PRELIMINARY ASSESSMENT OF THE FEASIBILITY OF STRAW BIOMASS AS A RENEWABLE ENERGY SOURCE

By

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ABSTRACT

Biomass is an attractive source of energy due to its seemingly inexhaustible supply. Use of biomass is generally perceived by society to be benign relative to fossil fuels and nuclear power in terms of environmental, health, and safety impacts. Environmental impact will vary, however, depending on type of biomass, scale and method of resource recovery, conversion technology utilized and energy end-uses.

Every year vast quantities of straw are produced in Western Canada. This biomass resource is generally regarded as a possible energy source, but environmental and social constraints which limit availability of this resource are not well established. To improve the data base in this area, this report provides a study of wheat, oats and barley straw production and availability in Manitoba Department of Agriculture Crop Districts 3, 4 and 5.

Straw availability is a complex and controversial resource management issue. It is difficult to accurately predict annual straw availability for energy production because of the cyclic nature of grain production. Therefore, this analysis concentrates on estimating future average straw availability, recognizing that actual availability may deviate from the average.

In addition, two biomass conversion technologies are considered for converting straw to usable fuels. On the basis of estimates of average annual quantities of straw available in the study area, preliminary estimates of potential energy yields were obtained. These are compared to present petroleum consumption in order to determine replacement potential. Results show that energy content of straw could potentially replace significant quantities of petroleum in Manitoba.

Finally, collection costs of straw are also considered.

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TABLE OF CONTENTS

ABSTRACT ii

ACKNOWLEDGEMENTS iv

TABLE OF CONTENTS vi

LIST OF TABLES x

LIST OF FIGURES xiii

METRIC PREFIXES AND BASIC CONVERSIONS xiv

ENERGY CONTENT OF FUELS. xv

LIST OF SYMBOLS xvi

Chapter | Page

1. INTRODUCTION - RENEWABLE ENERGY FROM AGRICULTURE AND THE LAND RESOURCE BASE. . . . 1

2. OVERVIEW OF STUDY 7

   2.1 Problem Statement 7

   2.2 Objectives 7

   2.3 Methods. 9

   2.4 Importance of Study 10

   2.5 Scope and Limitations 11

3. DEVELOPMENT OF STRAW BIOMASS INVENTORY. . . . 13

   3.1 Review of Agricultural Biomass Inventories 13

   3.2 Inventory Procedure 18

      3.2.1. Introduction 18

      3.2.2. Selection of Straw for Inventory 18

      3.2.3. Selection of Study Area. . . 27

      3.2.4. Selection of Wheat, Oats and Barley Yield Data Base . 34

TABLE OF CONTENTS (Cont'd)

3.2.5. Selection of Wheat, Oats and Barley Acreage Data. . . 43

3.2.6. Factors Considered in Determining Straw Available . . . 43

4. RESULTS OF STRAW BIOMASS INVENTORY. 60

4.1 Overview 60

4.2 Conversion to Metric Units 61

4.3 Computation of Detailed Straw Available Estimates. 61

4.3.1. Straw Available (t/ha) in the CLA Study Area (Risk Area 12) 68

4.3.2. Total Straw Available in the Study Area 71

4.3.3. Geographic Distribution of Straw Availability (t/ha) in Study Area Municipalities 71

4.3.4. Geographic Distribution of Total Straw Available . . 87

4.4 Constraints on Straw Availability. . . 87

4.4.1. Straw Needed as a Soil Mulch 87

4.4.2. Summerfallow 91

5. ENERGY POTENTIAL OF STRAW IN THE STUDY AREA . 94

5.1 Introduction 94

5.2 The Chemical Composition of Straw. . . 97

5.3 Ethanol from Cellulose 101

5.3.1. The Maximum Theoretical Yield of Ethanol from Straw.101

5.3.2. Acid Hydrolysis. 103

5.3.3. Enzymatic Hydrolysis 105

TABLE OF CONTENTS (Cont'd)

5.3.4. Petroleum Extender Potential of Straw Derived Ethanol in Manitoba. 107

5.3.5. Production of Ethanol from Hemicellulose 109

5.3.6. The Economics of Ethanol from Cellulose 109

5.4 The Gasification of Biomass 110

5.4.1. Introduction 110

5.4.2. General Operating Characteristics of Gasifiers 111

5.4.3. Biomass Gasification: Development and Applications 115

5.5 Constraints on Utilization of Biomass Fuels 119

5.5.1. Gasohol. 122

5.5.2. Methanol/Gasoline Blends (Methaline) 125

5.5.3. Alcohol Fuels: Environmental Impact. 127

5.5.4. Food and Fuel. 129

6. STRAW COLLECTION LOGISTICS AND COSTS . . . 131

6.1 System Flow Model: Description . . . 131

6.2 Flax Collection System Characteristics 131

6.3 Systems Available for Field Recovery of Straw. 135

6.4 Straw Collection Costs 136

6.5 Restraints for Cereal Grain Straw. . 139

6.5.1. Management System. 139

6.5.2. Attitudes of Growers . . . 140

TABLE OF CONTENTS (Cont'd)

6.5.3. Straw Handling Methods: Potential Improvements. . . 142

7. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS . . 142

7.1 Summary and Conclusions 142

7.1.1. Average Annual Straw Yields, Straw Available and Straw Needed 142

7.1.2. Theoretical Energy Potential 144

7.1.3. Collection Logistics and Costs 144

7.2 Recommendations 145

LITERATURE CITED 148

Appendix 1 161

Appendix 2.1 162

Appendix 2.2 163

Appendix 2.3 165

Appendix 3.1 167

Appendix 3.2 168

Appendix 3.3 169

Appendix 4.1 170

Appendix 4.1.1 171

Appendix 4.2 172

Appendix 4.2.1 173

Appendix 4.3 174

Appendix 4.3.1 175

Appendix 4.4 176

Appendix 4.5 177

LIST OF TABLES

Table		Page
3.1	A Summary of Selected Straw Biomass Studies in Canada	14
3.2	A Summary of Selected Crop Residue Biomass Studies in the United States. . . .	17
3.3	Criteria Involved in the Selection of Wheat, Oats and Barley Straw for Inventory.	19
3.4	Climatic Characteristics for the Hard Spring Wheat Region (HSWR) and the South Central Lowland Area (SCLA)	29
3.5	Major Characteristics of Land Resource Units within South Central Lowland Area and Southeast Lake Terrace and Southern Interlake Area	31
3.6	Study Area: Population Distribution	33
3.7	Soil Associations Suitable for Crop Production in Crop Districts 3, 4 and 5 . .	38
3.8	Classification of CLA Soil Associations by MCIC Soil Zones and Basis for Productivity Index Rating	41
3.9	Nutrients in Various Amounts of Straw (kg/ha)	46
3.10	Estimates of Small Grain Straw Needed for Wind Erosion and Soil Management (t/ha) . .	51
3.11	Soil Texture, Soil Problems and Recommended Practices for CLA Soils.	52
3.12	Average Expected Straw Reduction due to Normal Tillage Practices in the CLA. . .	54
4.1	Standard and Metric Wheat, Oats and Barley Volume and Weight Equivalents for Grain and Straw	62
4.2a	Weighted Wheat Yields on Better Drained Risk Area 12 Soil Zones	64
4.2b	Weighted Wheat Yields on Poorly Drained Risk Area 12 Soil Zones	65

LIST OF TABLES (Cont'd)

Table		Page
4.3	Average Annual Wheat Straw, Stubble and Straw Available in Risk Area 12	67
4.4	Average Annual Wheat, Oats and Barley Straw Yields and Straw Available (t/ha) in Risk Area 12	69
4.5	Total Available Wheat, Oats and Barley Straw in Crop Districts 3, 4 and 5 (1973 - 1976)	72
4.6	Average Annual Wheat, Oats and Barley Straw Yields and Straw Available (t/ha) in Central Municipalities	81
4.7	Average Annual Wheat, Oats and Barley Straw Yields and Straw Available (t/ha) in Eastern Municipalities	82
4.8	Average Annual Wheat, Oats and Barley Straw Yields and Straw Available (t/ha) In South Central Municipalities	83
4.9	Average Annual Wheat, Oats and Barley Straw Yields and Straw Available (t/ha) in Southwestern Municipalities and Portage la Prairie	84
4.10	Total Available Wheat, Oats and Barley Straw in Selected Study Area Municipalities (1976)	88
4.11	Straw Available (t/ha) when Straw Needed is 0.9 t/ha in Risk Area 12	90
4.12	Total Available Wheat, Oats and Barley Straw When Straw Needed is 0.9 t/ha in Crop Districts 3, 4 and 5 (1975-1976). .	92
4.13	Percentage Summerfallow in Crop Districts 3, 4 and 5 (1976)	93
5.1	Bioconversion Routes and Potential End-Uses for Energy Produced from Biomass	95

LIST OF TABLES (Cont'd)

Table		Page
5.2	The Chemical Composition of Straw	98
5.3	Maximum Theoretical Yield of Ethanol from Straw	102
5.4	Maximum Theoretical Ethanol Yield from Available Straw via Acid Hydrolysis	104
5.5	Major Types of Promising Pretreatment Technologies for Enzymatic Hydrolysis	106
5.6	Maximum Theoretical Ethanol Yield from Available Straw via Enzyme Hydrolysis	108
5.7	Major Types of Wood Gasification Technologies under Development in North America and Europe	112
5.8	Potential Applications for Biomass Fuels by Demand Sector and Energy Type	120
6.1	Flax Straw Costs Per Tonne at a Central Collection Site	137

LIST OF FIGURES

Figure		Page
2.1	Crop Districts: Southern Manitoba	8
3.1	Wheat Straw - Chemical Composition and Possible Utilization for Each Component	26
3.2	Province of Manitoba: Crop Insurance Risk Areas	36
3.3	Manitoba Crop Insurance Corporation Research Questionnaire	42
4.1	Weighted Wheat Yields on B-Class Soils in Risk Area 12	66
4.2	Municipality of Rockwood Soil Zone Map	74
4.3	Municipality of Woodlands Soil Zone Map	75
4.4	Municipality of Hanover Soil Zone Map	77
4.5	Municipality of Ste. Anne Soil Zone Map	78
4.6	Municipality of Tache Soil Zone Map	79
5.1	Schematic of a Gasifier Reactor	113
5.2	Schematic of a Round Bale Gasifier	118
6.1	System Flow Model for Collection of Cereal Grain Straw	132

METRIC PREFIXES

Prefix	Symbol	Number
deca	da	10^1
hecto	h	10^2
kilo	k	10^3
mega	M	10^6
giga	G	10^9
tera	T	10^{12}
peta	P	10^{15}
exa	E	10^{18}

BASIC CONVERSIONS

Area

1 acre = 0.4047 hectare (ha)

1 sq mi = 2.58 sq kilometres (km^2)

Volume/Capacity

1 round bale = 350 kilograms (kg) approximately

1 standard bale = 18 kg approximately

1 imperial gallon (IG) = 4.54 litres (L)

Weight

1 pound = 0.4536 kg

1 short ton = 0.90185 tonne (t)

1 ton per acre = 2.24 t/ha

Energy

1 Btu = 1055.87 Joules (J)

1 Btu/SCF = 27.0 MJ/m^3

ENERGY CONTENT OF FUELS

Fuel	Unit	Btu	SI Equivalent	
			Unit	MJ
Gasoline	IG	150,000	L	34.9
Diesel	IG	166,000	L	39.0
Light Fuel Oil	IG	166,000	L	39.0
Heavy Fuel Oil	IG	180,000	L	42.0
Natural Gas	000 cu.ft.	1,031,000	M^3	38.4
Methanol	IG	75,000	L	17.5
Ethanol	IG	99,000	L	23.0

LIST OF SYMBOLS

CLA	Central Lowland Area
EtOH	ethanol
FF	fallow fertilized
FU	fallow unfertilized
HBG	high Btu gas > 15 MJ/m^3
MBG	medium Btu gas 7 - 15 MJ/m^3
LBG	low Btu gas < 7 MJ/m^3
MCIC	Manitoba Crop Insurance Corporation
MDA	Manitoba Department of Agriculture
MeOH	methanol
MON	motor octane number
MSW	municipal solid waste
RON	research octane number
SF	stubble fertilized
SU	stubble unfertilized
USDA	United States Department of Agriculture

CHAPTER 1

INTRODUCTION - RENEWABLE ENERGY FROM AGRICULTURE AND THE LAND RESOURCE BASE

In recent years, there has been a dramatic increase in the number of reports and discussion papers on the feasibility of using various energy sources and technologies in Canada. Energy analysts generally agree that renewable resources and conservation ought to play an increasingly important role in reducing reliance on non-renewable resources. However, there is also considerable disagreement as to the extent of substitution which can be achieved in Canada through greater utilization of alternate energy sources such as direct solar power and biomass sources.

The basis for the polarized divergence of opinion depends to a large extent on differences in perception of energy problems by "soft energy path" advocates on the one hand and conventional technology proponents on the other. Examples of Canadian "soft energy" studies may be found in Lovins (1976), Alternatives (1979; Winter 1980, Spring 1980); conventional energy scenarios for Canada are outlined in Gander and Belaire (1978).

Notwithstanding this controversy, biomass[1] is

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[1]Biomass is a class of renewable carbonaceous materials of solar origin. Potentially available biomass includes wood waste and forestry residues, food processing wastes, agricultural crop residues and animal wastes.

widely regarded as an important and potentially viable source of renewable energy in Canada (Middleton Associates 1976). For example, wood (Marshall et al 1975) and agricultural residues (Timbers 1976) are promising sources of biomass fuels in Canada. A number of alternative energy studies have revealed that biomass-derived liquid fuels (ethanol and methanol) can become a feasible alternative to petroleum in the transportation sector (Park 1978; Reed and Lerner 1973) and as a source of thermal heat for some residential (Chemical and Engineering News 1979), commercial and industrial applications (Nadis 1979; Schooley et al 1978; Osler 1977).

Proponents of alternative energy sources advocate the use of local sources wherever possible to reduce reliance on nonrenewables. This is based on the notion that balanced development of all appropriate local sources reduces social, economic and environmental risks associated with dependency on expensive fossil fuels. The potential for developing supplementary sources of energy from local renewable resources differs from region to region in Canada. From the point of view of biomass, however, wood is the most plentiful source; other important local and regional biomass energy supplies are municipal solid wastes, agricultural crop residues and animal manure.

Research by Agriculture Canada and others indicates that agricultural crop residues, especially cereal grain straw,[1] are produced in vast quantities in Canada, and represent a sizeable portion of total agricultural biomass produced (Downing, 1975). Total Canadian agricultural biomass production as food and feed from cereal grains, oil seed and horticultural crops is 39.6 million tonnes annually, and forage and pasture produces an additional 78.3 million tonnes (Timbers and Downing 1976; Timbers 1976). Thus, total agricultural biomass production is about 118 million tonnes annually.

Main sources of agricultural crop residues are cereal grain straw, oilseed crops, corn stover and horticultural crops. Approximately 51 million tonnes of oil seeds and cereal grain straw are produced annually in Canada, the bulk of it in Western Canada (Timbers 1976). Ontario is the main producer of corn stover (2 million tonnes) and horticultural crop residues (1.3 million tonnes).

Not all of the residue is available for removal as an energy source or other industrial purposes. In Western Canada, crop residues (straw) are important as trash cover and soil mulch. To minimize erosion and maintain soil quality, straw should be returned to the soil. Generally, straw production and availability increases from the west to more humid areas in the north and east.

[1]Agricultural crop residues are the "waste" materials remaining on the field after the food component has been harvested. Straw is the above-ground residue produced by cereal grain crops.

Several sources report an average availability of 1.1 t/ha (Timbers 1976; Timbers and Downing 1976).

Western Canada has approximately 40 million hectares of improved land (Hedlin 1978). Roughly 5.4 million hectares, 11.8 million hectares and .45 million hectares are used for hay and pasture, summerfallow and miscellaneous crops respectively (McGinnis 1973). Wheat, oats, barley, flax and rapeseed are grown on 22.4 million hectares. An average of 24.6 million tonnes of straw are available in Western Canada annually, mainly from wheat, oats and barley crops (i.e. 22.4 x 1.1 t/ha). This straw represents an appreciable energy source as the theoretical heat value is about 418.2 PJ.[1] It can be used to improve the energy efficiency of farms (Jensen 1975; Southwell and Rothwell 1976; Timbers _et al_ 1976) and offset the high energy cost of Canadian agriculture (Canadian Resourcecon 1974).

Since solar and biomass energy systems are based on renewable resources, they are an improvement over conventional energy systems. It would not be appropriate to assume, however, that such systems are completely benign with respect to their environmental and social impacts (Harte and Jassby 1978). To neglect environmental aspects of alternative energy systems may intensify existing environmental problems caused by patterns of long-term

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[1]This calculation assumes a heat value for straw of 17 MJ/kg.

resource use, some of which have been harmful to the environment. To the extent that conventional economic theory treats externalities as social costs, it has contributed to this situation.

Historically, industrial societies have expanded in terms of commodity production and energy and resource consumption due to economic policies which emphasize maximization of GNP or economic growth, maximization of technology and minimization of consumer goods durability. Social questions related to distribution of wealth are largely ignored as it is assumed that individual shares of wealth increase as the whole increases. In terms of resource supply, conventional economics assumes that global resources are infinite and that ecological systems are not a constraint on economic growth. Economic policies have therefore emphasized a maximization of resource throughput in the economy. As a result, industrial production systems have often been indiscriminately imposed on ecosystems without much regard for their fragility or capacity and the cumulative environmental and social costs have been borne by society at large.

With regard to the utilization of agricultural residues as an alternative energy source, the important question is whether removal for biomass would be deleterious to soil fertility and its long term food producing capability. For example, straw returned to the land provides crop nutrients, helps to maintain soil tilth and improve soil porosity. Conversely, when straw is consistently removed or burned, nutrients which are foregone must be replaced by fertilizers or manure. Moreover, the potential for wind and water erosion increases on land which is left bare. Runoff from crop-land contains chemicals and sediments which can have a detrimental effect on water supplies and water quality in agricultural areas.

The prospect of collecting straw for energy purposes on a large scale represents a potential resource management conflict. If straw is to be removed for energy purposes, then the need for straw as a soil amendment to maintain long-term fertility and food-production capacity of soils must be fully examined. As pressures to use straw as an energy source increase, the agricultural community will need to determine how much straw is surplus to quantities required for soil management needs, so that climatic and agricultural limitations affecting straw availability become known. This study will identify problems associated with straw as an energy source and hopefully induce others to look at the utilization of biomass energy sources from this perspective.

CHAPTER 2

OVERVIEW OF STUDY

2.1 Problem Statement

Straw biomass on the Canadian prairies represents an energy source which could be used for specific end-uses in agriculture and other sectors to offset petroleum consumption. However, more needs to be known about constraints affecting straw availability.[1] The following objectives outline how these problems are treated in this study.

