC MATTER LOSSES FROM 'A' HORIZONS, BY SOIL ZONE, PRAIRIES




SOURCE: Mc Gill, Campbell, Dormaar, Paul, and Anderson (1981,#48), p. 80.

River area, are in fact at moderate or greater risk of soil organic matter loss, considering current (1976) crop distribution. The north-central portion, where precipitation is higher, is in less danger due to greater continuous cropping of cereals and oilseeds.

The slow but general trend to increased use of row crops (e.g. corn for silage) may lead to increased organic matter loss (Coote, Dumanski, and Ramsey, 1981, #19). The further adoption of conservation tillage techniques will most likely have the opposite effect (Campbell and Biederbeck, 1980, #11).

## 2.3 Loss of Organic Soils

Organic (or peat) soils form from decaying plant materials in bogs and marshes where decomposition proceeds more slowly than accumulation (Coote, 1983, #17). Drainage and agricultural use reduces accumulation and areates the soil, thus speeding up decomposition. Organic soils also shrink (subside), lose buoyancy, and are compacted by machinery. Organic soils, if improperly farmed, can become very susceptible to wind and water erosion.

A small area of organic soils is found in southeastern Manitoba to the north and east of the Prairie grassland (Coote, 1983, #17; Coote, Dumanski, and Ramsey, 1981, #19). There, clearing of organic soils often involves burning to get rid of all or part of organic materials and to incorporate peat ashes into the soil (Michalski, 1981, #50). In areas intended for cereals or hay, these soils have considerable problems of trafficability and nutrient immobilization.

## 3.0 CHEMICAL DETERIORATION

Three major types of chemical deterioration occur on Prairie soils:

1) Salinization (discussed in section 3.1).
2) Acidification (3.2).
3) Contamination (3.3).

### 3.1 Salinization

Several distinct types of phenomena are sometimes discussed as salinity. Many soils may be said to exhibit "primary" salinity; these are geologically saline and have not had productive capacity in the agricultural era. Solonetzic soils are an example (reviewed in section 3.1.5). The discussion below (3.1.1 to 3.1.4) focusses on secondary or man-induced salinity in dryland farming. Dryland salinity may occur as a spread of salinity, or the development of newly saline soils where surface soils were not previously affected (Anderson et al., 1984). Salinity problems are also associated with irrigated fields, although methods for solution of this situation appear simpler in these cases (section 5.4.7 below).

#### 3.1.1 Processes

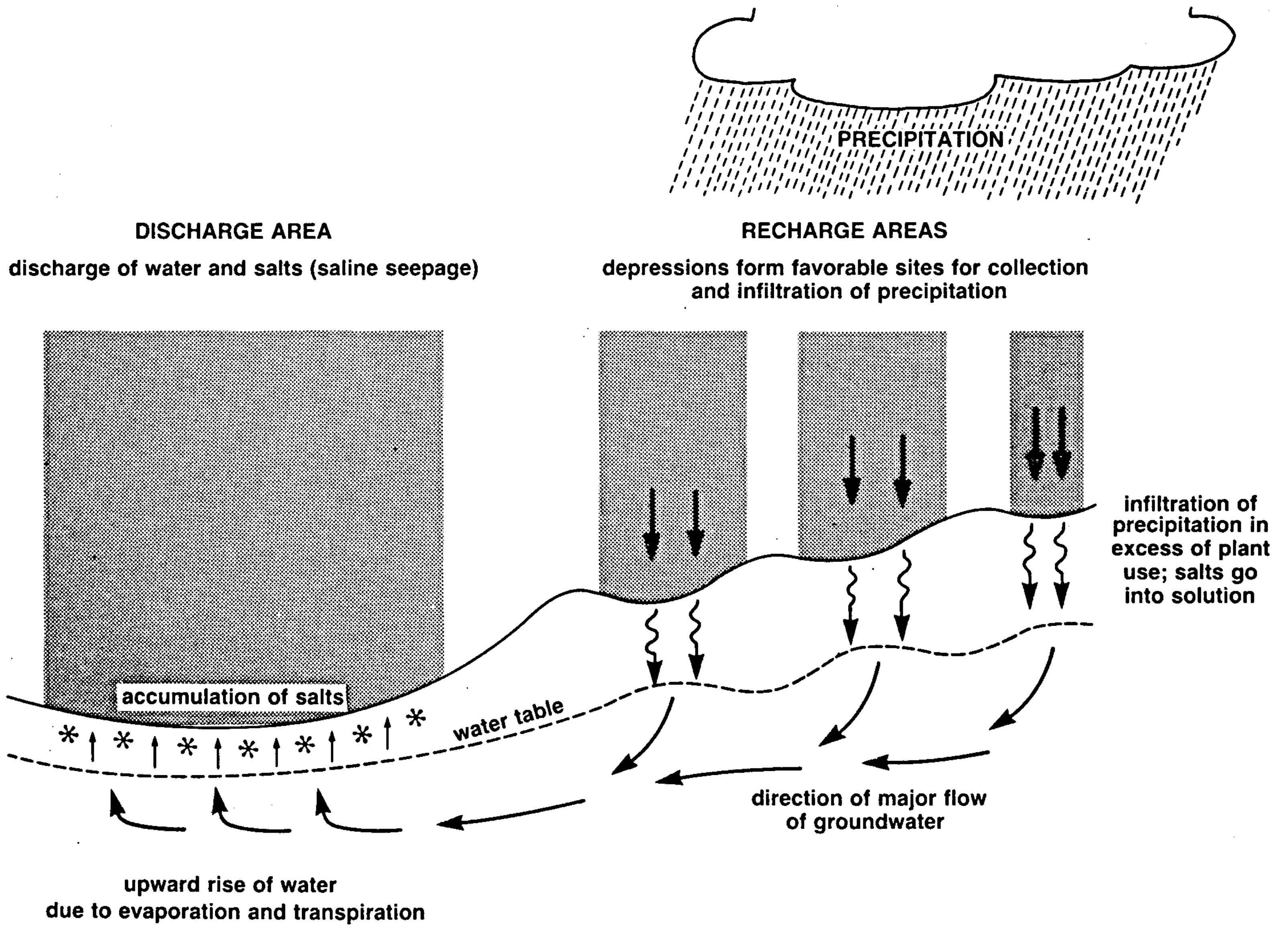
One method by which salinity occurs has been emphasized by the recent literature. Saline seeps result from rainfall and snow melt on an upslope position (or recharge area) in excess of crop requirements (Henry and Johnson, 1977, #31). This excess water percolates down through the soil until it reaches an impermeable or slowly permeable subsoil layer (Figure 3.1). Then, it flows along the layer, picking up salts as it goes. It may reach a point at which the water table is close to the surface, whether within the same field or several miles away. If the water table at this point reaches a level close to the surface, especially in periods of high rainfall or runoff, salt-laden water can rise to the surface by capillary action. Such water then evaporates leaving salts at the surface--often a white salt crust appears. In hot, dry periods, and under summerfallow, salts can accumulate very rapidly. Thus, local geology, surface topography, salts from glacial tills, and the semi-arid climate of parts of the Prairies create the necessary conditions for saline seeps (Hendry and Shwartz, 1982). Weather and summerfallow may determine the speed and extent of the growth of seeps.

While saline seeps are likely responsible for most salinity in Alberta, there are other potential explanations. Recent work in Saskatchewan has suggested that at least the following additional processes are important causes of salinization (Henry et al., 1985):

1) Artesian salinity--artesian pressure bringing water and salts to the surface.
2) Local recharge--from sloughs or local depressions.

Of 29 study sites examined in this Saskatchewan research project, only one was a saline seep. Artesian salinity was found to be responsible for 18 of the 29 sites and was

## FIGURE 3.1:
## FORMATION OF A SALINE SEEP




SOURCE: Lilley (1982,#38), p. 7.

thought by Henry et al. (1985) to be the dominant cause of salinity in Saskatchewan.

Saline soils tend to stay wet for long periods. Salt accumulations interfere with plant germination, establishment, and growth, starving the plant of water and nutrients, due to the high osmotic pressure of the salt-laden water.

3.1.2 Location, Extent, and Trends

Although naturally saline areas (e.g. solonetzic) pre-date agriculture, man-caused saline patches first appeared on the Prairies in the 1940s. The Prairie Farm Rehabilitation Administration (PFRA, 1983, #58) indicates that most of the currently cultivated area (including the Peace River area and other areas of agricultural growth) are at risk of salinity development. Vander Pluym, Paterson, and Holm (1981, #67) have conservatively estimated that at least 4% of all Prairie cropland and rangeland, or 2.2 million hectares, were affected by dryland saline seeps by the mid-1970s (Manitoba 7.2%; Saskatchewan 6.6%; PFRA, 1983, #58). (About 1.5 million hectares of this area was under cultivation.) Although most patches are less than 10 hectares in area, on some farms replacement land has had to be purchased to maintain an economic farm unit. In some districts, as much as 16% of the area was salinized as long ago as 1973 (McCracken, 1973).

Virtually all Prairie soils are at some risk of salinization according to Coote, Dumanski, and Ramsey (1981, #19). The most extensive and severely affected lands are in south-western Alberta (approximately Vulcan to Warner), the south-western plains of Manitoba, and in Saskatchewan in the Quill Lakes (Yorkton to Watrous) area east of Saskatoon, as well as in the south-east near Weyburn. In addition, over 100,000 hectares or about 25% of all irrigated land, almost all in southern Alberta is considered salinized to some degree. Older irrigation districts are the most affected. Anderson et al. (1984) also note the large area of solonetzic soils, more than 7% saline, from Vegreville to Hanna, southeast of Edmonton. It is worth noting here that as yet neither of the maps, which these descriptions are based upon, is considered definitive. It is currently expected that by the end of 1985, the Land Resource Research Institute of Agriculture Canada will have available for all of Canada more detailed and accurate maps of the risk of salinization and other degradation problems.

There appears to be considerable controversy over the rate of expansion of seep areas. PFRA has forecast 10% per annum increases, yet Vander Pluym, Paterson, and Holm (1981, #67) predict imminent stabilization of the total salinized area. Anderson et al. (1984) and Stewart (1985a) each suggest 1% as a more "reasonable" estimate. Recent reductions in summerfallow area in Alberta and Manitoba may somewhat reduce seep area increases there, although a time lag might be expected in changes in the rate of salinization.

Irrigation-caused salinity in Alberta is increasingly controlled by significantly improved water distribution and use and by subsurface drainage.

3.1.3 Causes

While salinity may occur naturally, such areas tend to be static in size. Natural recharge to groundwater is generally low on the Prairies, indeed almost non-existent (Vander Pluym, Paterson, and Holm, 1981, #67). Typically, saline seeps occur due to the replacement of perennial native grasslands with annual grain crops. This alters the quantity of recharge and thus groundwater levels and flow patterns (Coote, 1983, #17). Grains, especially those grown with short fallow rotations, use less water and have shallower rooting systems (figures 3.2 and 3.3). The extensive use of summerfallow, which most often accompanies grain production is the major man-induced cause of salinity (Figure 3.4). Fallowed land retains for the following growing season only 25% of the moisture received. Alterations to groundwater recharge may also be caused by the construction of railways, roads, irrigation canals, dugouts, urban areas, and the creation of barriers (e.g., fences, shelterbelts, etc.); by over-irrigation or poorly managed irrigation; and by over-grazed rangeland and clear-cut forests (Coote, 1983, #17; Vander Pluym, Paterson, and Holm, 1981, #67). There is also concern about the potential impacts on salt movement related to surface mining (Hermans and Goettel, #32).

### 3.1.4 Consequences

PFRA (1983, #58) estimates that in 1982 farm income losses due to productivity reductions caused by salinity reached $257 million in total. Assuming a 10% increase per annum in saline area (see below), it projects income losses cummulating to a further $931 million by 1990, and $4.4 billion by 2000.

Vander Pluym, Paterson, and Holm's (1981, #67) estimate of losses for western Canada is even greater--$36.5 million per year, although only $5.5 million of this is from cultivated dryland. The rest is from irrigated areas ($15 million) and rangeland ($16 million). Total loss to the farm and business community exceeds $186 million per year. In addition, the land lost to salinity has resulted in a real estate loss to date of an astounding $3.0 billion.

Often farm operations on saline areas must be avoided in order to prevent bogging down equipment. This may cost the farmer time and create delays. Thus cultivation and harvesting costs may be increased and the harvest delayed, increasing the danger of frost and snow damage.

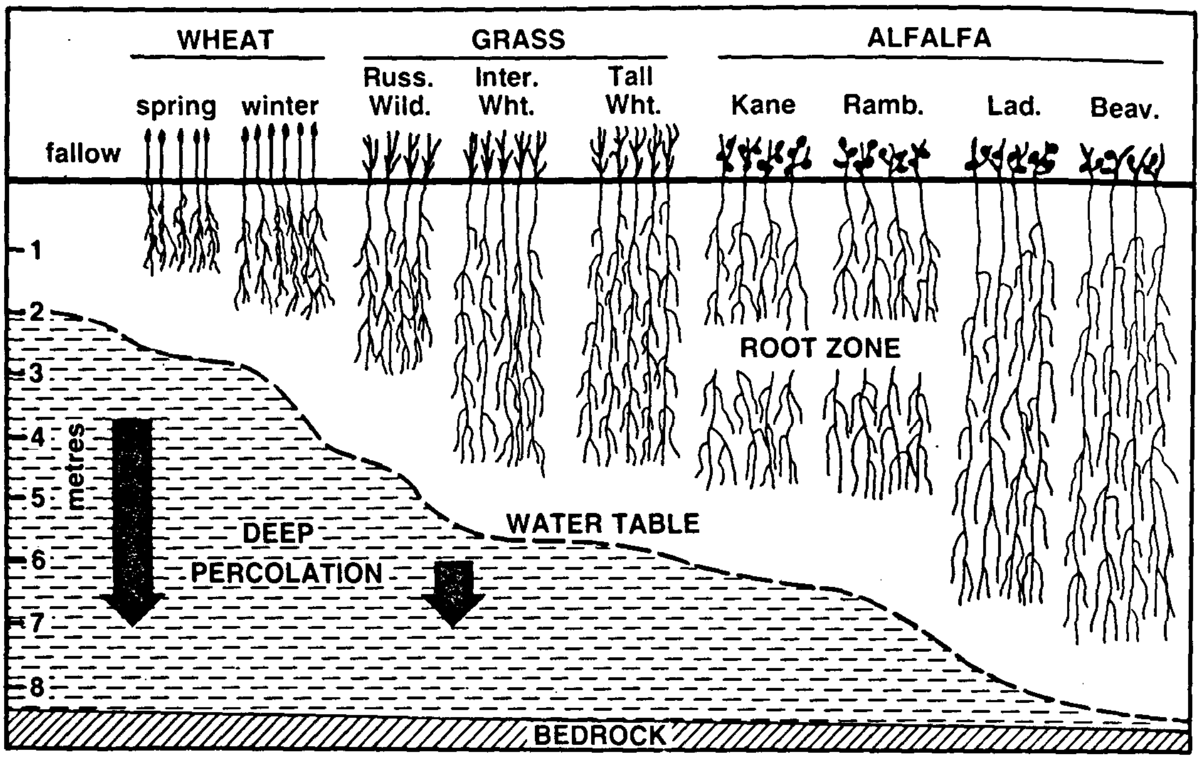
While controversy about the rate of salinity expansion may well invalidate the above estimates, the recent Senate Committee hearings on soil degradation concluded that salinity is the major soil degradation issue on the Prairies, due to the high economic costs (Canada/Standing Senate Committee on Agriculture, Fisheries, and Forestry, 1984, #14).

Potentially high nitrate, sodium, and other chemical concentrations in saline seep water represent a possible health hazard to livestock and humans (PFRA, 1983, #58). Numerous fish and livestock kills have occurred (Miller et al., 1981). In addition, seeps may accelerate eutrophication in nearby down-slope reservoirs by the delivery of nutrients; algae toxic to wildlife and livestock may develop due to seep water.

### 3.1.5 The Case of Solonetzic Soils

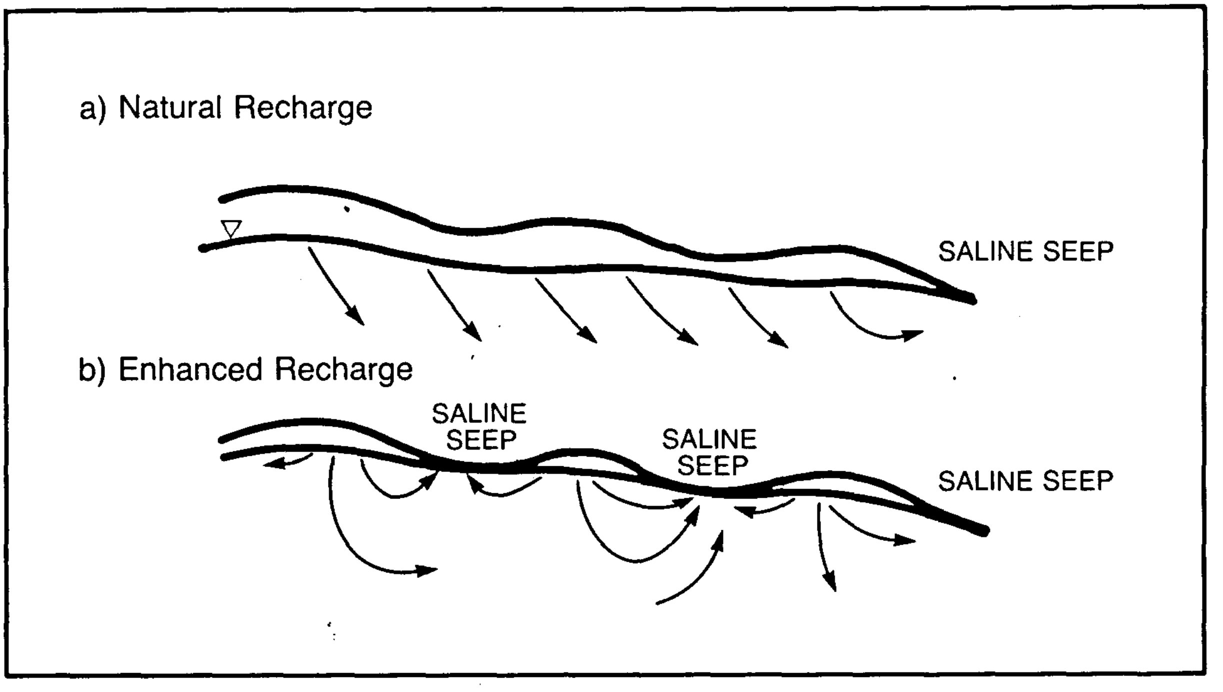
Solonetzic soils are a broad group of hard-pan soils occurring naturally on soil formed from materials high in sodium salts (Hermans and Palmer, 1982, #33; Cairns and

## FIGURE 3.2:
## ROOTING AND WATER TABLE DEPTHS WITH WHEATS, GRASSES, AND ALFALFA



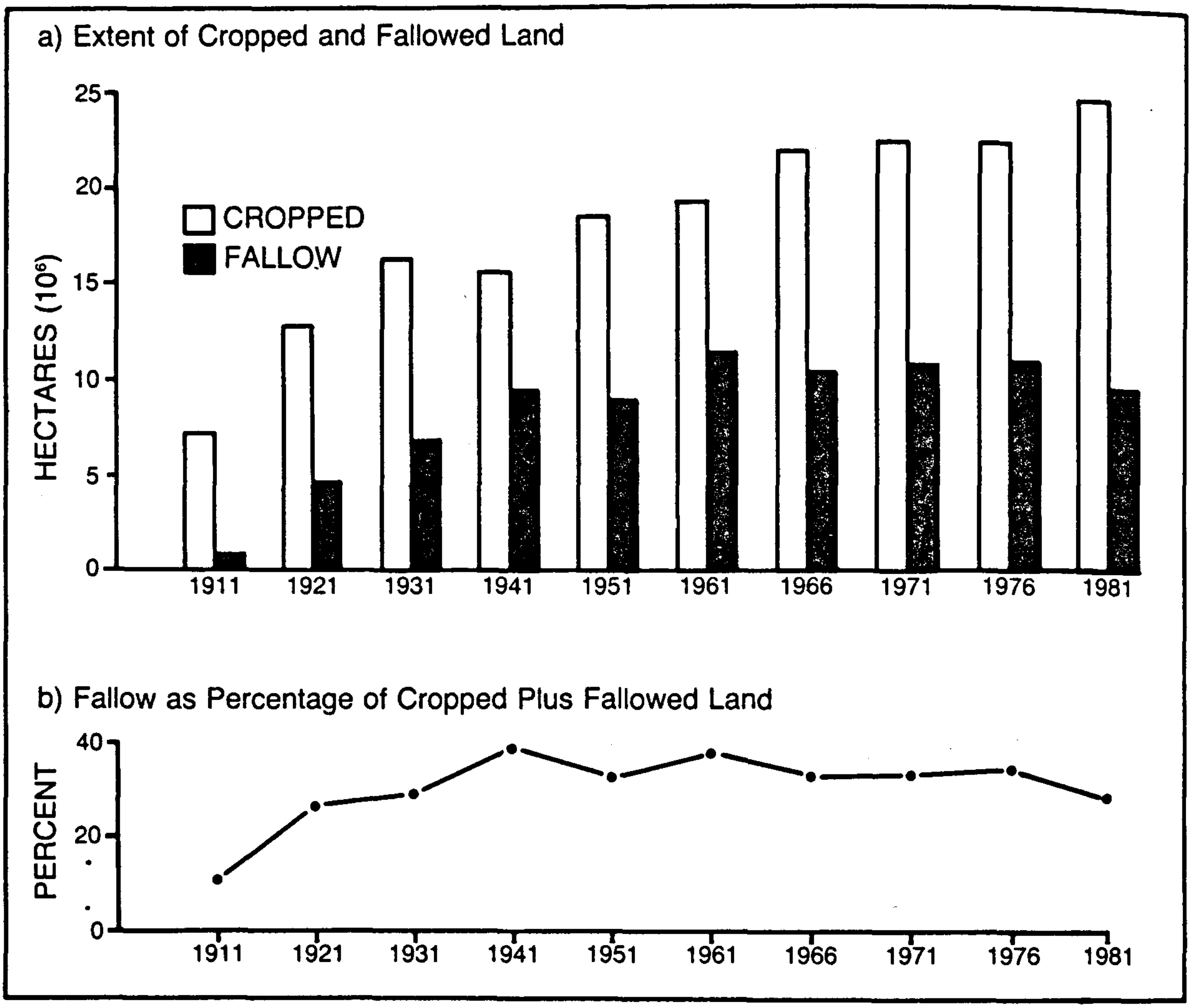

SOURCE: Vander Pluym (1982,#66), p. 16.

## FIGURE 3.3:
## EFFECT OF CHANGING RECHARGE RATES ON THE FORMATION OF SALINE SEEPS




SOURCE: Hendry and Schwartz (1982), p. 38.

## FIGURE 3.4: EXTENT AND PROPORTION OF SUMMERFALLOW, PRAIRIES, 1911-1981




SOURCE: Biederbeck, Robertson, and Mc Kay (1981,#6), 271; Statistics Canada (1982).

Bowser, 1977, #8). Impacts on productivity and management differ, because of different management and due to the three types of Solonetzic soils--solod, solodized solonetz, and solonetz--each with differing characteristics, due to the extent of leaching which has occurred. Often called burn-out or blow-out soils, their tough, impermeable clay pan at 5 to 30 or more centimetres (0.39 inch to the centimetre) below the surface restricts water and root penetration and water availability. It also makes seedbed preparation difficult. Crop yields are limited by quantity of salts, poor physical conditions, low fertility, and the association of acid conditions. The tendency for Solonetzic soils to be found in complex associations in a single field often results in uneven growth in the field.

About 6 to 8 million hectares of Solonetzic soils mark flat terrain areas of the grasslands and parklands (Cairns and Bowser, 1977, #8). Often the landscape is potmarked with shallow pits (PFRA, 1983, #58). The condition is widely scattered across the Prairies (Figure 3.5). It is most notable in the area from Vegreville to Taber in eastern Alberta, in the Peace River area, along the American border in south-western Saskatchewan and south-eastern Alberta, around Weber in Saskatchewan, and around Winnipeg. Almost three-quarters of Solonetzic soils are found in Alberta, where they constitute about 30% of the arable land (Toews, 1973).

## 3.2 Acidification

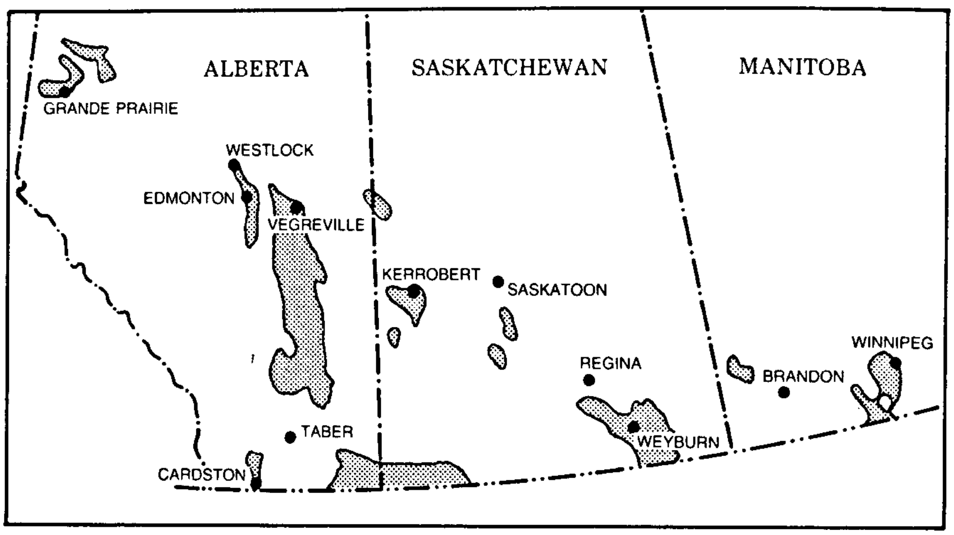
### 3.2.1 Processes and Causes

Acidification is the process by which bases are removed from the soil exchange complex and replaced by hydrogen and aluminium (Coote, Dumanski, and Ramsey, 1981, #19). The impact of acid additions to the soil is related to its acid-alkaline balance and its buffering capacity (Hoyt, Nyborg, and Ukrainetz, 1981, #34). Acidity is generally expressed by the pH level, a logarithmic value from 1 to 14, centred on 7.0; acidic soils are generally defined as having pH less than 6.0.

In general, the current acidity of Prairie soils is still largely determined by soil parent materials. Parts of the Prairies (e.g. eastern Saskatchewan) in fact have high pH values which provide considerable buffering (Rostad, Kiss, and Anderson, 1983). The rapidly increasing use of fertilizer containing ammonium or urea, which have strong acidifying actions, is the major human cause of increases in acidity of Prairie soils (Hoyt, Nyborg, and Ukrainetz, 1981, #34). For example, the use of nitrogen fertilizers in Alberta increased fourfold in the 1970s.

In addition, industrial emissions, especially of sulphur dioxide from large natural gas processing plants, smelters, and coal-fired thermal power and other plants in Alberta, enter the soil both through acid precipitation and direct absorption from the air. Low frequency of rains and the use of low-sulphur-content coal, however, tend to make industrial emissions of little import on the Prairies at present (Webb, 1982, #68). Coote's (1983, #17) estimate, based on the relative contribution of fertilizers and atmospheric sources, indicates that fertilizers are presently responsible for

**FIGURE 3.5:**
**MAIN SOLONETZIC AREAS, PRAIRIES**




SOURCE: PFRA (1983,#58), p. 216.

93%, 100%, and 96% of increased acidity in Manitoba, Saskatchewan, and Alberta respectively. A projected six-fold increase in the use of coal by 2006 though may make acidity from this source more significant (Webber and Warne, 1979).

The removal of bases through harvesting is also a contributor to increased soil acidity (McGill, 1982, #46; PFRA, 1983, #58). Deep ploughing of soils with acidic subsoils (e.g. Grey Luvisols) may also tend to increase soil acidity (PFRA, 1983, #58). Erosion may increase or decrease soil acidity, depending on the subsoil; for example, Grey Luvisol soils tend to become more acid.

Most agricultural crops grow best in neutral pH soils. Low clay and organic matter content makes soils especially sensitive to acidification. Slightly acid soils (pH = 5.5 to 6.5) are the most sensitive to lowered pH. When soil pH reaches 5.5 or less, toxic reactions to soil aluminium (which is more soluble at low pH) may affect the productivity of wheat, barley, rapeseed, and alfalfa; manganese toxicity may affect rapeseed. Soils with pH below 6.0 may also restrict the availability to plants of nitrogen, phosphorous, molybdenum, and other nutrients from the soil and fertilizers. It may also limit bacterial activity, thus reducing yields of legumes and some other crops (McGill, 1982, #46). In both cases, soil productivity is reduced, the amount depending on both the soil and the particular tolerance of the crop to acidity.

### 3.2.2 Location, Extent, and Trends

Most Prairie soils are naturally neutral, or even alkaline (pH greater than 7). Coote, Dumanski, and Ramsey (1981, #19) identify acidity to be of only "low risk" over most of the Prairies. Their risk assessment is based on the present soil pH and level of calcium carbonate and the acidity of atmospheric deposits. They identify several areas as at higher risk than the rest of Prairie soils: the low natural pH Grey Luvisolic, Grey Brown Chernozemic, Black Chernozemic, and Solonetzic soils in east-central Alberta; throughout the Peace River area; and in the north-western area of cultivated land in Saskatchewan near Meadow Lake and Lloydminster. Many of these areas have more than 15% of their soils with pH under 6.0 (Anderson et al., 1984). South-eastern Saskatchewan (Weyburn-Estevan) and the extreme south-west of that province (Consul-Bracken), as well as a small area near Dauphin, Manitoba, also have considerable amounts of acidic soils (Anderson et al., 1984; Hoyt, Nyborg, and Ukrainetz, 1981, #34).

Extensive soil testing by Penney et al. (1977, #56) in Alberta, where the problem is the most serious on the Prairies, shows that the proportion of soils with a pH of 6.0 or less varies considerably, from 5% or less in the southern portion to 31% in the Peace River area. They concluded that acidification is a problem of considerable importance in terms of reduced crop yields in that province, especially in the Peace River area. Hoyt, Nyborg, and Ukrainetz (1981, #34) have estimated areas of acid soils, based on soil samples taken in Alberta and British Columbia between 1962 and 1972. They found 530,000 hectares of cultivated land on the Prairies with pH less than 5.5 and an additional 1,825,000 hectares with pH of 5.5 to 6.0. About 23% of this estimated acid soil (pH = 6.0) is located in the Peace River area where 31% of soils are acid. Another 59% of the total is in the rest of Alberta and 17% in Saskatchewan.