2.2 Objectives

1. The first objective is to estimate total quantities of available wheat, oats and barley straw in Crop Districts 3, 4, and 5 (Red River Valley) in Manitoba (Fig. 2.1). Chapters 3 and 4 explain how the estimates are derived and the results of the analysis.
2. The second objective is to determine the energy potential of available quantities via a) the conversion of straw cellulose to ethanol and b) the on-farm gasification of straw. Constraints on utilization of biomass fuels are also identified. Chapter 5 contains this analysis.
3. The third objective is to estimate the cost of straw collection when it is delivered to a central collection site. Chapter 6 deals with this problem.

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[1] Straw availability refers to surplus available for energy in excess of that required as a soil mulch.

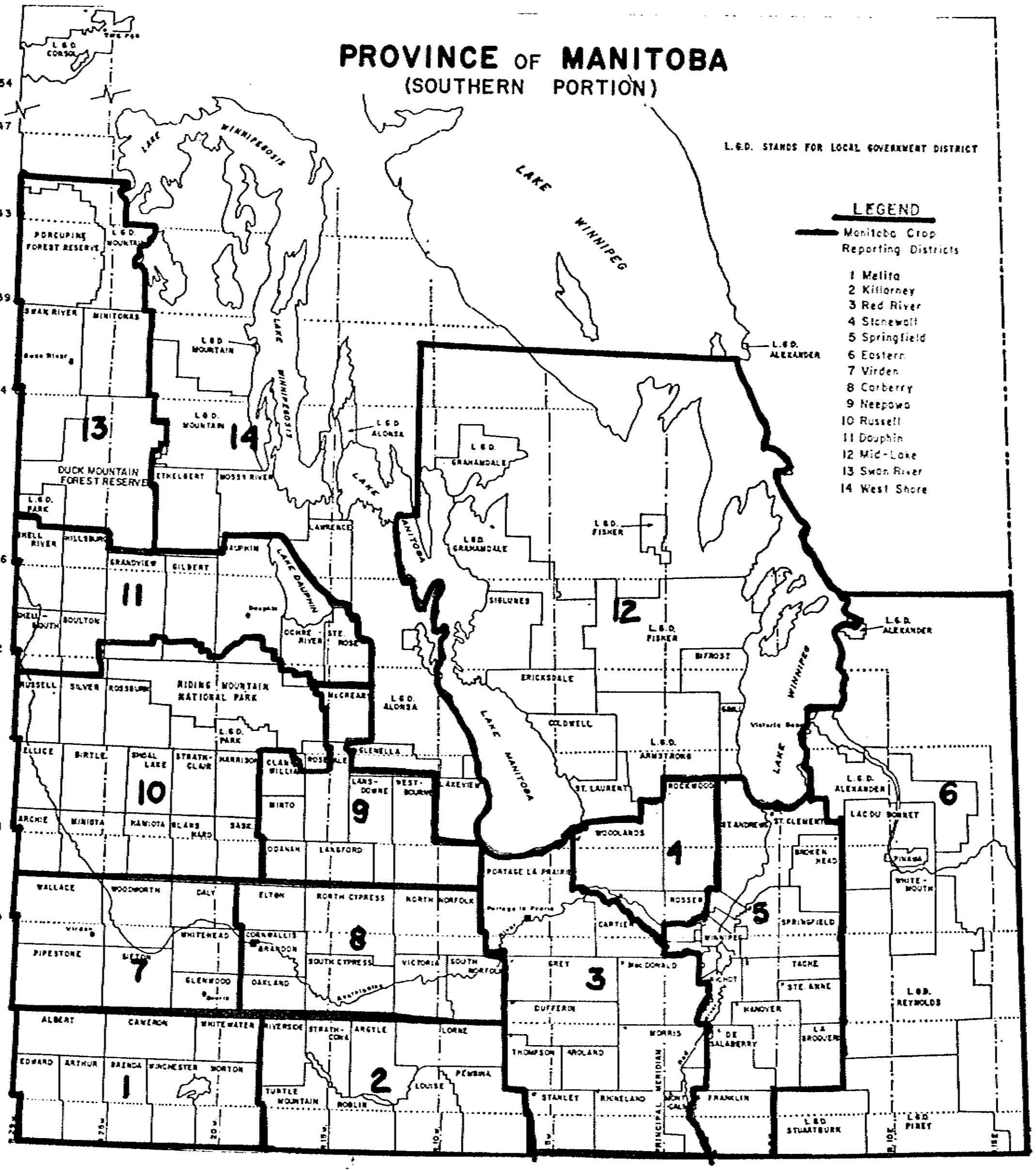

Fig. 2.1 Crop Districts: Southern Manitoba

SOURCE: Manitoba Dept. of Agriculture (M.D.A.). 1976. 1976 Yearbook, Manitoba Agriculture. Queen's Printer, Winnipeg.

NOTE: Crop District boundaries were reorganized and renumbered in 1977.

2.3 Methods

Fulfilling these objectives involves the following analyses:

1. Literature review - An extensive literature review was undertaken to gather information on the topics of crop residues and energy, crop residue inventories and crop residues and soil management. Appendix 1 summarizes information files of technical and research institutes searched by computer. Major librairies used are also listed.

2. Cereal straw inventory - Development of straw inventory for wheat, oats and barley crops in the study area involved a series of analyses:

(a) Review of existing crop residue studies to determine what information gaps exist in Manitoba's straw resource base and to review crop residue inventory designs.

(b) Identification of soil groups in the study area and description of each in terms of geographic extent, topography, drainage characteristics, natural fertility, major soil problems, and agricultural capability.

(c) Determination of average per hectare yields for wheat, oats and barley in each municipality in the study area and for the study area as a whole.

(d) Calculation of the average proportion of total straw yield per hectare normally left as stubble by each crop in the study area.

(e) Determination of the recommended amount of straw needed as a soil amendment for study area soils.

(f) Calculation of straw available per hectare by crop.

(g) Application of straw available per hectare estimates for each crop to actual wheat, oats and barley acreages in municipalities and the study area as a whole to obtain estimates of total straw available.

This inventory is designed to provide data on available straw density (yield per hectare) for wheat, oats and barley and geographic distribution of straw available.

3. Energy potential analysis - Analysis of the theoretical energy content of straw involved a review of major research developments in two major technical areas: ethanol from cellulose via hydrolysis, and gasification. These data were compared with petroleum fuels consumption in Manitoba to determine the theoretical petroleum extender value of straw as an energy source.

4. Straw collection costs - Data obtained from flax collection operations in Southern Manitoba are the basis for estimating costs of straw feedstock at a central site.

2.4 Importance of Study

This study discusses future utilization of a resource. It is assumed straw will be utilized when all the relevant economic, social and political factors have been weighed. It is hoped that this report will provide useful background information for such purposes. In this regard the report provides:

1. a method for estimating straw available;

2. realistic available straw data;

3. preliminary theoretical estimates of energy potential of available straw, and

4. a data base which could aid in the development of policies and guidelines aimed at improvement of agricultural practices and land use management.

2.5 Scope and Limitations

The utilization of biomass as an energy source in ways which are not environmentally and socially disruptive raises many complex questions and issues. For example, the production of dedicated biomass for energy as on large energy plantations is an area where all the environmental and social implications are not fully understood (Fraser et al 1979; Calef 1976; Clark 1975).

Since this is a small-scale research project, some important questions could not be addressed, due to time and manpower limitations. Farmer attitudes, for example, are a key social factor not dealt with here. Scope of the research is as follows:

1. Cereal crops chosen for analysis in this study are wheat, oats and barley.

2. The study area comprises Crop Districts 3, 4 and

5 in Manitoba.

3. Data used to determine straw production averages are for the years 1960 to 1977[1] inclusive and are based on four management practices: fallow fertilized, fallow unfertilized, stubble fertilized and stubble unfertilized.

4. Considerations of variables affecting straw needed as a soil amendment include soil factors such as soil organic matter, potential for erosion and soil fertility. Other factors considered are stubble produced, the effect of tillage practices on straw and straw burning.

5. Straw collection costs include baling, collection, transportation costs and a payment for straw to the farmer.

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[1] As the MCIC does not use the crop district as their data collection unit, it was not necessary to make allowance for crop district boundary changes in 1977. Further discussion of the yield data base is in Chapter 3.

CHAPTER 3

DEVELOPMENT OF STRAW BIOMASS INVENTORY

3.1 Review of Agricultural Biomass Inventories

Table 3.1 summarizes studies which have estimated straw production in Manitoba. With the exception of the Biomass Energy Institute (1976) study which applied a weight per area ratio to determine straw production, straw production estimates were obtained by using volume (grain in bushels) to weight (straw in pounds) ratios.[1] For example, a grain-straw ratio of 1:1.5 for wheat indicates that a wheat crop normally produces 1.5 units of straw for every unit of grain. Thus a 1345 kg/ha wheat crop produces approximately 2017 kg/ha of straw. It should be noted that the various studies do not disagree significantly on the appropriate grain-straw ratio for each type of crop. Weight per area ratios are generally not as consistent as volume-weight ratios (Intergroup 1978).

As can be seen in Table 3.1, both Kanoksing (1975) and Intergroup (1978, Vol. D) estimated total average annual straw production for the province on the basis of three years' production data. Estimated average annual production for all crop districts in Manitoba from the major cereal grain crops is about 6.0 to 6.7 million

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[1]This study used the metric equivalent of imperial grain: straw units, i.e. kg/ha.

TABLE 3.1

A SUMMARY OF SELECTED STRAW BIOMASS STUDIES IN CANADA

Study	Data Sources/ Time Period	Study Areas	Types of Crop Residues	Grain: Straw Ratio	Total Straw Manitoba (t)
Kanoksing (1975)	M D A Yearbooks (1968-70) Canada Yearbook	1) Canada 2) Manitoba 3) Crop District #3, Manitoba	wheat oats barley rye grain corn	1:1.5 1:1.2 1:1.0 1:1.2 1:1.0	6,792,896 (6,590,785)[a]
Intergroup Consulting Economists (1978) Vol. D	(1974-1976)	1) Canada 2) All Provinces 3) Manitoba: all crop districts	wheat oats barley rye flaxseed rapeseed mixed grains grain corn	1:1.25 1:1.3 1:1.0 1:2.0 1:1.5 1:2.0 - 1:1.0	6,792,896 (5,022,000)[a]
Biomass Energy Institute (1976)	M D A Yearbook (1974)	1) Manitoba: all crop districts	wheat oats barley other	This report assumes straw is produced at 2.24 tonnes/ha.	6,047,100
Partridge and Hodgkinson (1977)	M D A Yearbooks (1967-76)	1) Manitoba 2) Crop Districts 3, 4 and 5	wheat oats barley	1:1.5 1:1.4 1:1.0	5,640,000

NOTE: a) Annual straw production of wheat, oats and barley only.

tonnes. The Intergroup estimate is based largely on the same crops Kanoksing considered because they deducted rapeseed production and 10 percent of the flax from total production. These figures correspond with the Biomass Energy Institute (1976) one year estimate. The Partridge and Hodgkinson (1977) estimate, however, is somewhat less (5.0 million tonnes). Although it is based only on wheat, oats and barley production, it would seem to indicate that on a long-term basis, total annual straw production is lower. Since the long run yield reflects a greater variety of growing conditions, it is probably a more reliable indicator of annual straw yields for the province.

The number in brackets in the total straw column indicates the portion of annual straw production produced by wheat, oats and barley. Estimates range from 85 to 93 percent which indicate that straw and residue production from other crops in Manitoba are very small compared to wheat, oats and barley.

In Crop Districts 3, 4 and 5, wheat, oats and barley straw production represents 30 to 33 percent of the total straw produced in Manitoba in most years (Partridge and Hodgkinson 1977). In terms of straw available from wheat, oats and barley, however, this area produces up to 66 percent of the average provincial total (Intergroup 1978, Vol. D). This is due to climatic conditions and other uses which mitigate against straw availability in other crop districts.

In recent years there has also been a proliferation of agricultural biomass assessments in the United States. An overview of selected major studies is presented in Table 3.2. These studies were designed to obtain information and data on a large scale and the use of computer programs is common to these analyses. The United States Department of Agriculture (USDA) team study of agricultural residues in various regions probably represents the definitive approach to analyzing how much residue can be removed without exceeding soil erosion tolerance limits (Larson 1979).

In summary, existing straw biomass analyses indicate the kinds of straw produced, the amount of straw produced, and provide preliminary estimates of the amount available for removal. It should be noted that most of the results for Manitoba are based on short term yield averages. Further, such averages assume homogeneous growing conditions in crop districts which are in fact large, heterogeneous units. Existing straw inventories have not emphasized differences in straw yield on specific soil types, differences in straw required for soil management on these soils, average yields in the long term, and variations in quantities produced by sub-units within the crop districts. These elements, then, are the basis for the present analysis.

TABLE 3.2

A SUMMARY OF SELECTED CROP RESIDUE BIOMASS STUDIES IN THE UNITED STATES

Author(s)	Data Sources	Study Areas	Types of Crop Residues	Method for Estimating Biomass
Stanford Research Institute Alich et al. (1976) Vol. 1 and 2	1971-1973 State Agriculture Reports U.S. Census of Agriculture	Conterminous United States: National County-by-County Study	All Crops Except Hay and Forage Including Food Process Wastes	A 3 yr. avg. crop yield was calculated for each crop in a county. A residue factor was developed that, when multiplied by the county production for the crop, generated a figure for total residues. All data is on computer files.
Stanford Research Institute (1976) Vol 1. 1-8	As above	A 1) Ten Site Survey 2) Eight Regional Studies	1) All Crops Within Each Survey Area 2) All Crops	1) Selection of ten areas 2) Evaluation of residues in each area in terms of quantity, use and energy value 3) Socio-economic analysis of area and its energy needs 4) Evaluation of economic feasibility of conversion
Midwest Research Institute Benson (1976)	-	National Study of Land Resource Areas (L.R.A.)	1) Grains and grasses 2) Food component of food crops 3) Residues 4) Forages 5) Grasses	1) Estimated annual agricultural biomass in 000's air-dry tons 2) Geographic distribution of each type was analyzed 3) Biomass availability was calculated 4) LRA's were ranked on the basis of avg. biomass/ac.
U.S. Dept of Agriculture (Larson 1979)	Soil Conservation Service U.S.D.A. 1973-75	1) 4 Regions: Great Plains Corn Belt The Southeast Oregon	Corn Stover Small Grain Straw Grain Sorghum Soybean Straw Cotton Stalks	1) Residue produced per acre was calculated for crops in each major land resource area (MLRA) of the study area. 2) The Universal Soil Loss Equation (USLE) was applied to determine residues needed to control wind erosion in each MLRA.

3.2 Inventory Procedure

3.2.1 Introduction

This analysis provides a description of key elements in the straw inventory. In addition, cereal grain agriculture in the study area is assessed from a straw production perspective. This approach has not been emphasized previously in Western Canada, likely due to the lack of a commercial market for straw.

Both straw and stubble have been given a great deal of attention in Western Canada, mainly from the point of view of maximizing soil fertility and improving soil conservation. The inevitable financial exigencies imposed on farmers by ever-increasing fuel prices, however, generates economic conditions which favour examining straw production capability of cereal grain crops and the feasibility of straw recovery for energy purposes.

Such an analysis entails conversion of cereal grain yield data for the study area in terms of the procedures outlined in section 2.3. This section provides a discussion of factors affecting choice of crops, study area and data base, as well as definition of elements used to determine straw production, straw needed and straw availability.

3.2.2. Selection of Straw for Inventory

Table 3.3 outlines the major factors which should

TABLE 3.3

CRITERIA INVOLVED IN THE SELECTION OF WHEAT, OATS, AND BARLEY STRAW FOR INVENTORY

	Major Considerations		Sub-Categories
1.	Physical and Chemical Composition	A.	Physical - Morphology - Height
		B.	Chemical - Energy content
2.	Straw Production Characteristics	A.	Quantities of straw produced
		B.	Time straw is available
		C.	Accessibility
		D.	Amount of straw available
		E.	Potential for increasing production
3.	Competitive Uses	A.	Other current uses
		B.	Potential alternative uses, non-energy
4.	Collectibility	A.	Farmer Attitudes
5.	General Constraints	A.	Environmental
		B.	Techonological
		C.	Institutional/Legal
		E.	Political/Social

be considered as selection criteria in a comprehensive inventory of all agricultural residues and straw in a given area. Due to time, manpower and other resource constraints, it is beyond the scope of this analysis to evaluate fully each crop in the study area in terms of all the criteria listed.

The decision to study wheat, oats and barley in greater detail was made primarily on the basis of quantities of straw produced and their apparent energy potential, as indicated in the review of existing inventories. Also, wheat, oats and barley crops have historically ranked as the top three in the study area in terms of seeded area and total production.

Therefore, straw production from these crops rank similarly, relative to residues and straw produced by other crops in Manitoba. This does not imply, however, that other cereal grain crops such as mixed grains, rye and buckwheat, root crops, hay and forages and corn are not potentially important sources of bio-energy.

3.2.2.1 Physical Characteristics

The stem of cereal grain plants consists of five or six hollow tubes which are joined together at the nodes. Nodes are solid areas - generally five - at which point the leaves branch out. Miles (1977a, b) reports that straw stems have uniform wall thickness ranging from .0024 to .04 centimetres. The diameter of stems ranges from .02 to .07 centimetres.

Wheat, oats and barley varieties commonly grown in Manitoba do not vary greatly in height (Faculty of Agriculture 1977). Durum wheat varieties are long-strawed generally ranging from 97 to 102 centimetres. Bread wheat varieties are slightly shorter - 91 to 93 centimetres. Most oats varieties tend to be slightly shorter than wheat - 81 to 90 centimeters - but two varieties - Harmon and Rodney - have characteristics similar to bread wheat. Most barley varieties are shorter than wheat and oats ranging from 78 to 93 centimetres. Height of crop can vary from year to year depending on temperature and soil moisture conditions during the planting and growing seasons.

3.2.2.2 Chemical Composition

Mechanical support of the heavy seed head (spike) depends largely on the strength of the stem. Whereas proteins and starches are concentrated in the kernels, stems and leaves are made up of structurally stiffer, lignified fibres. The main chemical constituent of straw is cellulose ($C_6H_{10}O_5$), a polymerized carbohydrate made up of glucose units linked together. Straws vary greatly in their chemical composition according to variety and age. Straw consists of a small number of main components which, although chemically quite simple in themselves, are very difficult to separate due to complex molecular bonding. This subject is discussed in more detail in section 5.2 in relation to the topic of the energy potential of straw.

The energy content of oven-dry cereal grain straw is reported to be 18 MJ/kg (Lapp, pers. comm.). Experiments with cereal grain straw in Manitoba reveal that at 10 percent moisture content, the heat values of wheat, oats, and barley are 17.5, 12 and 13 MJ/kg respectively (Lapp, pers. comm.)

3.2.2.3 Quantities of Straw Produced

The measurements for quantities of straw produced are yields per hectare and total production. Partridge and Hodgkinson (1977) report that between 1967 and 1976, average straw yield in Crop Districts 3, 4 and 5 was 2.5t/ha for wheat and 1.9 t/ha for oats and barley.

Wheat, oats and barley crops have historically accounted for the largest proportion of cropland in Manitoba. These crops therefore out-rank other crops in terms of total production, and therefore, produced the largest quantities of straw. For Manitoba as a whole, it has been estimated on a three-year basis (1974 - 76) that straw production from wheat, oats and barley was about 5.0 million tonnes per annum, or 85 percent of total straw production (Intergroup 1978, Vol. D). The remaining 15 percent is produced by rye, flax, rapeseed, mixed grains, and grain corn stover.

3.2.2.4 Time Straw is Available (Seasonality)

In a normal season, wheat, oats and barley are harvested late in the third quarter of the year (late August, early September). Bread wheat usually ripens in 90 to 100 days but durum varieties take 100 to 107 days (MDA 1979). The maturity period for oats is 93 days and for barley 85 to 88 days (MDA 1979).

At harvest time farmers are preoccupied with removing the grain crop from land. As a result of these operational constraints, straw collection would have to follow grain harvesting, unless the two operations can be combined without delaying the efficiency of harvesting.

3.2.2.5 Accessibility of Straw

To a large extent, feasibility of collection and utilization of straw depends on quick and easy removal from the field. Although there are no geographical or physical barriers in the study area, climatic conditions may delay harvesting and thus eliminate time available for straw removal. Hail storms frequently flatten grain crops in the study area. Collection of the crop for biomass energy may be a form of salvage under such circumstances (Partridge, pers. comm.).

3.2.2.6 Amount of Straw Available

The amount of straw which can be removed from cropland (excluding fallow land) is known as straw available. There are several notable aspects of cereal grain agriculture which must be considered in estimating average annual straw available. The first factor is the quantity of straw needed for optimal management of study area soils. Important soil factors affecting straw needed include soil structure and organic matter, soil fertility, and the erosional susceptibility of soil. Second, management practices such as harvest operations, post harvest operations, post harvest tillage operations and straw burning, affect straw availability. Farmers are primarily concerned with harvesting the grain and completing fall tillage operations as quickly and efficiently as possible. Thus combine cutting heights are set to minimize grain losses and maximize grain throughput. Maximization of straw output is not an important consideration.

A full discussion of these factors in more detail follows in section 3.2.6

3.2.2.7 Potential for Increasing Production

On the basis of several studies of agriculture in the prairie provinces, there seems to be general agreement that cereal grain production can be increased in the future (Hedlin & Rigaux 1976; Rennie 1977; Hedlin 1978). Kraft and Dyck (1976), for example, conclude that yields do not appear to have reached a plateau in Manitoba and that increased production can be expected in the 1980's. This optimism is largely based on the assumption that economic factors conducive to increased production will be favourable. A critical constraint affecting potential production increases, is the limited quantities of unimproved Class 1-3 land. Most of the unimproved land suitable for agriculture is marginal Class 4 land (Hedlin 1967).

3.2.2.8 Other Current Uses and Potential Applications

Alternative uses for straw may limit the quantities of wheat, oat and barley straw available for energy recovery. Unlike in eastern Canada, where large quantities of straw are used as animal bedding (Timbers 1976), straw in western Canada is returned to the soil or burned. A small quantity is used for feed and animal bedding for wintering cattle in Manitoba. On the basis of an allowance of .54 tonnes per animal (Intergroup 1978, Vol. D), 91,206 tonnes would have been required for wintering cattle in 1977, excluding calves in Crop Districts 3, 4 and 5 (MDA 1977b).

Straw consists of several totally different compounds, each of them suitable for specific applications (Fig. 3.1). In addition to energy, straw has potential as food, feed, fibre, fertilizer, and chemicals. In Europe, straw is used to a much greater extent as a structural fibre in paper and fibre board, and as an animal feed component. In North America, it is unlikely that straw would displace wood as a source of pulp for paper and fibre for structural materials. Stramit Corporation of Edmonton, however, is currently manufacturing building panels from

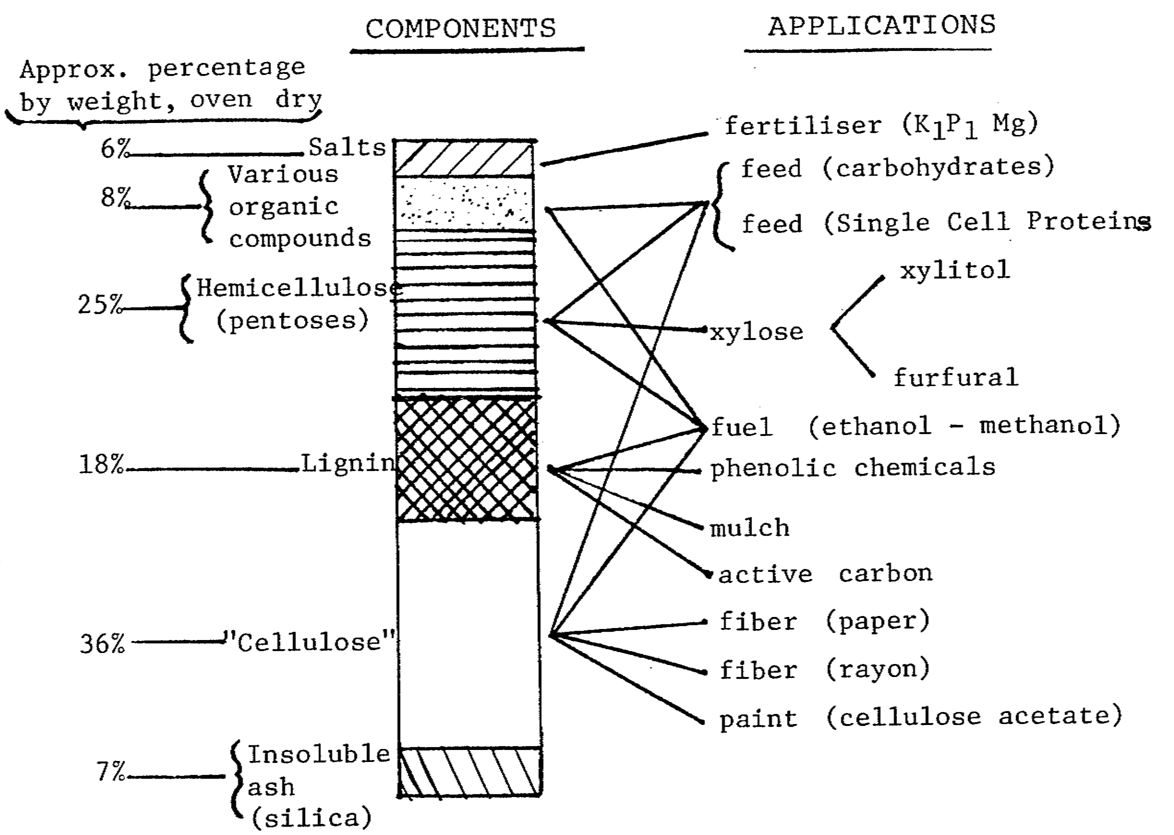

Figure 3.1

WHEAT STRAW--CHEMICAL COMPOSITION AND POSSIBLE UTILIZATION FOR EACH COMPONENT

SOURCE: B. A. Rykens. 1977. Some possible multiple uses for straw. Report on Straw Utilisation Conference. Feb. 24, 25, 1977, Oxford, England. ADAS, MAFF.

straw (Rimington 1977). In addition, it would appear that straw has potential as a source of animal feed (Winnipeg Free Press 1978; see also Table 5.3).

3.2.2.9 Collectibility

Collectibility refers to factors constraining or enhancing the collection of straw. Collection of available straw raises questions regarding feasibility of integrating such activities with traditional harvesting operations. Partridge and Hodgkinson (1977) note that from the farmer's point of view, straw collection should not interfere with grain harvest and post-harvest tillage.

3.2.2.10 General Constraints

The factors listed as general constraints in Table 3.3 are barriers to and/or benefits from utilization of straw as an energy source. They are equally important as basic questions of resource supply. Environmental and agricultural constraints are discussed in more detail in section 3.2.6 in terms of factors determining straw available. Economics are dealt with in Chapter 6 but only insofar as they relate to costs of straw collection.

3.2.3 Selection of Study Area

Elsewhere in this study, Crop Districts 3, 4 and 5, known locally as the Red River Valley, have been designated as the study area. The principal reason for this choice is that this area produced large volumes of straw annually (Partridge and Hodgkinson 1977; Intergroup 1978, Vol. D). With specific reference to the study area, this section elaborates on climatic and physical factors which affect the amount of surplus straw available. Secondly, there are several aspects of the region that tend to enhance the potential feasibility of local straw utilization.

Data presented in Table 3.4 indicate that climatic conditions in the study area, as represented by data for the South Central Lowland Area, are slightly more favourable for agriculture than in the Hard Spring Wheat Region as a whole. The main factors responsible for this advantage are the combination of higher precipitation levels and a slightly longer growing season. There is, on the average, a growing season water deficit. The mean annual precipitation for the study area ranges between 545 mm. and 585 mm. The last killing spring frost normally occurs between May 14 and 17, and the first autumn frost normally occurs between September 24 and 29 (Faculty of Agriculture 1977). Thus the growing season ranges between 110 and 120 days.

In contrast to western portions of the Hard Spring Wheat Region where drier conditions prevail, the combined presence of excessive moisture in many years, poorly

TABLE 3.4

CLIMATIC CHARACTERISTICS FOR THE HARD SPRING WHEAT REGION (H S W R) AND THE SOUTH CENTRAL LOWLAND AREA (S C L A)

Characteristic	H S W R	S C L A
Thermal		
Mean annual		
air temperature (C)	0.6-3.0	1.0-3.3
- frost free period (days)	100-115	110-120
Growing Degree-Days		
Above 5.5 C	1330-1640	2050-2400
- corn heat units	1415-1680	2325-2600
Moisture		
Mean annual precipitation		
(May 1 - Sept. 30) (mm)	290-370	305-370
- Soil water deficit)		
to Aug. 13	100-175	40-175
to Sept. 30	125-280	85-235

SOURCE: Faculty of Agriculture. 1977. Principles and practices of commercial farming. 5th ed. Winnipeg: Faculty of Agriculture, University of Manitoba.

drained clay soils, and widespread salinization are the major soil problems for agriculture in the study area. The fine texture clays are often heavy and difficult for tillage. Implications of these soil conditions as far as straw management is concerned is that the incorporation of combine straw and organic matter are recommended to help maintain and improve soil tilth and alleviate salinity (Table 3.5). To the extent that straw is needed for soil conservation and management, it constrains the amount of straw available for energy purposes.

Paradoxically, the second major limitation to crop production in the study area is drought. Droughts may occur throughout the entire growing season, as in 1961 and 1974, or significant water deficits may occur periodically during the growing season. At these times, some of the lighter soils (e.g. Emerson-Portage-Altona soils), which are predominantly in the southern and western parts of the study area, are particularly susceptible to wind erosion. It is therefore recommended that an adequate crop or trash cover is maintained on these soils.

Notwithstanding these limitations and constraints, there is evidence to indicate that climate and soil conditions are not significant barriers to collection of surplus straw in the study area. For example, summerfallowing, which is widespread through the brown and dark brown soil belts of the prairies, is generally practised less frequent-

TABLE 3.5

MAJOR CHARACTERISTICS OF LAND RESOURCE UNITS WITHIN SOUTH CENTRAL LOWLAND AND SOUTHEAST LAKE TERRACE AND SOUTHERN INTERLAKE AREA[a]

Soil Associations	Dominant Soil (Sub Group)	Topography and Materials	Drainage	Soil Management Problems[a,b]	Fertility and Agricultural Suitability[a,b]
Portage-Altona	Orthic Black Rego Black	Level, calcareous, lacustrine loam to clay loam	Good	- Susceptible to erosion - Grasses and legumes needed for organic matter - Trash cover essential	- High natural fertility - Special crops and grain crops
Emerson	Gleyed Rego Black	Level, calcareous lacustrine loam to clay loam	Imperfect to good	- Poor internal drainage - Localized salinity - High lime content - Slight erosion susceptibility	- Good to fairly good fertility - Suitable for all local crops
Red River-Osborne	Gleyed Rego Black Rego Humic Gleysol	Level, calcareous lacustrine clay	Imperfect to good	- Widespread salinity, flooding, poor internal drainage - Return of combine straw desirable	- High to moderate fertility - Especially suited to grain crops
Semple-Zora Stead	Gleyed Dark Grey Orthic Dark Grey	Level, calcareous clayey lacustrine veneers over till	Imperfect to poor	- Poor internal drainage	- Continuous cropping to grains - Mixed farming

SOURCES:

a) Faculty of Agriculture. 1977. Principles and Practices of Commercial Farming. 5th ed. Faculty of Agriculture. University of Manitoba. Winnipeg, Manitoba.

b) W.A. Ehrlich et al. 1953. Report of Reconnaissance Soil Survey of Winnipeg and Morris Map Sheet Areas. Soils Report #5. Manitoba Soil Survey.

ly in the study area. In fact, many farmers employ continuous cropping systems. A high ratio of fallow acreage to cropland is indicative of dry climatic conditions that mitigate against removal of straw needed for reducing wind erosion losses. Furthermore, the percent of total cropland under fallow indicates the corresponding reduction in total production that could be obtained if the land is used to grow crops. In a two year wheat-fallow rotation system, yield per hectare is actually only half that obtained since only one crop is obtained every two years (Hedlin and Rigaux 1976). As a final comment on the favourable climatic conditions in the area, it should be noted that soil scientists generally agree that summerfallow is not necessary in the black soil zone (Ripley 1969; Hedlin 1978).

On the social and economic side, a preliminary evaluation reveals that the region has several characteristics which tend to enhance the prospects of utilizing straw as an energy source. First, the population of the study area is large enough to provide a significant local market for energy produced from straw. The majority of the urban population is concentrated in metropolitan Winnipeg (Table 3.6), which is centrally located in the study area. Population concentration and central location are important factors affecting optimal location of a prospective central processing and conversion facility.

TABLE 3.6

STUDY AREA: POPULATION DISTRIBUTION

Census Subdivision	Urban[a]	Rural[a]	Farm[b]	Total
Brokenhead		2,898	1,281	
- Beausejour (T)	2,422			
- Garson (V)	290			5,610
Cartier		2,896	1,309	2,896
Desalaberry		2,670	1,216	2,670
Dufferin		2,592	1,572	
- Carmab (T)	2,272			
Franklin		2,168	1,066	4,864
Grey		2,062	1,404	2,168
Hanover		6,931	2,210	2,062
- Steinbach (T)	5,979			
- Niverville (V)	1,251			14,161
La Broquerie		1,523	527	1,523
McDonald		3,247	1,458	3,247
Morris		3,270	1,779	
- Morris (T)	1,572			4,842
Montcalm		1,794	825	
- Emerson (V)	756			2,550
Portage la Prairie		7,193	2,697	
- Portage la Prairie (C)	12,555			19,748
Rhineland			2,497	
- Altona (T)	2,480	4,550		
- Gretna (V)	510			7,540
Rotchot		3,768	718	3,768
Rockwood				
- Stonewall (T)	1,862	5,962	2,014	
- Teulon (V)	873			8,661
Roland		1,032	554	1,032
Rosser		1,269	647	1,269
Springfield		6,944	1,855	6,944
St. Andrews		6,831	1,839	16,693
- Selkirk (T)	9,862			
Stanley		4,572	2,214	
- Modern (T)	3,886			8,458
St. Clements		5,724	1,262	5,724
St. Francis Xavier		692	230	692
Ste. Anne		2,876	922	
- Ste. Anne (V)	1,174			4,050
Thompson		1,390	803	1,390
Total	47,658	84,854	32,899	132,512
Winnipeg				
- City	560,875			560,874
- St. Paul East		3,369	74	3,443
- St Paul West		2,570	111	1,681
TOTAL	608,532	90,793	33,084	699,510

SOURCES:

[a]Statistics Canada. 1976. Census of Canada. Population Geographic Distributions. Publication No. 92-806. Ottawa.

[b]Statistics Canada. 1976. Census of Canada. Agriculture, Manitoba. Publication No. 96-807. Ottawa.

NOTE: [a]T - Town, V - Village, C - City.

Population of other regional towns and cities in the study area is from 1562 to 12,555 and the spatial distribution is relatively uniform.

Table 3.6 shows three components of total municipality population: urban, rural and farm. The rural and farm components are not mutually exclusive, as they come from separate sources. That is to say, the rural figure includes farm population and it is shown as total municipality population if urban population is nil (e.g. Cartier, Franklin). Total non-Winnipeg population is relatively evenly distributed among the three categories: urban (47, 568 - 36 percent), rural (non-farm, 51,955[1] - 36 percent), and farm (32,899 - 25 percent).

3.2.4 Selection of Wheat, Oats and Barley Yield Data Base

Criteria used to select the appropriate yield data base were developed during review of the residue inventories. Although inventories provide estimates of straw production at the level of the crop district, none have examined potential production variations within these large and often heterogeneous areas. To undertake such an analysis requires two types of data: first, yields per hectare for wheat, oats and barley obtained on each type

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[1]Rural non-farm are rural residents not engaged in farming or living on a farm and not living in a town or village. It is the difference between rural and farm (84,854 - 32,899 = 51,955).

of soil, and for major agricultural practices in each municipality, and for the whole study area; second, planted wheat, oats and barley acreages in each municipality and for the whole study area. The criteria used for selecting yield data used in this study are as follows:

1. The boundaries of the wheat, oats and barley yield data reporting unit must correlate roughly with the study area boundaries and encompass variations within Crop Districts 3, 4 and 5; and

2. The yields must reflect yields obtained by farmers using "normal" or commonly adopted agricultural practices as opposed to experimentally determined yields, e.g. Cooperative Cereal Grain Trials data. Furthermore, data must be available for a continuous 10 - 15 year period so as to be representative. The data base developed by the Manitoba Crop Insurance Corporation (MCIC) generally meets the requirements.

3.2.4.1 Correlation of Boundaries

The basic yield data statistical reporting unit used by MCIC is the risk area.[1] MCIC has subdivided the southern agricultural part of Manitoba into 16 risk areas (Fig. 3.2). All of Risk Area 12 lies within Crop Districts 3, 4 and 5 and it is predominant in the study area. Parts

[1] A risk area is a geographic area comprised of similar soils and the basic unit used for computing crop insurance coverage rates by MCIC.