There are large areas of cultivated land with pH between 6.1 and 6.5 (3.3 million hectares in 1972). In Saskatchewan, Rostad, Kiss, and Anderson (1983) found 6.6 million hectares with pH between 5.5 and 6.5. A further one million hectares, or 40% of that estimated above, likely became acid (pH less than 6.0) from 1972 to 1985. By 1996, about 48,000 hectares more are projected to become acidic from industrial sources alone.

### 3.2.3 Consequences

Crop responses to liming of acid soils on the Prairies (the preferred response--see section 5.5.1 below) demonstrate the potential for losses of soil productivity through acidity (Penney et al., 1977, #56). Even mildly acid soils (pH 5.5 to 6.0) have often been found to restrict significantly the growth of alfalfa, barley, clover, etc. on the Prairies. Collins (1982) has estimated that $85 million of production is lost annually in Alberta alone. However, no estimates of the total cost of soil acidification on the Prairies were found in the literature surveyed.

## 3.3 Soil Contamination

Deterioration of soil quality by additions (other than salts, sulphur, and nitrogen) may occur through spills and atmospheric fallout, sewage and industrial sludge disposal, pesticide residues, and biological contamination (Coote, Dumanski, and Ramsey, 1983, #19). In general, soil chemical contamination is not a serious problem on the Prairies, but McGill (1982, #46) notes that it is the interaction among chemicals which is likely to be the greater danger. For example, metals often increase in solubility as soils become more acidic. Also, the application of two pesticides in the same soil may change the persistence (and thus effects) of either.

### a) Spills and Fallout

Spills from oil pipelines and wells cause some soil contamination problems on several hundred hectares per year in Alberta and Saskatchewan (Coote, Dumanski, and Ramsey, 1981, #19; McGill, 1982, #46). In 1979 for instance, there were about 600 oil and saltwater spills in Alberta, 110 of which were in excess of 1,260 barrels (Webb, 1982, #68). Spills may cause nutrient immobilisation through altering soil properties and killing soil organisms, may have toxic effects on certain crops, and may even interfere with water movement (McGill, 1982, #46; Webb, 1982, #68). The quality and quantity of groundwater may also be impacted by drilling for enhanced recovering systems, which utilize water to force oil from underground strata. Further problems are anticipated when farmers attempt to reclaim abandoned oil well sites, generally two hectares per quarter section. Reclamation procedures for such wells in the past often will not allow these lands to be returned to agricultural production. Burning of crude oil near wells and windblown dust (largely from stock piles at salt and potash mines) have also resulted in contamination of nearby soils (Canada Soil Fertility Committee, ca 1970; Coote, 1983, #17).

b) Sludge Disposal

Coote, Dumanski and Ramsey (1981, #19) warn that sludge disposal may become a problem in the vicinity of larger Prairie centres, particularly if industrial waste is included. Metals in sludges may have toxic effects on crops, animals, and humans (McGill, 1982, #46). Monitoring of sludge content and elimination of toxic elements is essential. Calgary, Regina, Saskatoon, Yorkton, and Winnipeg currently dispose of sludge on farmland (Webber, Schmidke, and Coehen, 1978). Many smaller communities with lagoon capacity problems also provide sewage water for irrigation (Canada Soil Fertility Committee, ca 1970).

c) Pesticide Residues

Residues of herbicides, insecticides, fungicides, nematocides, etc. in the soil may result in a variety of potential outcomes (McGill, 1982, #46):

1) Reduced plant growth in succeeding crops.

2) Residues bound to the soil, with subsequent release as a large toxic "pulse."

3) Disturbed soil biological processes.

4) Reduced biological control.

5) Metals in residues, which may be toxic to man and animals.

Generally, it is felt that there is as yet no pesticide residue problem of significance on the Prairies (McGill, 1982, #46; Coote, Dumanski, and Ramsey, 1981, #19). Persistent chemicals (e.g. the organochlorine pesticides) are by law or practice being applied in lesser amounts; biological decomposition is thus reducing their presence in the soils.

## 4.0 PHYSICAL DETERIORATION

Physical deterioration of land on the Prairies is caused by the following processes:

1) Soil compaction (discussed in section 4.1).

2) Mixing and disturbance (4.2).

### 4.1 Soil Compaction

Soil compacts when its structure deteriorates and the volume of air spaces is reduced. Compaction may be caused by the following (Coote, 1983, #17):

1) Repeated loading by heavy machines (wheel compaction).

2) The shattering of clods and vibrating smaller particles into denser arrangements by high speed tillage or deliberate shattering.

3) Loss of organic matter--the binding material (see section 2.2).

4) The squeezing of air out of the soil and collapsing of soil structure by working it when wet (decreased porosity).

Soil compaction interferes with root growth, reduces water movement in the soil (confounding drainage and increasing erosion), and increases energy requirements for tillage.

Normal tillage operations do not appear to be compacting Prairie soils (Cameron et al., 1981, #9). In fact, in dry conditions, some packing at seed level is practiced to improve seed emergence (Lindwall and Dubetz, 1977, #40). Areas of moderate relative risk are nevertheless scattered throughout the Prairies, especially in the Peace River area, the Red River Basin, and Saskatchewan (Coote, Dumanski, and Ramsey, 1981, #19). Wet soils, clay soils, and those with high water tables are most prone to machine-traffic related compaction.

### 4.2 Mixing and Disturbance

#### 4.2.1 Processes, Causes, and Consequences

Soil mixing and disturbance typically occur as a result of open surface mining for coal, sand, gravel, or stone and the installation of oil or gas pipelines (Coote, 1983, #17). Extensive coal deposits underlie agricultural land on the Prairies. Surface mining generally follows stripping topsoil and subsoil from the remaining overburden. There are a variety of practices for dealing with this soil. It may be either stockpiled (with subsoil separate or mixed) for land reclamation or placed on adjacent already mined areas. Regardless, the nature of subsoil material is altered drastically. Saline seepage may result and surface topography (and thus groundwater flows) may be altered. Grading and levelling are necessary before agricultural use. Due to the long periods of use and the extensive topographic changes caused by quarrying for sand, gravel, and stone, there is much less chance to reclaim the associated land for agricultural use. Other mining activities, for example potash, salt, gypsum, and silica result in only small areas of land disturbance (Coote, Dumanski, and Ramsey, 1981, #19).

Pipeline installations generally return mixed soil to the trench resulting in poorer yields for most crops. This appears to be attributable to lower soil organic matter, less nitrogen and available phosphorous, and poorer soil structure due to compaction (Culley et al., 1982). Prairie soils seem little impaired by this, however. Indeed, Solonetzic soils are often improved by the associated soil mixing.

4.2.2 Location, Extent, and Trends

In Alberta, coal mining currently is more a phenomenon of the foothills than the plains. Nevertheless, according to Hermans and Goettel (1980, #32), about 53% of proven reserves recoverable by surface mining and 90% of recoverable unproven reserves in Alberta are on the plains. Two-thirds of coal deposits in the central and southern districts of Alberta is located on Canada Land Inventory (CLI) classes 1 to 4 agricultural land; 21% on classes 1 and 2. Much of these deposits is in the central portion of the province, especially north-west and south of Edmonton.

Alberta has implemented strict controls, requiring rehabilitation of stripped lands for agriculture. Under Alberta's 1963 reclamation legislation, the emphasis in mine rehabilitation was on simple revegetation. Since the passage of the new act in 1973, the development of a suitable growth medium has been the focus of reclamation (Hermans and Goettel, 1980, #32). Proper handling of soil materials, including the separation and storage of top soil and subsoil and slope contouring, is now required and practiced. Mine reclamation is ensured by the 1973 legislation, which requires pre-development reclamation plan approval and inspection by the province's reclamation council (Brocke, 1985). In order to sell land after mining, certification from the province is required. Little land has been certified at these mine sites as yet.

Since the late 1940s, a total of about 3,500 hectares have been disturbed by the six significant coal strip mines now active on the plains of Alberta (Brocke, 1985). Two of these mines are located west of Edmonton (within 80 kilometres) in the Grey Luvisol soil zone. One of the mines is on former wildland; the other is on CLI class 3 to 5 land and was previously in a mix of forage and annual crops. The other four mines are within 300 kilometres south-east of Edmonton in the Solonetzic soil belt. They are also on class 3 to 5 land previously under annual crops and pasture. To date, about 1,900 hectares has been reclaimed in all. Both mining and reclamation had accelerated through the 1970s, although the market for coal has grown considerably more slowly since. In 1983, 206 hectares were disturbed and 205 hectares reclaimed in the six mines (Brocke, 1985).

Hermans and Goettel (1980) see much greater future strip coal mining activity--5,665 hectares per year by 2006, based on a dramatic increase in the domestic market over the next twenty years. They suggest disturbance of 28,000 hectares at any given time. In all, about 69,000 hectares will have been disturbed in Alberta between 1975 and 2004 (Hermans and Goettel, 1980, #32). Areas devoted to haul roads, rail lines, and associated buildings would at least again double these affected areas, although these lands would be subject to compaction and other degradation (more than to disturbance). Hermans and Goettel though seriously question whether land can be restored to equal productivity in the five years that these estimates assume. It is unlikely that all after-reclamation subsidence would be completed in that time. The cycle for mining, preliminary reclamation, and restoration of full agricultural production realistically appears to take about ten years (Coote, 1983, #17). Thus, they believe that the total of land disturbed at any given time will be even greater, perhaps doubled.

Recent downward trends in the rapid growth rate seen in the late 1970s, on which Hermans and Goetell's work has based, may suggest much lower future levels of disturbance. For example, Marshall (1982) projects annual disturbance of only 590 hectares per year between 1980 and 2000.

In Saskatchewan, the five active strip coal mines are located in agricultural regions. They are generally in areas producing wheat, but also on land previously utilized for forage, pasture, and old strip mines (McKechnie, 1985). Four are found in the traditional mining area at Estevan-Bienfait in the south-east and one has recently opened at Coronach in the south-central part of the province.

Since the 1930s, somewhat over 5,000 hectares have been mined in the Estevan basin; only about 1,000 hectares of this have been the subject of a reclamation effort (Douglas, 1979). Reclamation of any kind only began in Saskatchewan in 1971. The Provincial Government has recently issued reclamation guidelines for all of Saskatchewan's strip coal mines--in 1983 at the Coronach mine and in 1984 for the Estevan basin mines. These require that stripped lands with good capability for agriculture (CLI classes 1 to 4) should be returned to agricultural uses. Thus, all currently mined agricultural lands in Saskatchewan too are being reclaimed to agriculture. About 250-400 hectares of land are new newly disturbed for strip coal mining each year (McKechnie, 1985). Based on strong current demands for Saskatchewan coal, it is estimated that this amount will continue to increase to approximately twice these levels by 2000.

Few problems have been encountered with pipelines to date, although there are about 500,000 kilometres of "main line" alone on the Prairies. Continued construction of pipelines is a certainty. Based on experience in eastern Canada, construction in the more humid, northerly areas will be more likely to have adverse effects (Coote, 1983, #17; Shields, 1983).

Coote, (1983, #17) has estimated that 9,000 hectares have been disturbed by construction materials in each of Alberta and Manitoba, and 11,000 hectares in Saskatchewan. As was previously noted, there is little chance of "reclaiming" previously farmed lands for any further agricultural use after this type of mining occurs.

## 5.0 SOLUTIONS

Many technical or farm-level solutions to degradation problems have been suggested or examined in the literature surveyed. A summary list is found in Table 5.1. The methods proposed or evaluated often deal with one or more types of degradation and have additional independent advantages (e.g., yield enhancement). These solutions are discussed in turn in this chapter. Generally, the techniques are compared to conventional cultural practices, usually summerfallow with the associated extensive use of tillage for weed control. The chapter concludes with a discussion of the potential economic benefits of soil conservation.

These solutions may most often be seen to relate to several of the following:

1) prevention--stopping "it" from happening.
2) control--managing "its" effects.
3) rehabilitation--returning the soil to a more productive state.
4) management--of a natural condition (e.g. solonetzic soils, acidity).

Due to the nature of degradation problems and their solutions, there is no simple way to categorize the solutions into these categories. Table 5.2 indicates in general which measures may be used for which roles.

### 5.1 Wind and Water Erosion: Prevention and Control

#### 5.1.1 Conservation (Zero or Minimum) Tillage

Conservation tillage (CT) refers to alternative tillage systems involving less tillage of the soil--zero-till, minimum tillage, no-till, etc.. In no-till, for example, crops are planted directly into the untilled stubble of previous crops. In other CT systems, some tillage operations are maintained. These techniques generally "reduce the exposure of soil to the potentially erosive effects of wind and water" (Batie, 1983, #3). CT and its attendant phenomena--stubble mulch or trash management, reduced summerfallow, flex cropping, reduced monoculture of spring wheat, moisture conservation (by snow management for example), extended crop rotations, etc.--are by far the most frequently proposed reactions to a range of degradation problems, including erosion, organic matter loss, and salinization. CT substitutes chemical weed control and soil amendments for the mechanical tillage of summerfallow. It also generally involves continuous cropping or extended crop rotations, surface mulching with crop residues, and other necessary moisture management techniques. Strip cropping is also often used in combination with CT techniques (Goettel, Hermans, and Coote, 1981, #28; see 5.1.6 below).

Surface mulch of crop residues (trash management) reduces surface wind velocity and increases water infiltration (due to less surface sealing), therefore reducing erosion. These residues are least affected by the wide blade cultivator and sub-surface equipment; heavy-duty cultivation and

TABLE 5.1:

PROPOSED AND EVALUATED MEASURES FOR LAND DEGRADATION PROBLEMS

<table>
<tr><th colspan="2">Loss of Soil Materials</th><th>Chemical Deterioration</th></tr>
<tr><th>Wind and Water Erosion Control<br>(1)</th><th>Conservation of Organic Materials and Soil/ Efficient Use of Soil<br>(2)</th><th>Salinity Control<br>(3)</th></tr>
<tr>
<td>Conservation tillage, especially residue management (see also col. #2 and 3 moisture conservation; #58, 6, 7, 3, 28, 35, 65, 57, 20).<br><br>Chemical fallow (#6, 40).<br><br>Grassed waterways (#58).<br><br>Gully control (#58).<br><br>Terracing (#58, 21).<br><br>Windbreaks and shelterbelts (#58).<br><br>Contour farming (#58, 11, 3).<br><br>Strip cropping (#58, 3).<br><br>Cover cropping/"winter" cropping (#31, 58, 53, 51, 36, 35).<br><br>Forages and legumes in rotation (#58, 6, 46, 66, 48, 28, 22, 30, 49, 64, 57, 36).<br><br>Slot mulching (#58).<br><br>Removing erosion-sensitive lands from cropping (#3).<br><br>Full assessment of production systems.<br><br>Organic farming (see col.#2).</td>
<td>Conservation tillage (#58, 55, 40, 11, 6, 9, 64, 22, 35, 57, 59, 39, 44, 48, 60, 53, 54, 69, 35, 47, 26, 65, 41, 36, 49, 5, 7, 20; see col #1).<br><br>Forages and legumes in rotation (see col. #1).<br><br>Continuous cropping, extended rotations, or flex-cropping (reduced summerfallow; #58, 16, 62, 39, 13, 40, 53, 69, 35, 36, 70, 63, 49, 71).<br><br>Organic Farming.<br><br>Nitrification inhibitors/ fertilizer nesting and banding on irrigated soils (#48).<br><br>Organic soil management (#50):<br>--maintenance of high water tables (#17).<br>--winter flooding (#17).<br>--copper (#17).</td>
<td>Conservation and efficient use of soil moisture:<br>--residue management (see col. #1).<br>--snow management (#51, 58, 53, 11, 6, 63, 54, 52, 40, 7, 27, 39):<br>--windrowing.<br>--straw shaping/trap strips/swathing at alternate heights<br>--snow fencing.<br>--shelterbelts (see col. #1).<br>--crop barriers.<br>--winter cropping (see col. #1).<br>--flex-cropping or reduced summerfallow (#58, 6, 53, 11, 16, 40, 51, 55, 30, 70, 31, 57, 62, 66, 35, 36, 29; see col. #2).<br>--terracing (#21; see col. #1).<br>--irrigation from sloughs (#21).<br>--seedling management (#36, 40).<br>--contour farming (#58, 11, 3).<br><br>Convservation tillage (#35, 53, 31; see col #1).<br><br>Continuous cropping (#67, 38; see col. #2).<br><br>Cropping of recharge areas with deep-rooting, interceptor crops (forages; #58, 38, 31, 67, 66, 57).<br><br>Rotation of deep-rooting crops (#11, 16, 31, 3, 58; see Forages and legumes in rotation, col. #1).<br><br>Early detection of seeps (#58).<br><br>Weed control (#58, 31; see col. #2).<br><br>Fertilizer application in recharge and saline areas (#58, 11, 6, 31, 29, 36).<br><br>Salt-tolerant crops (#58, 31, 66, 67).<br><br>Surface drainage (#58, 67, 31, 67, 38, 66).<br><br>Management of excess snow (#58).<br><br>Land levelling (#38).<br><br>Full assessment of production systems.<br><br>Irrigation management:<br>--subsurface drainage (#58, 67, 38, 66).<br>--canal lining (#66).<br>--cut-off curtain (#66).<br><br>Management of solonetzic soils:<br>--deep ploughing (#58).<br>--deep subsoiling (#58).<br>--chemical application (#58, 31).<br>--crop rotations (#58).<br>--drainage (#58).<br>--tillage (#38).</td>
</tr>
</table>

TABLE 5.1:

PROPOSED AND EVALUATED MEASURES FOR LAND DEGRADATION PROBLEMS

| Other (4) | Physical Deterioration (5) |
|---|---|
| Acidification control:<br>- liming (#58, 46, 34, 10).<br>- acid-tolerant crops (#58, 34).<br>- application of organic materials (#58).<br>- deep ploughing (#34, 46).<br>- nitrification inhibitors/banding (#34).<br>- legumes (#34).<br><br>Oil contamination reclamation:<br>- oil - tillage, fertilizer, or drainage (#19, 46, 68).<br>- brine - calcium or organic additions or drainage (#68). | Compaction:<br><br>High flotation tires (#22).<br><br>Increased tractor power (#22).<br><br>Fibrous rooted plants (#17).<br><br>Conservation tillage (#9, 60).<br><br>Scheduling field work (#22).<br><br>Controlled wheel traggec (#9).<br><br>Deep tillage (#9). |

TABLE 5.2:

DEGRADATION SOLUTIONS AND THEIR POTENTIAL ROLES

<table>
<tr><th>Degradation Problems / Potential Roles</th><th>Prevention</th><th>Control</th><th>Rehabilitation or Management of a Man-Induced Problem</th><th>Management or Improvement of a Natural Condition</th></tr>
<tr><td rowspan="12">Erosion (5.1).</td><td colspan="2">Conservation Tillage (5.1.1).</td><td></td><td></td></tr>
<tr><td colspan="2">Chemical Fallow (5.1.2).</td><td></td><td></td></tr>
<tr><td colspan="2">Windbreaks and Shelterbelts (5.1.3).</td><td></td><td></td></tr>
<tr><td colspan="2">Grassed Waterways, Gully Control, and Terracing (5.1.4).</td><td></td><td></td></tr>
<tr><td colspan="2">Contour Farming (5.1.5).</td><td></td><td></td></tr>
<tr><td colspan="2">Strip Cropping/Contour Cropping (5.1.6).</td><td></td><td></td></tr>
<tr><td colspan="2">Cover Cropping/"Winter" Cropping (5.1.7).</td><td></td><td></td></tr>
<tr><td colspan="2">Forages and Legumes in Rotation (5.1.8).</td><td></td><td></td></tr>
<tr><td colspan="2">Slot Mulching (5.1.9).</td><td></td><td></td></tr>
<tr><td colspan="4">- - - -Removing Erosion Sensitive Lands from Production (5.1.10). - - - -</td></tr>
<tr><td>Full Assessment of Production Systems and Crops (5.1.11).</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Organic Farming (5.2.2).</td><td></td><td></td></tr>
<tr><td rowspan="8">Loss of Organic Materials and Soils (5.2; 5.3).</td><td colspan="2">Conservation Tillage (5.1.1).</td><td></td><td></td></tr>
<tr><td colspan="2">Forages and Legumes in Rotation (5.1.8).</td><td></td><td></td></tr>
<tr><td colspan="2">Extended Rotations, Flex-Cropping, and Continuous Cropping (5.2.1).</td><td></td><td></td></tr>
<tr><td colspan="2">Organic Farming (5.2.2).</td><td></td><td></td></tr>
<tr><td colspan="2">Nitrification Inhibitors/Nesting and Banding on Irrigated Soils (5.2.3).</td><td></td><td></td></tr>
<tr><td colspan="2">Maintenance of High Water Tables (5.3).</td><td></td><td></td></tr>
<tr><td colspan="2">Winter Flooding (5.3).</td><td></td><td></td></tr>
<tr><td colspan="2">Copper Fertilizer Supplement (5.3).</td><td></td><td></td></tr>
</table>

| | | | |
|---|---|---|---|
| Salinity (5.4). | Early Detection of Seeps (5.4.2).<br>Soil Moisture Management (5.4.1):<br>--snow management.<br>--irrigation from sloughs.<br>--reduced tillage for seeding.<br>--interceptor cropping of recharge areas.<br>--crop rotation in recharge areas.<br>Early Detection of Seeps (5.4.2).<br>Fertilizer Application (5.4.3).<br>Surface Drainage (5.4.5).<br>Land Levelling (5.4.6).<br>Irrigation Methods (5.4.7):<br>--subsurface drainage.<br>--canal lining/cutoff curtains. | Salt-Tolerant Crops (5.4.4). | |
| Solonetzic Soils (5.5). | | | Deep Ploughing (5.5.1).<br>Chemical Applications (5.5.2).<br>Crop Rotations, Drainage, and Tillage (5.5.3). |
| Acidity (5.6). | - - - - - - - Liming (5.6.1). - - - - - - - - - - - - - - - - - - - - - - - -<br>Nitrogen inhibitors, fertilizer nesting and banding, legumes, organic matter additions (5.6.3). | Acid-Tolerant Crops (5.6.2).<br>Deep Ploughing (5.6.3). | |
| Contamination (5.7). | Organic Farming (5.2.2). | Oilspills--nutrient addition, tillage, drainage (5.7). | |
| Physical Deterioration (5.8). | High Flotation Tires.<br>Increased Tractor Power.<br>Rotations with Fibrous-Rooted Plants.<br>Proper Tillage.<br>Controlled Wheel Traffic.<br>Conservation Tillage(5.1.1). | Deep Tillage. | |

disc-type implements tend to remove more residue (Anderson, 1961; Fenester et al., 1965). Standing, as opposed to flattened, residues are more effective against wind erosion (Woodruff and Siddoway, 1973). Siltation (but not necessarily nutrient pollution) of receiving streams by residues is also reduced in CT (Baker and Laflen, 1983, in #65). Unger and McCalla (1980) report CT crop yields similar to those from conventional tillage fields, although yields may be higher in dry conditions and lower under cool, moist conditions. Long-term yields can be expected to be significantly higher for CT, due to lower levels of erosion (Crosson, 1981, #20). CT, however, generally requires higher levels of management skills, more knowledge of equipment and chemicals, and careful adjustment of tillage and seeding equipment. Efficient fertilizer application and vigilant, informed, and timely control of weeds and other pests are also necessary (Crosson, 1981, #20).

The literature is unclear if conservation tillage systems require more nitrogen fertilizer application than conventional tillage to produce similar yields (Crosson, 1981, #20; Witmuss, Olson and Laine, 1975). In CT, nitrogen fertilizer is applied at or near the surface. This may increase soil acidity in the top five centimetres. The liming required to counteract acidity adds to cost and mechanical operations. Further, lime is not currently easily or cheaply available on the Prairies.

Fertilizer applications under conservation tillage (because of much lower levels of water erosion) contribute less nitrogen, phosphorous, etc. to receiving streams (Crosson, 1981, #20). The key question nevertheless may be "how much pollution is there by plant-available nitrogen or nitrate, ammonia, and phosphorous?"--the last of which may produce increased eutrophication. Nitrate pollution also presents a health hazard for both humans and fish. Some studies show that eroded soil from CT fields contains higher amounts of "pollutants" which are plant-available. In sum, it is not clear whether conservation tillage is a greater or lesser water pollution threat. Rather this question depends on the degree of reduction of erosion which is acheived by CT.

The control of weeds, generally by herbicides versus tillage, is an essential aspect of CT; the degree of reliance on herbicides varies considerably. Johnson and Hennig (1976, #36, 367) state that:

> Maximum weed control in all crops represents the most positive and proven method of reducing nitrogen waste or possibly even losses.

Costs and management skills for herbicides are generally considerably higher in CT, mainly because the weed control effects of tillage must be replaced. Higher herbicide use is also required since (1) crop residues may tie up some of the chemicals and (2) increased weed growth accompanies the greater soil moisture (Crosson, 1981, #20). A greater percentage of perennial weeds in CT may also require a larger variety of herbicides. Insects and diseases may be more extensive, since crop residues represent favourable habitat for these pests. Surface residue may interfere with the application of pesticides. Crop rotation (e.g., cereals and oilseeds) may also be used to control weed problems (Biederbeck, Robertson, and MacKay, 1981, #6).

Overall, conservation tillage appears to have a cost advantage of 5 to 10% in areas of well-drained soil, adequate control of weeds, and potential for double-cropping (Crosson, 1981, #20). Significantly less labour (almost 50%) and less fuel (10-25 litres per hectare annually) are required for CT, but machinery costs are higher for farmers who wish to retain the conventional tillage option. It is not yet known how all crops on all types of soils respond to CT (Cosper, 1983, in #65).

The reduced tillage associated with CT appears to have less impact on field nesting birds such as pheasants and other wildlife and provides more habitat (Rodgers and Wooley, 1983, in #65). These findings appear true despite the greater chemical use. The problem of rodents digging and eating seeds and seedlings may thus be accentuated, however. Unfortunately too, higher fertilizer and pesticide inputs may damage the soils and the associated aquatic and terrestrial ecosystems (Rodale, 1984).

Less tillage tends to have a variety of other beneficial effects:

1) Reduced speed of organic matter decomposition and nitrogen release maintains the levels of these materials in the soil (Biederbeck, Robertson, and MacKay, 1981, #6).
2) Soil aggregation is maintained or improved (Biederbeck, Robertson, and MacKay, 1981, #6).
3) Surface compaction due to the weight of implements and tractor wheel slip is reduced (Davies, et al., 1973), although there is little evidence of soil compaction on the Prairies (Coote, 1981, #17; Coote, Dumanski, and Ramsey, 1981, #19).
4) Increased soil moisture retention (de Jong and Rennie, 1967) results in less contribution to saline seeps. (if rotations are extended).

Unfortunately, Zentner (1984, #69) has noted that the short-run economics of neither continuous cropping nor CT are as yet attractive for all farmers.

One of the key features of the replacement of summerfallow with CT approaches is the need to manage soil moisture. This aspect of CT is most closely associated with salinization; it therefore will be discussed in section 5.4. Continuous cropping, extended rotations (which still involve fallow), and flex cropping also contribute to the efficiency of soil moisture use. These approaches will be discussed in section 5.2.

### 5.1.2 Chemical Fallow

Tillage of summerfallowed land for weed control tends to mix or bury crop residue with the soil, increasing its erosion-sensitivity. Lindwall (1977, #39) has shown that the average frequency of tillage operations on the Prairies exceeds the optimum for weed control. The recent availability of effective, non-residual herbicides may make it possible to carry out significantly less tillage, notably in the Brown Chernozem soil zone. The use of chemicals, as opposed to tillage, for weed control on fallowed land reduces erosion, conserves moisture, and produces equivalent or higher yields (Lindwall and Dubetz, 1984, #40; Biederbeck, Robertson and MacKay, 1981, #6). On the other hand, Campbell, Paul, and McGill (1976, #13) have suggested that the availability of soil nitrogen to plants is reduced temporarily when herbicides are substituted for tillage. Nevertheless, the economics of the chemical fallow system are improving as the costs of fuel and tillage equipment rise (Unger and McCalla, 1980).

5.1.3 Windbreaks and Shelterbelts

Windbreaks and shelterbelts may be used to control wind erosion by lowering windspeed. Several types of trees and bushes, tall wheatgrass, and flax are used on the Prairies. With pruning to limit competition for moisture, barriers also trap snow and reduce transpiration from crops and evaporation from soil, providing increased soil moisture reserves (see section 5.4.1 below). The effect of such barriers on yields is dependent on the nature of the barrier, the type of soil, and the particular species used (Prairie Farm Rehabilitation Administration--PFRA, 1983, #58; Nicholaichuk, 1980, #51).

On the other hand, barriers may contribute to water erosion and salinity and may compete with crops for soil moisture and nutrients. Shelterbelts too are costly, have no immediate benefit, may delay tillage and seeding due to slow melting snowdrifts, occupy cropland, reduce fieldwidth (thus the ease of use of large machinery), require trimming and thinning, and harbour pests and diseases.

5.1.4 Grassed Waterways, Gully Control, and Terracing

Broad, shallow waterways lined with grass or grass-legume sod may be used to minimize erosion from runoff (PFRA, 1983, #58). Water velocity is slowed by the grass and gullying is thus prevented. When vegetative cover alone will not stabilize the waterway, engineering controls are often necessary to eliminate gullying (PFRA, 1983, #58).

The PFRA (1983, #58) has concluded that terracing has only limited application on the Prairies, due to prohibitive costs, maintenance requirements, and limited life expectancy. Its effect on yields by runoff reduction though may be considerable (Barnes, 1938).

5.1.5 Contour Farming

Contour cropping across a slope or contour ploughing of slopes (of between three and eight percent) can be effective in retaining runoff (moisture) on the land and thus minimizing soil erosion (PFRA, 1983, #58). Erosion can be reduced by as much as one-half (Batie, 1983, #3). Increases in cost are low, except in areas of uneven topography, and are fully compensated for by increased productivity.

5.1.6 Strip Cropping/Contour Cropping

The use of alternate rows of erosion-resisting crops with either fallow or rows of erosion-susceptible crops can reduce wind erosion (PFRA, 1983, #58). These rows are ideally oriented at right angles to prevailing "erosive" winds. Strip cropping along contours is also used to reduce water erosion; it is then called "contour cropping." This "rearrangement" of fallow and crop patterns demands increased farm management and greater care and skill with equipment. Except that stripped fields may not be grazed, strip cropping has little impact on overall farm economics.

5.1.7 Cover Cropping/"Winter" Cropping

Crops such as fall rye and winter wheat protect against wind and water erosion in the fall and spring (Nicholaichuk, 1983, #67). Also, they may produce higher yields than spring-sown crops, reduce saline seeps, redistribute farm labour requirements, and reduce losses due to disease, frost, and summer drought (Biederbeck, Robertson, and MacKay, 1981, #6). Fall rye or spring grains planted in August or September will add fibre, improve soil condition, remove excess moisture, and hold nutrients (PFRA, 1983, #58). In this period, these crops can also be used for limited grazing. Winter crops, unfortunately, may be subject to winterkill, although snow management techniques can reduce this danger.

### 5.1.8 Forages and Legumes in Rotation

Rotations which include grasses, grass-legumes, and legumes (e.g., annual pulse crops--peas, beans, lentils, etc.) have a range of advantages (PFRA, 1983, #58):

1) Improve the physical character of the soil, reducing erosion-sensitivity.
2) Maintain higher organic matter levels in the soil.
3) Assist in salinity control, due to their high water use.
4) Enhance soil capability to provide essential nutrients, notably nitrogen and sulphur.

This method sometimes called "green manure," is generally economic only in an integrated livestock enterprise. It is less practical in some drier Prairie soils, due to the high moisture demands of these crops.

### 5.1.9 Slot Mulching

Slot mulching is a promising, new method for the reduction of runoff and erosion from summer rains (PFRA, 1983, #58). A narrow trench filled with compacted straw or residue at 4 to 6 metre intervals down slopes experiencing water erosion may significantly increase water infiltration.

### 5.1.10 Removing Erosion-Sensitive Lands From Production

The "current trend of conversion of fragile land historically utilized for grazing to arable cropping should be discouraged" (Stewart, 1985b). Most often erosion-sensitive lands are best left in or returned to pasture or woodland (Batie, 1983, #3).

### 5.1.11 Full Assessment of Production Systems and Crops

The adoption of new agricultural production systems (such as continuous corn production on the Prairies) may have impacts on soil tilth and erosion. As well, increases in production of canola may have resulted in greater soil deterioration, due to the tendency to grow canola on summerfallow, to the frequent use of tillage for herbicide incorporation, and to canola's limited stubble residue (Stewart, 1985b). Conservation techniques or recommendations need to be developed along with production systems changes or new crops.

## 5.2 Prevention and Control of Loss of Organic Materials and Soils: The Efficient Use of Soil

A variety of the methods discussed in the previous section on soil erosion may also be used to limit the loss of organic materials (see tables 5.1 and 5.2). These include conservation tillage, forages and legumes in rotation, and others. Extended rotations flex cropping, and continuous cropping (discussed immediately below) may represent appropriate compromise approaches for soil conservation, where climate does not warrant, or economics are unfavourable to, conservation tillage.

### 5.2.1 Extended Rotations, Flex Cropping, and Continuous Cropping

The continuous use of fields for cropping (continuous cropping or "re-cropping"), and the reduction of frequency of fallow in rotation schemes, both tend to maintain organic matter at higher levels than cropping systems based on frequent fallow (Campbell, Paul, and McGill, 1976, #13; Ridley and Hedlin, 1968). These schemes limit wind and water erosion, as well as salinity. Lindwall and Dubetz (1984, #40) note:

> Re-cropping land that should not be fallowed offers the greatest potential for maintaining our soil's productivity.

Rotations may be extended if the farmer practices flex cropping. In this practice, the decision to crop or fallow is made in the spring, based on soil moisture reserves at the time of planting. Preparation, market, and quota considerations complicate this otherwise simple decision.

If extended rotations include increased nitrogen fertilizer application, greater nitrogen availability from the soil results (PFRA, 1983, #58). Continous cropping (the elimination of summerfallow) has higher input costs (fertilizers and herbicides) and presents greater risks of crop failure. At present, it can be utilized successfully in the Grey Luvisol and Black Chernozem soil zones, and, with snow management, in the Dark Brown Chernozem zone. (Extended rotations are now practical in the Brown Chernozem zone too.) Johnson (1977, #35) names these soils, as well as coarse-textured soils, as priority areas for the reduction of summerfallow. He also targets land with a moderate to high salinity hazard and that susceptible to water erosion. While the associated use of greater quantities of nitrogen fertilizer may tend to acidify soils that are now neutral to slightly acid, this last is not currently a problem on the majority of Canada's Prairie soils (section 3.2.2; Coote, Dumanski, and Ramsey, 1981, #19; PFRA, 1983, #58).

### 5.2.2 Organic Farming

Organic farming is actually a set of modern production systems which largely exclude chemical additives (US Department of Agriculture, 1980). These systems rely on crop residues, animal manures and other organic wastes, legumes, mechanical cultivation, mineral bearing rocks, and aspects of biological pest control. Organic farming systems require a high degree of management sophistication. In certain circumstances, they can increase water infiltration and long-term nutrient availability, decrease energy requirements, and provide greater wildlife opportunities (Cacek, 1984). These systems can also offer more financial stability, due to the lower investments in fertilizers and pesticides and the greater flexibility associated with their diversity.

### 5.2.3 Nitrification Inhibitors/Fertilizer Nesting or Banding

Irrigation tends to increase soil organic matter content. It also heightens the associated dangers of loss of nitrogen by leaching and denitrification, and loss of sulphur by leaching. Nitrification inhibitors in the fertilizers and the nesting or banding of fertilizer application close to seeds or plants may overcome these problems (McGill et al., 1981, #48).

## 5.3 Organic Soil: Management

Maintenance of high water tables and winter flooding can limit losses of organic soil (Coote, 1983, #17), but generally requires expensive and complex drainage and pumping systems. Losses by oxidation may also be diminished by the inhibition of bacterial and enzyme action, through the addition of copper as a fertilizer supplement (Mathur et al., 1979).

Burning of organic soils, which destroys the top layers, has been somewhat discouraged by Manitoba's Fires Prevention Act, 1970 (Michalski, 1977, #50). In addition, that province's Land Rehabilitation Act, 1971 gives municipalities the power to prohibit burning of stubble.

## 5.4 Salinity: Prevention, Control, and Rehabilitation

### 5.4.1 Conservation and Efficient Use of Soil Moisture

a) Snow Management--Perhaps the most promising techniques for salinity prevention and control (in association with conservation tillage and continuous cropping, i.e., reduction of summerfallow) are those involving snow management. A variety of barriers may be used to hold and redistribute additional snow on the land and thereby increase soil moisture retention from snow melt in the root zone. In some cases, this can eliminate entirely the need to summerfallow for this purpose. Barriers that are both competitive and non-competitive for the resultant soil moisture may be used:

1) non-competitive barriers:
   --windrowing.
   --straw shaping/trap strips/swathing at alternate heights.
   --snow fencing.

2) competitive barriers:
   --windbreaks and shelterbelts (discussed in section 5.1.3).
   --crop barriers.

Due to the additional snow held, and thus higher moisture reserves in the root zone, considerable yield increases have been achieved (Black and Siddoway, 1976). Net economic benefits to the farmer are usually positive, despite the costs of establishing and maintaining barriers (Nicholaichuk, 1980, #51). Snow management techniques also offer protection against wind and water erosion and the winter injury of winter grains.

There is considerable potential for expansion of winter wheat and for prevention of salinity by these snow management techniques in parts of the Prairies:

i) Windrowing--Windrowing or snow ridging involves mechanically forming ridges of snow at given intervals after a reasonable amount has accumulated in early winter. The results of this practice in terms of yield enhancement are positive but variable, dependent on the weather. The practice is also not economic in all years. It requires skill, knowledge, and good timing and is "miserable work" (Nicholaichuk, 1980, #51; Steppuhn, 1980).

ii) Straw Shaping/Trap Strips/Swathing at Alternate Heights--Attachment of deflectors to the swather to leave "trap" strips of taller straw at 6 to 7 metre spacing or less (1 machine width) is a promising technique for snow management and soil moisture conservation (Dyck, 1982; Nicholaichuk and Dyck, 1983 in #43; PFRA, 1983, #58; Nicholaichuk, 1980, #51; Nicholaichuk and Reid, 1980). Considerable net economic benefit results. Research is still required to design and test an optimal attachment for swathers.

iii) Snow Fencing--Snow fencing studies have demonstrated the beneficial effects of managing snow with snow fence barriers for subsequent crop yield (Nicholaichuk, 1980, #51). Nevertheless, the method is not really practical for agricultural land on the Prairies.

iv) Crop Barriers--Barriers of tall grass in single or double rows function as quite effective snow managers (Black and Siddoway, 1976). Flax, rapeseed, or mustard may also be used for crop barriers (Nicholaichuk, 1983, #53). Such barriers require little extra management, but like windbreaks and shelterbelts may compete with the crop for soil moisture.

Deep snow drifts may contribute to seeps (Sommerfeldt and MacKay, 1982). Standing stubble together with the elimination of barriers that trap excess snow will minimize such build-ups. Areas of inevitable accumulation should be seeded to deep-rooted perennials (PFRA, 1983, #58).

b) Irrigation from Sloughs--Farmers have occasionally experimented with irrigation from sloughs, a procedure which utilizes blown snow or runoff. This procedure may increase cultivated area and reduce saline seep (de Jong and Cameron, 1980, #21).

c) Reduced Tillage for Seeding--Many farmers carry out tillage operations in order to bury plant residues before or during seeding. Yet this approach produces a "dry, loose seed bed, and subsequently a poor crop stand" (Lindwall and Dubetz, 1984, #40, p. 123). The farmer therefore perceives summerfallow to be necessary for moisture retention. The farmer may in fact be sacrificing a sufficient amount of spring soil moisture to jeopardize the crop, plus losing the benefits of residues in the retention of subsequent rainfall (Johnson and Hennig, 1976, #36; Rennie and Day, 1957). Reduced tillage alone may conserve sufficient soil moisture reserves to allow more frequent cropping of a field.

d) Interceptor Cropping of Recharge Areas--Growing deep-rooted "interceptor" crops in the recharge areas of saline seeps may dry out subsoil and restore the water storage capacity of the soil over a period of several years (Henry and Johnson, 1977, #31; Brown and Cleary, 1978). Alfalfa is the most effective, rooting to six metres in four to five years and using more than 760 millimetres of water per year (Miller et al., 1981; Brown, 1982). Sainfoin, safflower, Russian wild-rye grass, tall wheatgrass, and sweet clover may also be used, although not all are suited to Canada's Prairies (PFRA, 1983, #58). In general, a profitable interceptor crop has not yet been found for the conditions of our Prairies.

e) Crop Rotation in Recharge Areas--
Alternating deep rooting annual crops, such as safflowers and sunflowers, with cereals every several years uses the deep soil water not utilized by the cereals.

5.4.2 Early Detection of Seeps

Early detection of saline seeps is critical to the prevention of loss of growth crop from salinity. Visual signs of seeps include the following (PFRA, 1983, #58; Brown and Krall, 1981; Henry and Johnson, 1977, #31):

1) Prolonged surface wetness after a substantial rain.
2) Iron mottling in the subsoil.
3) An area of excessive crop growth or foliage which remains green long after the rest.
4) The presence of common field weeds--Russian thistle, kochia, wild barley, and goosefoot--or, in uncultivated areas, the presence of areas of dominant samphire, desert salt grass, and greasewood.

Halvorson and Rhoades (1976) have shown how the "four-electrode resistivity technique" may be used for the following essential detection tasks:

1) Estimation of root zone salinity in the field.
2) Identification of potential seep areas.
3) Location of recharge areas.
4) Measurement of water salinity.

Also, remote sensing can provide "rapid, synoptic, and time-sequential data for use in detecting and mapping active or potential seeps" (PFRA, 1983, #58; p. 77).

Recharge areas are often difficult to isolate (PRFA, 1983, #58). A groundwater contour map is the most accurate procedure; it uses data from a system of wells to determine groundwater movement. In small drainage areas, a local technician may delineate recharge areas through his working knowledge of the local soil and geology, as well as by soil probing. A four probe system gridding the upslope edge of the seep area will also indicate the source of the saline flow, but not the extent of the recharge area. A careful field inspection should be part of all of these approaches, because subsurface texture differences may complicate the situation.

5.4.3 Fertilizer Application

Adequate fertilization (based on soil tests) of soils in recharge areas increases rooting depth and water use (PFRA, 1983, #58). These increase yield and reduce the leaching of soluble salts and the quantity of water potentially lost to seeps (Campbell and Biederbeck, 1980, #11). Phosphate fertilization as part of the seeding of cereal grains on moderately saline soils also provides "excellent" yield increases (Henry and Johnson, 1977, #31).

5.4.4 Salt-Tolerant Crops

Saline areas should not be left bare. Highly saline areas (electrical conductivity of saturated water extracts from surface soil of over 8 to 10 millisiemens per centimetre) should be seeded to permanent forage crops, such as alfalfa, or a mixture of forage crops (Lawrence, 1980; PFRA, 1983, #58). Such forage may have a high nitrate content, but crop choices for salinizing areas are often limited by wetness and the salt-tolerance of the crop. Barley is the most salt-tolerant cereal grain, especially six-row barley (Vander Pluym, 1982, #66).

5.4.5 Surface Drainage

Drainage of intermittent, natural and artificial ponds is an effective, important, and usually inexpensive way to control seepage (Vander Pluym, 1982, #66; Lilley, 1982, #38). Both open grassed trenches and buried pipe are used. Such ponds may be used for irrigation, because the water is salt-free (see 5.3.1 above). Their drainage adds to the area available for cropland. Large, semi-permanent potholes should not be drained (Miller et al., 1981), since disruption of their claypan will result in increased seepage. The loss of wetland habitat for waterfowl, marshbirds, and shorebirds, is also a significant negative impact (Kruser, 1984). Disposal of the outflow (high in dissolved solids) is a further problem (Lilley, 1982, #38). A licence for such drainage is required in Alberta; advice to design an effective system is available from that province's Agriculture and Environment departments.

5.4.6 Land Levelling

Land levelling may be used to reduce ponding or wet spots in field depressions and provide more even soil moisture distribution (Lilley, 1982, #38). This approach is limited by topography and cost. It too may destroy wetlands and thus habitat for a variety of waterfowl and other birds.

5.4.7 Irrigation Methods

a) Subsurface Drainage--Subsurface drainage is the most important and widespread salinity control in current usage on irrigated areas on the Prairies (Vander Pluym, Paterson, and Holm, 1981, #67). Such drainage is used to control high water tables (waterlogging) and to desalinize the root zone (thus raising yields). For dryland areas, high costs and the danger of pollution normally restrict use of this method; PFRA, 1983, #58. There are a number of significant problems with the current execution of subsurface drainage works:

1) The technique is not appropriate on fine textured soils.
2) Drains are often installed outside the main water-bearing strata.
3) Installation conditions or techniques are sometimes poor.

b) Canal Lining/Cut-off Curtains--Canal lining has been extensively used to decrease leakage to saline seeps, as well as to increase canal flow capacity (Vander Pluym, 1982, #66). The method is very expensive (e.g., $50-60 per metre for 2 to 4 farmers).

Plastic cut-off curtains at the depth of the impermeable layer along canals are increasingly being used (Vander Pluym, 1982, #66). Tile drainage then diverts the intercepted canal leakage.

## 5.5 Solonetzic Soils: Management and Improvement

A variety of methods are available for the management and improvement of this natural soil condition.

5.5.1 Deep Ploughing

Deep ploughing and the subsequent mixing of the A, B, and C soil horizons, in equal portions is a common method of reclaiming Solonetzic soils for production. This is due to improved soil conditions, increased pH, etc.. A plough depth of 40 to 60 centimetres is necessary to ensure that the layer containing gypsum (if present) is reached (Toews, 1973; Henry and Johnson, 1977, #31). Yield increases with this technique may be substantial and are relatively permanent (PFRA, 1983, #58).

5.5.2 Chemical Application

Liming can prove beneficial to solonetzic soils, particularly acid soils. Its costs and the lack of availability of lime on the Prairies make it less attractive (PFRA, 1983, #58). Other chemical methods used include the following:

1) Gypsum mixing with subsoil (Carter et al., 1977).

2) Ammonium nitrate--the most desirable nitrogen source for grass production (Cairns et al., 1967).

3) Sulphur and several sulphur and nitrogen-sulphur compounds (e.g., ammonium bisulphite; Cairns and Beaton, 1976).

5.5.3 Crop Rotations, Drainage, and Tillage

Extended crop rotations gave higher gross returns than fallow systems on Solonetzic soils in a single experiment at Vegreville, Alberta (PFRA, 1983, #58).

Surface drainage lessens salt accumulation during soil drying. Natural shallow waterways opened with a one-way disc cultivator will allow adequate drainage. Subsurface drainage is not cost-effective, due to the slow movement of water in these soils (PFRA, 1983, #58).

Tillage operations on Solonetzic soils must be done when the soil is neither too wet, nor too dry.

5.6 Acidification: Prevention, Control, and Management

5.6.1 Liming

Liming is a successful, long-term (10 to 15 years), and cost-effective response to acidification, even though the initial costs of $30 to $40 per tonne are an impediment (Hoyt, Nyborg, and Ukrainetz, 1981, #34). These costs will decline if the volume of use on the Prairies increases significantly from present minimal levels. Unfortunately, lime availability is currently a considerable problem on the Prairies, especially where it is needed most (Coote, Dumanski, and Ramsey, 1981, #19). Thus, lime is not used to any great extent there as yet.

Returns to liming depend on the severity of acidity, the sensitivity of the crops, and the need for long-term liming. Research on the applications and types of lime, publicity on the approach, and a capability for soil analysis on lime soils are all required. Prevention of acidity should be a high priority too (see section 5.6.3 below).

5.6.2 Acid-Tolerant Crops

The growing of acid-tolerant crops, such as oats, buckwheat, and rye, is a temporary measure to delay yield losses on acidifying soils (Hoyt, Nyborg, and Ukrainetz, 1981, #34). Wheat, trefoil, grasses, and corn are relatively acid-tolerant (pH ranges 5.5 to 7; PFRA, 1983, #58).

5.6.3 Other Solutions

The addition of organic matter, such as peat, alfalfa meal, or manure, decreases the pH level at which crop toxic reactions occur or increases soil pH (PFRA, 1983, #58). Other potential solutions include the following (Hoyt, Nyborg, and Ukrainetz, 1981, #34):

1) Deep ploughing of soils with lime layers in the subsoil.
2) Nitrogen fertilizers with inhibitors against the nitrifying process.
3) Banding of nitrogen fertilizer.
4) Fixing of atmospheric nitrogen through legumes.

These are practical only to the extent that they are or remain cheaper than liming.

## 5.7 Oil Contamination: Reclamation

Rehabilitation of land contaminated by oil spills is often possible in one to ten years (Webb, 1982, #68; McGill, 1982, #46):

1) By adding nutrients to the soil to speed up the decomposition of oil by soil microbes.
2) By tillage to restore tilth and to incorporate fertilizers.
3) By drainage where necessary.

Some cases of rehabilitation of oil contaminated soil are complicated by spillage to the subsoil and by the combination of oil and brine (salt-water used in oil recovery). Brine-affected soils are more of a problem because more brine (than oil) is spilled, brine recovery is less efficient than that of oil, and salts are not biodegradable (Webb, 1982, #68).

## 5.8 Physical Deterioration: Prevention and Control

High flotation tractor tires are a promising approach which may make possible seeding, with minimal damage to soil structure by compaction, under wet or slow-draining field conditions (Miller, 1981). In addition, tractor power increases can reduce field work time, thus lowering the need to be on wet fields (Dyer, 1982, #22). Adoption of crop rotations with fibrous-rooted plants (versus monoculture row cropping) and proper tillage methods that avoid shattering clods can limit soil compaction (Coote, 1983, #17). Controlled wheel traffic is sometimes practised on farms where numerous operations are required (Cameron et al., 1981, #9). Traffic is restricted to narrow lanes, allowing the majority of the field to be left untouched. Deep tillage (chiselling or subsoiling) may be used where a plough pan or dense soil layer under the plough pan restricts drainage or crop growth (Cameron et al., 1981, #9). Conservation tillage methods have been shown to improve soil structure, to increase soil bulk density, to improve water transport characteristics and aeration, and to increase available water (Cameron et al., 1981, #9; Campbell, 1983, #60). The resulting lower soil temperatures though may retard seed germination (Crosson, 1981, #20).

## 5.9 Potential Economic Benefits of Soil Conservation Measures

Up to 15,000 years of physical, chemical, and biological processes were needed to develop Prairie soils. Because the time required to renew the soil resource depleted by removal or degradation of surface horizons is so long, Foss (1983, #25) feels soil systems should be regarded as a non-renewable resource. They may reach a point where further production is uneconomic or conservation is for nought, particularly if salinity is the problem.

PFRA (1983, #17) notes the many immeasurables of estimating the potential economic benefits of soil conservation, but nevertheless has presented measures of the benefits of dealing with three conservation problems (Table 5.3). Assuming price declines caused by higher production, PFRA projects that benefits for the control of erosion, salinity, and acidity control will still amount to $233 million annually by 1990, $440 million annually by 2000, and $2.8 billion cumulative to 2000. Notably, almost two-thirds of the benefits are related to the control of salinity. In addition, indirect benefits to the economy were estimated at a $398 million increase in the Gross Domestic Product of the Prairies and $498 million for Canada in 1990, and $744 million and $930 million respectively in 2000. These estimates do not include the various costs of soil conservation measures or the cost-savings or benefits from reductions in externalities. Zentner (1984, #69, p. 201) suggests that the estimates must be considered low--that "true values may be several times higher." On the other hand, Anderson et al.'s (1984) recent overview questions the projected rate of salinity increases over the next two decades and thus the extent of these benefits.

TABLE 5.3:

POTENTIAL ECONOMIC BENEFITS OF SOIL CONSERVATION, 1982-2000[a,b]

| Conservation Problem | Annual Benefits ('000,000) 1990 | Annual Benefits ('000,000) 2000 | Cumulative Benefits ('000,000) 1982-2000 |
|---|---|---|---|
| Salinity[c] | $149.36 | $336.05 | $1,790.30 |
| Erosion | $16.35 | $36.79 | $195.99 |
| Loss of Available Nitrogen | $67.62 | $67.62 | $790.45 |
| TOTAL BENEFITS | $233.33 | $440.46 | $2,776.74 |

[a] A 5% discount rate was used to determine the present value of the cumulative benefits.
[b] A decline in prices of 0.28% for each quantity increase of 1% is assumed except for nitrogen--constant prices assumed.
[c] Based on a low estimate of the already saline area.

SOURCE: PFRA, 1983, #17, p. 265.

## 6.0 THE ROLES OF GOVERNMENTS

Governments play a role, wittingly and unwittingly, in the nature and quality of management of Prairie soils. This chapter reviews the current (section 6.1) and potential roles of governments (6.2) in soil conservation issues, as revealed by the literature. Recommendations, evaluations, and warnings from the surveyed literature are explored in the latter section.

### 6.1 Current Roles

The issues surrounding government policy for soil management are complex and contentious. While a tentative commitment to soil conservation has been made by the Federal Government and most of the provinces, Lok (1983, #41) finds that the evidence of strong commitment is still lacking by and large. By contrast, in the US where the problems are similar, an intensive direct soil conservation program has been in place for 40 years (Batie, 1983, #3). Resources committed to soil conservation in the US states adjacent to the border are three to ten times those on Canada's Prairies (Figure 6.1).

Most of Canada's provinces have preliminary studies on the extent of agricultural soil erosion (Lok, 1983, #41). And many have policies and programs to provide information and expertise vis-à-vis erosion. Financial assistance is available, for example, from Alberta's Soil Conservation Area Program, through which local municipalities may demonstrate soil conservation or reclamation of degraded areas. Some provinces also have the power to take action against those farmers who permit excessive erosion (e.g. Alberta: Soil Conservation Act, 1980). For recent overviews of relevant federal and provincial legislation, see Coote (1983, #17) and Barlott (1983, #4).

The Environmental Council of Alberta (1984) has recently recommended a range of responses to the soil degradation challenge:

1) The establishment of an Agricultural Resources Conservation Board charged with the province's responsibility for "conservation, maintenance, and enhancement of the agricultural land base."

2) The development of an agricultural land use classification which identifies the soil's ability to sustain different types of agriculture.

3) The establishment of Soil Reclamation Districts by landowners.

4) Modification of the Canadian Wheat Board's quota system to discourage summerfallow.

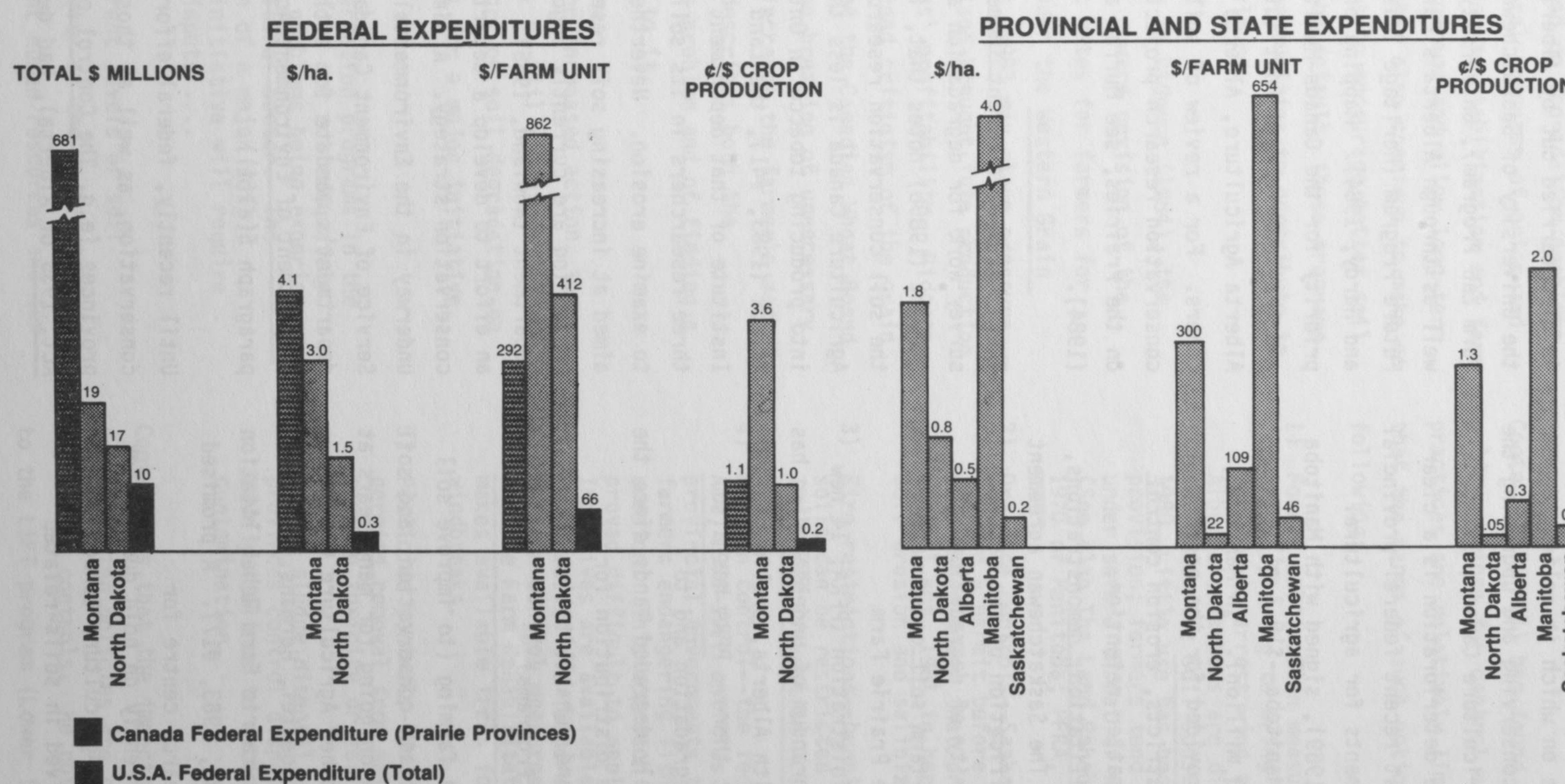
5) The requirement of a permit, which specifies conditions under which new land may be cleared or broken for cultivation.

6) Assistance to the beef industry by freer inter-provincial trade or provincial marketing aid.

7) Research on the maintenance of and amendments to the soil, soil reclamation, and agricultural chemicals.

8) The limitation of northern agricultural expansion to the fringes of current areas, pending more knowledge of potential expansion areas.

# FIGURE 6.1: FEDERAL, PROVINCIAL, AND STATE EXPENDITURES ON SOIL AND WATER CONSERVATION, CANADA AND U.S.




SOURCE: PFRA (1983,#17), pp. 30-32.

The federal Agri-Food Strategy recognizes that expansion of production to identified targets, and the supply base on which it relies, depend in large part on "conserving and upgrading the land resource" (Agriculture Canada, 1981, p. 14). Soil resource deterioration is a clear emphasis in the most recent federal-provincial cost-sharing agreements for agricultural development (1984-1989), signed with Manitoba and Saskatchewan (Manitoba--$18.2 million; Saskatchewan--$26.0 million). In Manitoba, funding has been provided for the organization of conservation districts, erosion control research, organic matter retention, salinization rehabilitation, demonstrations, and soil surveys. The Saskatchewan agreement involves the identification of the nature, location, and severity of degradation and provision of an on-farm soil conservation service through the Prairie Farm Rehabilitation Administration (PFRA; 14 new positions). A memorandum of understanding has also been signed with Alberta, preliminary to a similar agreement there. PFRA has also worked to reduce degradation and to rehabilitate severely degraded lands since the 1930's through tree distribution for shelterbelts and land rehabilitation (Community Pasture Programs).

Research on dryland farming (to improve soil moisture storage, trash conservation, and soil stability) has been on-going for many years at Swift Current and other Agriculture Canada research stations (Goettel, Hermans, and Coote, 1981, #28; Prairie Farm Rehabilitation Administration--PFRA, 1983, #17). A promised soil and water research centre for Saskatchewan is currently on hold due to lack of funds. While 60 Agriculture Canada personnel are involved in soils-related research on the Prairies, not all of them work on soil conservation by any means. Research is also carried out by Alberta Agriculture, the University of Saskatchewan (including the Farm Lab Program), University of Alberta, as well as through Alberta's Farming for the Future Program (Heritage Trust Fund; Murray and Hardy, 1984). Mapping of degradation is a priority for the Canada-Manitoba Soil Survey and the Saskatchewan Institute of Pedology, Alberta Agriculture, Alberta Environment, and others. For a review of soil degradation and conservation research projects and activities on the Prairies, see Murray and Hardy (1984).