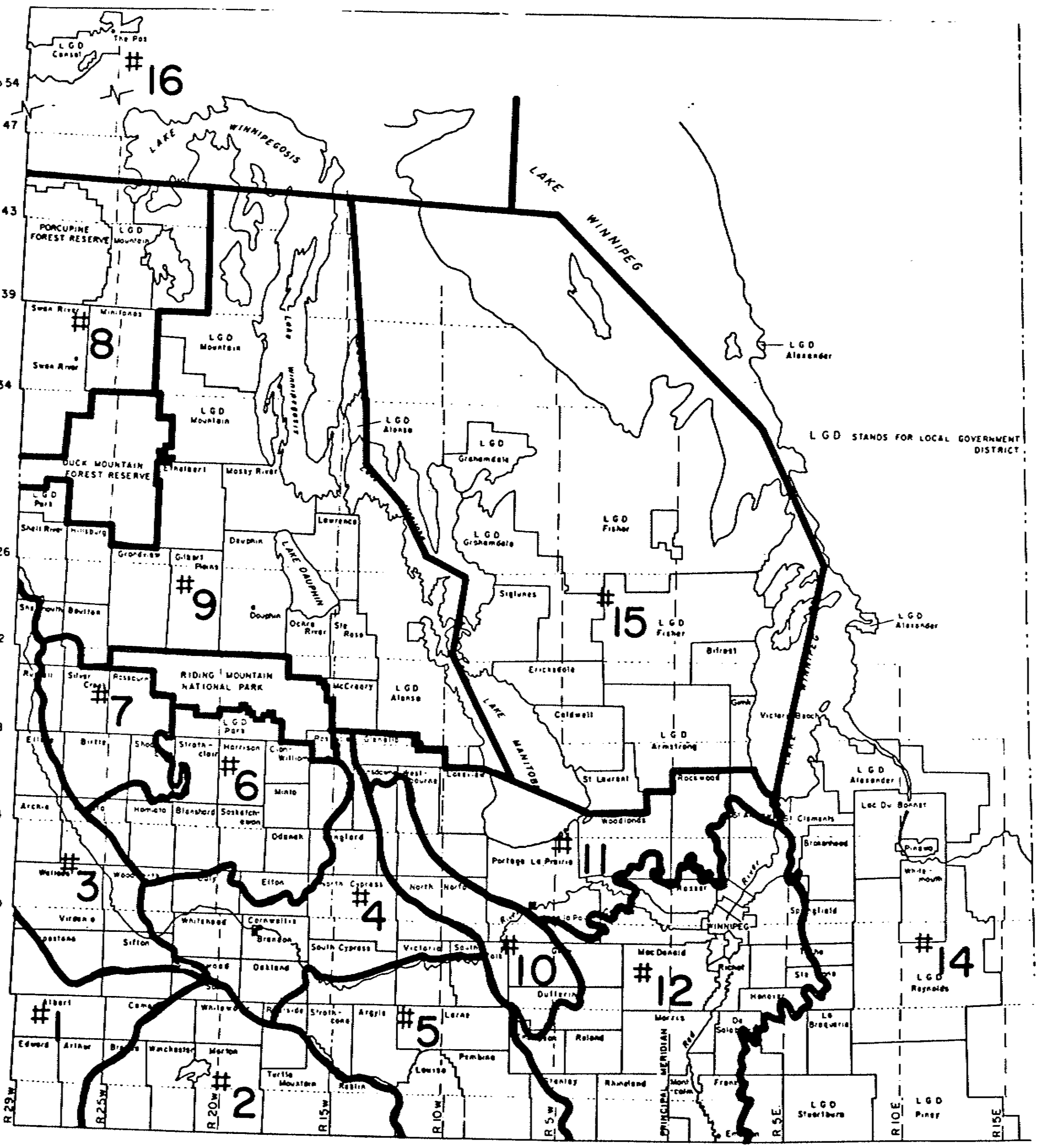

Fig. 3.2

PROVINCE of MANITOBA
CROP INSURANCE RISK AREAS

of Risk Areas 5, 10, 11 and 14 are also present. A small part of Risk Area 5 lies in the extreme southwest corner of the study area. Risk Area 10 protrudes into the study area along the western boundary. Risk Areas 11 and 14 occupy the northern and eastern periphery of the study area respectively.

Risk area boundaries are basically delineated by grouping soil associations[1] with similar physical characteristics. Table 3.7 lists soil associations in risk areas found in the study area in descending order of total area. Risk Area 12 is basically the level, lacustrine plain[2] lying below the 255 metre (850 foot) contour line, and the primary agricultural production unit in the Red River Valley. Thus the unit delineated here will be referred to as the Central Lowland Area (CLA), to distinguish it as the major crop production sub-unit of Crop Districts 3, 4 and 5.

MCIC risk area yield data are statistically summarized by soil 'zones' or classes. These soil zones represent group(s) of soil associations having similar physical characteristics and therefore produce similar wheat,

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[1]A sequence of soils of about the same age, derived from similar parent materials, and occurring under similar climatic conditions, but having variations in relief and drainage.

[2]Lacustrine deposits are materials deposited by lake water and later exposed either by lowering of water level or land uplift. Texture ranges from sands to clays.

TABLE 3.7

SOIL ASSOCIATIONS SUITABLE FOR CROP PRODUCTON
IN CROP DISTRICTS 3, 4 and 5

Risk Area	Soil Association	Area (ha)	% Of Total Area
5	Darlingford[a] Snowflake[a] Pembina[a]	255,837	16.7
11	Oakville[e]	41,543	2.7
	Portage[c]	35,614	2.3
	Woodlands[e]	33,280	2.1
	Riverdale[f]	29,931	2.0
	Lakeland[e]	15,851	1.0
	Burnside[c]	6,952	0.5
	Peguis[a]	4,966	0.3
		168,137	10.9
12	Red River Assoc.[f]		
	- Red River Clay	367,062	23.9
	- Osborne Clay	341,190	22.2
	- Myrtle	16,191	1.0
	- Morris	4,047	0.2
	Altona[c]	91,831	6.0
	Emerson[b]	58,388	3.9
	Horndean[b]	20,736	1.3
	St. Norbert[b]	15,734	1.0
	Red River-Emerson[b] Transition	14,766	1.0
	Fort Garry[b]	14,766	1.0
	Modern-Gretna[a]	10,735	0.7
		955,466	62.3
14	Zora[b]	20,920	1.4
11 and 14	Marquette[b]	71,751	4.7
	Semple[b]	62,535	4.0
		134,286	8.7
	Total	1,534,626	100.0

SOURCES:

[a]Data obtained from Soils Report No. 4.
[b]Data " " " " No. 5.
[c]Data " " " " No. 7.
[d]Data " " " " No.'s 4 and 5.
[e]Data " " " " No.'s 5 and 7.
[f]Data " " " " No's 4, 5 and 7.

NOTE:

Risk Area 12 includes the Agassiz, Leary and Birds Hill Associations which are not suitable for agriculture. Total area is 10,700 ha.

Risk Area 5 soils are excluded from further consideration because they are not in the Red River Valley. This group of soils are shown in this table as they lie in the southwest corner of Crop District 3 and are part of the total study area.

oat and barley yields. The MCIC uses 10 soil zones identified by the letters A to J[1]; A soils are the most fertile and J soils are the least fertile. The term soil zone as identified by the letters A - J, is actually a misnomer as these 'zones' are essentially soil productivity indices which were developed originally by Ridley et al (1966). Factors influencing productivity rating of a soil association include soil factors (e.g. organic content, parent material, etc.) and climatic factors (temperature and rainfall). The method of rating the soil is explained in the excerpt shown below (Ridley et al 1966).[2] The general productivity rating of each soil zone and its

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[1]This study analysed the yields for Risk Area 12 soil zones A to E only. For zones F to I, the data base is sparse and inconsistent for many years, reflecting the fact that F to I account for only 5 percent of Risk Area 12 total acreage (Ewanek 1976).

[2]Information available from Soil Survey reports provided the basis for the rating of soil productivity in Manitoba. Various mapped soil units of major significance in crop production (benchmark soils) were selected and long-term (35 year) average yields of wheat, oats and barley were determined for them. These yield statistics were obtained from records of the Dominion Bureau of Statistics, Sanford-Evans Statistical Service, and the Veterans Land Act Administration. An indexing system consisting of ten classes was established and the benchmark soils were allocated to the appropriate class in order of magnitude of the long-term crop yields. All soils that were recognized and mapped by the Soil Survey were then compared (according to soil profile characteristics) with the benchmark soils, and were placed in the appropriate index class. The classes were assigned a numerical rating from one to ten. The most productive soils received the highest rating. In general terms these were deep, well drained, medium to fine textured soils such as the Portage, Carroll, Darlingford, Holland and Kenville soils. Coarse textured soils such as Stockton or poorly drained soils such as Osborne were given correspondingly lower ratings.

corresponding CLA soil association(s) are identified in Table 3.8; a detailed rating of major soil characteristics of each association complements the general rating. As more crop yield and management data became available, the MCIC modified and extended the original classification by statistically separating soil zone yields on the basis of drainage characteristics. Well drained soil zone associates are designated by the risk area numbers (e.g. B_{12}, C_{12}) and poorly drained Risk Area 12 soil zone associates as plus (+) soils, designated by the number 32 (e.g. D_{32}, E_{32}).

3.2.4.2 Representativeness of MCIC Data

Farmers who wish to purchase crop insurance are asked each year to complete a questionnaire which is designed to obtain information about using fallow or non-fallow land, crop yield and fertilizer application rates. Information is recorded on a quarter-section basis (Figure 3.3). Data are aggregated by risk area to compute average crop yields annually for each soil zone according to use of fallow or non-fallowed land, and fertilizer. The questionnaire also requests the soil zone rating of each quarter-section submitted for insurance coverage. This information can be obtained from MCIC municipality maps showing soil zone ratings of all land on a quarter-section basis.[1]

[1]Examples may be found in section 4.3.1.

TABLE 3.8

CLASSIFICATION OF C L A SOIL ASSOCIATIONS BY M C I C SOIL ZONES AND BASIS FOR PODUCTIVITY INDEX (PI) RATING

General PI Rating (% of total Area)	General Characteristics and Basis for Overall Rating	Corresponding Soil Association[b]	Rating For Local Associate	Characteristics Of Local Associate[c]	Long Term Average Wheat Yield For PI Rating (kg/ha[a])
A (.001)	A Hor. - 31 cm				
	Highly Fertile				
	Well Dr.	Portage			1,880
	A Hor. - 13-25 cm				
	Well Dr. - Fine Tex.	Oakville			
B (1.5)	A Hor. 25-50 cm				
	Inter. DR, CL-C	Altona			
	A Hor. 25-41 cm	Sperling			1,680
	Well Dr.	Riverdale			
	Well Dr. C	Oakville			
C (22.9)	Well Drained		C+	Intermed.	
	Clay Loams	Altona	C+	Drained	
	Mod. Dr.	Burnside			
	A Hor. 13-38 cm	Emerson			
	A Hor. 18-25 cm	Ft. Garry	C+		
	A Hor. 20-25 cm	Marquette	C+		1,480
	A Hor. 20-23 cm	Morden	C+		
	A Hor. 20-30 cm	Myrtle	C+		
	A Hor. 18 cm	Peguis	C+		
	A Hor. 20-25 cm	Red River	C+		
		Red River-Emerson Transition	C+		
	A Hor. 13 cm	Semple	C+		
	A Hor. 15 cm	St. Norbert	C+		
D (42.6)	Poorly Drained				
	VFSL, Si - L	Altona	D+	Alkalinized Phase	
		Emerson	D+		
		Ft. Garry	D+		
	A Hor. 15-38 cm	Horndean	D+		
	A Hor. 13-30 cm	Lakeland	D+		
		Marquette	D+		
		Morris			1,345
		Oakville			
	A Hor. 13-20cm	Osborne	D+		
		Pequis			
		Red river	D+		
	A Hor. 13-38 cm	Red River-Emerson Transition	D+		
	A Hor. 13 cm	Semple	D+		
	A Hor. 15-30 cm	Steinbach	D+		
	A Hor. 15-28 cm	Zora	D+		
E (28.0)	Poorly Drained,	Emerson	E+	Slightly	
	Slightly Salinized	Ft. Gerry	E+	Saline	
		Horndean	E+		1,210
		Lakeland	E+		
		Marquette	E+		
		Osborne	E+		
		Peguis	E+		
		Red River	E+		
		Red River	E+		
		Red River-Emerson Transition	E+		
		Semple	E+		
		Steinback	E+		
		Zora			

SOURCES AND NOTES: [a]For explanation of assumptions underlying the PI ratings and the relationship between wheat yields and the ratings, see Ridley et al. (1966). Zones F to J comprise 4.9 percent.

[b]P.I. Committee. 1976. Productivity indices. Table showing maximum indices for soil associations and soil series. Manitoba Crop Insurance Corportion.

[c]Descriptions of soil conditions associated with poorly drained associates were obtained from Soil Surveys 4, 5 and 7.

Hor. = Horizon, Dr = Drained,

QUESTIONNAIRE - For Research Purposes Only

THE MANITOBA CROP INSURANCE CORPORATION

NAME AND ADDRESS | CONTRACT NUMBER | AGENT | MUNICIPALITY | CROP YEAR

MCIC

MUN	LEGAL DESCRIPTION 1/4 (NW NE / SW SE)	SEC	TWP	RGE	E OR W	ZONE	CULT AC	FALLOW AC	PASTURE AC	CROP	YEAR	AC	YLD	FERT	LBS	FERT	LBS	CROP	YEAR	AC	YLD	FERT	LBS	FERT	LBS	CROP	YEAR	AC	YLD	FERT	LBS	FERT	LBS	CROP	YEAR	AC	YLD	FERT	LBS	FERT	LBS

R	POR	NUMBER	PAR

M.C.I.C. COPY

I UNDERSTAND THAT THIS INFORMATION WILL BE USED FOR RESEARCH PURPOSES ONLY

SIGNATURE ____________________

FIG. 3.3

The MCIC data collection system has been operating continually since 1960. Available data represents yields obtained over an 18 year period. A wide range of climatic conditions have occurred during this period and thus farmers encountered a wide variety of adverse and good growing conditions.

3.2.5 Selection of Wheat, Oats and Barley Acreage Data

The Manitoba Department of Agriculture Yearbook (1977b) contains data concerning the acreage, yield and production of crops in each crop district.

Statistics Canada, Census of Agriculture: Manitoba (1976) provides data on number of acres for crops in each municipality.

3.2.6 Factors Considered in Determining Straw Available

This section describes how the MCIC straw production data was processed to provide estimates of straw available. As straw available is a function of straw needed, a discussion of factors affecting straw needed is included.

3.2.6.1 Soil Factors Affecting Straw Needed

Soil Organic Matter and Structure

Cereal straw is organic matter and as such is part of the organic fraction of the soil. The organic fraction is undecomposed and decomposed plant and animal (micro-organisms) matter, known as humus and it generally constitutes 5 percent by weight of the surface layer (Ridley, n.d.).

Organic matter plays an important role in determining the degree of soil aggregation and its presence improves soil structure. Aggregation refers to the propensity of minute soil particles to bind together, forming larger aggregates, which increases aeration, water penetration and soil tilth.[1] Organic matter tends to improve aggregation of soil particles because it is a spongy substance. Benefits of organic matter have been well demonstrated by research (Harris et al, 1966).

Poor drainage and difficult tillage characteristics of the heavy clays in the CLA are partially due to the fact that these soils have small, tightly packed particles which tend to reduce the rate of water infiltration. Research by Emmond (1971) indicates that as the amount of humus increases, so does aggregation of clay soils. It seems logical to assume then that applications of straw would help to alleviate the conditions associated with low soil aggregation.

Further evidence that organic matter tends to improve soil aggregation of clay soils was demonstrated by Spratt (1966). He compared a conventional summer fallow-

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[1] Soil tilth is the physical condition of soil as related to its ease of tillage, fitness of seedbed, and impedance of seedling emergence and root penetration.

wheat-stubble-wheat rotation with a longer rotation involving use of alfalfa, a nurse crop, and intertilled corn. Soil aggregation was considerably higher for the latter rotation.

Soil Fertility

Turning to the relationship between straw and soil fertility, it is widely acknowledged that straw tends to promote soil fertility (Allison 1973; McCalla and Army 1960; Ridley n.d.). When straw decomposition occurs, 13 mineral elements necessary for plant life are released into soil[1] (Adams *et al*, n.d.). In addition, carbon, hydrogen and oxygen are also released. Quantities of major plant nutrients returned to the soil from the decomposition of straw are sizeable (Table 3.9). As fertilizer costs continue to increase so will economic losses incurred when straw is burned and nitrogen is lost.

The significance of increasing soil fertility by addition of straw every year is that average yields are improved when continuous cropping is used. Ridley and Hedlin (1968) found that after 37 years, clay soils which produced a crop every year had a higher organic matter

[1]The minerals released are the following: nitrogen, phosphorous, potassium, sulfur, iron, and to a lesser extent boron, calcium, magnesium, manganese, zinc, copper, cobalt and molybdenum.

TABLE 3.9

NUTRIENTS IN VARIOUS AMOUNTS OF STRAW IN kg/ha

Source	Crop	Yield	Straw Yield	Nitrogen	Phosphorous	Potassium
Wallace[a] (1959)	wheat	-	2,721 kg/ha	17	4.5	24
	oats	-	2,057 kg/ha	17	5.6	40
	barley	-	2,259 kg/ha	17	5.6	34
Pittman[a] (1962)	wheat	2,688 kg/ha	4,032 kg/ha	22	5.6	40
	oats	3,048 kg/ha	4,267 kg/ha	28	17	91
	barley	3,451 kg/ha	3,451 kg/ha	19	6.8	50
Partridge and Hodgkinson (1977)[b]	wheat	-	-	6.2	0.7	6.2
	oats	-	-	6.2	1.8	19
	barley	-	-	5.9	1.0	13.3

NOTE: a) Wallace (1959) and Pittman (1962) data were reported in imperial units and then converted to metric units.
b) These data are expressed in kg/t.

and yielded more wheat, oats and barley. Research at Brandon by Ferguson (1976) shows that repeated applications of straw can increase organic matter and yields on non-fallowed land. Furthermore, depression of yields often attributed to the fact that the presence of straw induces nitrogen immobilization does not seem to be a major problem in Manitoba (Ferguson and Gorby 1964).