There has been a recent increase in soil survey work for degradation assessment. Yet Stewart (1985b) notes that, for example, all the soil conservation research carried out by Agriculture Canada is less than its research into producing tobacco in Ontario. According to Lok (1983, #41), the Land Resource Research Institute of that department has engaged only three researchers in its soil degradation unit to examine erosion. Nevertheless, discussion aimed at increasing soil research and monitoring are currently ongoing in the department (Nowland, 1985). This as part of an effort to develop a departmental soil conservation strategy. A similar exercise is underway in the Environmental Conservation Service of Environment Canada under that department's mandate for soil quality (Department of Environment Act, 1970, paragraph 5(a)(i)).

Until recently, federal efforts at soil conservation, as well as those of the provinces (e.g. The Control of Soil Drifting Act, 1935 of Alberta), had declined. In fact, of the $20+ million annual federal budget for agri-food development programs, none was specifically focused on degradation problems. While various federal programs of price and income support, such as stabilization and farm credit tend to encourage and allow long-term farm management, they also continue to make no specific provisions to encourage better soil management. Thus by default, these programs miss excellent opportunities to contribute to sustainable agriculture.

Further, according to Pidgeon (1984), the recent substantial upward revision of the Crows Nest freight rates for farmers for grain shipments under the Western Grain Transportation Act, 1983 may place pressure on more marginal land brought into production to maintain farmers' profitability. Pidgeon also notes widespread criticism of the grain marketing quotas of the Canadian Wheat Board, which encourage the breaking of unnecessary land in order to increase the farmer's market quotas. Pidgeon describes both the complexity of this problem and of finding a workable solution to it.

Noting the need for increased action, the PFRA's (1983, #58, p. xii) recent, comprehensive report on soil degradation on the Prairies calls for a major initiative, noting that:

> Existing conservation programs in the prairie provinces are not adequately assessing the problems being experienced in the agricultural sector. The implementation of a major soil conservation initiative will require considerable inputs ....

Just to reach current levels of soil conservation activity on the US Great Plains, three times current human resources and ten times current funding are necessary (Figure 6.1).

Coote (1983, #17) has found that legislated policy options for control of farming practices are relatively limited. He notes that the range of such options includes the following:

1) Forced cultivation measures--such as the chisel plowing to bring clods to the surface to arrest wind erosion, which Alberta's farmers are directed to carry out under the Soil Conservation Act, 1980. Little use has been made of this provision; farmers tend to respond only under severe threat of wind erosion. (See also The Land Rehabilitation Act, 1970 of Manitoba; PFRA, 1983, #58.)

2) Drainage controls--Saskatchewan farmers require a permit before drainage is undertaken under that province's Drainage Control Act, 1981 in hopes of avoiding soil erosion and salinization.

3) Fire restrictions--burning of organic soils can be restricted under Manitoba's The Fires Prevention Act, 1970.

4) Erosion control--the federal Fisheries Act, 1976-1977 entitles prairie provincial governments to act against farmers endangering fish habitat by soil erosion. This approach has generally proved difficult to apply to agriculture. Incentives are available in many provinces to aid farmers to undertake erosion control measures. And the Prairie Farm Rehabilitation Act, 1970 makes available trees for establishing windbreaks.

5) Pesticide controls--federal legislation permits removal from sale of products causing toxicity or soil pollution.

6) Sewage sludge disposal controls--most provinces control disposal and several have guidelines to avoid soil contamination.

Coote notes that the impacts of production and marketing policies are greater than legislated controls. He points, for example, to the LIFT program (Lower Inventories for

Tomorrow, 1970-1971), which substantially raised the area of summerfallow on the prairies by supporting reduced production. Such policies can and do significantly affect the management practices brought to bear on Prairie soils.

## 6.2 Potential Roles

Recommendations for government actions in the soil degradation literature reflect the broad range of problems involved in soil management on the Prairies, as well as the disparate backgrounds of the researchers and agencies which put forward the ideas.

The AIC (Agricultural Institute of Canada, 1980/ has called for an improvement of the information base for soil erosion with a "catalogue" of needs, including the following:

1) Documentation of the extent and degree of soil erosion affecting productivity and environmental pollution.

2) Quantification of soil physical changes, effect on crop yield, and tillage requirements.

3) Establishment of tolerable soil loss levels.

The Canadian Federation of Agriculture (CFA, 1982, #15), in its backgrounder on soil degradation, supported the objective of the Strategy for Agricultural Resource Research for Canada (Canada Committee on Land Resources Services, 1980, p. 9):

> To assess the amount, kind and severity of land degradation in Canada, and to develop improved land management practices to maintain and improve soil (and water) quality and productivity.

The CFA and others have called for research to encourage conservation farming:

1) A study of beef production to compare and contrast pasture- and grain-fed beef vis-à-vis soil and energy conservation, production capacity, market supply and demand, farmer income, and consumer demand (CFA, 1980, #15, p. 47).

2) Further development of improved technology, such as the following:
   a) windbreaks, bufferstrips, and minimum tillage systems (Goettel, Hermans, and Coote, 1981, #26, p. 157).
   b) snow management and other water saving techniques (Clark and Furtan, 1981, #16).
   c) the design of equipment and systems for handling and retaining crop residue on land, seed and fertilizer placement, and placement or incorporation of pesticides (Johnson, 1977, #35).

3) Land evaluation research for lands under consideration for use as agricultural land. Use of this data in regional planning may ensure that, for example, land with a high risk for erosion is not brought into production (Dyer, 1982, #22).

PFRA (1983, #17) calls for basic research and development in the following areas:

1) The exact cause of saline seeps.

2) The effects of soil losses.

3) The optimum levels of organic matter.

4) The means to ensure efficient use of soil nutrients.

5) A national, regional, and local level inventory of land degradation problems.

6) Development and refinement of mitigating technologies.

The recent Senate Committee recommends greater funding for soil conservation research in soil and water conservation institutes, both by the Federal Government and in university-based regional centres (Canada/Standing Senate Committee on Agriculture, Fisheries, and Forestry, 1984,

#14). It also has a variety of proposals for the further development of farm extension and technology transfer:

1) PFRA extension into British Columbia (the Peace River area).

2) All federal lands developed as conservation showcases, especially Research Stations.

3) Increased training of field workers through agricultural colleges and the federal Skills Growth Fund.

4) Increases in legislation authorizing the establishment of conservation districts.

The CFA (1980, #15, p. 46) also wants to review the means of extending soil conservation advice to farmers, considering demonstration farms and programs of education (these two are also encouraged by Goettel, Hermans, and Coote, 1981, #26 and Hoyt, Nyborg, and Ukrainetz, 1981, #34), as well as moral persuasion--the standard route. Hoyt, Nyborg, and Ukrainetz feel this is especially true for acid soils, which require in-field tests and recommendations. Dyer (1982, #22) feels that farmers still have to be convinced that the risk of land degradation affects their financial well-being and that of their children. This is in addition to their need to be advised on the more mundane, mechanical aspects of conservation techniques. Dyer further recommends increased publishing of up-to-date soil conservation information. The CFA (1982, #17) too favours this approach, recommending a code of practice for conservation-oriented farm management principles. PFRA (1983, #58) calls for an effective technology transfer system:

1) Technical and diagnostic services to develop plans for individual farmers similar to the US Soil Conservation Service.

2) Back-up diagnostic services and labs to provide both detailed and regional-level information.

3) Demonstration sites.

There is widespread acknowledgement of the importance of awareness by the public of the nature and severity of land degradation (PFRA, 1983, #58). Soil conservation groups, public meetings, promotional material, and a comprehensive public education program are all needed. Coote (1983, #17) hopes that better public understanding of the farmer's economic situation will encourage better soil management, even to the point of consumer acceptance of higher food prices. To these ends, the Senate Committee recently recommended (Canada/Standing Senate Committee on Agriculture, Fisheries and Forestry, 1984, #14):

1) A National Soil Conservation Week.

2) Primary and secondary school level studies focusing on land degradation.

3) A national conference to foster co-ordination and co-operation.

4) A National Council on Soil and Water Conservation.

While education and extension are a key, many proposals for direct or indirect incentives to action are also to be found (e.g. subsidies for introductory liming demonstrations; Coote, 1983, #17). Incentives allow the public to relieve the farmer of some of the financial burden for sustainable soil management. The Senate Committee report also recommended financial incentives through federal-provincial agreements and accelerated capital cost allowances for a range of ends, such as the following:

1) Conservation tillage machinery and works.

2) Preservation of wetlands.

3) Purchase of fertilizer and herbicides.

4) Investments in agricultural research.

Hoyt, Nyborg, and Ukrainetz (1981, #34) have called for government assistance to lower the price of lime (for acid soils), which is not yet used in significant quantities. Dyer (1982, #22) believes that there is presently a general lack of financial incentives to engage in soil conservation. He proposes that conditions for aid under other programs require "sustainability." Projects which lead to highly sustainable practices should be emphasized.

Coote (1983, #17) notes that many government policies may affect the relative areas of grains, oilseeds, and forages (e.g., Lower Inventories for Tomorrow Program--LIFT, grain quotas, crop insurance, etc.). He proposes a program to encourage crop rotations, especially ones including forages. The re-establishment of a less specialized system of livestock production on mixed farms (through changes in the marketing, transportation, and processing sectors) would also have the benefit of returning more livestock manure to the soil. Support for use of legumes, either through a subsidy program or a guaranteed market, is suggested by Clark and Furtan (1981, #16). Manipulation of agricultural pricing policies is another potential route to encourage use of soil conservation measures (Biederbeck, Robertson, and McKay, 1983, #6).

Anderson and Associates (1981, #2) have proposed a variety of "incentives" to discourage summerfallow:

1) Reduction of the relative price of chemical fertilizer, fuel, herbicides, and other farm inputs.

2) Raising prices for grain and alternative crops, which improve soil quality (e.g. forages) and the improvement of marketing opportunities.

3) Raising the value of agricultural land.

4) Risk reduction through price stabilization, improved crop insurance, etc..

5) Payments to farms to switch to continuous cropping or penalties for summerfallow.

6) Research on yield-increasing, but not capital-intensive, technologies (e.g. wheats with nitrogen-fixing characteristics).

7) Elimination of influences encouraging extensive agriculture (e.g. the Canadian Wheat Board's grain quota formula).

8) Differential land taxation policies (e.g. assessment procedures in Ontario).

9) Direct and indirect subsidies for grain production and farm inputs.

The CFA (1982, #15) has called for strong government support for rehabilitation programs where degradation has gone beyond the control of the individual farmer. It also recommends the development of a federal policy "on the maintenance of the soil in permanent production potential." This policy should be co-ordinated with and uniformly applied by all government departments and quasi-government bodies (including conservation authorities). Simultaneous co-ordination with an integrated agricultural policy, which includes production, marketing, and stewardship, is also essential.

On the other hand, Furtan and Van Kooten (1984, #26) suggest that justification for government intervention must involve more than demonstration that private decisions are causing land degradation and the resulting "social inefficiencies." It must further be shown that government action will "move society closer to its desired level of [soil] conservation" (p. 192). McConnell (1983, #45) argues that (in his view and based on an American case) the only important externality of soil erosion is water pollution. He would not support government intervention aimed at bringing soil loss into balance, unless the impacts of pollution provided the justification.

## 7.0 TOWARD SUSTAINABLE PRAIRIE AGRICULTURAL PRODUCTION

The Senate Committee report on soil conservation concluded that degradation constitutes a serious problem in all regions of Canada (Canada/Standing Senate Committee on Agriculture, Fisheries, and Forestry, 1984, #14). Lack of priority for solving these problems has stemmed from insufficient public awareness of the problem. A national commitment should be shown through a meeting of First Ministers and the development of a comprehensive federal and provincial soil and water conservation policy.

The Prairie Farm Rehabilitation Administration (PFRA, 1983, #58), in its review of Prairie soil conservation issues, highlighted significant problems--salinization, erosion, loss of organic matter, acidification, and inadequate water management. Improved crop varieties, herbicides, fertilizers, and planting techniques have continued to increase agricultural productivity in the past several decades. This has masked the effects of declines in the native capacity of the land resource brought on by monocropping, erosion, pesticide-resistant insects, reduced soil organic matter, and other factors (figures 7.1 and 7.2). These productivity losses threaten the ability of the Prairie land base to sustain current production levels, much less significantly increase them.

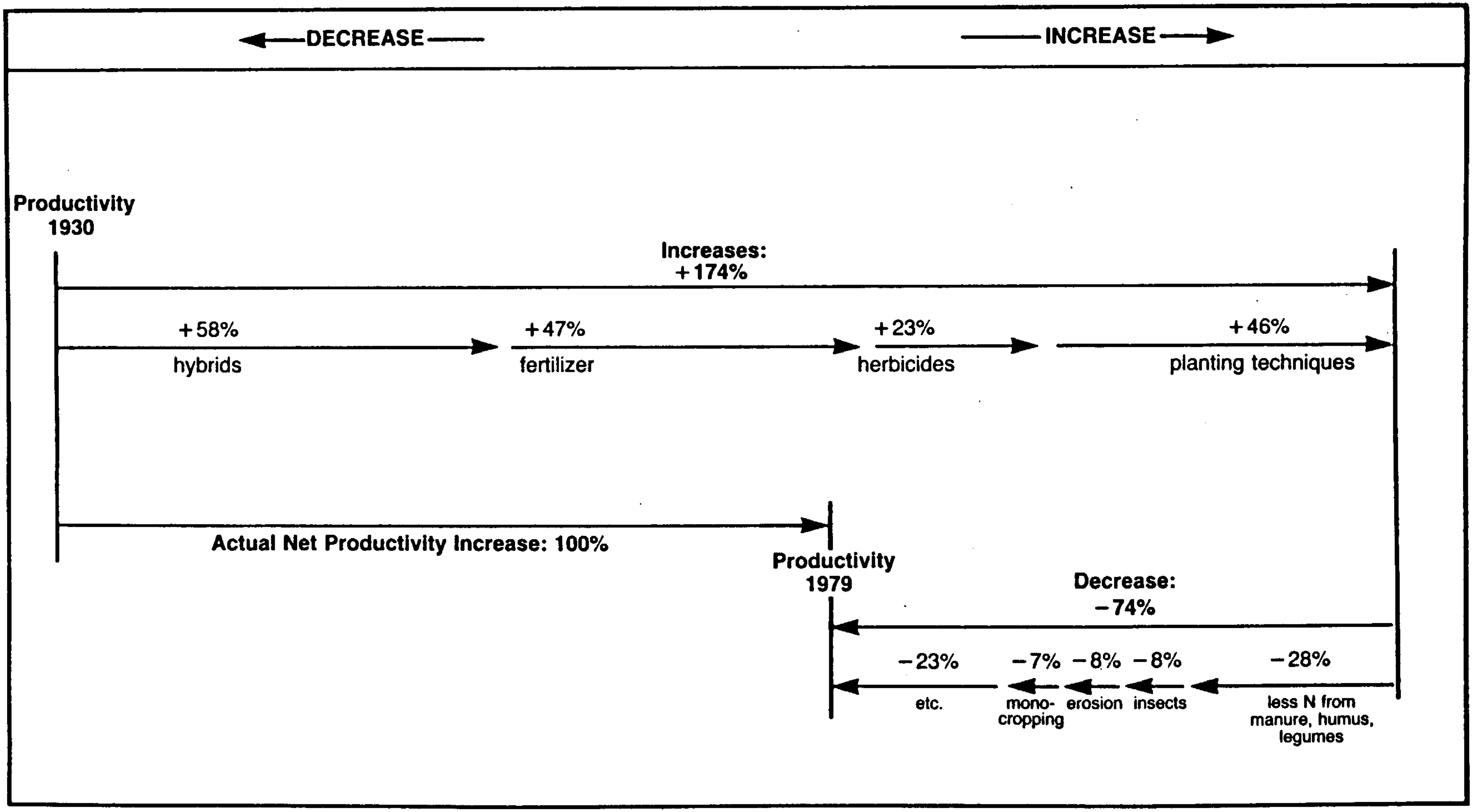
A wide variety of specific solutions (farm-level; Table 5.1) and government actions have been discussed in chapters 5 and 6. Some of these are not compatible with one another. Broad-based, well considered, and integrated responses to these problems are clearly required. Such responses would need to be based on actions by local and other farm organizations and agricultural professionals, as well as local, provincial, and federal governments. Education of the public, the farmer, and the extension worker are clearly necessary. Expansion of soil conservation research, demonstration, and extension is a critical necessity. A review and adjustment of current government programs for any impediments, as well as potential positive opportunities, is essential. Incentives for improved soil management may also be needed. All of these are available options and should be considered as elements in our responses to the problems of land degradation.

The Soil Conservation Society of America (Ontario Chapter in Canada/Standing Senate Committee on Agriculture, Fisheries, and Forestry, 1984, #14, p. 1) asks the pointed question:

> "Must we wait for crisis conditions before action is taken to safeguard our scarce and dwindling soil resource base?"

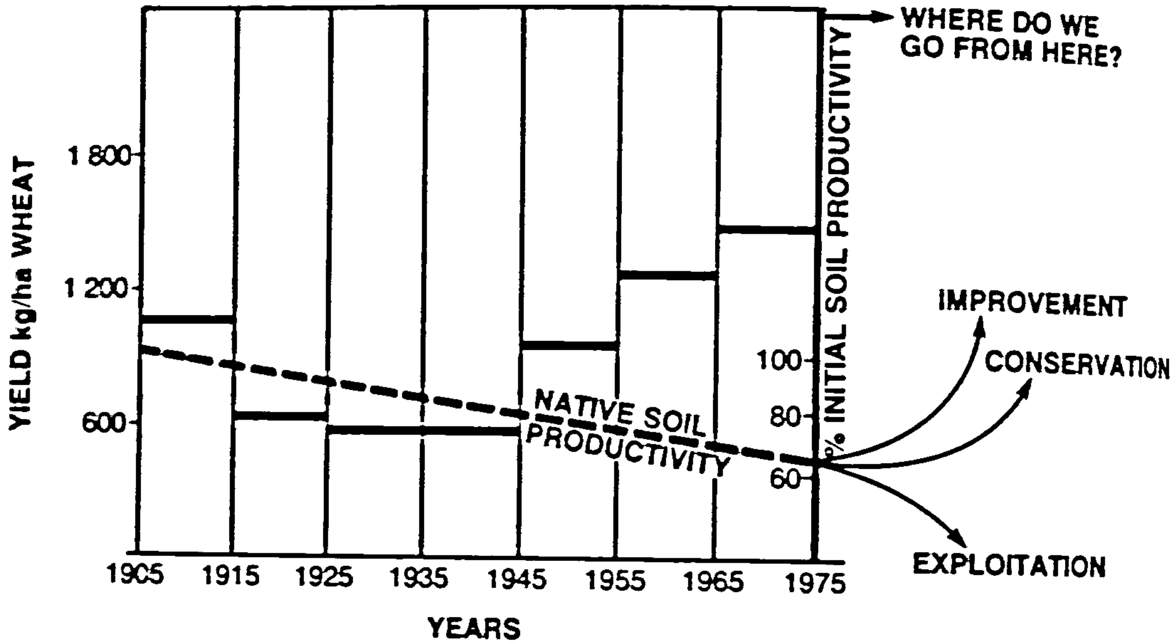
Must we?

**FIGURE 7.1:**
**INFLUENCES ON PRODUCTIVITY (CORN, MINNESOTA)**




SOURCE: Based on Cardwell (1982) in Leskiw and Bentley (1983).

## FIGURE 7.2:
## SOIL PRODUCTIVITY LOSS HAS BEEN MASKED BY IMPROVED TECHNOLOGY




SOURCE: Rennie and Ellis (1977,#61), p. 52.

## 8.0 ADDITIONAL REFERENCES


Agriculture Canada. 1981. Challenge for Growth: An Agri-Food Strategy for Canada. AGR-6-81DP. Ottawa.

Agricultural Institute of Canada. 1980. "Soil Erosion on Agricultural Land in Canada." Agrologist, 9: 4, 23-28.

Alden, E. and M. Vescera. 1984. "Thorns of Plenty." Harrowsmith, 58: 38-51.

Allison, F.E. 1973. Soil Organic Matter and Its Role in Crop Production. Elsevier. New York.

Anderson, D.T. 1961. "Surface Trash Conservation with Tillage Machines." Canadian Journal of Soil Science, 41: 99-114.

Anderson, M. et al. 1984. Agricultural Land Degradation in Western Canada: A Physical and Economic Overview. Regional Development Branch, Agriculture Canada. Ottawa.

Baker, J.L. and J.M. Laflen. 1983. "Water Quality Consequences of Conservation Tillage." Journal of Soil and Water Conservation, 38: 3, 186.

Barnes, S. 1938. Soil Moisture and Crop Production Under Dryland Conditions in Western Canada. Publication 595, Canada Department of Agriculture. Ottawa.

Barney, G.O., P.H. Freman, and C.A. Ulinski. 1981. Global 2000--Implications for Canada. Pergamon. Willowdale.

Beesley, K.B. and L.H. Russwurm. 1981. The Rural-Urban Fringe--Canadian Perspectives. Geographical Monograph No. 10, Atkinson College, York University. Toronto.

Bennett, Jennifer. 1982. "Reap the Wild Wind." Harrowsmith, 43: 60-71 and 106-107.

Biederbeck, V.O. et al. 1980. "Effect of Burning Cereal Straw on Soil Properties and Grain Yields in Saskatchewan." Soil Science Society of America Journal, 44: 103-111.

Black, A.L. and F.H. Siddoway. 1976. "Dryland Cropping Sequences Within a Tall Wheatgrass Barrier System." Journal of Soil and Water Conservation, 31: 101-105.

Brocke, Larry. 1985. Personal communication. Chairman, Development and Reclamation Review Committee (Alberta Environment). Edmonton.

Brown, P.A. 1982. "Pick the Right Alfalfa to Dry Saline Seeps." Crops and Soils Magazine, 34: 22.

Brown, P.A. and J. Krall. 1981. Saline Seep Handbook. Bulletin 1209, Co-Op Extension, Montana State University. Boseman.

Brown, P.L. and E.C. Cleary. 1978. "Water Use and Rooting Depths of Crops for Saline-Seep Control." Dryland Saline-Seep Control. Proceedings, Meeting on Submission on Salt-Affected Soils, 11th International Soil Science Society Congress. Edmonton. pp.7.1-7.7.

Bryant, C.R. and L.H. Russwurm. 1979. "The Impact of Non-Farm Development on Agriculture: A Synthesis." Plan Canada, 19: 2, 122-139.

Bryant, C.R., L.H. Russwurm, and A.G. McLellan. 1982. The City's Countryside: Land and its Management in the Rural Urban Fringe. Longman. London. 262 pp.

Cacek, Terry. 1984. "Organic Farming: The Other Conservation Farming System." Journal of Soil and Water Conservation, 39: 6, November-December, 357-360.

Cairns, R.R. et al. 1967. "Effects of Nitrogen Fertilization of Bromegrass on Solonetzic Soils." Canadian Journal of Soil Science, 47: 1-6.

Cairns, R.R. and J.D. Beaton. 1976. "Improving a Solonetzic Soil by Nitrogen-Sulphur Materials." Sulphur Institute Journal, Fall-Winter, 10-12.

Canada Committee on Land Resources Services. 1980. A Strategy for Agricultural Land Resource Research for Canada. Prepared for the Canadian Agricultural Services Coordinating Committee.

Canada Soil Fertility Committee. ca. 1970. "Soil Pollution in Canada." Unpublished report. Agriculture Canada. Ottawa. 8 pp.

Cardwell, V.B. 1982. "Fifty Years of Minnesota Corn Production: Sources of Yield Increases." Agronomy Journal, 74: 984-990.

Carter, M.R. 1977. "Amelioration of a Brown Solodized Solonetz Soil by Surface Application of Gypsum Plus Ammonium Nitrate." Canadian Journal of Soil Science, 57: 139-145.

Collins, R. 1982. "We Must Stop Killing Our Soil." Reader's Digest, August, 53-57.

Cosper, Harold R. 1983. "Soil Suitability for Conservation Tillage." Journal of Soil and Water Conservation, 38: 3, 152-155 (see bibliography, #65).

Culley, J.B. et al. 1981. Impacts of Installation of an Oil Pipeline on the Productivity of Ontario Cropland. Research Branch, Agriculture Canada. Ottawa.

Davies, D.B. et al. 1973. "Relative Effects of Tractor Weight and Wheel Slip on Causing Soil Compaction." Journal of Soil Science, 24: 399-408.

de Jong, E. and D.A. Rennie. 1967. "Physical Soil Factors Influencing the Growth of Wheat." Canadian Centennial Wheat Symposium. Western Co-op Fertilizers Ltd.

Douglas, Gary. 1979. "Reclamation and the Saskatchewan Coal Industry." Proceedings, Canadian Land Reclamation Association. Regina. pp. 34-38.

Dyck, F.B. 1982. "Swather Attachment for Snow Management." Weekly Letter, #27, Swift Current Research Station, Agriculture Canada. Swift Current, Saskatchewan.

Energy Resources Conservation Board. 1980. Conservation in Alberta. Report 80-36. Calgary. 26 pp.

Environment Council of Alberta. 1984. Maintaining and Expanding the Agricultural Land Base in Alberta: Summary Report and Recommendation. ECA 84-17/RR1. Edmonton.

Fenester, C.R. et al. 1965. "Performance of Tillage Implements in a Stubble Mulch System III. Effects of Tillage Sequences on Residues, Soil Cloddiness, Weed Control, and Wheat Yield." Agronomy Journal, 57: 52-55.

Government of Canada. 1981. Federal Policy on Land Use. Department of Supply and Services, Ottawa.

Halvorson, A.D. and J.D. Rhoades. 1976. "Field Mapping Soil Conductivity to Delineate Dryland Saline Seeps With Four-Electrode Technique." Journal of the Soil Science Society of America, 40: 571-575.

Hendry, M.J. and F. Schwartz. 1982. "Hydrogeology of Saline Seeps." Soil Salinity. Proceedings, First Annual Western Provincial Conference, Rationalization of Water and Soil Research and Management, November 29-December 2. Lethbridge, Alberta. pp. 215-231.

Henry, J.L., P.R. Bullock, T.J. Hogg, and L.D. Luba. 1985. "Artesian Pressure as a Soil Salinization Factor in Saskatchewan." Canadian Journal of Soil Science, In press.

Johnson, W.E. 1961. "Wind and Water Erosion in Western Canada." Agricultural Institute Review, 16: 3, 12-15.

Kirkland, K.J. and H.M. Hustenson. 1978. Management Practices Contributing to Soil Erosion in Saskatchewan, 1975-77. Publication #385, Extension Division, University of Saskatchewan. Saskatoon.

Kachanowski, R.G. and E. de Fong. 1985. "Evaluation of the Erosion Index for the Prairies." Canadian Journal of Soil Science. In press.

Kruser, Ben. 1984. "The Life and Hard Times of a Prairie Pothole." Harrowsmith, 13: 35-39.

Lawrence, T. 1980. "Grasses and Legumes for Saline Soils." Weekly Letter, No. 3, Swift Current Research Station, Agriculture Canada. Swift Current, Saskatchewan.

Leskiw, L.A. and C.F. Bentley. 1983. An Overview of Current Trends and Thinking Regarding The Sustainability of the Productivity of Farmed Lands With Emphasis on Western Canada. For Canadian Advisory Council. Edmonton. 68 pp.

Marshall, I.B. 1982. Mining, Land Use, and the Environment I: A Canadian Overview. Land Use in Canada Series No. 22, Lands Directorate, Environment Canada. Ottawa. 280 pp.

Mathur, S.P. et al. 1979. "The Mitigating Effect of Residual Fertilizer Copper on the Decomposition of an Organic Soil in Situ." Soil Science Society of America Journal, 43: 1, 200-203.

McCracken, L.J. 1973. "The Extent of the Problem." Proceedings, Alberta Dryland Salinity Workshop. Lethbridge, Alberta. pp. 3-15.

McCuaig, J.D. and E.W. Manning. 1982. Agricultural Land Use Change in Canada: Process and Consequences. Land Use in Canada Series No. 21, Lands Directorate, Environment Canada. Ottawa. 213 pp.

McGill, W.B. et al. 1974. "Methods of Accelerating Oil Decomposition in Soil." Proceedings. Workshop on Reclamation of Disturbed Lands in Alberta, Northern Forest Research Centre. Information Report NOR-X-116. pp. 118-138.

Mckechnie, Ruth. 1985. Personal communication. Lands Directorate, Environment Canada. Ottawa.

McRae, James D. 1980. The Influence of Exurbanite Settlement on Rural Areas: A Review of the Canadian Literature. Working Paper No. 3, Lands Directorate, Environment Canada. Ottawa. 35 pp.

Miller, M.R. et al. 1981. "Saline Seep Development and Control in the North American Great Plains: Hydrogeological Aspects." Agricultural Water Management, 4: 115-141.

Murray, D.R. and J.R. Hardy. 1984. Soil Degradation and Conservation Projects in Canada. R and E Report No. 84-1, Regional Development Branch, Agriculture Canada. Ottawa.

Nicholaichuk, W. and D.W.L. Read. 1980. "Snow Management By Swathing at Alternative Heights." Proceedings, 1980 Soil Fertility Workshop. Saskatoon. pp. 55-58.

Nichalaichuk, W. and F.B. Dyck. 1983. "Soil Moisture Management." Proceedings, Fifth Manitoba-North Dakota Zero Tillage Workshop, Jan. 20-21. Brandon, Manitoba.

Nowland, John F. 1985. Personal communication. Research Branch, Agriculture Canada. Ottawa.

Pidgeon, E.R. 1984. How Specific Federal Policies May Impact on Prairie Soil and Moisture Conservation. Regional Development Branch, Agriculture Canada. Ottawa.

Prairie Farm Rehabilitation Administration. 1984. Prairie Soils: The Case for Conservation. Soil and Water Conservation Service. Regina.

Rennie, D.A. 1983. "Organic Matter--Fertility Loss in Saskatchewan." Proceedings, Saskatchewan Soils: A Fragile Resource. Soils Workshop, Saskatchewan Federation of Agriculture. Regina.

________ and T.C. Day. 1957. Tracer Fertilizer Research Report. Department of Soil Science, University of Saskatchewan. Saskatoon.

Ridley, A.O. and R.A. Hedlin. 1968. "Soil Organic Matter and Crop Yields as Influenced by Frequency of Summerfallowing." Canadian Journal of Soil Science, 48: 315-322.

Rodale, Robert. 1984. "Alternative Agriculture." Journal of Soil and Water Conservation, 39: 5, 294-296.

Rodgers, Randy D. and James B. Wooley. 1983. "Conservation Impacts on Wildlife." Journal of Soil and Water Conservation. 38: 3, 212-213.

Rostad, H.P.W., J.J. Kiss, and A.J. Anderson. 1983. Surface pH of Saskatchewan Soils. Factsheet, Publication M67, Saskatchewan Soil Survey Unit, University of Saskatchewan. Saskatoon.

Shields, J.A. 1983. Possible Impacts of Pipeline Construction on Farmland. Land Resource Research Institute, Agriculture Canada. Ottawa.

Simpson-Lewis, W. and R. McKechnie. 1981. Land and the Automobile: A Selected Bibliography. Working Paper No. 12, Lands Directorate, Environment Canada. Ottawa.

Simpson-Lewis, W., R. McKechnie, and V. Neimanis. 1983. Stress on Land in Canada. Folio No. 6, Lands Directorate, Environment Canada. Ottawa.

Snyder, J.R. et al. 1980. "Economics of Snow Management for Agriculture in the Great Plains." Journal of Soil and Water Management Conservation, 21-24.

Sommerfeldt, T.G. 1977. "The Lull Before the Storm." Dryland Salinity and Seepage in Alberta. Proceedings, the Alberta Dryland Salinity Committee. Alberta Agriculture.

________ and D.C. MacKay. 1982. "Dryland Salinity in a Closed Drainage Basin at Nobleford, Alberta. Journal of Hydrology, 5: 25-41.

Statistics Canada. 1982. 1981 Census of Canada: Agriculture: Canada. Cat. No. 96-901. Ottawa.

Stewart, John. 1985a. Personal communication. Saskatchewan Institute of Pedology. Saskatoon.

________. 1985b. "The Situation in Saskatchewan." draft chapter X of report for Science Council of Canada "Soil Degradation in Canada." (To be published as a part of the national report.)

Steppuhn, H.W. 1980. "Windrowing Snow to Increase Soil Water." Paper No. 80-407, Canadian Society of Agricultural Economics Annual Meeting. Edmonton.

Toews, B. 1973. "Deep Ploughing Solonetzic Soils in Alberta." Proceedings, 17th Manitoba Soil Science Meeting. 107-111.

Toogood, J.A. 1977. "Wind and Water Erosion Control Problems in Alberta." Proceedings, Soil Conservation Workshop. Alberta Agriculture. Red Deer.

Unger, P.W. and T.M. McCalla. 1980. "Conservation Tillage Systems." Advances in Agronomy, 33: 1-58.

U.S. Department of Agriculture. 1980. Report and Recommendations on Organic Farming. Washington, D.C. 94 pp.

Vander Pluym, H.S.A. et al. 1981. "Degradation by Salinization." Proceedings, 18th Annual Soil Science Workshop, 9-40.

Webber, H.J. and G.A. Warne. 1979. "Sulphur Emmissions--Alberta Energy Industries." Paper read at meeting of the Air Pollution Control Association. Edmonton.

Webber, M.D., N.W. Schmidke, and D.B. Coehen. 1978. "Sewage Sludge Utilization on Land--The Canadian Scene." Canada Centre for Inland Waters, Environment Canada. Presented to Conference, Utilization of Sewage Sludge on Land. Oxford, United Kingdom.

Witmuss, N.P., L. Olson, and D. Lane. 1975. "Energy Requirements for Conventional Versus Minimum Tillage." Journal of Soil and Water Conservation, 30: 2, 72-75.

Woodruff, N.P. and F.H. Siddoway. 1973. "Conservation Tillage." Proceedings. National Conference sponsored by the Soil Conservation Society of America.

## PART II

## 9.0 A LISTING OF THE SURVEYED LITERATURE


1. Anderson, D.W. and E.G. Gregorich. 1984. "Effect of Soil Erosion on Soil Quality and Productivity." Soil Erosion and Land Degradation, Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 105-113.

2. Marv Anderson and Associates Limited. 1981. Factors Affecting Summerfallow Acreage in Alberta. Environment Council of Alberta, ECA 81-17/IB1. Edmonton. 156 pp.

3. Batie, Sandra S. 1983. Soil Erosion: Crisis in America's Croplands? Conservation Foundation. Washington, D.C. 128 pp.

4. Barlott, P.J. 1983. "An Overview of Soil Conservation Legislation in Western Canada." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 178-184.

5. Beaton, J.D. 1980. "The Role of NPKS." Proceedings, Prairie Production Symposium: Soils and Land Resources. Canadian Wheat Board Advisory Committee. Saskatoon. 124 pp.

6. Biederbeck, V.O., J.A. Robertson, and D.C. MacKay. 1981. "Influence of Management Practices on Degradation." Agricultural Land: Our Disappearing Heritage. Proceedings, the 18th Annual Soil Science Workshop, February 24-25. Edmonton. pp. 256-320.

7. Black, A.L., F.H. Siddoway, and J.K. Aase. 1982. "Soil Moisture Use and Crop Management (Dryland)." Soil Salinity. Proceedings, First Annual Western Provincial Conference, Rationalization of Water and Soil Research and Management, November 29-December 2. Lethbridge, Alberta. pp. 215-231.

8. Cairns, R.R. and W.E. Bowser. 1977. Solonetzic Soils and Their Management. Publication 1391, Agriculture Canada. Ottawa. 37 pp.

9. Cameron, D.R. et al. 1981. "Physical Aspects of Soil Degradation." Agricultural Land: Our Disappearing Heritage. Proceedings, the 18th Annual Soil Science Workshop, February 24-25. Edmonton. pp. 186-255.

10. Campbell, C.A. 1983. "Positive Changes with Zero Till: Improvement in Soil Organic Matter and Related Properties." Zero Tillage. Proceedings, Fifth Manitoba-North Dakota Zero Tillage Workshop, January. Brandon, Manitoba. pp. 60-88.

11. ________ and V.O. Biederbeck. 1980. "Changes in the Quality of Soils of the Prairies as a Result of Agricultural Production." Proceedings, Prairie Production Symposium: Soils and Land Resources. Canadian Wheat Board Advisory Committee. Saskatoon. pp. 1-108.

12. Campbell, C.A., J.B. Bole, and W. Nicholaichuk. 1983. "Soil Conservation Research in the Brown and Dark Brown Soil Zones--Agronomic Significance of Cultivation Practices." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 266-284.

13. ________, E.A. Paul, and W.B. McGill. 1976. "Effect of Cultivation and Cropping on the Amounts and Forms of Soil N." Proceedings of the Western Canada Nitrogen Symposium. Edmonton. pp. 7-101.

14. Canada/Standing Senate Committee on Agriculture, Fisheries, and Forestry. 1984. Soil at Risk: Canada's Eroding Future. Committees and Private Legislation Branch, The Senate of Canada. Ottawa. 129 pp.

15. Canadian Federation of Agriculture. 1982. Soil Conservation Policy: A Backgrounder. Ottawa. 50 pp.

16. Clark, J. Stephen, and W. Hartley-Furtan. 1981. Economic and Soil Depletion Effects of Cropping Practices in Saskatchewan. Report to Saskatchewan Department of Agriculture. Department of Agricultural Economics, University of Saskatchewan. Saskatoon. 47 pp.

17. Coote, D.R. 1983. "Stresses on Land Under Intensive Agricultural Use." Stress on Land in Canada. Folio No. 6, Policy Research and Development Branch, Lands Directorate, Environment Canada. Ottawa. pp. 228-257.

18. ________. 1984. "The Extent of Soil Erosion in Western Canada." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 34-48.

19. ________, J. Dumanski, and J.F. Ramsey. 1981. An Assessment of the Degradation of Agricultural Lands in Canada. LRRI Contribution No. 118, Research Branch, Agriculture Canada. Ottawa. 86 pp.

20. Crosson, Pierre. 1981. Conservation Tillage and Conventional Tillage: A Comparative Assessment. Soil Conservation Society of America. Ankeny, Iowa. 35 pp.

21. de Jong, E. and D.R. Cameron. 1980. "Efficiency of Water Use by Agriculture for Dryland Crop Production." Proceedings, Prairie Production Symposium: Soils and Land Resources. Canadian Wheat Board Advisory Committee. Saskatoon. 36 pp.

22. Dyer, J.A. 1982. "Sustainability in the Canadian Agri-Food System." Canadian Farm Economics, 17: 3, 23-28.

23. Environment Council of Alberta. 1982. Irrigation Agriculture in Alberta. Staff Report, ECA 81-17/IB8. Edmonton. 74 pp.

24. Fairbairn, Garry Lawrence. 1984. Will the Bounty End? The Uncertain Future of Canada's Food Supply. Agricultural Institute of Canada/Western Producer Prairie Books. Saskatoon. 160 pp.

25. Foss, J.E. 1983. "Benefits of Erosion Control." Zero Tillage. Proceedings, Fifth Manitoba-North Dakota Zero Tillage Workshop, January. Brandon, Manitoba. pp. 53-59.

26. Furtan, W.H. and G.C. Van Kooten. 1984. "Economics of Soil Conservation and Land Degradation." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 185-194.

27. Goettel, A.W. 1977. "A Perspective of Resource Development on Agricultural Land." Soil Conservation, Reclamation and Research. Proceedings, the Alberta Soil Science Workshop, February. Edmonton. pp. 93-107.

28. ________, J.C. Hermans, and D.R. Coote. 1981. "Degradation by Erosion." Agricultural Land: Our Disappearing Heritage. Proceedings, the 18th Annual Soil Science Workshop, February 24-25. Edmonton. pp. 134-158.

29. Hedlin, R.A. 1980. "The Place of Summerfallow in Agriculture on the Canadian Prairies." Proceedings, Prairie Production Symposium: Soils and Land Resources. Canadian Wheat Board Advisory Committee. Saskatoon. 25 pp.

30. ________. 1981. "Farming for Tomorrow." Paper presented to the semi-annual meeting of the Canada Grains Council, October 27-28. Saskatoon. 11 pp.

31. Henry, J.L. and W.E. Johnson. 1977. The Nature and Management of Salt-Affected Soils in Saskatchewan. Saskatchewan Department of Agriculture. Regina. 26 pp.

32. Hermans, J.C. and A.W. Goettel. 1980. "The Impact of Surface Mining on Agriculture in Alberta." Proceedings, Symposium, Adequate Reclamation of Mined Lands? March 26-27. Billings, Montana. pp. 11-1 to 11-10.

33. Hermans, J.C. and C.J. Palmer. 1982. "Management of Solonetzic Soils." Soil Salinity. Proceedings, First Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management, November 29-December 2. Lethbridge, Alberta. pp. 301-315.

34. Hoyt, P.B., M. Nyborg, and H. Ukrainetz. 1981. "Degradation by Acidification." Agricultural Land: Our Disappearing Heritage. Proceedings, the 18th Annual Alberta Soil Science Workshop, February 24-25. Edmonton. pp. 41-71.

35. Johnson, W.E. 1977. "Conservation Tillage in Western Canada." Journal of Soil and Water Conservation, 32: 1, January-February, 61-65.

36. ________ and A.M.F. Hennig. 1976. "Soil and Crop Management to Reduce N Losses." Proceedings, the Western Canada Nitrogen Symposium. Edmonton. pp. 354-380.

37. Lee, Linda K. 1980. "The Impact of Landownership Factors on Soil Conservation." American Journal of Agricultural Economics, December, 1070-1076.

38. Lilley, John. 1982. Dryland Salinity in Alberta. Environment Council of Alberta. ECA 82-17/IB-13. Edmonton. 39 pp.

39. Lindwall, C.W. 1977. "Crop Residue Management to Prevent Wind Erosion and Conserve Soil Moisture." Soil Conservation, Reclamation, and Research. Proceedings, Alberta Soil Science Workshop, February. Edmonton. pp. 81-92.

40. ________ and S. Dubetz. 1984. "Conservation Tillage." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 121-129.

41. Lok, S. Chris. 1983. "Soil Erosion and the Sustainability of Agricultural Production." Proceedings, Canadian Society of Agricultural Economics. Truro, Nova Scotia. pp. 30-38.

42. MacKenzie, J.G. 1968. "Economics of Grain-Fallow Rotations and Fertilizer Use in the Prairie Provinces." Canadian Farm Economics, 3: 3, August, 15-27.

43. Manitoba-North Dakota Zero Till Farmers Association. 1983. Zero Tillage. Proceedings, Fifth Manitoba-North Dakota Zero Tillage Workshop, January. Brandon, Manitoba. 160 pp.

44. Massee, T.W. 1983. "Conservation Tillage Obstacles on Dryland." Journal of Soil and Water Contamination, July-August, 339-341.

45. McConnell, Kenneth E. 1983. "An Economic Model of Soil Conservation." American Journal of Agricultural Economics, February, 83-89.

46. McGill, W.B. 1982. Soil Fertility and Land Productivity in Alberta. Environment Council of Alberta, ECA 82-17/IB16. Edmonton. 123 pp.

47. ________. 1984. "Soil Conservation Requires Agricultural Systems Research." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 241-248.

48. ________, C.A. Campbell, J.F. Dormaar, E.A. Paul, and D.W. Anderson. 1981. "Soil Organic Matter Losses." Agricultural Land: Our Disappearing Heritage. Proceedings, the 18th Annual Soil Science Workshop, February 24-25. Edmonton. pp. 72-133.

49. ________ and P.B. Hoyt. 1977. "Effect of Forages and Rotation Management on Soil Organic Matter." Soil Conservation, Reclamation, and Research. Proceedings, the Alberta Soil Science Workshop, February. Edmonton. pp. 33-80.

50. Michalski, L.A. 1977. "Organic Soils in Eastern Manitoba." Proceedings, Manitoba Soil Science Meeting, Dec. 7-8. Winnipeg. pp. 121-126.

51. Nicholaichuk, W. 1980. "Snow Management to Provide Additional Water for Agriculture." Proceedings, Prairie Production Symposium: Soils and Land Resources. Canadian Wheat Board Advisory Committee. Saskatoon. 38 pp.

52. ________. 1982. "Snow Management for Salinity Control?" Soil Salinity. Proceedings, First Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management, November 29-December 2. Lethbridge, Alberta. pp. 233-257.

53. ________. 1983. "Current Conservation Technology in Saskatchewan." Proceedings, Saskatchewan Soils--A Fragile Resource. April 7-8. Regina. 12 pp.

54. ________ and F.B. Dyck. 1983. "Soil Moisture Management." Zero Tillage. Proceedings, Fifth Manitoba-North Dakota Zero Tillage Workshop, January. Brandon, Manitoba. pp. 89-104.

55. Pelton, W.L. 1980. "Tillage for Cereal Crop Production." Proceedings, Prairie Production Symposium: Soils and Land Resources. Canadian Wheat Board Advisory Committee. Saskatoon. 28 pp.

56. Penney, D.C. et al. 1977. "An Assessment of the Soil Acidity Problem in Alberta and Northwestern British Columbia." Canadian Journal of Soil Science, 57: 157-164.

57. Pohjakas, K. 1982. "Salt Movement and Salinity in Dryland and Irrigated Soils." Soil Salinity. Proceedings, First Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management, November 29-December 2. Lethbridge, Alberta. pp. 41-53.

58. Prairie Farm Rehabilitation Administration. 1983. Land Degradation and Soil Conservation Issues on the Canadian Prairies. Soil and Water Conservation Branch, Agriculture Canada. 326 pp.

59. Rennie, D.A. 1982. "The Deteriorating Soils of the Canadian Prairie." Span, 25: 3, 99-101.

60. ________. 1983. "Prairie Farming Systems Will Change Dramatically." Paper presented to the Conference on Life in the Canadian Prairies in the Year 2003, October 13-15. Regina.

61. ________ and J.G. Ellis. 1977. The Shape of Saskatchewan. Publication M41. Saskatchewan Institute of Pedology, University of Saskatchewan. Saskatoon.

62. ________, G.J. Racz, and D.K. McBeath. 1976. "Nitrogen Losses." Proceedings, the Western Canada Nitrogen Symposium. Edmonton. pp. 326-353.

63. Rennie, D.A. and D.B. Wilkinson. 1984. "Water Nitrogen Deficiency and Innovative Farming Practices." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 345-356.

64. Slinkard, A.E. 1984. "The Role of Forages and Legumes in Conservation- Tillage Systems." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 337-344.

65. Soil Conservation Society of America. 1983. "Conservation Tillage: A Special Issue." Journal of Soil and Water Conservation, 38: 3, May-June, 320 pp.

66. Vander Pluym, H. 1982. "Salinity in Western Canada." Soil Salinity. Proceedings, First Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management, November 29-December 2. Lethbridge, Alberta. pp. 9-23.

67. ________, B. Paterson, and H.M. Holm. 1981. "Degradation by Salinization." Agricultural Land: Our Disappearing Heritage. Proceedings, 18th Annual Alberta Soil Science Workshop. February 24-25. Edmonton. pp. 9-40.

68. Webb, Calvin. 1982. The Impacts of Linear Developments, Resource Extraction, and Industry on the Agricultural Land Base. ECA 82-17/IB25, Environment Council of Alberta. Edmonton. 87 pp.

69. Zentner, R.P. 1984. "Economics of Soil Conservation in Western Canada." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 195-219.

70. ________, C.A. Campbell, D.W.L. Read, and C.H. Anderson. 1984. "An Economic Evaluation of Crop Rotations in Southwestern Saskatchewan." Canadian Journal of Agricultural Economics, 32: 1, March, 37-54.

71. ________ and C.W. Lindwall. 1978. "An Economic Assessment of Zero Tillage in Wheat-Fallow Rotations in Southern Alberta." Canadian Farm Economics, 13: 6, 1-6.

## 10.0 ANNOTATED BIBLIOGRAPHY

1. Anderson, D.W. and E.G. Gregorich. 1984. "Effect of Soil Erosion on Soil Quality and Productivity." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 105-113.

This paper discusses what is meant by soil quality and examines the ways in which erosion deteriorates soil quality and leads to reduced productivity. It offers a background to the problem of soil erosion in the Canadian Prairies. Management techniques such as summerfallowing and erosion control practices are given a brief overview. Erosion control practices may not be cost effective in the short run compared to manipulative techniques, such as deep tillage to enhance water infiltration. It is felt though that they may prove most beneficial in the long run because of a general increase in soil quality.

The impact of erosion on soil productivity can be felt in four ways:

1) Loss of plant-available soil-water storage capacity.

2) Loss of plant nutrients.

3) Degradation of soil structure.

4) Increased variability of soils within a field.

Major problems in assessing the impact of erosion on productivity include the masking effect of improved agricultural technology and the replacement of lost nutrients with fertilizers. In addition, the relative effects of erosion on soil productivity depend to a considerable degree on the nature of the soil profile. The authors feel a simulation model approach may be of utility in estimating the actual impact of soil erosion on productivity in Western Canada.

2. Marv Anderson and Associates Limited. 1981. Factors Affecting Summerfallow Acreage in Alberta. Environment Council of Alberta, ECA81-17/IB1. Edmonton. 156 pp.

This study identifies and determines to what extent the benefits and costs of summerfallow affect a farmer's decision to utilize the practice. There are numerous region-specific reasons why a farmer summerfallows. The economic benefits from summerfallow are however short-run and accrue directly to farmers. Many of the costs are long-run and accrue to society. Since the decision to use the practice is made by individuals, the level of summerfallow will likely be higher than optimal from society's point of view.

These analyses indicate that farmers will adjust their summerfallow area (crop rotation) substantially with adequate inducement. Any number of programs could be developed which would very effectively and efficiently curtail summerfallow in Alberta:

1) Direct or indirect subsidies to farmers for grain and for farm inputs (excluding land).

2) Assessment practices for land taxation which discourage summer-fallow maintenance.

3) Directly paying farmers to switch to non-fallow cropping.

In this context, compulsory legislation to reduce summerfallow would probably be unnecessary.

3. Batie, Sandra S. 1983. Soil Erosion: Crisis in America's Croplands? The Conservation Foundation. Washington, D.C. 128 pp.

This analysis of the erosion problem documents the nature, extent, and effects of wind and water erosion in the US, examines the techniques available for reducing erosion, and identifies the factors influencing farmers' adoption of conservation practices. As well, the efficiency of present soil conservation programs in the US is investigated and various strategies for encouraging soil conservation discussed. Many examples from the Northern Plains states are applicable to the situation of the Canadian Prairies.

The severity of the erosion problem is difficult to measure in quantitative terms. Observations of the impact of erosion on soil loss and crop yield reductions though confirm that erosion represents a problem demanding immediate attention. Though numerous management practices are available to reduce erosion, many farmers are unwilling to adopt them: either they do not recognize they have soil erosion problems, or they prefer not to use certain conservation practices. Cost is often the culprit: the business-minded farmer who must remain competitive to stay in farming is not interested in unprofitable conservation practices. Even a farmer with a strong land ethic may be financially unable to practice conservation. Other factors influencing the adoption of soil conservation practices include leasing of land, tax policies, and loan policies.

Soil conservation programs in the US have been criticized for failing to achieve conservation goals. Other programs such as price support programs encourage farmers to continue using conventional approaches, thus exacerbating the problem of erosion. There _are_ cost-effective conservation strategies for governments from which to choose: they include targeting of conservation efforts, removing the most erodible lands from crop production, encouraging farmers to use low-cost practices (such as reduced tillage, residue retention, and contour plowing), and using some cross-compliance strategies. Since any conservation program must ultimately influence farmers, an understanding of the various factors affecting the adoption of conservation behaviour is crucial for the design of an effective public conservation program.

4. Barlott, P.J. 1983. "An Overview of Soil Conservation Legislation in Western Canada." _Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference:_ Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 178-184.

Barlott presents a brief review of current provincial legislation which deals directly with soil conservation and, in particular, addresses the control and prevention of soil erosion and land degradation. Though he concentrates on specific provincial legislation, a brief description of federal legislation is provided, i.e. the Agricultural and Rural Development Act and the Prairie Farm Rehabilitation Act. A summary of the applicable legislation in each of the four western provinces is presented and the key pieces of legislation are discussed. Alberta's laws (Soil Conservation Act and Agricultural Service Board Act) appear to be the most comprehensive in addressing soil erosion and soil degradation.

Barlott highlights some of the main soil conservation issues and problems, including the following:

1) The role of legislation in arresting soil degradation.

2) The responsibility of the farmer, society, and the country.

3) The reasons behind the ineffectiveness of existing legislation.

4) The necessity for a commitment from all levels of government to assist individual landowners to solve the problems of land degradation.

Barlott recommends that society's increasing concern and demand for the conservation of our soils be met by providing research, extension, education, and financial incentives programs combined with legislation--not legislation or regulations alone.

5. Beaton, J.D. 1980. "The Role of NPKS." Proceedings, Prairie Production Symposium: Soils and Land Resources. Canadian Wheat Board Advisory Committee. Saskatoon. 124 pp.

The role of nitrogen, phosphorus, potassium, and sulphur (NPKS) macronutrients in reaching the Canadian Wheat Board's production targets for the 1990's is reviewed. An understanding of the production capacities of these nutrients, their importance in aiding crops withstand various stresses, and their influence on moisture use efficiency is thus rendered. The extent of NPKS deficiencies in the Prairie Provinces is examined and the consumption of fertilizer nutrients discussed. A review of the developments for improving fertilizer use efficiency enables, in the author's opinion, an appreciation of the many noteworthy contributions of the western Canadian fertilizer industry.

Crops grown under the harsh climatic conditions of Western Canada are often stressed during at least part of the growing season by temperature and the lack of soil moisture. These stresses often lead to serious problems of wind erosion, salinization, diseases, and weeds. It is felt that high nutritional levels of NPKS help crops withstand these stresses. Also, the high yields obtained through proper use of NPKS fertilizers lower the production cost per tonne and increase the profit from each tonne harvested. As a result, returns per acre are maximized or in times of depressed crop prices, losses are minimized. The author concludes that large increases of NPKS fertilizers will be necessary to reach and sustain the 1990 crop production goals. Considerable expansion in manufacturing capacity for these nutrients is therefore necessary.

6. Biederbeck, V.O., J.A. Robertson, and D.C. Mackay. 1981. "Influence of Management Practices on Degradation." Agricultural Land: Our Disappearing Heritage. Proceedings, the 18th Annual Soil Science Workshop, February 24-25. Edmonton. pp. 256-320.

This extensive review of the extent to which cropping, tillage, and irrigation practices have caused soil deterioration in the Canadian Prairies highlights the necessity of defining management practices that will prevent further land degradation. Dryland cropping practices such as crop rotations, summerfallowing, snow management (as an alternative method of moisture conservation), and crop residue management are discussed. Their likely effects on the efficiency of water use, soil organic matter and nutrient dynamics, soil structure, and other physical properties are examined. As well, the promise offered by as yet limited research and testing of new soil water-crop management practices is considered. It may form the basis for the "new look" in western Canadian agriculture.

Adoption of summerfallowing has augmented the vulnerability of soils to erosion, and apparently lead to a considerable expansion of soil salinity. Mismanagement of irrigation schemes has also resulted in a considerable increase in the area of saline soils. Retention of crop residues and reduction in frequency of tillage operations are promising techniques to prevent further deterioration of the soil. Snow management techniques may prove to be the tool to eliminate much of the present area in fallow. When fallow is necessary, as is frequently the case in the drier regions, strip cropping should be practiced for wind erosion protection. Incorporation of more forage crops, including legumes, will aid in maintaining soil structure and fertility, and it is probable that the increasing costs of nitrogen fertilizers will make the use of legume crops more economic. Government land use and agricultural pricing policies must encourage farmers to adopt or to continue to use good soil management practices.

7. Black, A.L., F.H. Siddoway, and J.K. Aase. 1982. "Soil Moisture Use and Crop Management (Dryland)." Soil Salinity. Proceedings, First Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management, November 29-December 2. Lethbridge, Alberta. pp. 215-231.

This paper identifies and discusses the strategies for soil, water and crop management necessary to increase water-use efficiency, and thus halt the continued development and expansion of saline seeps. Such strategies are based on the following considerations: (1) Moisture conservation and storage, (2) Specific crop water requirements and rooting depths, (3) Crop residue management, (4) Disease and weed control, (5) Proper fertilization. Observations from the US Northern Great Plains can be compared readily with the situation in the dryland areas of the Canadian Prairies, because of similar climatic and soil characteristics.

Methods of increasing soil water storage during non-crop periods are essential to a greater water-use efficiency. In addition, the authors feel any major increase in precipitation-use efficiency on dryland will come from a thorough evaluation of the necessity of summerfallow in existing and potential cropping systems: summerfallow must be used judiciously. The selection of alternative cropping strategies must be based on a knowledge of the amount of plant-available soil water present at the time of seeding and the expected precipitation at a locality.

The major conclusions drawn in this evaluation of management strategies follow:

1) Methods of increasing water conservation during non-crop periods must include the control of volunteer cereal grains and weeds in the fall plus provisions for snow management through proper use of crop residue and vegetative barriers in the winter.

2) Leaving crop stubble or establishing a tall wheat-grass barrier system, or both, to trap and hold snow augments available soil-water supplies.

3) Optimizing the efficient use of available soil water supplies and growing season precipitation requires careful cultivar selection, establishing a good stand, a good weed control program, optimum fertilization, and timely farming operations.

8. Cairns, R.R. and W.E. Bowser, 1977. <u>Solonetzic Soils and Their Management</u>. Publication 1391, Agriculture Canada. Ottawa. 37 pp.

This paper gives an overview of the importance of solonetzic soils in Western Canada, with emphasis on their adverse effects on productivity and the special management problems these naturally-occurring soils present to the farmer. Cairns and Bowser discuss the potential benefits of drainage, tillage practices, seeding management, types of crops, and cropping systems to the productivity of solonetzic soils. As well, the use of fertilizers, lime, and gypsum is examined and the adverse effect of irrigation explained. A list of the practices found helpful in increasing productivity of solonetzic soils is provided: special attention must be given to surface drainage, seedbed preparation, seed placement, the use of forage crops, and fertilization. The authors feel that solonetzic soils are responsive to good management.

Soils so severely limited by the solonetzic condition that they will not produce even with good management may be deep plowed to a depth of at least 45 cm. Deep plowing results in an increase in soil pH from the introduction of calcium carbonate into the A horizon from the C horizon, and the increased availability of moisture. For the soils studied, the less productive the B horizon (or the greater the resistance to root penetration), the more responsive the soil was to deep plowing.

9. Cameron, D.R., C. Shaykewich, E. de Jong, D. Chanasyk, M. Green, and D.W.L. Read. 1981. "Physical Aspects of Soil Degradation." Agricultural Land: Our Disappearing Heritage. Proceedings, the 18th Annual Soil Science Workshop, February 24-25. Edmonton. pp. 186-255.

This paper reviews the effects of current and long-term land management practices on the physical properties of Prairie soils related to soil productivity. It concentrates on the long-term effects of soil cultivation on soil aggregation, structure, bulk density, porosity, compaction, and soil water infiltration and storage. A brief discussion of the effect of organic matter losses on soil tilth follows.

Repeated cultivation has resulted in a loss of soil fertility, loss of soil by erosion, decreasing crop yields, and increasing difficulty in growing crops. Use of tillage, especially summerfallow tillage, has increased the potential for wind and water erosion. Losses in organic matter are a major concern, since they render soils more susceptible to water and wind erosion, compaction, restricted moisture infiltration, reduced plant root extension, and poorer aeration, not to mention the loss of nutrients. Zero tillage and stubble mulch farming techniques, by leaving plant residues on the surface, are effective in protecting the soil from erosion and thus providing better aggregate stability. Also zero-tilled soils tend to store water more effectively after a dry spell; some aeration problems may however develop in poorly drained soils. Prairie soils are more compact than when they were originally broken; however, mechanical compaction does not yet appear to be a serious problem.

Although the inherent soil productivity has decreased due to cultivation, yields have continued to increase during the past 40 years: these yield increases are primarily due to technological advances including weed control, fertilization, better machinery, and better varieties (see Figure 7.1). However, the continuing deterioration of the land base has serious implications for future production capacity.

10. Campbell, C.A. 1983. "Positive Changes with Zero Till: Improvement in Soil Organic Matter and Related Properties." Zero Tillage. Proceedings, Fifth Manitoba-North Dakota Zero Tillage Workshop, January. Brandon, Manitoba, pp. 60-88.

Campbell reviews some of the current information on the effect of conventional tillage on soil organic matter, on plant-available nitrogen, and on other fertility-related soil properties influenced by organic matter (such as soil tilth and aggregation, and water infiltration), providing a comprehensive account of the effects of summerfallow on Prairie soils and its physical consequences. Then the paper discusses the importance of conserving crop residues on the land as an alternative to summerfallow. Thus, it points out the effectiveness of zero-tillage in improving the aforementioned factors. In semi-arid regions of Saskatchewan and Alberta, the amount of crop residue produced is often inadequate to provide protection to the soil for the entire fallow period. Judicious and knowledgeable use of tillage implements, application of fertilizers, and fallow operation timing are therefore imperative. Campbell concludes by calling for the promotion of comprehensive management practices. (See also #43.)