Soil Erosion

Fine texture clays are generally not considered to be susceptible to wind erosion except possibly in the spring of very dry years before the crop emerges and in the fall after the crop is removed. After a dry summer, proper stubble management can prevent excessive erosion. Erosion is difficult to control, however, on a fallow field in a dry summer unless proper trash cover management measures are taken. Spring and fall are the most critical erosion periods in dry years due to the fact that average wind speeds are equal to or greater than 19 km/hr (Environment Canada 1975), the speed above which winds are generally considered to be erosive and soil erodibility is high (Skidmore and Woodruff 1968).

Straw management for erosion control is of greater concern on medium-texture soils, and essential on coarse-texture soils. Research has shown that proper straw management can be an effective means of preventing soil losses in excess of 11.2 t/ha per year, which is considered to be the erosion tolerance limit (Wischmeier and Smith 1978).

Soil conservation and erosion research undertaken by the Agricultural Research Service and Soil Conservation Service of the United States Department of Agriculture has produced a number of quantitative soil conservation planning techniques which are useful for estimating amount of residues needed for soil erosion management. The soil conservation research undertaken in the past four decades reflects a desire not to let the drastic soil losses experienced in the 1930's happen again.

Major contributions in the area of wind erosion research include development of a wind erosion prediction equation and appropriate methods of erosion control for dryland farming. Major factors affecting wind erosion and soil erodibility include percentage of land slope (I index), the climatic factor as indicated by soil moisture and wind-speed (C factor), soil surface roughness (K factor), the distance across the field length along the direction of the prevailing wind (L factor), and vegetation cover (V factor) - i.e. the quantity and type of residue (Skidmore and Woodruff 1968; Woodruff et al 1972). Thus the wind erosion equation is E = (I, C, K, L, V), where E is the average annual soil loss per unit area. Skidmore et al (1979) applied the wind erosion equation in the Great Plains to determine residues needed to control wind erosion (RN) and the fraction of residues remaining after tillage and weathering (RR).

The equation for obtaining surplus residues (SR, i.e., the amount produced beyond the amount needed for wind erosion control) is: SR = RP - RN/RR, where RP is the amount of residue produced.

Formulation of the universal soil loss equation (USLE) is another important development for conservation planning. This equation can predict soil loss due to run-off for specified conditions (Wischmeier and Smith 1978). The soil loss equation is:

$$A = RKLSCP$$

where

A = soil loss per unit area

R = rainfall and runoff factor

K = soil erodibility factor

L = slope-length factor

S = slope-steepness factor

C = cover and management factor

P = support practice factor, e.g., contouring strip cropping

This equation has proved to be a very useful means of predicting residues available (Gupta *et al* 1979; Lindstrom *et al* 1979; Campbell *et al* 1979).

Necessarily, such studies require an extensive national data base and collection system, especially for the climatic data such as windspeeds and rainfall. National inventories of agricultural land provide the basic land characteristics data (USDA 1971). The land data, along with the appropriate agricultural practices data are analyzed by a computer program which solves the erosion equation.

3.2.6.2 Straw Needed for Study Area Soils

Another important result of soil conservation research is development of criteria which prescribe the amount of straw required per unit area for different soil texture classes. Table 3.10 summarizes data extracted from a number of straw management studies. Estimates for the fine and medium texture classes are fairly uniform.

Several factors must be considered in applying the straw needed figures in Table 3.10 to CLA soils in these texture classes. First, the straw needed per unit area in the Great Plains of the United States and the drier parts of the Canadian prairies is higher than in the CLA. A clay soil in Kansas or southern Saskatchewan requires higher amounts of straw for erosion protection than a CLA clay soil because erosion susceptibility is potentially greater in the drier areas. On the other hand, excessively poor drainage conditions create soil problems which can be ameliorated by returning straw to the soil (Table 3.11). On the basis of the more humid conditions in the study

TABLE 3.10

ESTIMATES OF SMALL GRAIN STRAW NEEDED FOR WIND EROSION AND SOIL MANAGEMENT (t/ha)

Source	Area Used as Basis For Estimate	Condition of Straw for Optimal Protection	Soil Texture		
			Fine	Medium	Coarse
Chepil and Woodruff (1954)	U.S. Great Plains	Semi-Erect-Flat	1.1	2.6	2.8
Woodruff *et al.* (1972)	U.S. Great Plains	Flattened	1.0	1.8	2.2
Koelsch *et al.* (1977)	Kansas	Flattened	1.1	1.0-1.3	1.5
Grainews	Canadian Prairies	Semi-Erect	0.6-1.1	1.7	2.2

TABLE 3.11

SOIL TEXTURE, SOIL PROBLEMS AND RECOMMENDED PRACTICES FOR C L A SOILS

Soil Association	Soil Texture[2]	Soil Problems[a]	Recommended Practices[a]
Fine			
Burnside	S,C		
Fort Grey	C	1a, 3, 7	
Horndean Complex	C	1a-1b, 3, 4, 8	2a, 2b
Marquette	HC - C	1b, 2, 3	2a, 2b
Morden-Gretna	C	2, 4	2a, 2b
Oakville	Si - C	1b	2a, 2b
Penguis	C	1b, 8	2a, 2b
St. Nobert	C	2, 8	2a, 2b
Red River Association			
- Red River	C	1a,-1b, 2, 8	1, 2a
- Osborne	HC - C	1a, 2, 3, 7, 8	2a, 2b
- Morris	C	2, 5, 8	2a
- Murtle	C		
Medium			
Riverdale	FSL - S,C		
Semple	C - CL	1b	
Altona	D: FSL; S: SCL	5,9	2a, 3
Emerson	D: SCL; S: SiL - SiC	2, 3, 7, 9	3
Lakeland	D: FSL - SiCL; S: CL - C	1b	2a
Portage			
Red River-Emerson Transition	SiCL - C	3, 7, 5, 9	3
Sperling	VFSL - Sic	9	
Steinback	FSL - FSCL	1b, 9	
Zora	SL - VFSCL	1b, 7, 9	2a
Woodlands	FSL - C	1b, 3, 7, 8	2a
Coarse			
Asgassiz Almasippi Birds Hill Leary	Coarse LS - S	5, 6, 9	Not Suitable for grain crops

SOURCES:

[a]Ellis et al. 1943. report of the reconnaissance soil survey of South Central Manitoba.

Ehrlich et al. 1957. Report of the reconnaissance soil survey of Carberry area.

Ehrlich et al. 1953. Report of the reconnaissance soil survey of Winnipeg-Morris area.

NOTES: Soil Problem Definitions

1. Poor drainage: a - surface, b - internal.
2. Poor physical structure of clay (compaction) in very dry or wet years.
3. Local salinized areas, lowers fertility.
4. Local alkalinized areas.
5. Low organic matter for best physical condition.
6. Low water retention capacity.
7. Local high lime areas.
8. Tillage heavy and difficult.
9. Susceptible to wind erosion and soil drifting.

Definition of Recommended Practices:

1. Tillage practices suitable to maintaining soil tilth and friability.
2. Addition of organic matter: a - grasses and legumes, b - return of straw.
3. Protective crop cover or trash cover.

Texture Definitions:

C - Clay	H - Heavy Clay	Si - Silty	S - Sandy
L - Loamy	F - Fine	D - Dominant Texture	S - Secondary Texture

area and the particular soil conditions, the recommended minimum amount of straw needed annually for soil management is somewhat less than the minimum needed for fine texture soils in drier areas where soils are susceptible to erosion (i.e., 1.1t/ha), but greater than the minimum needed for slightly erodible soils (0.6 t/ha), because of the poor soil structure of local clays. Thus, it seems reasonable to assume that 0.8 - 1.0 t/ha (an average of 0.9 t/ha) of straw are needed on CLA soils for long-term soil management and conservation.

3.2.6.3 Tillage Practices and Straw Yields

This section provides a comparison of straw reductions due to commonly used tillage practices in the CLA when a) total straw produced is incorporated and when b) straw available is removed. The first approach involves incorporation of total straw yield - stubble and combine straw - while the latter involves only the incorporation of stubble or one-third of total straw produced. The purpose of this analysis is to ascertain whether normal tillage practices are a major constraint to straw removal.

The effect of commonly used tillage practices on cereal grain straw in the CLA is shown in Table 3.12. Values for percentage reduction by each operation reflect what could occur for a given set of conditions. Since residue reduction is a function of such variables as speed and depth of operation, stubble height and the degree of

TABLE 3.12

AVERAGE EXPECTED STRAW REDUCTION DUE TO NORMAL TILLAGE PRACTICES IN THE CLA

Tillage Machines	Expected % Reduction Buried By Each Operation[a]	Range of Avg. Annual Straw Yield and Stubble (33% of Total) t/ha		Normal Fall Tillage Treatment For Poorly Drained Clay-C. Loam Soils[b]	Expected % Straw Buried (t/ha)	Expected Amount of Straw Buried After Fall Operations (t/ha)		Expected Amount of Straw Unburied (t/ha)	
Mixing Implements		Light to Moderate				Light	Moderate	Light	Moderate
Disc Equipment									
			Light	Cultivator: 1x	15	0.38		2.1	
Tandem Disc	50		2.5	2x	30	0.75		1.7	
Harrow	50	Total Straw Yield	Moderate 4.5	Combination: Tandem Disc 1x Cultivator 1x	65		2.9		1.6
Discer	40								
Cultivators									
Heavy Duty Cultivator	15	Stubble Only	Light 0.85	Cultivator 1x	15	0.12			0.61
			Moderate 1.5	Cultivator 1x	15		0.22		1.3

SOURCE: a) D. T. Anderson. 1963. Some farm requirements for the Palliser Triangle. Canadian Agricultural Engineer, 5: 4-6.

b) Compiled from H. E. Tolton. 1959. A guide to tillage practices. Manitoba Soil Science Third Annual Meeting. Winnipeg, Manitoba; J. R. D. Partridge. Personal Communication. M.D.A., Feb. 1980; Grainews. 1976. Handling heavy stubble and straw; Manitoba Soil Science Sixth Annual Meeting. 1962. Tillage and cropping practices.

NOTE: b) The various tillage options straw reduction calculations assume continuous cropping to wheat, oats, barley, rapeseed and flax; that harrowing may take place in conjunction with tillage and that no burning occurs. Further, that straw is not completely buried under the surface after these operations; it is assumed to be flattened and projecting from the top of the soil and oriented at an angle. In addition, it also assumed that one operation with a disc in the spring is required to prepare a proper seedbed.

soil pulverization, the range of reduction, particularly with mixing type implements (disc and cultivators), may vary by as much as 50 percent (Anderson 1963; 1964). Reported reductions presented in Table 3.12 are those which can normally be expected. Therefore, it follows that percentages of residue buried and the amount of straw buried and unburied after fall operations are also estimates of what can normally be expected.

Table 3.12 shows average annual total straw yields ranging from 2.5 t/ha (light) - which is the average annual straw yield of wheat in the CLA (Partridge and Hodgkinson (1977) - to 4.5 t/ha (moderate). Tillage machines and the number of operations (i.e., 1x or 2x) normally used by farmers are shown in terms of straw conditions (light or moderate) and the amount of straw to be incorporated - total straw or stubble only.

The amount of total straw buried is obtained by matching the appropriate tillage operation with the straw yield range. For example, for light straw yields up to about 2.5 t/ha either one (2.5 x 15 percent) operation with a heavy duty cultivator expectedly reduces and buries up to 0.38 t/ha and 0.75 t/ha respectively. The amount of loose, unburied straw is therefore 2.5 - 0.38 = 2.1 t/ha and 2.5 - 0.75 = 1.7 t/ha respectively for each of the above operations. As the straw yield increases, additional operations are needed to manage the straw properly.

Thus, amounts of unburied straw on land after fall tillage of total straw exceeds the recommended minimum needed for fine texture clays (0.9 t/ha).

Table 3.12 also shows the implications of removing all straw available from the soil and returning only the stubble.[1] Under average growing conditions, farmers generally adjust combine cutting heights so that stubble is about one-third the height of the standing crop. In fact, this height is recommended by MDA (1979) as an effective means of preventing the spike from contact with the ground and promoting faster drying.[2]

When a 2.5 t/ha straw yield is cut at one-third its height, the weight of the stubble is 0.83 t/ha[3], which is only 0.07 t/ha less than the minimum needed on fine texture soils and less than the recommended minimum straw needed for medium textured soils. Only 0.61 t/ha remains after one tillage operation with a heavy duty cultivator,

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[1]This would be the case if and when collectible combine straw is collected for energy utilization.

[2]It is assumed that farmers would continue to follow this practice even if straw became an energy source. This might induce farmers to cut stubble lower, thus increasing the amount of loose, collectible straw.

[3]This assumes that one-third the height of the crop equals one-third of the total straw weight per hectare. One British source suggests that a 2.5 cm. (1") reduction in cutting height increases the straw yield 0.11 t/ha (100 lb./ac) (Wood 1974). Thus a 2.5 t/ha (2,000 lb/ac) straw yield represents 0.83 t/ha (720 lb/ac) or about 16.5 cm. (6.5") of stubble. Therefore the above assumption seems reasonable.

which is about 0.3 t/ha less than the straw needed on fine texture clays. Removal of available straw is not a problem in the moderate straw yield range. Straw left after fall tillage is 1.3 t/ha.

Since 2.5 t/ha is, according to Partridge and Hodgkinson (1977), the average straw yield of wheat in the CLA, about 0.85 t/ha of stubble is left on the land as stubble in most years if available straw is removed. Because this amount is very close to the recommended minimum needed on the average for fine texture clays (0.9 t/ha), it would seem reasonable to suggest that the annual (or once every 2 years if a rotation is used) removal of available straw (1.6 t/ha) in most years would not exacerbate soil problems. Further, as stubble increases proportionally with total straw produced, the amount of stubble exceeds straw needed when yields exceed 2.5 t/ha. Thus, current tillage practices do not seem to be a major constraint to straw removal under light to moderate straw conditions.

3.2.6.4 Root Organic Matter

In addition to the organic matter returned to the soil by decaying straw left on the land, it is estimated that grain crops also contribute about 2 to 3 t/ha of root organic matter (Ripley, 1969; Peill, 1980). On the average a total of about 2.8 (2 + 2.5 - 1.7) to 3.8 (3 + 2.5 - 1.7) tonnes of organic matter are returned to the soil if available straw (1.7 t/ha) for a 2.5 t/ha straw yield is removed for energy utilization (assuming 0.8 t/ha remains as stubble).

3.2.6.5 Straw Burning and Straw Availability

Burning of straw is a widespread fall cultural practice in Manitoba, particularly in heavy straw years. The extent to which this practice is employed varies throughout the province. In 1976, the number of farmers who burned stubble varied from as much as one percent in some areas to 75 percent in other areas (MDA 1976a). In the agricultural area near Winnipeg, burning is a common practice. A study by Zittlau (1978) points out that 19 out of 30 farmers sampled in the municipality of Odanah, and 12 out of 30 sampled in Strathcona, burned stubble and other native vegetation. Deleterious effects of burning have been well documented by research. Burning of straw means the direct loss of nitrogen, a major plant nutrient, and also sulfur. Both nutrients are burned off as gases during the burning process (Partridge 1978). A major problem associated with straw burning is that the total removal of all straw leaves the soil exposed and subject to erosion (MDA 1976a). Connected to the continuous destruction of all straw is the fact that the soil structure deteriorates and tillage becomes more difficult. Studies completed at Basswood, Manitoba between 1972 and 1977 show that five percent more power was required to till burned plots over unburned plots (MDA 1977a). Further, not burning straw and stubble helps to increase moisture retention by trapping snow, by reducing the rate of runoff from heavy rains or snow melt and by reducing the velocity of the wind which decreases the rate of evaporation (MDA 1976a; Rae 1968).

Presentations by farmers to the Manitoba Clean Environment Commission (1977) hearings on peat and residue burnings revealed that farmers in general do not disagree with the general principle that burning is a wasteful and detrimental practice, and that straw ought to be returned to the soil. It would appear, however, that some farmers may not be equipped to incorporate long, heavy straw, even if they are cognizant this is possible with good management techniques and need not prevent proper seedbed preparation or decrease yields. Additionally, in some years moisture conditions may make straw chopping too tough an operation at times, even if the proper chopping equipment is available. Thus, burning is seen by some farmers as a necessary management tool when straw yields are very heavy.

CHAPTER 4

RESULTS OF STRAW BIOMASS INVENTORY

4.1 Overview

Having discussed major aspects of the inventory including the study area, data base and factors affecting straw production, this chapter provides a description of the procedure used to compute average annual straw production and discussion of the results. Key elements of the inventory analysis are:

1. Conversion of yield data in standard units to metric units (t/ha).

2. Computation of detailed average annual straw production estimates for specific soil zones in the study area and municipalities. This section provides a description of the procedure used to determine long-term average annual (15 - 18 years) wheat, oats and barley straw yields in terms of specific fertilizer and management practices. These detailed estimates are used to determine by soil zone the average straw availability factors of each crop.

3. Straw Production Analysis. In order to determine total available regional straw production, straw availability factors for each crop were multiplied by actual crop acreages in Crop Districts 3, 4 and 5. Similarly, straw production for a municipality was obtained by multiplying appropriate straw availability factors by municipal acreage data.

4.2 Conversion to Metric Units

Annual MCIC crop yield computer outputs present yield data for the risk asrea and municipalities[1] in bushels per acre. All yield values between the minimum and maximum yield that occurred between 1960 and 1977 for each crop were converted to pounds per acre (Column 1), and then to straw yield equivalents by applying the appropriate grain to straw ratio (G:S, Column 2). Table 4.1 indicates the straw yields for the minimum and maximum yields only; the straw yields in both standard and metric for all other yields are in Appendix 2. The standard grain and straw yields were converted to metric units by multiplying each yield by the appropriate metric conversion factor (Column 6). Further, it should be noted that MCIC yields are weighted yields which are derived statistically by computer from the questionnaire data (Figure 3.3) by applying the following formula:

$$\text{Weighted Yields} = \frac{(\text{acres x yield})}{\text{acres}}$$

4.3 Computation of Detailed Straw Available Estimates

The procedure for obtaining average annual wheat, oats and barley straw yields from the primary yield data

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[1]MCIC does not normally report yields by municipality. A program was written to obtain these yields. My appreciation for helpful assistance in this task is extended to Craig Wood and Herb Sulkers of MCIC.

TABLE 4.1

STANDARD AND METRIC WHEAT, OATS AND BARLEY VOLUME AND WEIGHT EQUIVALENTS FOR GRAIN AND STRAW

Yield Range of Crop[a] bu/ac	Standard Units					Metric Units				
	Grain	Straw		Stubble		Grain	Straw		Stubble	
	1 lbs/ac[b]	2 lbs/ac X(G:S ratio)[c]	3 tons/ac (2/2,000)	4 lbs/ac (2x33%)	5 tons/ac (4/2,000)	6 kg/ha[d]	7 kg/ha X(G:S ratio)	8 t/ha (7/1,000)	9 kg/ha (7x33%)	10 t/ha (9/1,000)
Wheat										
Minimum 10	600 (10x60)	900	0.45	300	0.14	672 (10x67.25)	1,008	1.0	333	0.33
Maximum 50	3,000	4,500	2.5	1,485	0.74	3,362	5,043	5.0	1,664	1.6
Oats										
Minimum 10	340 (10x34)	476	0.23	157	0.07	381 (10x38.1)	533	0.53	176	0.17
Maximum 90	3,060	4,284	2.1	1,414	0.70	3,429	4,800	4.8	1,584	1.58
Barley										
Minimum 10	480 (10x48)	480	0.24	158	0.07	531 (10x53.1)	531	0.53	175	0.17
Maximum 90	4,320	4,320	2.1	1,425	0.71	4,779	4,779	4.7	1,577	1.5

SOURCES:

a) Minimum and maximum weighted yields derived from M.C.I.C. data base, 1960-1977.

b) P. Kanoksing. 1975. Feasibility for energy recovery from cereal crop residues. M.Sc. Thesis, University of Manitoba: 1 bu wheat = 60#; 1 bu barley = 48#; 1 bu oats = 34#. D. Partridge, pers. comm.

c) J. R. D. Partridge and D. G. Hodgkinson. 1977. Manitoba crop residues as a biomass energy course. T. and S. papers. Man. Agron. Ann. Conference, Dec. 13, 14, 1977. G:S ratios: wheat, 1:1.5; oats, 1:1.4; barley, 1:1.0

d) Manitoba. 1979. Man. Agr. Service Coordinating Comm. 1979. Field crop recommendations. Metric conversion factors: 1 bu/ac wheat = 67.25 kg/ha; 1 bu/ac oats = 38.1 kg/ha; 1 bu/ac barley = 53.1 kg/ha.

on the computer outputs involves two operations. Table 4.2 (a) displays Risk Area 12 wheat yields on well-drained clays (designated by subscript 12) in 1977 and also the format used by MCIC to report yields by soil zones (B - J), various management practices (summer fallow and stubble) and fertilizer treatments (unfertilized or fertilized); Table 4.2 (b) shows 1977 Risk Area 12 wheat yields on poorly drained clays (designated by subscript 32). To obtain a clearer picture of the variation in wheat, oats and barley straw yields for the four management combinations, various soil zones and two drainage conditions, these data were plotted on graphs, an example of which is included as Figure 4.1. This particular graph shows Risk Area 12 wheat straw yields for soil zone B over a 15 year period for fallow fertilized and stubble fertilized and an 18 year period for fallow unfertilized and stubble unfertilized. The vertical axis shows the equivalent straw yield of wheat yields between the minimum and maximum values for 1960 to 1977 in metric units. The horizontal axis shows the time period of the study.

Average annual straw yield (weighted) for each graph line was obtained by summing individual yields and dividing by the number of years. These numbers were then put on tables which summarize the straw yield data by crops and soil zones. Table 4.3, for example, shows Risk Area 12 average annual wheat straw yields (No. 1) obtained on

TABLE 4.2(a)

WEIGHTED WHEAT YIELDS ON BETTER DRAINED RISK AREA 12 SOIL ZONES[a]

-03E20 1977 C R O P I N S U R A N C E Q U E S T I O N N A I R E S - CROP 01 RISK AREA 12 05/07/78

FALLOW RANGES OF FERTILIZER NUTRIENT (LBS. PER ACRE) N = 000 - 999 P = 000 - 999 K = 000 - 999

STUBBLE RANGES OF FERTILIZER NUTRIENT (LBS. PER ACRE) N = 000 - 999 P = 000 - 999 K = 000 - 999

	FALLOW					STUBBLE					FALLOW & STUBBLE				
	N	ACRES	W-YLD	M-YLD	S.D.	N	ACRES	W-YLD	M-YLD	S.D.	N	ACRES	W-YLD	M-YLD	S.D.
B_{12} FERT	6	310	48.55	46.67	9.83	77	5,190	37.83	37.95	7.33	83	5,500	38.43	38.58	7.80
UNFERT	8	345	43.26	41.63	9.97	3	95	45.00	45.00		11	440	43.64	42.55	10.82
BOTH	14	655	45.76	43.79	9.87	80	5,285	37.95	38.21	7.69	94	5,940	38.82	39.04	8.24
C_{12} FERT	30	1,013	41.91	41.73	9.47	468	27,962	32.90	32.18	7.43	498	28,975	33.22	32.76	7.89
UNFERT	26	751	37.11	37.81	9.83	19	576	33.39	32.21	10.36	45	1,327	35.49	35.44	10.33
BOTH	56	1,764	39.86	39.91	9.75	487	28,538	32.91	32.18	7.56	543	30,302	33.32	32.98	8.15
D_{12} FERT	35	1,396	41.26	40.89	9.20	464	24,779	32.91	32.59	8.24	499	26,175	33.35	33.17	8.57
UNFERT	9	331	35.41	38.67	10.59	14	586	26.01	26.00	5.88	23	917	29.40	30.96	10.06
BOTH	44	1,727	40.14	40.43	9.41	478	25,365	32.75	32.40	8.26	522	27,092	33.22	33.07	8.64
E_{12} FERT	27	900	38.57	38.96	10.06	205	11,128	33.85	33.66	7.84	232	12,028	34.21	34.28	8.28
UNFERT	25	924	30.94	32.68	9.42	9	545	25.96	26.11	4.94	34	1,469	29.09	30.94	8.69
BOTH	52	1,824	34.70	35.94	10.17	214	11,673	33.48	33.34	7.88	266	13,497	33.65	33.65	8.42
F_{12} FERT	9	445	35.71	35.33	4.09	99	5,215	37.89	36.64	8.07	108	5,660	37.72	36.53	7.81
UNFERT	6	149	22.82	24.17	5.85	4	282	18.56	17.25		10	431	20.03	21.40	9.30
BOTH	15	594	32.48	30.87	7.34	103	5,497	36.90	35.88	9.03	116	6,091	36.47	35.25	8.96
G_{12} FERT	3	105	31.90	33.33		17	752	35.37	33.41	8.82	20	857	34.95	33.40	8.31
UNFERT	1	45	25.00	25.00		2	65	29.31	28.50		3	110	27.55	27.33	
BOTH	4	150	29.83	31.25		19	817	34.89	32.89	8.48	23	967	34.11	32.61	8.04
I_{12} FERT	1	38	40.00	40.00		1	52	35.00	35.00		2	90	37.11	37.50	
UNFERT															
BOTH	1	38	40.00	40.00		1	52	35.00	35.00		2	90	37.11	37.50	
J_{12} FERT															
UNFERT	1	155	23.00	23.00							1	155	23.00	23.00	
BOTH	1	155	23.00	23.00							1	155	23.00	23.00	
FERT	111	4,207	40.54	40.30	9.31	1331	75,078	33.76	33.24	8.00	1442	79,285	34.12	33.78	8.32
UNFERT	76	2,700	33.77	35.18	10.37	51	2,149	27.94	28.86	10.24	127	4,849	31.19	32.65	10.74
BOTH	187	6,907	37.90	38.22	10.05	1382	77,227	33.60	33.07	8.13	1569	84,134	33.95	33.69	8.54

NOTE: [a]Due to the large data base it is not practicable to append a full set of the MCIC data.

TABLE 4.2(b)

WEIGHTED WHEAT YIELDS ON POORLY DRAINED RISK AREA 12 SOIL ZONES

A03E20 — 1977 CROP INSURANCE QUESTIONNAIRES - CROP 01 RISK AREA 32 — 05/07/78

FALLOW — RANGES OF FERTILIZER NUTRIENT (LBS. PER ACRE) N = 000 - 999 P = 000 - 999 K = 000 - 999

STUBBLE — RANGES OF FERTILIZER NUTRIENT (LBS. PER ACRE) N = 000 - 999 P = 000 - 999 K = 000 - 999

	FALLOW					STUBBLE					FALLOW & STUBBLE				
	N	ACRES	W-YLD	M-YLD	S.D.	N	ACRES	W-YLD	M-YLD	S.D.	N	ACRES	W-YLD	M-YLD	S.D.
C_{32} FERT	130	6,930	35.28	36.22	11.25	655	51,821	30.97	30.52	8.10	785	58,751	31.48	31.46	8.95
UNFERT	51	2,338	28.74	29.94	9.23	37	2,157	20.63	20.41	7.50	88	4,495	24.85	25.93	9.73
BOTH	181	9,268	33.63	34.45	11.07	692	53,978	30.56	29.98	8.38	873	63,246	31.01	30.91	9.17
D_{32} FERT	221	13,275	34.18	35.58	9.91	1363	109,450	30.81	30.48	7.88	1584	122,725	31.17	31.19	8.38
UNFERT	71	2,967	31.74	32.52	10.43	53	2,726	25.27	25.26	8.09	124	5,693	28.64	29.42	10.13
BOTH	292	16,242	33.73	34.84	10.11	1416	112,176	30.67	30.29	7.94	1708	128,418	31.06	31.07	8.52
E_{32} FERT	140	8,246	34.78	34.55	12.31	1062	86,952	30.70	30.26	8.09	1202	95,198	31.05	30.76	8.79
UNFERT	31	1,448	32.18	33.16	11.29	41	2,522	18.99	19.05	10.76	72	3,970	23.80	25.13	12.99
BOTH	171	9,694	34.39	34.30	12.11	1103	89,474	30.37	29.84	8.47	1274	99,168	30.76	30.44	9.16
F_{32} FERT	13	910	37.90	36.62	8.12	39	3,053	30.56	30.28	6.67	52	3,963	32.24	31.87	7.50
UNFERT	3	220	31.59	31.67		1	25	28.00	28.00		4	245	31.22	30.75	
BOTH	16	1,130	36.67	35.69	7.60	40	3,078	30.54	30.23	6.59	56	4,208	32.18	31.79	7.26
G_{32} FERT	2	55	41.82	45.00		1	15	35.00	35.00		3	70	40.36	41.67	
UNFERT	1	140	23.00	23.00		1	150	35.00	35.00		2	290	29.21	29.00	
BOTH	3	195	28.31	37.67		2	165	35.00	35.00		5	360	31.38	36.60	9.76
H_{32} FERT						1	98	35.00	35.00		1	98	35.00	35.00	
UNFERT															
BOTH						1	98	35.00	35.00		1	98	35.00	35.00	
U_{32} FERT	2	40	6.00	6.00							2	40	6.00	6.00	
UNFERT															
BOTH	2	40	6.00	6.00							2	40	6.00	6.00	
FERT	508	29,456	34.70	35.41	11.06	3121	251,389	30.80	30.41	7.98	3629	280,845	31.21	31.11	8.65
UNFERT	157	7,113	30.67	31.73	10.15	133	7,580	22.06	22.09	9.24	290	14,693	26.23	27.31	10.85
BOTH	665	36,569	33.91	34.54	10.95	3254	258,969	30.55	30.07	8.20	3919	295,538	30.96	30.83	8.89

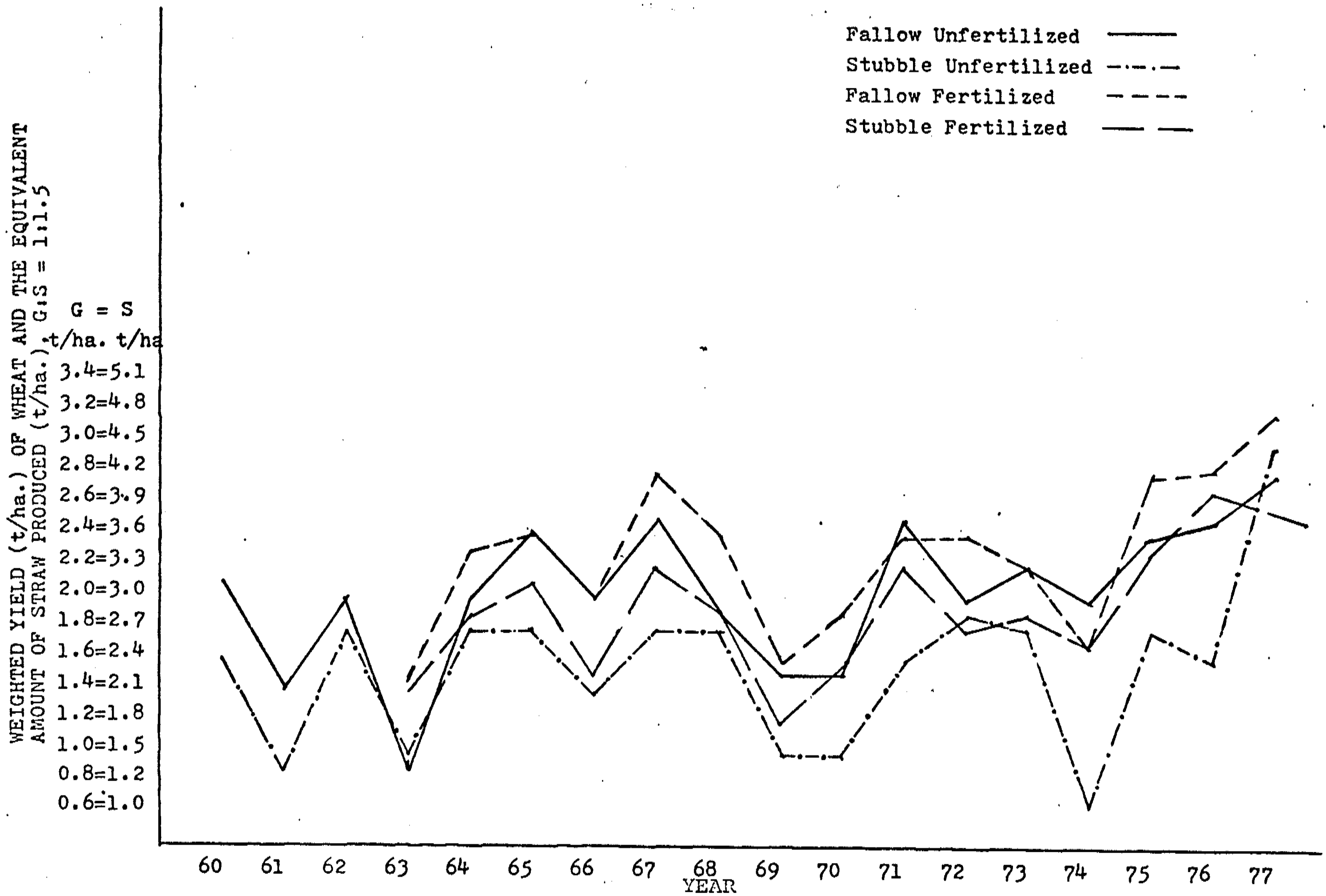

FIG. 4.1

WEIGHTED WHEAT YIELDS: B12 SOIL ZONE

TABLE 4.3

AVERAGE ANNUAL WHEAT STFAW, STUBBLE AND STRAW AVAILABLE IN
RISK AREA 12

SOIL ZONE	YIELD FACTOR	WELL DRAINED FF	WELL DRAINED SF	WELL DRAINED FU	WELL DRAINED SU	POORLY DRAINED FF	POORLY DRAINED SF	POORLY DRAINED FU	POORLY DRAINED SU
B	1.	3.4	2.8	3.0	2.3				
	2.	1.1	.9	1.0	.7				
	3.	2.3	1.9	2.0	1.6				
C	1.	2.9	2.7	2.8	2.2	2.6	2.2	2.2	1.7
	2.	.9	.9	.9	.7	.8	.7	.7	.5
	3.	2.0	1.8	1.9	1.5	1.8	1.5	1.5	1.2
D	1.	3.1	2.8	2.7	2.0	2.1	2.0	2.2	1.7
	2.	1.0	.9	.9	.6	.7	.6	.7	.5
	3.	2.1	1.9	1.8	1.4	1.4	1.4	1.5	1.2
E	1.	2.8	2.7	2.5	2.0	2.3	2.0	2.0	1.7
	2.	.9	.9	.8	.5	.7	.6	.6	.5
	3.	1.9	1.8	1.7	1.4	1.6	1.4	1.4	1.2

NOTES: Fallow fertilized (FF) and stubble fertilized (SF), 15 years (1963-1977)
Fallow unfertilized (FU) and stubble unfertilized (SU), 18 years (1960-1977)

1. Average annual straw yield (t/ha)
2. Average annual stubble left in field (1 x 33%)
3. Average annual straw available

Blank spaces indicate data not available.

various soil zones for good and poor drainage conditions. Straw yield data was then used to derive detailed estimates of average annual straw available for particular practices. This was accomplished by deducting from each straw yield an allowance of 33 percent which represents stubble left in the field on the average (No. 2). The difference between these figures is straw available or the amount of straw biomass potentially collectible for energy (No. 3). The overall average for all practices in each soil class is also shown.

The results of this analysis are discussed in the following sections.

4.3.1 Straw Available (t/ha) in the CLA Study Area (Risk Area 12)

Table 4.4 presents overall average annual straw yield results on a per hectare basis for wheat, oats and barley on well drained and poorly drained soils in Risk Area 12. Appendices 3.1, 3.2 and 3.3 provide additional Risk Area 12 data in terms of minimum and maximum straw yields which occurred during the study period. Further discussion of each crop follows below:

4.3.1.1 Oats

Oats crops on better drained Risk Area 12 soils generally produce the highest quantities of straw. Straw available varies from 1.8 t/ha on E_{12} soils to 2.8 t/ha on

TABLE 4.4

AVERAGE ANNUAL WHEAT, OATS AND BARLEY STRAW YIELDS[a]
AND AVAILABLE STRAW (t/ha) IN RISK AREA 12

Crop		Well Drained$_{12}$ B	C	D	E	Avg.	Poorly Drained$_{32}$ C	D	E	Avg.
WHEAT	STRAW YIELD	3.1	2.9	2.8	2.7	2.9	2.3	2.1	2.0	2.1
	AVAILABLE STRAW	2.1	2.0	1.9	1.8	2.0	1.6	1.4	1.4	1.4
OATS	STRAW YIELD	4.1	3.9	3.3	2.7	3.5	2.7	2.5	2.4	2.5
	AVAILABLE STRAW	2.8	2.7	2.3	1.8	2.4	1.8	1.7	1.6	1.7
BARLEY	STRAW YIELD	2.1	2.3	2.2	2.1	2.1	1.9	1.7	1.8	1.7
	AVAILABLE STRAW	1.4	1.6	1.5	1.4	1.5	1.3	1.2	1.3	1.2

NOTE: a) Overall soil zone yield averages represent the average of fallow fertilized, stubble fertilized, fallow unfertilized and stubble unfertilized practices, as shown in Table 4.3. Barley averages are based on stubble and fallow fertilized data.