11. Campbell, C.A. and V.O. Biederbeck. 1980. "Changes in the Quality of Soils of the Prairies as a Result of Agricultural Production." Proceedings, Prairie Production Symposium: Soils and Land Resources. Canadian Wheat Board Advisory Committee. Saskatoon. pp. 1-108.

In this paper, the probable consequences of several future scenarios leading to a sizeable increase (46%) in grain crop production by 1990 are assessed in terms of the soil system of the Canadian Prairies. The scenarios discussed are the consequences of each of the following:

1) Reduction in summerfallow area.

2) Considerable increase in fertilizer use.

3) Increase in stored water through manipulation of winter precipitation.

4) Increase in irrigation area

5) A continued move towards more extended crop rotations and minimum till.

An extensive summary of previous findings is presented with an emphasis on quantitative data. The probable effects of each scenario on (1) nutrient reserves, especially nitrogen, (2) soil organic matter and nutrient dynamics, (3) the soil physical-chemical properties, (4) soil erosion, and (5) soil salinity are discussed. As well, the role of legumes and grasses is considered.

The authors believe that, provided the socio-economic climate is favorable, the soil system should definitely take a turn for the better, if the scenarios outlined above come to pass. Irrigation and continuous use of herbicides, however, might present long-run problems in terms of increased salinity and groundwater pollution.

12. Campbell, C.A., J.B. Bole, and W. Nicholaichuk. 1983. "Soil Conservation Research in the Brown and Dark Brown Soil Zones--Agronomic Significance of Cultivation Practices." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institue of Pedology. Saskatoon. pp. 266-284.

The authors review briefly some of the causes and consequences of land degradation--soil erosion, leaching of nitrogen and loss of organic matter. The findings and recommendations of past research are discussed, and the attributes believed necessary for a system designed to reduce land degradation suggested. Research in progress relevant to the problems of such a system in the drier Brown soil zone in the south is cited, and future research suggested. The conflict between ethical principles and economic reality is then examined, as is the question of "who has responsibility for proper husbanding of the soil?"

Wind and water erosion on the Prairies have increased recently due to improper cultural practices, principally the following:

1) The big-field, big-machinery, big-operator complex.
2) Baling and selling of straw off the land for short-term gains.
3) Greater use of fall-applied fertilizers and pre-emergent herbicides that require extensive tillage for effective incorporation.
4) Excessive tillage of summerfallow.

Sufficient crop residues to increase soil stability should be preserved on the land. However, the most serious consequence of the existing cultural practices is the depletion of the soil organic matter with the resultant depletion of the nutrients available to the plant (primarily nitrogen) and the deterioration of soil structure and tilth. Recent research shows that this trend can be reversed by the use of proper cultural practices which include continuous cropping rotations. Under proper management, where careful stubble mulch tillage and especially proper fertilization is used, land degradation can be arrested, and may even be reversed to some extent. The authors suspect that recovery would be expedited by the use of zero or minimum tillage and the inclusion of green manures (legumes) in the crop rotation. They advocate the increased use of extended rotations which include an annual deep-rooted legume, and feel that the inclusion of a fall-seeded crop, use of reduced tillage, and seeding directly into stubble would be advantageous.

Though desirable theoretically, these techniques face three major problems in the drier areas of the south:

1) Farmers are afraid of being wiped out if they do not fallow.

2) No suitable annual legumes are available at present for inclusion in the rotation.

3) It is not yet established if winter wheat will be a viable crop in this area; fall rye is not universally popular among farmers, except in sandy soils.

Research into improved stubble management techniques, appropriate legumes, zero and minimum tillage, and improved efficiency of fertilizers will some day provide the solutions. More research resources are required to reach this end.

13. Campbell, C.A., E.A. Paul, and W.B. McGill. 1976. "Effect of Cultivation and Cropping on the Amounts and Forms of Soil N." Proceedings of the Western Canada Nitrogen Symposium. Edmonton. pp. 7-101.

This thorough review of published and unpublished literature on organic matter and nitrogen (N) in Canadian prairie soils provides the data necessary to predict what the effects of current cultivation practices will be on the future quality of organic matter. Facets examined include the following:

1) Factors affecting the distribution of soil N.

2) Forms and amounts of soil N.

3) Qualitative and quantitative effects of management and pedogenic factors.

The effect on various forms of nitrogen of breaking virgin land, forage cropping, rowcrops versus cereals, summerfallowing versus cropping, straw and stubble mulch, tillage, and applying barnyard and green manures is also discussed.

Cultivation leads invariably to large losses of organic matter and total N. The additional frequent tillage associated with the wheat-fallow rotation is more destructive than longer rotations. Practices, such as including forages or manure in the rotation, reduce or retard the rate of loss of organic matter and total N, but continuous cereal cropping is actually more effective in maintaining organic matter and total N at a high level. Intensive cropping in fact may result in maintenance of soil nitrogen for a longer period after breaking than would a wheat-fallow system. The successful use of a nitrogen model to describe and explain past, and predict future, soil nitrogen dynamics indicates the potential of such models in long-term management decisions.

14. Canada/Standing Senate Committee on Agriculture, Fisheries, and Forestry. 1984. Soil at Risk: Canada's Eroding Future. Committees and Private Legislation Branch, The Senate of Canada. Ottawa. 129 pp.

This Senate Committee under Senator Herbert O. Sparrow recently completed hearings across the country on soil degradation in Canada. By drawing public attention to the severity of soil degradation, the Committee hopes to increase public awareness--to make soil degradation a national issue.

The report outlines the various factors responsible for the rapid depletion of our soils and reviews soil conservation technologies (which have the potential to mitigate the problem) and the reasons behind the absence of these technologies. Also, the role of government in soil conservation is closely examined. Regional perspectives on soil degradation are presented. Case studies illustrate solutions to soil degradation which have been applied with success. Based on the evidence presented to it, the Committee makes a number of recommendations designed to increase public awareness of the problem and to improve the dialogue among the public, farmers, governments, and environmental experts. The report also provides in an appendix a thorough review of the nature and extent of soil degradation processes and a discussion of the impact of agricultural practices on soil quality.

A brief review of historical cropping practices and their effect on the soil serves to explain what factors have led to the serious soil degradation and resultant productivity decreases affecting the Prairies. The wheat-fallow rotation cropping system (summerfallow) is believed to be largely responsible for the decline in organic matter content, increased soil erosion, and the alarming increase in salt-affected land under cultivation in the southern Prairies. Also, extensive use of ammonium fertilizers is making the soil acidification problem worse, especially in the Peace River District but also in the Meadow Lake-Lloydminster area of northwestern Saskatchewan. Some control measures outlined include reduction of summerfallow, grassed waterways (for soil erosion control), contour cropping, and legume rotation. One of the most promising techniques is conservation tillage. However, additional research is necessary if conservation tillage methods are to receive wider acceptance.

15. Canadian Federation of Agriculture. 1982. Soil Conservation Policy: A Backgrounder. Ottawa. 50 pp.

This paper, which acts as a backgrounder for the Federation's proposal for a comprehensive soil conservation policy, provides a general overview of the seriousness of the land degradation problem in Canada. It summarizes very briefly the process of soil formation, emphasizing the role of organic matter. The evidence of the soil erosion processes, associated soil problems, and resultant degradation in the major agricultural regions of Canada are reviewed and some of the causes isolated. A brief review of the current research and conservation practices is also provided.

The CFA feels the uniformity of early recommendations and programs, made regardless of soil type, has been a misguided approach, and recognizes the need for site-specific recommendations for farm management practices. They also outline a series of policy-oriented objectives essential to the conservation of the soil resource. Of these, three stand out:

1) There is a need for a quantified national survey of soil conservation needs.
2) A federal policy on the maintenance of soil productivity is required.
3) Stewardship should shape this soil conservation policy.

The CFA states that if we fail to take these actions, present trends will lead to a bleak future in terms of soil quality and productivity.

16. Clark, J. Stephen and W. Hartley Furtan. 1981. Economic and Soil Depletion Effects of Cropping Practises in Saskatchewan. Report submitted to the Saskatchewan Department of Agriculture. Department of Agricultural Economics, University of Saskatchewan. Saskatoon. 47 pp.

A theoretical model of soil conservation depletion is used to analyze the impact of various cropping patterns on the soil resource. The assessment of the impact of various product prices and input costs on the cropping pattern provides an economic perspective of the problem of soil conservation and depletion in Saskatchewan. The model recognizes the importance of tillage-operation timing with respect to the potential nitrogen reserves, and develops decision-making criteria to ensure the maximization of long-term profit. Three different cropping practices are analyzed:

1) An unrestricted cropping practice, wheat, barley, rapeseed, fallow, alfalfa.
2) A positivistic cropping practice, wheat, barley, rapeseed, fallow.
3) Continuous cropping, wheat, barley, rapeseed.

Alfalfa is found to be a competitive alternative within the rotation, as well as a crop which conserves the soil resource; continuous cropping is identified as the least profitable. Fallow is then a rational decision in Saskatchewan agriculture, since the cost to farmers of not having the option to fallow was found to be significant.

The authors thus feel that any program designed to dampen the depletion consequences of fallow should take these costs into account. As a policy tool, a subsidy program or guaranteed market for legumes is thus a more efficient means of conserving soil than restricting fallow. The results of the study also indicate that the present trend of potential nitrogen depletion is likely to continue for the foreseeable future except through some type of active intervention on the part of the government. Moisture availability is the most limiting factor influencing not only land value and output, but also the conservation of the soil: research into snow management and other moisture saving techniques is encouraged.

17. Coote, D.R. 1983. "Stresses on Land Under Intensive Agricultural Use." Stress on Land in Canada. Folio No. 6, Policy Research and Development Branch, Lands Directorate, Environment Canada. Ottawa. pp. 228-257.

Intensive agricultural use in Canada has resulted in serious land degradation problems. This comprehensive overview of the physical processes of agricultural land degradation and their impact on the land resource details the importance of soil degradation to the national well-being. A short discussion of the economic impact of land degradation in terms of land values, productivity, and environmental costs explains the role of short-term economic pressures and their influences on farmers' adoption of conservation measures. Legislative and policy options for land degradation control in Canada are also discussed. Coote's classification of degradation types has formed the basis of the organizing matrix in the present report.

Three broad categories of negative effects arising from intensive agriculture are distinguished:

1) Loss of soil materials, including wind and water erosion, and loss of organic matter.

2) Chemical deterioration of agricultural land, including the development of salinity or acidity, and contamination with heavy metals.

3) Physical deterioration of agricultural land, including compaction, mixing, and disturbance.

The processes involved in each category are described, and the location and extent of each effect as well as their apparent trend are examined. Examples from representative areas illustrate each process.

Wind erosion, the spread of salinity, and the loss of organic matter and organic nitrogen are the most pressing problems in the Prairies. Summerfallowing is the major cause of their increased incidence. Other practices, such as burning of straw and stubble and intensive cropping of some irrigated soils, result in increased losses of organic matter and nutrients. A considerable reduction in summerfallow area and improved minimum tillage and stubble management are suggested to control these depletive effects. Measures such as (1) snow-trapping, (2) increased use of fertilizers, (3) inclusion of grasses or forages (such as alfalfa) in the rotations, (4) continuous cropping of small grains where precipitation is high enough, and (5) better markets for crops should encourage farmers to reduce summerfallow use, and maintain better soil productivity. Though the problem of soil acidity is not widespread, the lack of a viable liming industry can be expected to increase this problem in severity and area. Soil contamination and soil compaction are of less concern in Western Canada, but soil disturbance from surface mining and the installation of oil and gas pipelines in Alberta may increase salinity conditions.

In Coote's opinion, incentives contained within production and marketing policies at both the federal and provincial levels are likely to be of greater effectiveness than legislative controls. A few measures suggested for the reduction of soil degradation and for the better maintenance of Canada's agricultural resource include the following:

a) Increasing awareness by farmers of the severity of land degradation through improved extension programs.

b) Establishing grants and economic incentives for erosion control measures.

c) Implementing a program or policy to encourage rotations of crops, especially if forages are included in the rotations.

d) Changing marketing quotas, relative freight rates, import restrictions, crop insurance program, etc. to alter grain, oilseeds, and forage areas in order to reduce summerfallow area.

The need for a concerted national effort to achieve these goals is stressed.

18. Coote, D.R. 1984. "The Extent of Soil Erosion in Western Canada." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 34-48.

This paper briefly characterizes and quantifies the extent of soil erosion in western Canada, and provides some indications of the severity of the problem in continental terms. Area-specific examples illustrate the nature of soil erosion and the influence of cropping practices. A brief overview of measured soil erosion gives an indication of the scarcity of measured soil erosion data and the variability among those that are available.

Using the USLE (Universal Soil Loss Equation) approach with (1) Canadian input data, and (2) U.S. data (extrapolated to represent Western Canadian conditions), Coote estimates the extent of wind and water erosion in Western Canada. The recent decline observed in the rate of soil erosion reflects the considerable decrease in the percentage of land in summerfallow between 1976 and 1981. Conversely, the increase in row-crop area, mainly in Manitoba, has contributed to an increase in the potential for water erosion, but Coote states that this was not enough to offset the benefits obtained from the reduced rates of land under summer-fallowing. Despite this decline, the western Canada soil erosion rate is more than twice that in eastern Canada and is little less than the average for the US. Considering the fact that western Canadian soils are not as deep as those found in many parts of the US, Coote reminds us we do not have the luxury to abuse these soils. With almost all of the world's cropland suffering erosion to some degree, and some at alarming rates, Coote feels it is clearly to the benefit of western Canada to reduce soil erosion and preserve the crop growing and exporting capability to the greatest extent possible.

19. Coote, D.R., J. Dumanski, and J.F. Ramsey. 1981. An Assessment of the Degradation of Agricultural Lands in Canada. LRRI Contribution No. 118, Research Branch, Agriculture Canada. Ottawa. 86 pp.

This report presents a general qualitative assessment of the kind, location, extent, and severity of land degradation in the major physiographic regions of Canada. Land degradation processes discussed include (1) soil erosion by wind or water, (2) soil structure and fertility loss accompanying intensive tillage, (3) soil salinization, (4) soil acidification, (5) soil contamination by chemical residues, (6) soil disturbance, and degradation resulting from (7) the deterioration of drainage systems, (8) earthflows and landslides, and (9) permanent loss of organic soils through oxidation and other factors of subsidence. Maps of degradation risk are included for the major types.

The major points of concern in the Great Plains region are wind erosion, salinization and loss of organic nitrogen. Water erosion is a serious problem in the Peace River district. The practice of summerfallow seems to be the chief cause of these problems. The authors feel little is as yet being undertaken by way of preventive or ameliorative measures. Since most of the control work will have to be done at the farm level, they believe a large part of the solution depends on the development of innovative policies and programs at different levels of government aimed at providing assistance to the farmer.

20. Crosson, Pierre. 1981. Conservation Tillage and Conventional Tillage: A Comparative Assessment. Soil Convservation Society of America. Ankeny, Iowa. 35 pp.

The article reviews the economic and environmental advantages and possible disadvantages of conservation tillage relative to conventional tillage to analyze prospects for the spread of conservation tillage in the U.S. Since examples from the Northern Plains states are quite relevant to the Canadian Priaries, Crosson's conclusions have interesting implications here.

The difference in quantities of inputs and yields determine the average costs, and thus the relative economics of the two technologies. In areas with well-drained soils, adequate control of weeds with herbicides, and potential for double cropping, the economics clearly favor conservation tillage. Labour costs, machinery investment and operation costs, and fuel costs were found to be less with conservation tillage, though it demands more management skills. The costs of acquiring such skills were not thought to be important. Heavier applications of pesticides to control weeds, disease and insect infestations may, however, be necessary. As well, the requirement for more nitrogen fertilizers under given soil conditions may be a major cost factor. Conservation tillage though will give higher yields than conventional tillage on droughty soils or in areas such as in the southern Prairies where rainfall is a limiting factor. Conservation tillage minimizes erosion, but its increased reliance on pesticides, particularly herbicides, makes it a greater threat to the environment. This trade-off is crucial to further consideration of conservation tillage.

How much conservation tillage spreads will depend upon how society perceives and weighs the differing impacts of the two systems on the environment. The author believes society will actively encourage this "innovation."

21. de Jong, E. and D.R. Cameron. 1980. "Efficiency of Water Use by Agriculture for Dryland Crop Production." Proceedings, Prairie Production Symposium: Soils and Land Resources. Canadian Wheat Board Advisory Committee. Saskatoon. 36 pp.

Summerfallow is a major factor in limiting production because of it's inefficient use of the limited precipitation available to prairie agriculture. As well, the low efficiency of water storage during the fallow period causes land deterioration problems such as salinization and increased erosion. The authors examine the techniques necessary to ensure maximum utilization of the water resource, and analyze whether sufficient water is available to produce the increased yields required for future needs.

The present research shows that, up to 1970, there was no relationship between the area of stubble-seeded crops in Saskatchewan and precipitation during the previous fall and winter, as would be expected if summerfallowing were practiced only for its role in conserving water. This suggests that other benefits of summerfallowing must be at least as important to farmers as the need for water conservation: weed control and tradition probably head this list.

The authors feel an increase in average production of at least 25% should be possible with improved use of fertilizers and weed control. However, water-use efficiency varies widely from year to year, mainly due to climatic factors: wide fluctuations in yield must then be expected from year to year despite improved fertilizer application and pest control. Possible methods of increasing the overall water-use efficiency are minimum tillage, terracing, irrigation from sloughs, and manipulation of the snow cover. Tillage methods may cause minor improvements in water conservation, but a major improvement seems possible by snow management. The amount of water gained by snow management in essence would completely eliminate the need to summerfallow for moisture storage and thus reduce the incidence of wind erosion and salinization. In addition, snow management may make it possible to use legumes in rotations in the drier area of the Prairies, reducing the need for fertilizer nitrogen. In the push for higher production, some attention should also be paid to crop residue management as a source of nutrients and wind erosion protection. It is also an essential component in snow management.

22. Dyer, J.A. 1982. "Sustainability in the Canadian Agri-Food System." Canadian Farm Economics. 17: 3, 23-28.

The long-term sustainability of present agricultural production practices in Canada is examined by reviewing and summarizing published articles and discussions on the deterioration of the soil resource. This paper thus provides a general overview of the current problems facing Canada's agricultural land base and examines its future from a broad viewpoint. The author feels that although the country has excellent land research capability, preserving agricultural resources is still not a high enough national priority. A review of the current unsustainable practices illustrates the argument for increasing our efforts to conserve land and soil resources for future generations.

The main areas of concern in the Prairies are increasing wind erosion and the spread of soil salinization. These problems are aggravated by current management practices such as irrigation, overuse of summerfallowing, and a trend towards large working blocks to accommodate large machinery. Some solutions offered as alternatives include zero or minimum tillage, crop rotations including legumes and/or forages, better machinery, and improved insect, disease, and weed chemical controls.

To promote conservation of land resources and sustainable agricultural production systems, the author recommends the following:

1) The results of research on land use, land evaluation and production potential assessment, and land and soil degradation, should be considered in regional development planning.

2) On-farm and public awareness issues related to land resource conservation should be promoted.

3) Funding programs should be created as incentives for on-farm use of sustainable production practices to ensure future food production capability.

23. Environment Council of Alberta. 1982. Irrigation Agriculture in Alberta. Staff report, ECA81-17/IB8. Edmonton. 74 pp.

This report examines the present status of irrigation agriculture in Alberta, reviews concerns related to and the economics of irrigation; it also investigates the possibility of an expansion in irrigated area. The future role of irrigation agriculture is thus estimated. The main degradation link to irrigation lies in its role in the spread of salinity.

Accumulation of salts in the soil results mainly from the seepage of water from poorly-constructed and inadequately-maintained delivery systems. Several passive measures to prevent and control saline soils are possible:

1) The use of deep-rooted forage crops, such as alfalfa, to reduce soil water levels.

2) Continuous cropping to prevent build-up of the water table.

3) Use of salt-tolerant crops, such as barley.

4) Application of barnyard manure to saline spots to improve soil tilth and other soil characteristics.

Drainage may be necessary, however, if the severely saline soils are to be reclaimed, and production from slightly to moderately saline soils maximized. Also, drainage must be combined with measures to improve water-use efficiency. Rehabilitation of water distribution systems, reclamation of soils, and improvements in water-use efficiency are thought capable of rectifying most of the problems. Irrigation can then help offset losses in agricultural production due to non-agricultural consumption of land.

24. Fairbairn, Garry Lawrence. 1984. Will the Bounty End? The Uncertain Future of Canada's Food Supply. Agricultural Institute of Canada/Western Producer Prairie Books. Saskatoon. 160 pp.

In this study, undertaken for the Agricultural Institute of Canada, Fairbairn focuses on the implications for society of certain major environmental challenges facing food crop production in Canada. Easily readable and suitable for the general public, it provides an assessment of the fundamental issues affecting the agricultural land base and suggests measures for action. The threat of soil degradation to the long-term sustainability of agricultural production is recognized. The affects of traditional agricultural practices on soil quality are discussed, and potential solutions examined. The increasing importance of chemical fertilizers and pesticides is explained, and the question of whether agricultural production can be not only maintained, but even increased substantially, is examined. The author also examines the impact of urban growth encroaching on farmland, and stresses the importance of land as a limited resource. A brief outline of the possibilities brought about by genetic research is provided, and the need to reinforce Canada's agricultural research and development capabilities is emphasized.

The major problems identified in the Prairies are soil erosion, rapid loss of organic matter and nitrogen, and increasing salinity. Many factors were involved in this comparatively rapid depletion of prairie soils, but much of the blame today is being placed on one farming method in particular, summer-fallowing. Continuous cropping is selected as the most likely soil-conservation strategy, as well as an approach that would substantially increase national economic benefits from prairie agriculture. However, a more likely near-term improvement would be to reduce the frequency of summerfallow to every third year since continous cropping requires additional moisture. Snow management techniques may prove to provide the clearest and biggest potential gains in moisture conservation for Prairie agriculture. Other potential solutions outlined include crop rotations using winter wheat, and soil-improving legumes like alfalfa and sweet clover; mixed farming; and zero or minimum-till techniques. Despite advances in scientific knowledge and technology, our success in maintaining soil quality will remain a key factor in maintaining Canada's food production potential for the foreseeable future.

25. Foss, J.E. 1983. "Benefits of Erosion Control." Zero Tillage. Proceedings, Fifth Manitoba-North Dakota Zero Tillage Workshop, January. Brandon, Manitoba. pp. 53-59.

Foss believes soil erosion is a major problem that is underestimated by many, including scientists. The two most important factors in the rationale for erosion control programs are felt to be the nature of the land stewardship ethic and the effect of erosion on crop yield. Other factors, such as loss of nutrients and sediment generation and deposition, are also sufficient reasons for control. The influence of erosion on the soil system is then examined. Modifications to physical and chemical properties of soil profiles are discussed and the influence of landscape on erosion is briefly described. Foss stresses that removing productive surface horizons and exposing unfavorable surface materials is a permanent change for most soils. He emphasizes the need for improvement of soil conservation measures.

Suggestions for future directions of soil conservation programs are provided. These focus on the importance of the conservation ethic and conservation practices, such as zero-tillage. Foss feels there is a need to organize all agencies involved in erosion control to develop a comprehensive erosion control plan.
(See also #43.)

26. Furtan, W.H. and G.C. Van Kooten. 1984. "Economics of Soil Conservation and Land Degradation." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 185-194.

The individual farmer faces technological, economic, and institutional constraints within which he must choose how to use his land, how much soil conservation to practice, and conversely how much land degradation to allow. Economic parameters were found to be the primary influence on farmer decisions regarding conservation practices in Saskatchewan. Interest rates are one example: the lower the interest rate, the more the farmer is willing to pay to prevent soil deterioration. The high interest rates we have experienced recently explain the lack of adoption of conservation practices. Society has a stake in the agronomic practices of the individual farmer; thus we may have a reason for government intervention.

Direct and indirect methods of government intervention are examined from an economist's viewpoint. Direct methods could include regulations on the use of fertilizers or other chemicals, financial and management counselling provided free of charge, and subsidized farm mortgage rates. Indirect methods are preferred by economists, though:

1) Economic incentives for farmers who implement particular conservation measures.

2) Taxes on undesirable runoff into waterways.

However, the authors warn of the danger in substituting for one evil (excessive depletion) for another (ill-founded and ill-designed government policies). They point out that care should be taken before implementing further programs.

27. Goettel, A.W. 1977. "A Perspective of Resource Development on Agricultural Land." Soil Conservation, Reclamation and Research. Proceedings, the Alberta Soil Science Workshop, February. Edmonton. pp. 93-107.

Goettel discusses some of the concerns about surface mining on agricultural land, in the hopes of providing a better appreciation of the adverse effects on agricultural production if surface mining developments are allowed without due consideration to future land productivity. He examines the agricultural capability of lands underlain by coal reserves and estimates the area potentially disturbed by future coal development. Goettel asserts the necessity of a pre-planned coal mining and reclamation program for each new development. Planning must consider the land, its present and future uses, and the social impact a large development can have on a farming community. He discusses the Alberta Coal Development Policy, by which the government of Alberta recognizes the concerns of the coal industry and the public and that provision for discussion of these concerns can take place.

The author outlines what he feels are the necessary requirements for minimizing the adverse impacts of surface mining in areas of extensive agricultural activity. His main concerns reflect the following:

1) The need for more pre-planning by both industry and government.

2) The need for detailed and indepth soil and surface geology inventories to develop reclamation plans so that final land use meets the "equal to better productivity" objective of the coal policy.

3) The need for reclamation technologies workable under a wide variety of conditions, to be adopted into mining and reclamation plans.

4) The need for a change in philosophy where reclamation is an integral cost of mining coal and this cost is passed on to the consumer.

28. Goettel, A.W., J.C. Hermans, and D.R. Coote. 1981. "Degradation by Erosion." Agricultural Land: Our Disappearing Heritage. Proceedings, the 18th Annual Soil Science Workshop, February 24-25. Edmonton. pp. 134-158.

This paper reviews the causes, extent, and consequences of erosion on the Prairies, with the focus on wind erosion. Control methods are examined and existing research, extension, legislation, and programs identified. A great deal of emphasis is given to the historical background leading to the present concerns of land degradation, and to results and recommendations of previous studies. This material provides a good backgrounder on what has been attempted thus far to prevent further erosion.

Summerfallowed land is identified as a greater risk than other tilled land, which in turn is more of a risk than untilled land. Other factors contributing to the erosion problem in Western Canada are removal of crop residue and lack of suitable crop rotations. A crop residue or trash cover farming technique combined with strip farming is the basic method developed to deal with erosion. Another good substitute for fallow, where moisture conservation is not the prime reason for summerfallowing, is sweet clover plowed down as green manure. Recent studies on minimum and zero tillage, fertilizer application, and soil management have been aimed at finding means to increase yields without additional risk of erosion.

Extension programs provide the information necessary to encourage farmers to use existing technology. Municipal and provincial soil conservation programs are available to provide financial assistance to prevent or remedy serious erosion problems. A series of recommendations by the Agricultural Institute of Canada is summarized: they emphasize the need for further research to quantify erosion losses and to develop improved technology and soil conservation programs.

29. Hedlin, R.A. 1980. "The Place of Summerfallow in Agriculture on the Canadian Prairies." Proceedings, Prairie Production Symposium: Soils and Land Resources. Canadian Wheat Board Advisory Committee. Saskatoon, Saskatchewan. 25 pp.

Many papers identify summerfallow as the main cause of the deterioration in soil quality in the Prairie Provinces. Hedlin reviews the benefits of summerfallowing in terms of its effect on moisture storage and increase in supply of available nutrients. A detailed description of the extent of fallow on the Canadian Prairies provides information on the factors influencing the frequency of fallowing. Though Hedlin admits summerfallow is of low efficiency in moisture storage, he feels the moisture gained is an important contribution to increased crop yields. The increased level of nitrate nitrogen available to the crop through the use of summerfallow also benefits crop yields.

The benefits of summerfallowing still do not indicate a significant need for fallow in the Prairies, and with adequate market opportunities and economic incentives for farmers, the area of land in fallow could be reduced by 10 to 20%. But Hedlin warns that, if yields are to be maintained, there is a need for an increase in nitrogen and phosphorus fertilizers, which in turn has important implications in terms of their cost, transportation, storage, and application.

30. Hedlin, R.A. 1981. "Farming For Tomorrow." Paper presented to the semi-annual meeting of the Canada Grains Council, October 27-28. Saskatoon. 11 pp.

The author discusses the benefits of using forage as part of a regular cropping system, and assesses the practicability of an integrated grain livestock industry on the Canadian Prairies. A review of land degradation concerns provides an understanding of the soil depletive effects of present management practices, and of the corrective measures available to ensure future soil productivity.

Though perennial forages add nitrogen to the soil and reduce erosion, continuous cropping or good crop residue cover reduces erosion to acceptable levels. The high water use associated with forages explains why these crops are not commonly grown in the drier areas. In these areas, snow management offers good possibilities for extending cropping and reducing fallow area. Frequent summerfallow is a factor in the serious decline of soil organic matter, as well as a cause of increased wind and water erosion, salinization and deterioration of soil structure. Greater use of ammonia or nitrogen fertilizers has contributed to increased soil acidity.

The data reviewed indicate that we can expect an improvement in organic matter levels and tilth with the use of forage crops. However, where good yields of annual crops can be obtained and where the residues are returned to the soil, an adequate level of decomposing organic matter can usually be achieved and desirable soil tilth maintained. Hence perennial forage, useful as it is, is not an essential part of the cropping system for quality maintenance of all soils. Hedlin thus does not foresee an integration of the grain and livestock industries with all farmers having some livestock. Though this may be desirable from a soil management viewpoint, it is not essential. Economics also militates against it.

31. Henry, J.L. and W.E. Johnson. 1977. The Nature and Management of Salt-Affected Soils in Saskatchewan. Saskatchewan Department of Agriculture. Regina. 26 pp.

This bulletin discusses causes of salt-affected soils, reasons for the spread of salinity, and methods for preventing further spread and improving production on these soils. It provides good background material aimed at a lay audience. The properties, development, and management of saline, alkali, saline-alkali, and solonetzic soils are discussed and their effect on plant growth is explained.

Water and its movement is responsible for the concentration of salts at certain locations. As such, an understanding of the water flow pattern and water management is the key to any successful management program for saline soils. Management practices discussed include soil testing, crop rotation, the selection of salt-tolerant crops, interceptor cropping, use of fertilizers and manure, tillage and weed control, chemical amendments, and drainage and leaching. Most of these represent preventive or coping measures and do not solve the problem of salinity itself in saline soils. In fact, the use of chemical amendments is strongly disapproved since there are none which will neutralize the salts present in the soil, and thus only serve to relieve the farmer of some of his money. Drainage and leaching is the only known way to reclaim saline soils and put them back to a fully productive state. However, desalinization of the soil would not take place upon installation of drainage in dryland areas such as southern Saskatchewan, without extra water to leach the salts out. A proposed solution for some dryland areas would be to institute a program of surface drainage of small sloughs or other water bodies that are contributing to the problem. The impact of this drainage on wildlife habitat is not discussed in the article.