B_{12} soils. The overall average is 2.4 t/ha.

Oats straw yields are markedly lower on poorly drained soils. Straw available on C_{32} soils using fertilized stubble practices is 1.8 t/ha and it decreases to 1.7 and 1.6 t/ha for D_{32} and E_{32} soils respectively. Overall straw availability for this practice on C_{32}, D_{32} and E_{32} soils is 1.7 t/ha.

4.3.1.2 Wheat

Wheat crops on better drained soils have the next highest straw yields and straw available. The range of average straw yield for this group is from 2.7 to 3.1 t/ha, with an average yield of 2.9 t/ha.

Wheat yields are such that average annual stubble is at least 0.9 t/ha on D_{12} and E_{12} soils and increases to 1.1 t/ha on B_{12} and C_{12} soils. The analysis indicates an average 2.0 t/ha of straw is available from wheat crops on better drained clays in the CLA.

Wheat straw yield data is evidence of the strong influence of drainage conditions on yields. Straw yields on poorly drained soil associates are from 2.0 to 2.3 t/ha; the corresponding average is 2.1 t/ha, which is 0.7 t/ha less than yields on better drained associates. The net effect is that straw availability decreases markedly to an average of 1.4 t/ha on C_{32}, D_{32} and E_{32} soils, on the basis of data for all practices.

4.3.1.3 Barley

Barley crops tend to produce less straw than either oats or wheat. Average straw available for better drained soils is 1.5 t/ha and it decreases to 1.2 t/ha on poorly drained soils.

4.3.2 Total Straw Available in the Study Area

Table 4.5 indicates quantities of straw available in Crop Districts 3, 4 and 5 in the years 1973 to 1976. Total straw available for each year and crop is obtained by multiplying the appropriate availability factor by the number of hectares planted. Total straw available in each year can be obtained by adding wheat, oats and barley totals.[1]

Total straw available in 1973, 1974, 1975 and 1976 is 1.345, 1.496, 1.333 and 1.510 million tonnes respectively; the average is about 1.4 million tonnes. On a 3-year average basis wheat, oats and barley contribute 57, 24 and 19 percent respectively of total straw available from these three crops.

4.3.3 Geographic Distribution of Straw Availability (t/ha) in Study Area Municipalities

4.3.3.1 Organization of Municipality Data

Figure 2.1 shows 26 rural municipalities (exclu-

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[1]For example, total straw available in 1973 is as follows: 663,000 + 328,000 + 354,000 = 1.345 million tonnes.

TABLE 4.5

TOTAL AVAILABLE WHEAT, OATS AND BARLEY STRAW IN
CROP DISTRICTS 3, 4 AND 5 (1973-1976)

Crop	Year	ha (000)[a]	Straw Available Factors (t/ha) Well Drained	Poorly Drained	Avg.	Total Straw Available (000 Tonnes)	Average
Wheat	1973	390	2.0	1.4	1.7	663	815
	1974	546	2.0	1.4	1.7	928	
	1975	451	2.0	1.4	1.7	766	
	1976	532	2.0	1.4	1.7	904	
Oats	1973	164	2.4	1.7	2.0	328	330
	1974	145	2.4	1.7	2.0	290	
	1975	165	2.4	1.7	2.0	330	
	1976	186	2.4	1.7	2.0	372	
Barley	1973	272	1.5	1.2	1.3	354	276
	1974	214	1.5	1.2	1.3	278	
	1975	182	1.5	1.2	1.3	237	
	1976	180	1.5	1.2	1.3	234	

SOURCE: a) MDA 1973, 1974, 1975, 1976. Yearbooks. Manitoba Agriculture. Queen's Printer.

ding St. Paul East and West) situated within Crop Districts 3, 4 and 5. In addition, Figure 3.2 shows the position of Risk Area 12 boundaries in these crop districts relative to other risk areas and municipality boundaries. A municipality was excluded from further consideration in the straw yield analysis if any one of the following occurred:

1. If the entire municipality fell entirely outside Risk Area 12, e.g., La Broquerie, Brokenhead; both are in Risk Area 14.

2. If soils in a municipality are marginal. The municipalities of Woodlands and Rockwood are excluded as Risk Area 11 and 12 soil zones in these municipalities are classified as mainly in zones F to J; this is marginal agricultural land. A detailed picture of the geographic distribution of soils zones in a particular municipality can be obtained from the MCIC quarter-section municipality maps, examples of which are included as Figures 4.2 and 4.3.

3. If Risk Area 12 soil zone yield data could not be separated from Risk Area 10, 11 or 14 soil zone yield data, e.g., St. Andrews, St. Clements, Springfield, Franklin Grey, Dufferin, Ste. Anne.

This problem occurs because Risk Area12 soil zone yield data was not statistically disaggregated by computer from Risk Area 5, 10, 11 or 14 for municipalities in which

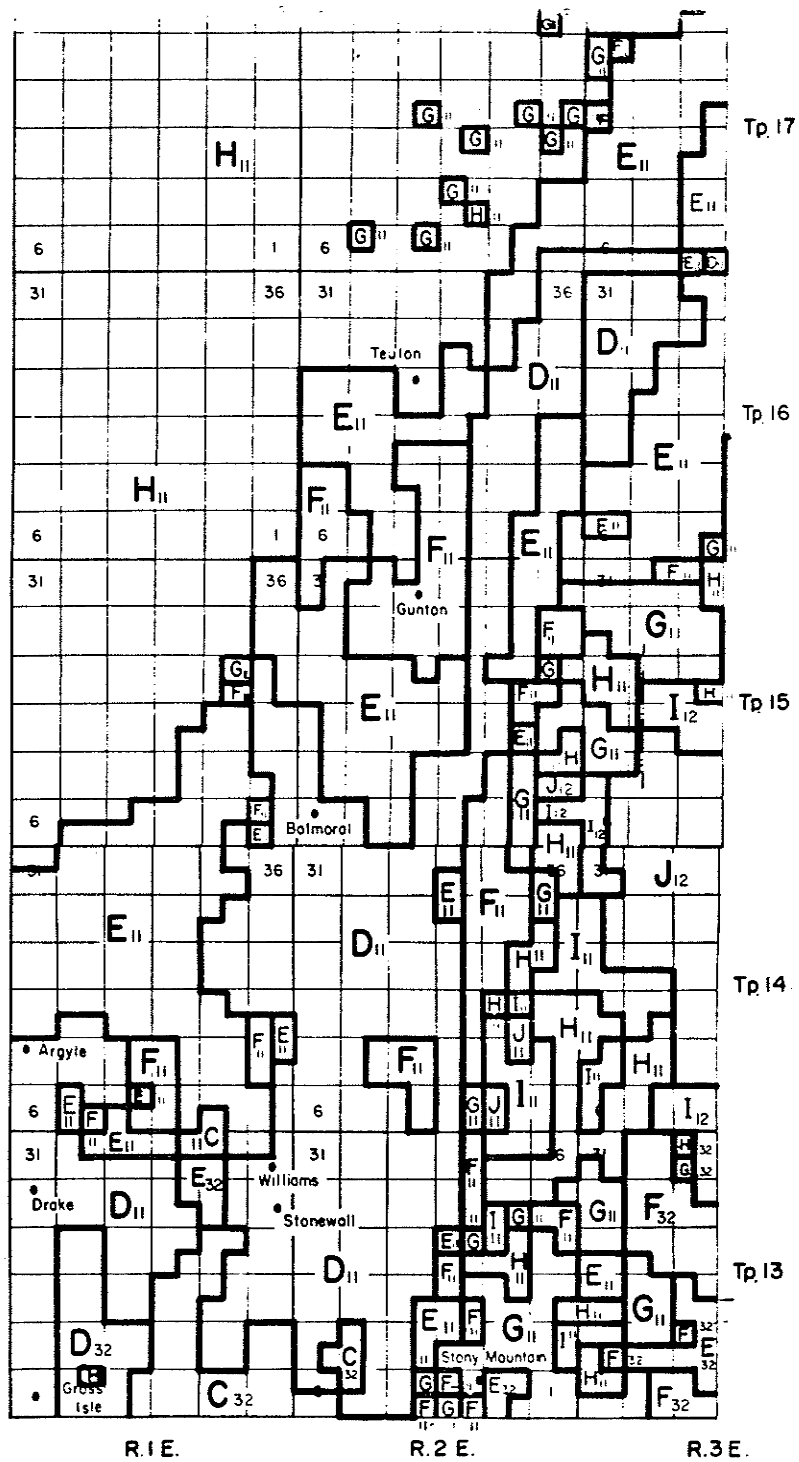

Figure 4.2

Municipality of Rockwood Soil Zone Map

– SOURCE: MCIC

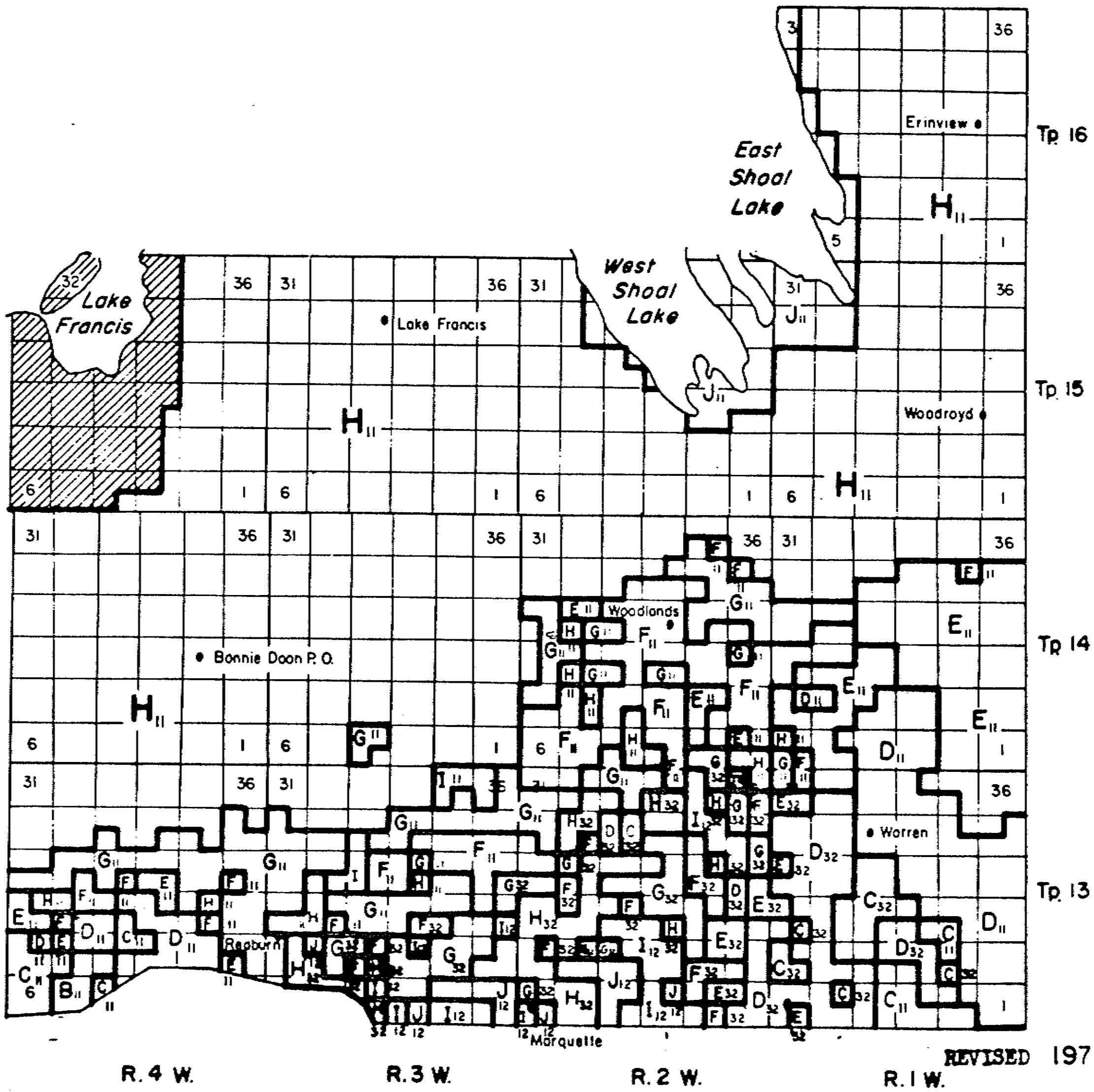

Figure 4.3

Municipality of Woodlands Soil Zone Map

- SOURCE: MCIC

two or more risk areas occurred. However, in some municipalities it was possible to determine visually whether soil zone yield data represented Risk Area 12 or 14 simply by checking the appropriate quarter-section maps. For example, soil zones C_{32} to F_{32} in municipalities of Tache, Ste. Anne, Hanover and Desalaberry soil zones C to F are Risk Area 12 and soil zones G_{14} to J_{14} belong in Risk Area 14 (Figures 4.4, 4.5, 4.6). Similarly, in Portage la Prairie soil zones A - C represent highly fertile Risk Area 11 soils, since these zones do not occur in Risk Area 10 or 12 in this municipality. In short, by checking for mutually exclusive soil zones as between two risk areas, some separation of soil zone yield data was possible. A total of 10 municipalities were excluded according to the above criteria.

The remaining 14 municipalities were grouped in five geographically similar areas:

1. Central Area - Cartier, McDonald, Morris, Rosser.
2. Eastern Area - Desalaberry, Hanover, Ritchot, Tache.
3. South Central - Montcalm, Rhineland, Roland.
4. Southwest - Thompson, Stanley.
5. Northwest - Portage la Prairie.

As a final comment on the MCIC municipality yields, it should be noted that a) well drained and poorly drained