32. Hermans, J.C. and A.W. Goettel. 1980. "The Impact of Surface Mining on Agriculture in Alberta." Proceedings, Symposium, Adequate Reclamation of Mined Lands? March 26-27. Billings, Montana. pp. 11-1 to 11-10.

The authors evaluate the potential impact of surface mining for coal on agriculture in Alberta. To do so, they examine the agricultural capability of lands underlain by coal fields and estimate the area to be disturbed by surface mining in the near future. One of agriculture's main concerns is whether or not lands that have been mined can be adequately reclaimed. We do not yet have the technology to ensure reclamation of all lands to equal productivity. Hermans and Goettel describe the direct and indirect impacts resulting from mining development. Since estimated energy demand will increase in the future, the authors feel the conflict between agriculture and coal mining is inevitable. Suggestions to minimize the impact of surface mining for coal are therefore provided.

About 67% of the coal fields in the Central and Southern districts of Alberta are located under arable land (CLI Classes 1 to 4). By the year 2004 at least 28,000 hectares will be disturbed by surface mining of plains coal at any one time. Therefore a total of at least 69,000 hectares will be disturbed from 1975 to 2004. In addition, land devoted to haul roads, buildings, and rail loops will at least double the land area affected by surface mining.

Direct effects resulting from strip mining may include subsidence, modifications to groundwater regimes and possible salinization, in addition to the problems of adequately replaced overburden. However, mine-related activities can also affect the productivity of farms many miles away from the mine site, i.e. transportation of coal by rail or road, electrical transmission lines, and pipelines from coal gasification plants. As well, additional employment opportunities due to mining may affect the agricultural communities in the form of new requirements for housing, business, etc. The affect on land values may have far-reaching effects. It is imperative that government and industry develop the necessary reclamation technologies and work with the agricultural community to minimize the impact of surface mining for coal. A change in philosophy is needed whereby reclamation is accepted as an integral cost of mining.

33. Hermans, J.C. and C.J. Palmer. 1982. "Management of Solonetzic Soils." Soil Salinity. Proceedings, First Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management, November 29- December 2. Lethbridge, Alberta. pp. 301-315.

This paper outlines the available management and reclamation techniques to improve and, in some cases, greatly increase production on solonetzic soils. The area of farmland affected by these naturally-occurring problem soils in the Prairies is described and the charactersitics of Solonetzic soils creating limitations to crop growth discussed. The overall emphasis of the paper nevertheless lies with describing and analyzing existing and potentail management practices. These involve surface drainage, seedbed preparation, fertilizer application, deep plowing, deep subsoiling, chemical amendments, and irrigation. These last four are given particular attention and detail. Adoption by farmers has been slow, due to the high cost and large risks involved. In addition, the natural variability in these soils makes it difficult to extrapolate information from one site to another. Therefore, further research is necessary to develop means of characterizing those solonetzic soil types that will respond best to the various management techniques.

34. Hoyt, P.B., M. Nyborg, and H. Ukrainetz. 1981. "Degradation by Acidification." Agricultural Land: Our Disappearing Heritage. Proceedings, the 18th Annual Alberta Soil Science Workshop, February 24-25. Edmonton. pp. 41-71.

Soil degradation by acidification and the implications of soil acidity for agriculture are described for the four provinces of Western Canada. The major causes of acidification are the increasing use of fertilizer, particularly nitrogen (N), and the acid precipitation of sulphur dioxide emitted from natural gas processing plants, smelters, and coal-fired power plants. The extent of land damaged by these chemicals is assessed, and the techniques available for controlling acidity are examined. Further, the need for government intervention is recognized.

The highest incidence of acid soils in the Prairies is in Alberta (70% of the total in Western Canada), followed by Saskatchewan; Manitoba has scant acid soil. Growing of acid-tolerant crops such as barley is one way of preventing yield losses due to soil acidity. But it is at best a temporary measure for farming acid soils on the Great Plains. Liming is the best technique for lessening soil acidity, but its costs have hampered its adoption by farmers. With the exception of deep ploughing of soils with lime layers that are shallow enough to be brought up, it is felt that no other management technique is likely to lessen soil acidity. Innovative methods such as banding of N fertilizers may decrease acidification, but their use will depend on their cost as opposed to that for lime.

If liming were to become a general practice, lime would become cheaper and liming would be both attractive and profitable to the farmer: it is suggested that major government assistance is needed to get a large volume of lime moving through a smooth-running infrastructure of supply, transportation, and application. As well, since the benefits of liming are spread out over many years and the initial cost is high, government guaranteed and assisted long-term loans should be made available to the farmer for buying lime.

35. Johnson, W.E. 1977. "Conservation Tillage in Western Canada." Journal of Soil and Water Conservation, 32: 1, January-February, 61-65.

The author assesses the possibility of reducing summerfallow area in western Canada. He examines the benefits and disadvantages of summerfallow management, chemical fallow and stubble management. Moisture conservation, crop establishment, soil physical properties, and weed, insect, and disease control are discussed.

Priority areas for reduction in summerfallow are the Black, Grey-wooded Luvisols, Dark Grey Chernozems, coarse-textured soils, land with a moderate to high salinity hazard, and land susceptible to severe water erosion. The period of fallow should be reduced on erodible soils by seeding winter rye or wheat in August or September of the fallow year. Reduced tillage operations give satisfactory results if seed placement is proper, weeds are controlled both mechanically and chemically, and sufficient fertilizers are used. Chemical fallow provides satisfactory erosion control, crop yields, and economic returns, but full chemical fallow involves high chemical costs to control all weeds and thus is uneconomic. As such, crop residue techniques are encouraged as they provide good erosion control, good moisture conservation, and comparable yields to chemical fallow. Nevertheless, problems in managing crop residues, weed control, seed placement, and incorporation of herbicides and fertilizers hamper the adoption of these techniques. Highest priority in conservation tillage research must then be given to the design of equipment and systems for mechanically handling and retaining crop residue on the land, and improving seed, fertilizer, and pesticide placement. Development of methods for incorporating soil-applied herbicides without excessive soil manipulation is of paramount importance.

36. Johnson, W.E. and A.M.F. Hennig. 1976. "Soil and Crop Management to Reduce N Losses." Proceedings of the Western Canada Nitrogen Symposium. Edmonton. pp. 354-380.

In an effort to assess the potential for increased nitrogen efficiency, the authors examine how various management inputs affect the level of nitrogen on the soil:

1) Crop selection, crop management, and cropping systems.
2) Erosion control.
3) Moisture conservation and utilization.
4) Weed control.
5) Basic soil management inputs dealing with denitrification losses.
6) Nutrient balance and pH.

Each input is treated on an individual basis. The discussion focuses on the necessary requirements for increasing the efficiency of nitrogen use, thereby reducing the potential for losses.

There is no one recipe for the most satisfactory level in the nitrogen economy. Seeding management, weed control, and balanced nutrient input are each required. With the added base of the related practices for erosion control and moisture conservation, reasonable efficiency in nitrogen use can be accomplished. A significant reduction in summerfallow, utilization of winter annuals, increased use of perennial forages and legumes in rotation, crop establishment to obtain maximum rooting, minimum tillage, and extended rotations are all necessary practices to exploit the nitrogen pool in the soil and to prevent losses to below the root zone.

37. Lee, Linda K. 1980. "The Impact of Landownership Factors on Soil Conservation." American Journal of Agricultural Economics, December, 1070-1076.

The influence of the organizational structure of landownership units on soil erosion, on a regional and national basis in the US, are examined in this study. Identification of significant differences among land ownership groups would permit development and implementation of more effective conservation policies.

Analysis of key land ownership variables hypothesized to influence soil erosion (i.e. type of organizational structure, income, and tenure characteristics) provide some insight into landownership impacts on soil conservation. Results indicate that nationally there are no significant differences in mean soil losses between different types of ownership groups. In addition, no significant differences in soil erosion rates exist between tenure groups at the national level, or within most regions. Instead, it was found that higher income landowners average less erosion than low income owners, due to a combination of less erodible land and more conservation practices. However, in regions with major erosion problems, mean rates of erosion do not differ among income groups, thus demonstrating that higher incomes alone may not result in improved management practices. Other factors such as owner attitudes toward conservation may also explain this difference. The analysis also shows that full landlords and part-owners appear to have a different relationship between net farm income and erosion than full owner-operators.

Thus, the author warns that policies designed to encourage conservation through income incentives may not have similar effects on all tenure groups. Even though land ownership factors do not appear to impact significantly on soil conservation when examined from a national perspective, the present analysis indicates that regional differences exist, at least with respect to income and tenure.
(See also #65).

38. Lilley, John. 1982. Dryland Salinity in Alberta. Environment Council of Alberta, ECA82-17/IB13. Edmonton. 39 pp.

Lilley discusses the causes of saline seeps, describes the extent and severity of saline seeps in Alberta, and examines the successes, problems, and implications of saline seep control. The lack of widespread adoption of reclamation measures is explained, and the need for a coordinated, well-planned effort by government to encourage reclamation of saline seeps is emphasized.

The spread in dryland salinity is believed to be mostly due to the extensive use of summerfallow. Lost yields, increased labour, and increased material inputs have resulted. Corrective measures that can be taken include the following:

1) Surface or subsurface drainage may be installed to reduce local groundwater recharge or to improve drainage in the seep area.

2) Recropping, or cropping with high water-use crops, can reduce recharge or increase the amount of water removed from the seep area.

These techniques are not widely implemented, however; high cost, lack of financial assistance, uncertainty of results, and length of time required to fully reclaim dryland seep areas deter their adoption. Acceptance of high water-use crops may be hindered by the inconvenience on grain farms, the associated increase in equipment needs, and the lack of markets.

Various actions are possible to improve control of dryland salinity. Direct and indirect government incentives would encourage a reduction in summerfallow, subsurface drainage, and methods using high water-use crops. The answer may however be in the continued rise in agricultural land prices--potentially a major incentive for reclamation of unproductive saline areas.

39. Lindwall, C.W. 1977. "Crop Residue Management To Prevent Wind Erosion and Conserve Soil Moisture." Soil Conservation, Reclamation, and Research. Proceedings, Alberta Soil Science Workshop, February. Edmonton. pp. 81-92.

The increased rate of wind erosion in southern Alberta emphasizes the constant need to use good erosion control practices. The author examines the beneficial impacts and adverse consequences of conventional, minimum, and zero tillage practices using results from field studies held ten years before. Their effect on soil moisture, quantity, and quality of crop residue, aggregate stability, and weed growth are discussed. Their impact on crop yield is also assessed.

Conventional tillage practices seem to aggravate the problem of soil erosion. Chemical fallow provides the best protection through better crop residue and moisture conservation. Evaporation rates are normally too high during the summerfallow season for either conventional or minimum tillage practices to conserve more than 20% of the precipitation received during that period. As well, the chemical fallow fields may be subject to erosion without adequate crop residue cover. Snow management practices are felt to be the most effective and practical means of improving moisture conservation in areas of adequate snow cover. On the other hand, the region which would most benefit from snow management practices is also the region where they will be the least effective, because of inadequate snow cover.

Though several studies have shown that tillage adversely affects the soil's physical properties, Lindwall suggests that both tillage and zero tillage may have a negative effect on aggregate stability. Despite these findings, the fields with little or no tillage continue to conserve more moisture and produce greater yields than conventionally tilled fields. The author suggests that the benefits of improved crop varieties and fertilizer management may have masked the effects of poorer soil fertility and structure. He believes the one practical application of zero-tillage lies in the area of recropping: flex-cropping, that is recropping whenever moisture reserves are adequate, would dramatically reduce summerfallow area and thus minimize the areas susceptible to soil erosion.

In conclusion, the author notes that the highly variable factors of weather, soil characteristics, and weed populations make it difficult, if not impossible, to define one tillage system (minimum or otherwise) that will always optimize the conditions necessary for maximum production. However, he believes a tillage system designed to maximize soil and water conservation will generally encourage higher and more stable production levels.

40. Lindwall, C.W. and S. Dubetz. 1984. "Conservation Tillage." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 121-129.

Soil conservation measures have evolved from erosion control practices such as strip cropping to chemical fallowing, recropping or continuous cropping, and finally to minimum and zero-tillage. The benefits and disadvantages of these farming practices are examined in the light of their effect on soil quality and productivity. The authors thus provide a detailed assessment of the effect of agricultural practices on the soil resource in the hope of increasing public awareness as to the importance of soil conservation.

The increased tillage associated with the summerfallow system is the main cause of increased soil erosion and loss of soil nutrients, as well as the spread of soil salinity. Although the technique of chemical fallow minimizes tillage on summerfallow and thus reduces soil erosion and associated fertility losses, recropping or continuous cropping seems to offer the greatest potential for maintaining soil productivity. Successful recropping or continuous cropping systems will make more efficient use of the limited and highly variable precipitation that occurs in semi-arid regions of the Prairies, while reducing problems of dryland salinity and soil erosion. Minimum or zero tillage practices also offer potential benefits such as reduced water and wind erosion, lower energy requirements, and greater moisture conservation. But the many problems associated with no-till cropping systems warrant additional research to investigate the merits of this practice. Nevertheless, the successful adoption of no-till cropping, even on a very limited area, demonstrates that many Prairie soils need very little, if any, tillage to be productive.

On the short-term economic basis, little or no incentive exists for controlling erosion. But since society will ultimately pay for soil erosion, there is an incentive for governments to subsidize soil conservation measures and/or penalize management practices which result in excessive soil degradation. In time, continued refinements of minimum tillage systems should provide their own incentives in terms of equal or higher yields and potential savings of time, labor, and energy.

41. Lok, S. Chris. 1983. "Soil Erosion and the Sustainability of Agricultural Production". Proceedings, Canadian Society of Agricultural Economics. Truro, Nova Scotia. pp. 30-38.

Soil erosion threatens the potential productivity of Canada's agricultural land. Its severity is examined, the many causes of increased soil erosion described, and the economic constraints to adoption of conservation practices detailed. The influence of present policies and programs is assessed and their drawbacks are identified. The case is made for a rational, informed, integrated approach to create a financial, marketing, technological, and political environment conducive to sustainable agriculture.

On the Prairies, extensive use of summerfallow and use of increased speeds by cultivation equipment have contributed to significant wind and water erosion problems. However, improved crop varieties, more efficient machinery, and the increased use of fertilizers, herbicides, and pesticides have masked erosion's negative yield effects. Market and production considerations have made long-term planning measures, such as soil conservation, exceedingly difficult to justify and to carry out. Producers have limited their investments to activities which provide immediate cash paybacks. In addition, new farm technologies (e.g. larger farm machinery) have rendered impractical traditional soil conservation practices, such as contour plowing and terracing. Despite provincial and federal support for soil conservation, the present policies and programs are not oriented specifically to erosion, or other land degradation problems. In short, the specific policy commitment required to deal adequately with the problem is weak. Indirect support for soil conservation through credit, stabilization, and other policies is absent. Producers cannot and should not be required to solve the problem on their own: public awareness of and responsibility for the problem is needed.

42. MacKenzie, J.G. 1968. "Economics of Grain-Fallow Rotations and Fertilizer Use in the Prairie Provinces." Canadian Farm Economics, 3: 3, August, 15-27.

Despite the claimed advantages of summerfallow, MacKenzie illustrates that as early as 1968 concern existed about its disadvantages. Under fallow, soil organic matter and trash cover are reduced and the soil surface exposed to wind and water erosion. Also, a large part of improved land is idle each year. The article thus examines the possibility of reducing, or even eliminating, land in summerfallow. It assumes that innovations and technological changes and practices, including fertilizer use, make it possible to maintain, if not increase, yields compared to levels achieved by using fallow. This economic perspective also enables an assessment of the impact of increased use of fertilizers and other crop production technology on rotation lengths, costs, and net returns. The extent to which fallow areas may be decreased and stubble-seeded area increased will depend on a combination of three factors:

1) Production costs per cultivated hectare which vary with changes in land use.

2) Yields on stubble-seeded crop in relation to fallow fields.

3) The price of wheat.

Unless the financial gain (measured by the increase in net returns per cultivated unit of area) is significant, the author feels the farmer will be inclined to stay with his present equipment and maintain the familiar fallow-wheat rotation. However, an increase in wheat yields as a result of greater use of fertilizer and other innovations, and/or an increase in the price of wheat, would encourage farmers to reduce summerfallow in favor of extended rotations.

43. Manitoba-North Dakota Zero Till Farmers Association. 1983. Zero Tillage. Proceedings, Fifth Manitoba-North Dakota Zero Tillage Workshop, January. Brandon, Manitoba. 160 pp.

The Manitoba-North Dakota Zero Till Farmers Association advocates the use of zero tillage as a management tool capable of reducing soil erosion and building up soil organic matter. The majority of papers provide technical information on the advantages and disadvantages of specific tools or machinery necessary or useful in reduced tillage systems. Other articles provide information on: (1) the characteristics and use of herbicides, (2) the manufacture and use of fertilizers, (3) chemical disease and insect control in a zero tillage system, (4) management programs for production of winter wheat and sunflower crops in a no-till system, and (5) stubble management and management of zero tillage field margins.

Three articles deal more specifically with zero tillage as a solution to soil degradation. See Foss (1983, #25), Campbell (1983, #10), and Nicolaichuk and Dyck (1983, #54).

44. Massee, T.W. 1983. "Conservation Tillage Obstacles on Dryland." Journal of Soil and Water Conservation, July-August, 339-341.

Attempts to use conservation tillage may result in reduced crop yield. Massee assesses the problems involved in this reduction of crop production: soil moisture, structure, temperature, and fertility; phytotoxic effects; weed control; plant pathogens; and other pests (rodents, insects) are all examined.

In dryland areas, the limited plant residue produced by wheat crops reduces the efficiency of soil moisture conservation. Massee feels soil moisture content and structure can be improved with conservation tillage. The reduced soil temperature associated with residue cover is not considered a problem in wheat production. Though extra nitrogen is required to obtain equal yields with conservation tillage, application of nitrogen fertilizer, especially by surface banding application, will provide a quick recovery of yields.

Among deterrents to the use of conservation tillage are the phytotoxic effects from residue decomposition, plant diseases in localized areas, and limitations of implements for seeding and fertilization. Proper management of residue and fertilizers should supply solutions to these problems. Growing wheat in widely spaced rows may also offer several advantages in conservation tillage systems--reductions in phytotoxic effects and weed and pest control.

45. McConnell, Kenneth E. 1983. "An Economic Model of Soil Conservation." American Journal of Agricultural Economics, February, 83-89.

This paper develops an economic model of agricultural production to determine when the individual's decision about soil use differs from what is preferable from society's viewpoint. Considering the depletion of soil only and abstracting from the environmental disruption caused by erosion, McConnell argues that the social and private rates of erosion are the same under most land tenure arrangements. Results of his study suggest that the asset market (land, implements, etc.) will account for the impact of soil erosion on agricultural productive capacity whether it is large or small. Water pollution is considered to be the major impact of soil erosion, not agriculture's future productive capacity. Thus the paper concludes that public policy should be directed towards reducing erosion only when it leads to significant pollution externalities. Nevertheless, information about soil depth (as a major component of the erosion problem) and its economic value should be disseminated and the impact of soil depth on the value of farms investigated.

46. McGill, W.B. 1982. Soil Fertility and Land Productivity in Alberta. Environment Council of Alberta, ECA82-17/IB16. Edmonton. 123 pp.

The author presents a comprehensive overview of the soil and landscape components affecting land productivity, and discusses how these may be affected positively or negatively by agricultural practices in both the short- and long-term. He reviews the factors affecting productivity in terms of their function and influence--including topography, temperature, water, structure and profile characteristics, soil depth and depth to bedrock, soil acidity, salt content, and soil organic matter.

McGill examines how man's activities affect these factors--tillage, summer-fallowing, use of fertilizers, manure and pesticides, liming, drainage, irrigation, sewage effluent, and sludge disposal on land. The extent of change due to salinization, acidification, organic matter and nutrient loss, chemical contamination and erosion are discussed and the effect of various management practices is examined. The last section briefly presents the results of past research, evaluates the role of research in conserving our agricultural land resource, and enumerates the priority areas for further research.

The author concludes that, on many farms, management practices have substantially improved land productivity and soil fertility through sound conservation techniques. But land degradation is encouraged by the resistance among some farmers to apply these techniques, the failure to use the Soil Conservation Act (of Alberta), grain export policies, and the grain quota system.

47. McGill, W.B. 1984. "Soil Conservation Requires Agricultural Systems Research." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 241-248.

Land degradation in Western Canada results from a land management and agricultural system which focuses on short-term economic gains. The fundamental difficulties are the following:

1) Misconceptions and inadequate links between biophysical data and economic analyses.
2) Incompatible technologies.
3) Difficulties in packaging technologies, i.e. soil conservation as a marketable product.

Soil conservation research is needed to ensure that technologies which promote soil conservation are internally consistent throughout a given agricultural system and that agricultural systems are compatible with and promote conservation. The emphasis then lies in developing systems that optimize and conserve the resource base.

The discussion points out the need for workable integrated alternatives to the present system, together with policy changes reflecting a desire to see such systems flourish in the West. One of these alternatives might be a system of closer integration of the livestock and grain industries, which would benefit land quality and assist the grain production arm of the operation so that both commodity groups, as well as the resource base, benefit. The formation of a soil conservation systems group would enable a concerted effort by economists and physical scientists towards reaching such a goal.

48. McGill, W.B., C.A. Campbell, J.F. Dormaar, E.A. Paul, and D.W. Anderson. 1981. "Soil Organic Matter Losses." Agricultural Land: Our Disappearing Heritage. Proceedings, the 18th Annual Soil Science Workshop, February 24-25. Edmonton. pp. 72-133.

This paper documents the causes and extent of soil organic matter lost as a result of agricultural activities in the Prairie Provinces, and identifies the effect of organic matter losses on agricultural productivity, on the environment, and on other degradation processes. Existing and future possibilities for maintaining soil organic matter are also discussed.

Loss of organic matter has three fundamental implications:

1) Loss of nutrient supplying power.

2) Deterioration of soil physical properties.

3) Environmental problems - i.e. groundwater pollution due to leaching of excess nitrogen; effect of denitrification on the ozone layer; greenhouse effect due to increased concentration of carbon dioxide in the atmosphere.

In general, it appears that loss of soil organic matter encourages aggregate disruption, soil compaction, erosion, low water infiltration, reduced water storage, and soil crusting. Adding manures or nitrogen fertilizers will maintain soil organic matter at some reasonable level. But these deteriorating effects are best offset by abundant root production within the soil, such as occurs with grasses and legumes in the rotation. A minimum or zero tillage cropping system, by maintaining crop residue on the surface, will also protect soil organic matter, but for these systems to work, good trash distribution is mandatory. Also, with good irrigation management it is possible to reduce organic matter losses to lower levels than under dryland conditions, but care must be taken to avoid leaching of nutrients and the spread of salinity.

Therefore, one of the best ways to add organic matter is through plant roots. Development of new biological and agricultural technologies to increase the input and return of nutrients to the system is required to maintain economically the organic matter content at its present level.

49. McGill, W.B. and P.B. Hoyt. 1977. "Effect of Forages and Rotation Management on Soil Organic Matter." Soil Conservation, Reclamation and Research. Proceedings of the Alberta Soil Science Workshop, February. Edmonton. pp. 33-80.

This paper examines the role of organic matter, identifies its sources, and reviews the impact of management and conservation practices on its level in Prairie soils. It provides a very detailed review of the threat of decline in organic matter.

Although the amount of organic matter in most Prairie soils is still not at dangerously low levels, the rate of decline has exceeded by a factor of three the ability to harvest from it. A model is used to analyze the effect of crop rotations on soil organic matter levels. Generally those crop rotations producing the greater below ground primary production have the most beneficial effect on soil. It appears that root production and death during the forage period of a rotation is responsible for the longer term benefits of a rotation on soil organic matter level. Thus summerfallowing is undesirable, and legumes and grasses desirable. Manures have little additional benefit that cannot be made up with commercial fertilizers. Plant production is thus the best way to conserve and reclaim soil. Though short rotations appear to be better in terms of preventing the fixed nitrogen from accumulating in soil as organic nitrogen, the authors feel that long rotations are more beneficial for maintaining organic matter levels over the long term.

50. Michalski, L.A. 1977. "Organic Soils in Eastern Manitoba." Proceedings, Manitoba Soil Science Meeting, December 7-8. Winnipeg. pp. 121-126.

Organic soils are an important resource for agricultural production in eastern Manitoba. Production problems arise though because peat soils are colder and wetter than mineral soils. Current management practices may have lead to a substantial loss of organic soils. This paper identifies the problems associated with cultivation of organic soils, and describes the consequences of current management practices. It does not supply solutions to the existing problems, however.

The majority of farmers consider burning the only way to bring peatland into agricultural production, particularly for cereal crops. However, extensive burning not only reduces the amount of organic material, but also can expose a subsoil often difficult to till or crop using standard practices. A surprisingly high percentage of farmers feel that the peat ashes add enough fertility to the subsoil, without addition of commercial fertilizers, and therefore favor continued use of burning. The hazards and environmental damages which can and have been caused by bog fires have led to the implementation of government restrictions on peatland burning. Alternative measures are urgently needed to cope with the problems of farming Manitoba's organic soils. Whether it be new tillage techniques or identification of profitable, new crops, research is imperative to provide satisfactory solutions for both the farmer and conservationist.

51. Nicholaichuk, W. 1980. "Snow Management to Provide Additional Water For Agriculture." Proceedings, Prairie Production Symposium: Soils and Land Resources. Canadian Wheat Board Advisory Committee. Saskatoon. 38 pp.

Nicholaichuk reviews the progress made in snow management, and discusses how this resource may be utilized to meet crop production goals set for 1990 by the Canadian Wheat Board. The climatological and hydrological aspects of snow are discussed in terms of their effect on the snow resource potentially manageable for agronomic purposes in the Prairies. The highly variable nature of snowfall common to much of the Prairie region must be considered in the planning for snow management. A detailed description of competitive and non-competitive snow barriers enables an assessment of the economics of some of the snow management practices: stubble management and vegetative barriers seem to offer the greatest potential.

Three avenues appear available for the production goals set for 1990:

1) Use snow management techniques to increase winter wheat production.
2) Reduce summerfallow areas through extension of the rotation. This also reverses the trend of increased salinity.
3) Increase production on existing cultivated lands through snow management.

52. Nicholaichuk, W. 1982. "Snow Management for Salinity Control?" Soil Salinity. Proceedings, First Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management, November 29-December 2. Lethbridge, Alberta. pp. 233-257.

The low water-use efficiency of the wheat-fallow rotation is the prime contributor to the spread of salinity and the decline in organic matter in the Prairies. A major shift in land-use practices is felt to be essential to the betterment of the land resource. The proposed approach is extension of the crop rotation.

Snow management, by stabilizing production through improved water management, offers one of the greatest potentials for extending cropping systems on the Canadian Prairies. Some of the snow management concepts that can be adapted to Prairie conditions are reviewed in an attempt to demonstrate the availability of techniques for doing so. A detailed description of competitive and noncompetitive snow barriers is given: snow manipulation by stubble management provides, in the author's opinion, the greatest potential to provide additional water for crops.

The author concludes that increased productivity for an extended cropping system becomes an economic incentive for producers to consider the practice of snow management, in addition to the control of salinity and organic matter loss.

53. Nicholaichuk, W. 1983. "Current Conservation Technology in Saskatchewan." _Proceedings, Saskatchewan Soils--A Fragile Resource._ April 7-8. Regina. 12 pp.

Conventional summerfallowing practices have a detrimental effect on the land and water resource: low water conservation efficiency results in increased erosion and salinity. Management techniques available to reduce this resource degradation are examined in terms of improved water-use efficiency, weed control, soil organic matter content, and increasing production to meet world requirements.

The adoption of minimum and zero tillage practices can increase the water conservation efficiency and reduce the problem of erosion. However crop diversification (with continuous cropping) promises better use of stored water. Snow manipulation by stubble management provides the greatest potential for additional water, not only to increase yield on stubble land, but to enable a major shift in land-use practices. As well, there are strong indications that winter wheat may pay major dividends in terms of increased moisture-use efficiency and increased production. Zero-till and extended cropping nevertheless offer an alternative to crop diversification while improving the moisture-use efficiency and soil organic matter. The long tradition of monoculture spring wheat will have to be abandoned, if effective weed control is to be achieved on stubble land.

Under current economic conditions, not all producers are willing to accept the risk associated with these practices until more is known about the details of these techniques, particularly their economic implications. Agencies such as PFRA and provincial conservation authorities should take an active part in promoting control practices.

4. Nicholaichuk, W. and F.B. Dyck. 1983. "Soil Moisture Management." Zero Tillage. Proceedings, Fifth Manitoba-North Dakota Zero Tillage Workshop, January. Brandon, Manitoba. pp. 89-104.

Conventional summerfallowing practices have lead to salinization and a decline in organic matter on the Canadian Prairies. The authors explain how summerfallowing was originally considered necessary for moisture conservation in the Great Plains area where wheat is the principal crop. Their paper then reviews some of the improved management techniques and their contribution to moisture conservation, including snow management and the adoption of minimum and zero-till. The authors feel that snow manipulation by stubble management provides the greatest potential to provide additional water. They provide concise details of the various competitive and non-competitive snow barriers and examine their efficiency to trap, distribute, and hold snow on the fields. They conclude that the zero-till environment, in particular the use of standing stubble, offers an alternative to crop diversification while improving the moisture use efficiency of prairie soils.

(See also #43.)

55. Pelton, W.L. 1980. "Tillage for Cereal Crop Production." Proceedings, Prairie Production Symposium: Soils and Land Resources. Canadian Wheat Board Advisory Committee. Saskatoon. 28 pp.

Zero-tillage is presented as an attractive alternative to other more conventional tillage systems in face of rising labor, fuel, machine, and land costs, and where the conservation and most efficient use of natural resources is of paramount importance. An overview of the evolution of tillage practices and their present status on the Canadian Prairies provides the background to a more detailed assessment of the benefits and disadvantages of conventional, minimum and zero-tillage practices. The problems related to zero-tillage are given detailed accounts, including discussions on trash management, weed control, seeding, soils, insects, diseases, and economics.

The detrimental effects of the summerfallow-crop rotation system emphasize the economic importance of land productivity. To meet projected market demands for 1990, it is felt that the application of known technology would achieve half of the required production increases. This implies that a substantial portion of the required production increases must come from an increase in cropped area, which in turn implies that the rate of reduction in summerfallow area must be increased. Zero-tillage may be the answer: if zero-tillage techniques can lead to improved moisture conservation, this technology will assist in reducing the rate at which dryland salinity is spreading while at the same time helping to meet the projected demand for increased production, provided the market exists and quota demands follow. Still, a major research effort is needed to define those areas most suited to zero-tillage, and to develop improved seeding and spraying equipment. Current and potential problems of weed control, fertilization, soil physical and chemical properties, plant residue phytotoxicity, and disease and insect control should be investigated. Above all, the economics of the practice must be fully evaluated.

56. Penney, D.C., M. Nyborg, P.B. Hoyt, W.A. Rice, B. Siemens, and D.H. Laverty. 1977. "An Assessment of the Soil Acidity Problem in Alberta and Northeastern British Columbia." Canadian Journal of Soil Science, 57: 157-164.

This paper estimates the extent of acid soils throughout Alberta and the British Columbia section of the Peace River region, and determines the effect of lime inputs on the yields of several major crops grown in field experiments on representative acid soils. The results of pH measurements on 88,000 soil samples on farms and from 28 field experiments show that soil acidity is a problem of considerable importance in these areas. The authors feel a moderate decline in soil pH would cause a large increase in the severity and extent of the soil acidity problem. This decline can be expected from the continued use of nitrogen fertilizers, since liming is not yet practiced because of its high cost.

Suggested remedies include the following:

1) Elimination of summerfallow.
2) Use of zero tillage for continued cropping.
3) Use of deep-rooted forage crops.
4) Salinity control practices such as surface and subsurface drainage.

It is also suggested that diversification of crops and recycling of crop residues be used to control salinity.

Lately, economic conditions have escalated land prices and thus have encouraged farmers to take better care of the soil resource. The author is optimistic that during the next generation, land management and salinity control practices on the Prairies will be greatly improved. A more stable and conservation conscious farming population will make use of the available technology to preserve the land base.

57. Pohjakas, K. 1982. "Salt Movement and Salinity in Dryland and Irrigated Soils." Soil Salinity. Proceedings, First Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management, November 29- December 2. Lethbridge, Alberta. pp. 41-53.

A review of the factors affecting soil salinity provides the background to an assessment of land management and salinity control practices in the Prairies. The attitude toward land is given high priority in this overview of the farmer's perception of the soil salinity problem and what he is willing to do about it.

Despite the availability of existing preventive and control measures, economic and other short-term considerations have so far curtailed their implementation. As long as a piece of land is considered essentially a business asset within the framework of one's lifetime or current market conditions, long-term capital investments and improvements for land conservation are not attractive alternatives. A change in attitude of people toward land is as important as the technical knowledge which is required to implement stabilizing measures.

Current irrigation practices have heightened the rate of the salinization process. The area irrigated will increase in response to increased production targets, thus exacerbating the problem of soil salinity.

58. Prairie Farm Rehabilitation Administration. 1983. Land Degradation and Soil Conservation Issues on the Canadian Prairies. Soil and Water Conservation Branch, Agriculture Canada. 326 pp.

Soil degradation threatens the future productivity of the Prairie agricultural land base. This major PFRA report documents its nature and quantifies its extent and severity. Management practices responsible for various forms of soil degradation are investigated and their impact on soil productivity assessed. The implications of soil degradation for the national economy are also outlined. The role of the PFRA since the Thirties is examined, and the need for immediate action to alleviate current soil degradation problems emphasized. Requirements for an effective and long range soil conservation program in the Prairies are thus recommended.

Key issues are the spread of salinity, wind and water erosion, and the loss of organic matter resulting mainly from summerfallowing and excessive tillage. Various control measures are suggested to mitigate increasing salinity and erosion problems, and to maintain optimum levels of organic matter and fertility. They include conservation tillage and elimination of base summerfallow.

Other soil conservation issues include soil acidification, management of solonetzic soils, and soil moisture conservation. Increasing use of fertilizers without complementary liming is identified as the major cause of soil acidification. Improvements in soil moisture conservation are possible with snow management, residue management and reduction in summerfallow.

There is then a need for a major soil conservation initiative by government that would include all aspects of soil conservation. More research and extension efforts are necessary to encourage the adoption of soil conservation techniques. As well, incentive funding to farmers is required to encourage implementation of conservation plans: this is considered essential in recognition of the short-term economic impediments to conservation technologies.

59. Rennie, D.A. 1982. "The Deteriorating Soils of the Canadian Prairie." Span, 25: 3, 99-101.

The two-year wheat-fallow rotation conventionally used on the Canadian Prairie has produced a marked deterioration in soil fertility, with the bare summerfallow bearing the main responsibility. Fallowing has been a major cause of soil erosion, has accelerated the rapid loss of organic matter, and has precipitated a major increase in the area of salt-affected soils. Rennie describes the effects of these adverse changes on prairie soil quality. He outlines the type of approach now required to improve soil quality, and thus maintain productivity in this vast area so vital to world grain supplies.

During the last decade or so, the escalating cost of inputs, the price of grain, and the marketing quotas used to control production have encouraged the continued intensive use of summerfallow. This long used water-inefficient cropping system has induced a downward trend in native soil productivity. To the farmer, this means relatively large amounts of fertilizer nitrogen are necessary for adequate crop yields: the days of cheap grain production in Western Canada are limited.

Because of the soil's much-reduced resistance to erosion, the practice of leaving crop residues at the surface as a stubble mulch is no longer an adequate measure for reducing the risk of wind erosion. The solutions appear to include the development of a new and radically different farming system, which has the overriding goal of maximizing water-use efficiency. Key components of this new farming system are snow management, minimum or zero cultivation, or chemical fallow, and optimum fertilizer and herbicide inputs. Research underway will determine if this system is economic.

60. Rennie, D.A. 1983. "Prairie Farming Systems Will Change Dramatically." Paper presented to the Conference on Life in the Canadian Prairies in the Year 2003, October 13-15. Regina.

Rennie discusses the various components of the "water-efficient farming system of tomorrow." Present crop-fallow or crop-crop fallow farming systems are notoriously water inefficient, resulting in rapid deterioration in quality of prairie soils. The key to improved water efficiency, he feels, is snow water and he recommends the use of snow management practices. These can result in a reduction of fallow area, a sharp reduction in risk of drought, yield increases, and an increase in production. Rennie thus provides an upbeat and optimistic view of a sustainable and prosperous agricultural industry on the Prairies, which can maintain high soil quality. Other "new look" components, which directly contribute to further increases in water-use efficiency, are also outlined (e.g. zero-till, no fall tillage, increase in winter wheat area, optimum use of fertilizers, and herbicides).

Several constraints, however, negate rapid farmer acceptance: grain quotas, recropping misconceptions, crop insurance coverage, transportation constraints (e.g. the Crow Rates), the lack of effective incentive programs, problems in technology transfer from the lab to the farmer, and the lack of major investments in research in this area.

61. Rennie, D.A. and J.G. Ellis. 1977, The Shape of Saskatchewan. Publication M41, Saskatchewan Institute of Pedology, University of Saskatchewan. Saskatoon.

The authors present an overview of the factors affecting the productive capacity of Saskatchewan's agricultural land resource. Climate, landscape, and soil are discussed in terms of their limitations to productivity. The distribution of CLI (Canada Land Inventory) classes for soil capability in Saskatchewan is briefly examined. The scientific developments responsible for the upward yield trends during the past 30 years are reviewed, while the effects on the land of agricultural practices are detailed. Despite the upward trend in crop yields, soil degradation is recognized as a serious problem in Saskatchewan, with the potential to affect future productivity. The most serious problems are wind and water erosion, loss of organic matter and nitrogen, and salinization. Each one is discussed in terms of its causes, consequences, and severity. Alternatives to a continuing decline in soil quality are proposed, and the need for guidelines on which to base improved soil management practices is stressed.

Overuse of summerfallow, and the excessive tillage associated with this practice, are the apparent reasons for the downward trend of native soil productivity. The authors are convinced that any major breakthrough must be based on cycling more of the precipitation through crops with substantially less water loss. They recommend regular additions of crop residues, together with minimal tillage, and a reduction in fallow area. The alternatives to a continuing decline in soil quality are to extend the cropping system, and (when and where summerfallowing is necessary to conserve moisture) to reduce summerfallow tillage to a minimum. The authors feel summerfallowing, like fertilizers, etc. should be a variable input, to be used only when conditions warrant. Farmers are advised, particularly in saline hazard areas and in the more humid regions of the province, to adopt a land-use practice consisting primarily of a sequence of crops, the selection of which is dependant on soil adaptation and market conditions. One practice offering considerable promise in the authors' opinion is the zero or no-till farming system.

62. Rennie, D.A., G.J. Racz, and D.K. McBeath. 1976. "Nitrogen Losses." Proceedings, the Western Canada Nitrogen Symposium. Edmonton. pp. 326-353.

Cultivation has led to a decline in the nitrogen (N) content of Prairie soils. This paper reviews the processes responsible for this deterioration of soil fertility by examining the soil nitrogen reserves, documenting the portion which has been cycled through crops, and speculating on the role played by other loss mechanisms, such as leaching, denitrification, and volatilization of ammonia. Present land-use practices, involving substantial areas of summerfallow, have resulted in much deeper penetration of precipitation than was possible prior to cultivation, and in so doing have increased the leaching of nitrogen from the root zone, in addition to inducing a marked increase in mineralization of soil N. In contrast, the authors feel the nitrogen content of soils which are more continuously cropped (assuming optimum N fertilizer practices), can be expected to remain relatively constant. They believe that continuing losses in the future are avoidable--that only in cases of land misuse, or more specifically, excessive summerfallowing, will substantial losses of nitrogen continue.

63. Rennie, D.A. and D.B. Wilkinson. 1984. "Water Nitrogen Deficiency and Innovative Farming Practices." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 345-356.

The problem of land degradation has relegated Western Canadian agriculture to a backyard operation say Rennie and Wilkinson. Factors identified as primarily responsible for the deteriorating soil quality include the high frequency of summerfallow, the loss of organic matter and nutrients due to erosion, and the remarkably inefficient use of available water to grow crops. The last has caused serious salinization of formerly productive agricultural soils.

Results from field-scale experiments in Saskatchewan are used to determine if water-efficient soil conserving practices can resolve this problem. These innovative practices include stubble management, snow management, fall herbicides applied when necessary, and early fall soil tests. Minimal tillage, early spring seeding, the selection of optimal varieties, and judicious use of herbicides are most important. It was found that soil conservation practices which are also water efficient pay major dividends in terms of yields, soil moisture (which ensures germination and optimum nitrogen fertilization), and soil protection from erosion and salinization. The authors make the following conclusions:

1) It should be possible to reduce the fallow area in Saskatchewan by half.

2) Snow water capture is feasible at a practical scale and should sharply reduce the drought on cropped land.

3) A yield increase of 60% in Saskatchewan is feasible.

4) The soil conserving practices embodied in the innovative rotation should markedly reduce the incidence of wind and water erosion.

4. Slinkard, A.E. 1984. "The Role of Forages and Legumes in Conservation Tillage Systems." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 337-344.

Legume crops benefit the soil resource in many ways:

1) Increased available soil nitrogen.
2) Improved soil structure.
3) Added organic matter to the soil.
4) Reduced soil and water losses.
5) Reduced leaching of plant nutrients.
6) Reduced salinization.
7) Increased yield of succeeding crops.

Despite these benefits, farmers in the Prairie Provinces do not use legume crops regularly in their rotations. The reasons for this reluctance are examined and possible alternative approaches discussed.

The author feels the use of legume crops, as conventionally managed, is not economically viable. However, the decline in organic matter, plus increased use of snow trapping, minimum tillage, new and improved legumes, earlier incorporation of seeds, dessication, winter wheat production, and better weed control have improved the economic viability of legume crops in the rotation. Results of the study indicate some promise for the use of annual legume crops as a fallow substitute in much of the Brown and Dark Brown Chernozem soil zones.

Yet, since farmers are often required to evaluate the benefits of a new practice on a short-term basis, Slinkard cautions that the use of annual legumes in the rotation must provide a net return greater than a fallow-wheat rotation, if it is to be widely adopted. The author is quite confident this will occur in the near future.

65. Soil Conservation Society of America. 1983. "Conservation Tillage: A Special Issue." Journal of Soil and Water Conservation, 38: 3, May-June. 320 pp.

This special journal issue highlights many of the important land management and agronomic considerations in using conservation tillage technology. A number of overview articles assess the impacts of conservation tillage, both positive and negative, on soil and water resources and on environmental quality. In addition, articles review extension efforts to gain farmer acceptance of conservation tillage, experiences of some farmers in using conservation tillage systems, and important research being undertaken. The issue's greatest contribution however lies in recognizing the complexity of conservation tillage systems and the degree of expertise needed to make them work. It emphasizes the need to create farmer awareness of soil loss and water conservation problems and to establish adequate communication linkages among conservationists, farmers, researchers, and agribusiness representatives.

Though conservation tillage is not a panacea, Myers points out it is one of the best ways yet found to meet national priorities for soil and water conservation. Many advantages, such as conserving soil moisture, reducing erosion, and reducing the number of tillage operations, encourage the adoption of conservation tillage. However, Cosper warns that these techniques are not adaptable to all soils, may provide a varied crop yield response on some soils, and require additional emphasis on crop management not associated with conventional tillage. As well, Hinkle describes other problems such as increased pest populations, increased susceptibility to plant disease, herbicide carryover, weed resistance, and shifts in weed species. The various obstacles to adoption of conservation tillage are detailed by Nowak who examines the decision-making process from the farmer's perspective. The influence of land tenure arrangements is assessed by Lee (see also #37), while water quality, energy, and wildlife implications of conservation tillage are examined by Baker and Laflen, Lockeretz, and Rodgers and Wooley, respectively. The need for increased research and extension efforts to eliminate these many obstacles is imperative (Ritchie and Follett). An article by King nevertheless demonstrates that recent technological developments in equipment and chemicals have made conservation tillage the practice of choice for effective, economic erosion control.

66. Vander Pluym, H. 1982. "Salinity in Western Canada." Soil Salinity. Proceedings, First Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management, November 29-December 2. Lethbridge, Alberta. pp. 9-23.

This paper deals with the serious problem of soil salinization in Western Canada. The characteristics, formation, and extent of saline seepage are discussed, and the costs and benefits of both dryland and irrigated saline seep controls are examined. Water causes salinization because it redistributes and accumulates the salts. Practices such as summerfallow, mismanaged irrigation, snow and water accumulation by barriers, and indeed sod breaking, increase the amounts of deep percolation and upset the balance of the hydrology system.

Measures dealing with soil salinity are available and feasible, although most of them are costly. Recommended dryland saline seep controls include the following:

1) Preventing the formation and deep percolation of "excess" water in the recharge area through surface water drainage, alfalfa, and flex-cropping (i.e. choosing cropping only if enough moisture is available in spring).

2) Lowering the water table in the discharge area by means of subsurface drainage and salt-tolerant crops.

The first measure is preferred because it controls the phenomenon at its point of origin, before it becomes a problem.

Even though government, through technical and financial assistance, can help the farmer, the author stresses that the bulk of the control effort and work must come from the farmer if the problem is ever to be resolved. Unfortunately, inadequate grain markets and prices and the consequent lack of cash are hampering the ability of the farmer to implement controls.

67. Vander Pluym, H.S.A., B. Paterson, and H.M. Holm. 1981. "Degradation by Salinization." Agricultural Land: Our Disappearing Heritage. Proceedings, the 18th Annual Alberta Soil Science Workshop, February 24-25. Edmonton. pp. 9-40.

Overgrazing and deforestation, breaking the sod, summerfallowing, water and snow accumulation, road and dam construction, and irrigation have increased the amounts of "excess" water percolating beyond the root zone. Thus, they have accelerated the saline seepage process. This comprehensive study examines the extent and rate of increase of saline seepage in Western Canada, outlines current control measures and programs, and discusses the socio-economic and environmental impacts of spreading salinity upon agriculture, land, and water resources.

Controls for saline seeps are identical to those discussed in #66. Saline seep control has a beneficial effect on the quality, productivity, and a esthetic value of the land. However, some pollution problems could evolve from saline drainage water. Though saline seep problems have neither forced any farmers off their land nor substantially reduced their incomes, the continued increase in salinization and the tripling of land prices in the last few years have created deep concerns. Proposals are being put forward to assist farmers financially with saline seep investigations and drainage. Yet, the farmer must become aware of the problem and its control, and must be willing to invest some of his own money and effort in order to maintain the land resource for future use.

68. Webb, Calvin. 1982. The Impacts of Linear Developments, Resource Extraction, and Industry on the Agricultural Land Base. ECA 82-17/IB25, Environment Council of Alberta. Edmonton. 87 p.

This report provides a perspective on problems created for the agricultural land base by urban-related activities. The activities discussed are grouped into three main categories:

1) Linear developments--including transmission lines, roads, and pipelines.

2) Resource extraction--including coal mining, and oil and natural gas exploration and extraction.

3) Industry--involving industrial land (i.e. industrial parks), thermal power generation, and natural gas processing and manufacturing industries.

Data on the amount and quality of land used for these activities is provided, and brief assessments of the difficulties in reconciling the impacts with the long-term agricultural potential of the land are made. The report also examines the ways in which legislation, policies, and decisions can affect the use of land.

Three main types of impacts are recognized:

1) Non-agricultural use of land which is capable of supporting agriculture.

2) Reduction in the productivity of land due to changes in the physical and chemical properties of the soil.

3) Increases in the cost of farming.

Though the total impact of linear developments, resource extraction, and industry on Alberta's agricultural land base is not known, it is estimated to be large and is expected to increase in the future. In addition, it is felt that as long as government and industry alike meet public demand for cheap goods and services, there is little incentive for the public to curb its demands, which would prove to be one way of conserving the land resource. Therefore, government leadership in the implementation of a conservation ethic through education, example, pricing, or legislation is also required.

69. Zentner, R.P. 1984. "Economics of Soil Conservation in Western Canada." Soil Erosion and Land Degradation. Proceedings, Second Annual Western Provincial Conference: Rationalization of Water and Soil Research and Management. Saskatchewan Institute of Pedology. Saskatoon. pp. 195-219

This paper provides one of the most complete and comprehensive discussions of the economic issues in soil conservation in Western Canada:

1) The social and economic factors that influence the rate of soil degradation from the viewpoints of individual producers and society.

2) The difficulties associated with measuring the long-term economic impacts or consequences of soil degradation.

3) The aggregate economic benefits of soil conservation.

4) The short-run economics of adopting several soil conserving technologies.

Research has shown that rotations with high proportions of summerfallow, such as the traditional two-year fallow-wheat rotation, contribute more to soil degradation than rotations with greater proportions of crop. Also, the extensive use of mechanical tillage systems to control weeds on summerfallow areas and on cropped areas prior to planting hastens the rate of soil degradation. Accurate estimates of the long-term economic consequences of soil degradation are essential to permit rational decision-making on soil use at the individual producer level, and for providing a basis for the development of public policies on soil conservation. However, the short-term economic goals of individuals often take priority over the long-term social benefits of conservation. Institutional restrictions, such as the grain delivery quota system, and government policies, such as freight rate subsidies and price support programs, may also create market distortions that encourage the continued use of soil depleting practices.

Research findings indicate that society would benefit substantially from additional investment in soil conservation efforts. The short-term economic performances of more intensive cropping systems, and minimum and zero tillage practices are promising. With proper stubble management and the use of recommended practices for fertilizers and herbicides, producers in the Brown soil zone can increase farm profits by adopting more intensive cropping systems. But the lack of additional economic incentives reduces producer adoption of this technology. Minimum and zero tillage offer considerable potential for improved soil conservation, but the high cost of the necessary herbicides make those treatments uneconomic. Suggestions of possible incentives for individual voluntary adoption of conservation technologies include easier access to credit, improvement of government assistance programs such as the Federal-Provincial Crop Insurance Program and the Western Grain Stabilization Program, and addition of new programs.

70. Zentner, R.P., C.A. Campbell, D.W.L. Read, and C.H. Anderson. 1984. "An Economic Evaluation of Crop Rotations in Southwestern Saskatchewan." Canadian Journal of Agricultural Economics, 32: 1, March, 37-54.

Historically, the predominant cropping program in south-western Saskatchewan has been the two-year fallow-wheat rotation. Economic benefits of summerfallow include higher and more stable crop yields resulting from increased soil moisture reserves for the growing season, soil nitrogen accumulation, and improved weed and pest control, thus providing higher and more stable net returns. However, summerfallow also has short-term and long-term costs. Short-term costs include the income forgone by allowing the land to be idle for a cropping season, plus the expenditures required to control weeds on the land during the 21-month fallow period. Long-term costs include the increased rate of land degradation and environmental pollution. Individual producers make the summerfallow decision. Since they do not incur the full costs of the practice, the use of summerfallow is often considered to be higher than optimal from society's viewpoint. This paper evaluates the economic performances of selected cropping rotations in order to provide information that will assist producers, scientists, and policy analysts to understand and to make rational future decisions regarding more efficient use of summerfallow.

Producers should consider selecting a more intensive crop rotation than has been the tradition--i.e. a three-year wheat rotation. Though producers must be prepared to accept some additional yield risk or income variability, crop insurance can assist in minimizing this additional risk. Continuous wheat cropping is clearly not favored over a three-year rotation: the authors feel it can only be recommended in periods of high expected grain prices and grain delivery quotas, and for producers who have the financial capability to purchase the extra resources required and to withstand major income fluctuations. As well, producers should consider introducing flax, fall rye, or oat hay into the wheat rotations only when the price of these grains is high relative to that for wheat, or when wheat delivery quotas are expected to be low compared to those for other grains. The proposed reduction in summerfallow use should have positive effects on the long-term degradation and pollution problems. However, since the results of this study underestimate the full costs associated with summerfallow, further research is needed to quantify better these long-run costs.

71. Zentner, R.P. and C.W. Lindwall. 1978. "An Economic Assessment of Zero Tillage in Wheat-Fallow Rotations in Southern Alberta." Canadian Farm Economics, 13: 6, 1-6.

The economic feasibility of producing spring wheat under zero tillage practices in the prairie region of Western Canada is assessed and the effectiveness of using herbicides to replace mechanical tillage operations evaluated. Results from a study of two-and three-year spring wheat rotations show that substantial savings in labour, fuel and oil, machine repairs, and overhead costs can be achieved with zero tillage. In addition, higher grain yields resulting from greater moisture conservation, and improved soil erosion control (resulting from greater quantities of surface residue), make zero tillage a potentially attractive alternative to conventional practices. However, zero tillage has an economic advantage over conventional tillage only if the savings in labour and machinery costs, combined with the greater returns from the increased crop yields, more than compensate for the added cost of herbicides. Zero tillage has therefore the greatest potential in a recropping system where herbicide requirements are low and yield advantages substantial. Further investigation of agronomic and economic aspects of zero tillage is required before recommendations for widespread adoption of zero tillage can be made.

## WORKING PAPER SERIES

No. 1: The Ecology of Reclamation of Land Disturbed by Mining: A Selected Bibliography of Canadian References. I.B. Marshall, 1980. En 73-4/1. ISBN 0-662-50724-X.

No. 2: Analysis of the United States Experience in Modifying Land Use to Conserve Energy. W.R.D. Sewell and H.D. Foster, 1980. En 73-4/2E. ISBN 0-662-10867-1.

No. 3: The Influence of Exurbanite Settlement on Rural Areas: A Review of the Canadian Literature. J.D. McRae, 1980. En 73-4/3E. ISBN 0-662-11085-4.

No. 4: The Land Impact of Federal Programs in the Cowichan Valley Regional District, British Columbia. L.R. Barr, 1980. En 73-4/4E. ISBN 0-662-11086-2.

No. 5: The Impact on Agricultural Land Use of Federal Policies and Programs in Kings County, Nova Scotia. S.G. Ryle and P. Gervason, 1980. En 73-4/5E. ISBN 0-662-11087-0.

No. 6: Energy Conservation Through Land Use Planning: A Synthesis of Discussions at a Symposium held in Montreal 26-28 March 1980. W.R.D. Sewell and H.D. Foster, 1980. En 73-4/6E. ISBN 0-662-90812-0.

No. 7: Assessment Procedures in Canada and Their Use in Agricultural Land Preservation. J.D. McCuaig and H.J. Vincent, 1980. En 73-4/7E. ISBN 0-662-11089-7.

No. 8: The Effects on Land Use of Federal Programs in the Windermere Valley. J.D. McCuaig and E.W. Manning, 1980. En 73-4/8E. ISBN 0-662-11117-6.

No. 9: Issues in Canadian Land Use. E.W. Manning, 1980. En 73-4/9. ISBN 0-662-51142-5.

No. 10: The Development of an Ecological Sensitivity Rating for Acid Precipitation Impact Assessment. Background Paper and Results of a Meeting on LRTAP Sensitivity Indices, Canada/United States Impact Assessment Working Group, Detroit, Michigan, December 2, 1980. D.W. Cowell, A.E. Lucas, and C.D.A. Rubec, 1981. En 73-410E. ISBN 0-662-11451-5.

No. 11: The Land Use Impacts of Small Craft Harbours: A Preliminary Investigation. J.D. McCuaig, E.W. Manning, V.P. Neimanis, and E.M. Peterson, 1981. En 73-4/11E. ISBN 0-662-11453-1.

No. 12: Land and the Automobile: A Selected Bibliography. W. Simpson-Lewis and R. McKechnie, 1981. En 73-4/12. ISBN 0-662-51259-6.

No. 13: The Agricultural Use of Marginal Lands: A Review and Bibliography. K.G. Beattie, W.K. Bond, and E.W. Manning, 1981. En 73-4/13E. ISBN 0-662-11454-X.

No. 14: Land Use Classification Systems: An Overview. R.C. Scace, 1981. En 73-4/14E. ISBN 0-662-11434-5.

No. 15: Survey of User Requirements for Land Use Data: Canada Land Use Monitoring Program. D.M. Gierman, 1981. En 73-4/15E. ISBN 0-662-11435-3.

No. 16: Problems in Mapping Non-productive Woodland Using the CLI Present Land Use Classification in Halifax County, Nova Scotia. P.N. Duinker, 1981. En 73-4/16E. ISBN 0-662-11436-1.

No. 17: Land Use Classification for Land Use Monitoring. D.M. Gierman, 1981. En 73-4/17E. ISBN 0-662-11439-6.

* No. 18: Earth Sciences of the Hudson Bay Lowland: Literature Review and Annotated Bibliography. D.W. Cowell, 1982. En 73-4/18E. ISBN 0-662-11539-2.

No. 19: Characteristics of Terrestrial Ecosystems Impinged by Acid Rain Across Canada. C.D.A. Rubec, 1981. En 73-4/19E. ISBN 0-662-11562-7.

No. 20: An Inventory of Federally Maintained Land Data. Arthur Petch and Sandy Macenko, 1982. En 73-4/20E. ISBN 0-662-11880-4.

No. 21: The Impact of Federal Activities on Fruitland Use: Annapolis Valley. Paul D. Bircham, 1983. En 73-4/21E. ISBN 0-662-11959-2.

No. 22: The Impact of Exurbanite Settlement in Rural Areas: A Case Study in the Ottawa-Montreal Axis. James D. McRae, 1982. En 73-4/22E. ISBN 0-662-11788-3.

No. 23: A Method to Assess the Implications of Future Urban Expansion on Rural Land. Chris Cocklin and Barry Smit, 1982. En 73-4/23E. ISBN 0-662-12058-2.

No. 24: Area Sampling Strategies in Relation to Land Use Monitoring Needs and Objectives. C.R. Bryant and L.H. Russwurm, 1983. En 73-4-24E. ISBN 0-663-12320-4.

No. 25: Methods of Preserving Wildlife Habitat. Bill Haigis and Will Young, 1983. En 73-4-25E. ISBN 0-662-92035-X.

* These publications are available only in the language of the originating regional office, as indicated by the title.

No. 26: Land Use Change on Wetlands in Southern Canada: Review and Bibliography. P. Lynch-Stewart, 1983. En 73-4/26E. ISBN 0-662-12675-0.

No. 27: An Overview of Crown Land Management in Canada. S.L. Macenko and V.P. Neimanis, 1983. En 73-4/27E. ISBN 0-662-12629-7.

No. 28: The Land Planning Framework of Canada: An Overview. R. Audet and A. Le Hénaff, 1984. En 73-4/28E. ISBN 0-662-12793-5.

No. 29: The Abandonment of Agricultural Land in Gaspé, Quebec: The Causes and the Impacts on Land Use. Diane Lamoureux. En 73-4/29E. ISBN 0-662-12799-4.

No. 30: Foreign Ownership of Land and Real Estate in Canada. E. Neville Ward with Susan J. Reid-Sen. En 73-4/30E. ISBN 0-662-13078-2.

No. 31: Marginal Land Utilization and Potential: Kent County, New Brunswick. Maurice Mandale with Maritime Resource Management Service, 1984. En 73-4/31E. ISBN 0-662-13079-0.

No. 32: The Impacts on Land Use of CMHC Municipal Infrastructure Assistance, 1961 to 1980. Paul D. Bircham and Wayne K. Bond, 1984. En 73-4/32E. ISBN 0-662-13101-0.

No. 33: The Impact of Federal Government Activities on Land Use in Renfrew County, Ontario. Nicole Lavigne, 1984. En 73-4/33E. ISBN 0-662-13113-4.

* No. 34: Land Use Monitoring on Wetlands in the Southwestern Fraser Lowland, British Columbia. Paul Pilon and M. Anne Kerr, 1984. En 73-4/34E. ISBN 0-662-13142-8.

No. 35: The Administration of Federal Subsurface Rights in Canada. S.L. Macenko and M.J. Williams, 1984. En 73-4/35E. ISBN 0-662-13191-6.

* No. 36: Manual for Regional Targeting of Potential Soil Erosion and Sediment Loading Problems. E.A. Snell, 1984. En 73-4/36E. ISBN 0-662-13192-4.

No. 37: Degradation of Canada's Prairie Agricultural Lands: A Guide to Literature and Annotated Bibliography. Paul Bircham and Hélène Bruneau, 1985. En 73-4/37E. ISBN 0-662-13797-3.

No. 38: The Agriculture-Forest Interface: An Overview of Land Use Change. Michael Fox and Sandra Macenko, 1985. En 73-4/38E. ISBN 0-662-13824-4.

* These publications are available only in the language of the originating regional office, as indicated by the title.

No. 39: Wetlands in the Montreal Region 1966-1981. J. Champagne and M. Melançon, 1985. En 73-4/39. ISBN 0-662-53591-X.

No. 40: The Eastern Ontario Subsidiary Agreement Drainage Program: Impacts on the Land Resource a Preliminary Appraisal. C.P. Cecile, M.J. Bardecki, and E.A. Snell, 1985. En 73-4/40E. ISBN 0-662-13882-1.