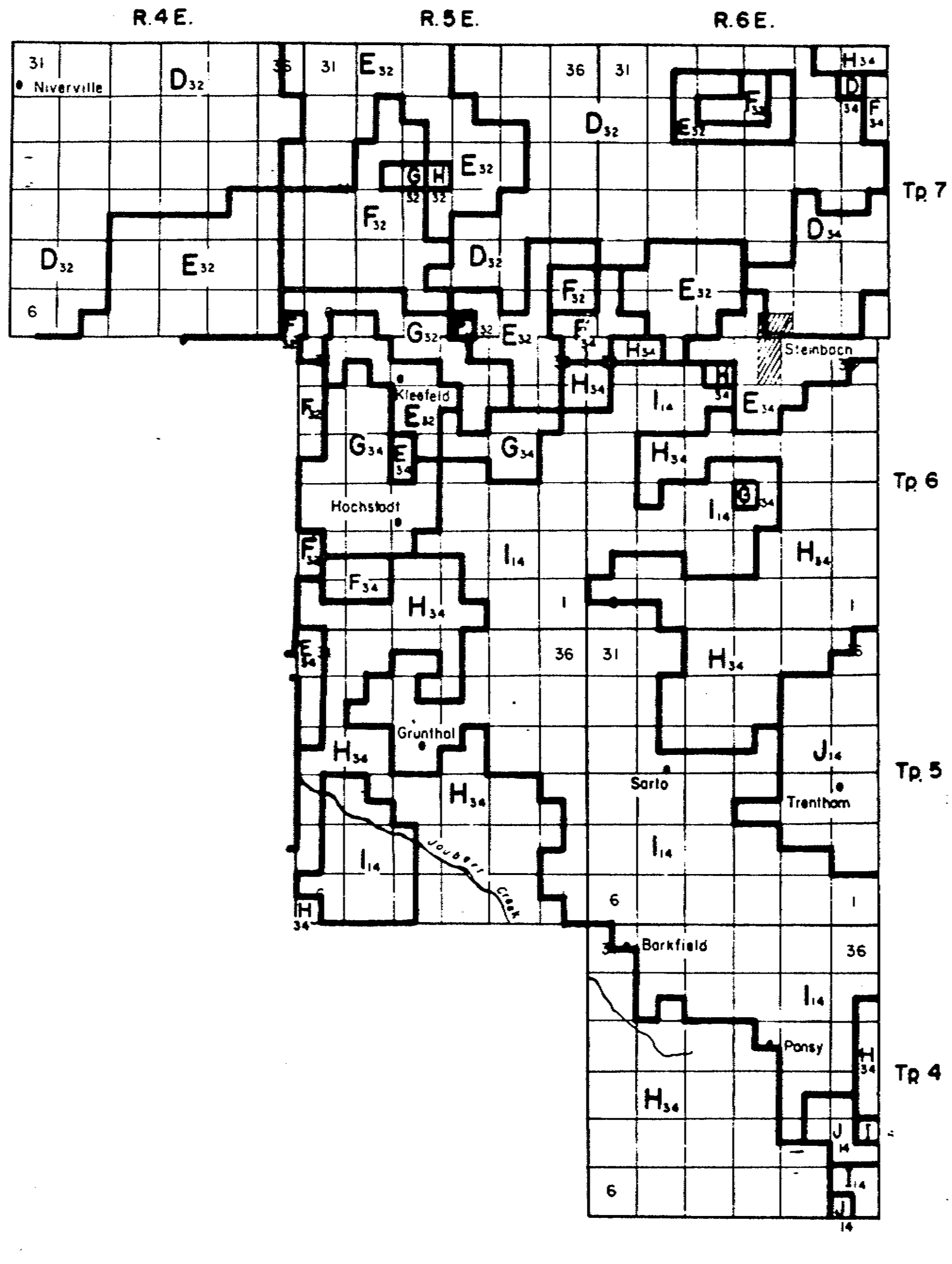

Figure 4.4

Municipality of Hanover Soil Zone Map

- SOURCE: MCIC

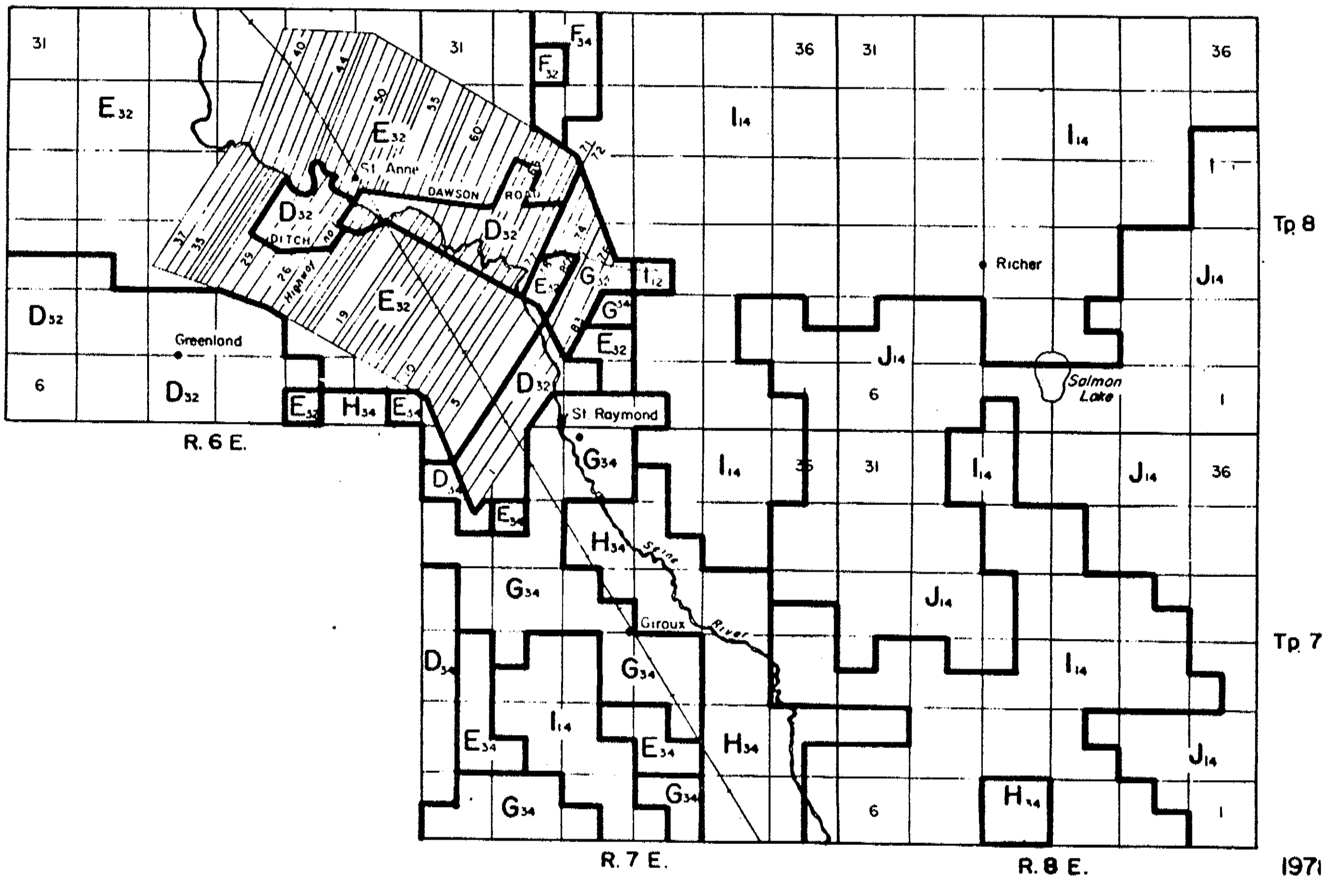

Figure 4.5

Municipality of Ste. Anne Soil Zone Map

- SOURCE: MCIC

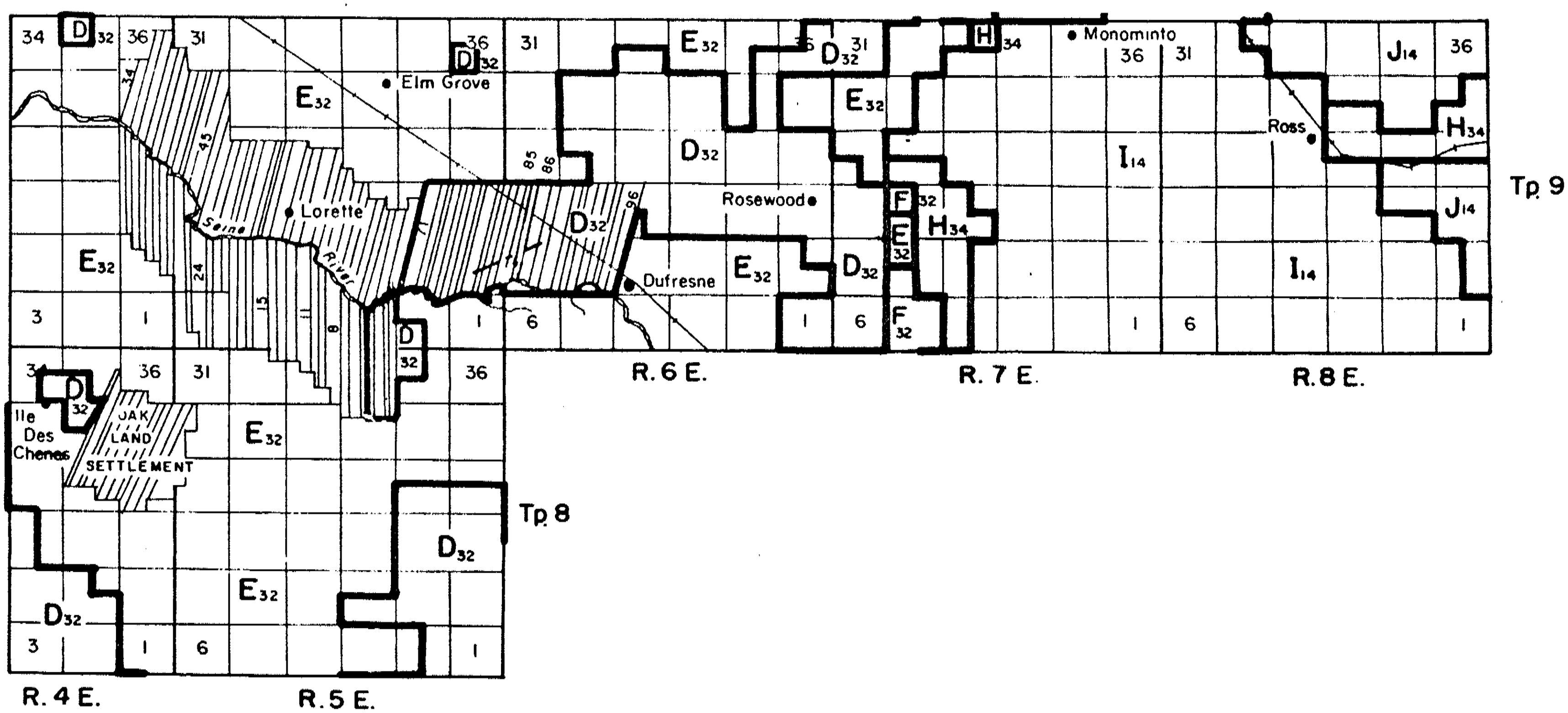

Figure 4.6

Municipality of Tache Soil Zone Map

SOURCE: MCIC

yields are not statistically disaggregated by computer, b) yields for unfertilized stubble and fallow practices are incomplete for many years, so these are eliminated from the straw yield analysis, and c) yield data for fertilized stubble and fallow are available for a 13 to 15 year period.

To solve the problem outlined in a), the MCIC quarter-section municipality maps were used as the basis for assessing what type of drainage conditions the yield data for a particular soil zone represents. For example, an examination of Morris shows poorly drained conditions throughout the municipality, as soil zone symbols are followed by number 32. Using this technique it was possible to determine that the Central and Eastern areas shown above represent mainly poor drained conditions; well drained conditions tend to predominate in the South-central, Southwest and Northwest.

4.3.3.2 Discussion of Municipality Results

Tables 4.6, 4.7, 4.8 and 4.9 summarize results of the straw yield analysis for selected municipalities. These data describe the geographic distribution of straw yields in Crop Districts 3, 4 and 5. Well-defined regional variations of yield patterns emerged. As one would expect, however, there is a high degree of correspondence with regional CLA yields as Risk Area 12 data is the base for

TABLE 4.6

AVERAGE ANNUAL WHEAT, OATS AND BARLEY STRAW YIELDS AND STRAW AVAILABLE (t/ha) IN CENTRAL MUNICIPALITIES[a]

CROP		CARTIER			McDONALD			MORRIS			ROSSER		
		C	D	E	C	D	E	C	D	E	C	D	E
WHEAT[b]	STRAW YIELD	2.4	2.2	2.1	2.3	2.1	2.1	2.4	2.3	2.2	2.6	2.5	2.5
	STRAW AVAILABLE	1.6	1.5	1.4	1.6	1.4	1.4	1.6	1.6	1.5	1.8	1.7	1.7
OATS[c]	STRAW YIELD	2.8	2.5	-	2.6	2.6	2.5	2.9	2.5	2.5	2.5	2.5	2.5
	STRAW AVAILABLE	1.9	1.7	-	1.8	1.8	1.7	2.0	1.7	1.7	1.7	1.7	1.7
BARLEY[c]	STRAW YIELD	-	-	-	1.9	1.8	1.6	2.0	1.9	1.7	1.9	1.8	1.8
	STRAW AVAILABLE	-	-	-	1.3	1.3	1.1	1.4	1.3	1.2	1.3	1.3	1.3

NOTE:
a. Yields on predominantly poorly drained clays
b. Yields for fallow and stubble fertilized practices (1963 - 1977)
c. Yields for stubble fertilized practices (1963 - 1977)

TABLE 4.7

AVERAGE ANNUAL WHEAT, OATS AND BARLEY STRAW YIELDS AND STRAW AVAILABLE (t/ha) IN EASTERN MUNICIPALITIES[a]

CROP		DeSALABERRY			HANOVER			RITCHOT			STE. ANNE/ TACHE		
		C	D	E	C	D	E	C	D	E	C	D	E
WHEAT[b]	STRAW YIELD	2.5	2.3	1.9	-	2.8	2.6	2.1	2.5	2.2	-	2.2	2.2
	STRAW AVAILABLE	1.7	1.6	1.3	-	1.9	1.8	1.4	1.7	1.5	-	1.5	1.5
OATS[c]	STRAW YIELD	2.9	2.8	2.4	-	-	2.4	2.4-	-	2.1	-	2.1	2.0[d]
	STRAW AVAILABLE	2.0	1.9	1.6	-	-	1.6	1.6	-	1.3	-	1.3	1.4
BARLEY[c]	STRAW YIELD	2.0	2.2	1.7	-	2.2	1.9	1.7	2.1	1.6	-	2.1[d]	-
	STRAW AVAILABLE	1.4	1.5	1.2	-	1.5	1.3	1.2	1.4	1.1	-	1.4	-

NOTE:
a. Yields on predominantly poorly drained clays
b. Yields for fallow and stubble fertilized practices (1965 - 1977)
c. Yields for stubble fertilized practices (1965 - 1977)
d. Tache

TABLE 4.8

AVERAGE ANNUAL WHEAT, OATS AND BARLEY STRAW YIELDS AND STRAW AVAILABLE (t/ha) IN SOUTH CENTRAL MUNICIPALITIES[a]

CROP		MONTCALM C	MONTCALM D	MONTCALM E	RHINELAND C	RHINELAND D	RHINELAND E	ROLAND C	ROLAND D	ROLAND E
WHEAT[b]	STRAW YIELD	3.0	2.8	2.6	3.1	3.0	2.8	3.1	2.8	2.7
	AVAILABLE STRAW	2.0	1.9	1.8	1.0	2.0	1.9	2.1	1.9	1.8
OATS[c]	STRAW YIELD	2.8	2.7	2.5	3.0	3.0	3.0	2.9	2.8	2.6
	AVAILABLE STRAW	1.8	1.8	1.7	2.0	2.	2.0	2.0	1.9	1.8
BARLEY[c]	STRAW YIELD	-	2.0	2.1	2.5	2.3	2.0	2.2	2.1	1.8
	AVAILABLE STRAW	-	1.4	1.4	1.7	1.6	1.4	1.5	1.4	1.3

NOTE:
a. Yields on predominantly poorly drained clays
b. Yields for fallow and stubble fertilized practices (1963 - 1977)
c. Yields for stubble fertilized practices (1963 - 1977)
d. Tache

TABLE 4.9

AVERAGE ANNUAL WHEAT, OATS AND BARLEY YIELDS AND STRAW AVAILABLE (t/ha) IN SOUTHWESTERN MUNICIPALITIES AND PORTAGE LA PRAIRIE[a]

CROP		STANLEY			THOMPSON			PORTAGE LA PRAIRIE		
		C	D	E	C	D	E	C	D	E
WHEAT[b]	STRAW YIELD	3.0	3.0	3.0	-	3.1	2.8	3.1	3.1	3.1
	AVAILABLE STRAW	2.0	2.0	2.0	-	2.1	1.9	2.1	2.1	1.1
OATS[c]	STRAW YIELD	3.0	2.7	2.6	-	2.7	2.3	2.9	2.7	2.7
	AVAILABLE STRAW	2.0	1.8	1.8	-	1.8	1.6	2.0	1.8	1.8
BARLEY[c]	STRAW YIELD	2.4	2.3	2.5	-	2.1	1.9	1.6	1.6	1.5
	AVAILABLE STRAW	1.6	1.6	1.7	-	1.3	1.3	1.1	1.1	1.1

NOTE:
a. Yields on predominantly poorly drained clays
b. Yields for fallow and stubble fertilized practices (1963 - 1977)
c. Yields for stubble fertilized practices (1963 - 1977)
d. Tache

both levels of analysis. Minimum and maximum yield data for municipalities may be found in Appendices 4.1 to 4.5.

Wheat

An examination of municipality wheat straw yields indicates that the highest average annual straw yields and thus amounts of straw available are associated with municipalities in the southcentral, southwest and northwest parts of the study area. This area is basically the well drained and medium-textured Emerson - Altona-Portage soil association area which represents about 25 percent of the CLA. Wheat straw yields on fertilized fallow and fertilized stubble range between 2.6 and 3.1 t/ha. The respective range for straw available in these areas is between 1.8 to 2.1 t/ha. The overall straw available factor in this area is 2.0 t/ha, which is the same as the CLA straw availability factor.

Tables 4.6 and 4.7 indicate that wheat straw yields are lower in the central and eastern parts of the study area where poorly drained clays predominate. The range of wheat straw yields for fallow and stubble fertilized practices is from 1.9 to 2.8 t/ha with an average of 2.3 t/ha. The corresponding range for amounts of straw available is 1.4 to 1.9 t/ha with an average of about 1.6 t/ha, which is 0.3 t/ha less than the regional average.

Oats

As with wheat yield patterns, oats straw yields are higher in the southcentral, southwest and northwest parts of the CLA. Average straw yields range between 2.4 and 3.0 t/ha; the average is 2.7 t/ha. Straw available ranges between 1.6 to 2.0 t/ha with an average of 1.8 t/ha.

In poorly drained areas the oats straw yield range declines; the range is from 2.0 to 2.9 t/ha and the average is 2.4 t/ha. The corresponding variation in straw availability is 1.3 to 2.0 t/ha with an average of 1.6 t/ha.

Barley

Municipality barley straw yield patterns in the study area parallel those of wheat and oats. The yield differences between well drained and poorly drained areas are not pronounced as wheat and oats differences between predominantly well drained and poorly drained areas. The barley straw yield range in well drained areas is from 1.5 to 2.5 t/ha and the average is 2.0 t/ha. The corresponding range for straw available is 1.1 to 1.7 t/ha with an average of 1.4 t/ha. The straw yield range in poorly drained areas is 1.6 to 2.2 t/ha with an average of 1.8 t/ha. For straw available the range is 1.1 to 1.5 t/ha; the average is 1.3 t/ha.

4.3.4 Geographic Distribution of Total Straw Available

Table 4.10 shows what portion of total straw available in Crop Districts 3, 4 and 5 could come from each group of municipalities. Although yields are higher in the southern and northwest part of the study area, contributions to total straw available is much less than that available from central and eastern areas, due to smaller wheat, oats and barley acreage. Contributions to total available straw grown in the central and eastern areas combined are 64, 80 and 60 percent respectively.

4.4 Constraints on Straw Availability

4.4.1 Straw Needed as a Soil Mulch

In section 4.3.1 total straw availability is determined by applying average straw availability factors (Table 4.5) for each crop to study area crop acreages. These straw availability averages reflect average annual straw availability estimates under the assumption that all loose combine straw, the difference between standing stubble (which is 33 percent with current agricultural practices) and total straw yield, can be collected following the grain harvest.

This section discusses the impact on straw availability when it is assumed that present harvesting practices may have to be adjusted so that at least 0.9 t/ha of stubble is returned to the land annually to provide

TABLE 4.10

TOTAL AVAILABLE WHEAT, OATS AND BARLEY STRAW
IN SELECTED STUDY AREA MUNICIPALITIES (1976)

Area	Wheat			Oats			Barley		
	Straw Available Factor	Crop Area (000 ha)	Total Available (tonnes 000)	Straw Available Factor	Crop Area (000 ha)	Total Available (tonnes 000)	Straw Available Factor	Crop Area (000 ha)	Total Available (tonnes 000)
Central	1.4	182	255	1.7	75	127	1.0	68	68
Eastern	1.4	204	326	1.5	49	73	1.0	57	57
South Central	1.9	86	163	1.9	9	17	1.2	31	37
Southwest	2.0	40	80	1.7	10	17	1.3	18	23
Northwest	2.1	41	86	1.8	7	13	1.1	25	27
Total	-	553	910	-	150	247	-	199	212

SOURCES a) Statistics Canada. 1976. Census of Agriculture: Manitoba, Cat. No. 92-806. Ottawa.

organic matter. Further this analysis assumes that in the event of large-scale organized grain straw collection, farmers would adjust harvesting practices to assure adequate amounts of organic matter are returned on the land. As noted in 3.2.6.3, it is assumed that 0.9 t/ha of straw returned annually is sufficient to maintain soil fertility in the study area.

Based on an analysis of long-term per unit straw yields it can be seen from Table 4.11 that under certain drainage conditions some crops have average annual straw yields close (1) to or in excess of 2.7 t/ha, the minimum yield above which at least 0.9 t/ha of stubble remain when the combine cutting height is set to have approximately 33 percent as stubble (2). These crops are wheat and oats grown on well drained soils and oats grown on poorly drained soils. Without any adjustment to present harvesting practices, the range of straw available annually from these crops is from 1.4 t/ha to 2.4 t/ha (3). The average annual yields of wheat grown on poorly drained soils and barley grown on both well and poorly drained soils are usually below 2.7 t/ha on the average. Thus the quantities of stubble from these crops tend to be slightly less than 0.9 t/ha by the amounts shown as additional straw needed (3a). The average annual straw deficit for these crops is between 0.1 and 0.4 t/ha.

TABLE 4.11

STRAW AVAILABLE (t/ha) WHEN STRAW
NEEDED IS THE RECOMMENDED 0.9 t/ha IN RISK AREA 12

		Wheat		Oats		Barley	
		WD	PD[a]	WD	PD	WD	PD
(1)	Avg. Straw Yield	2.9	2.1	3.5	2.5	2.1	1.7
(2)	Avg. Stubble left in field (1) x .33	0.9	0.7	1.1	0.8	0.7	0.5
(3)	Straw Available	2.0	1.4	2.4	1.7	1.4	1.2
(3a)	Additional straw needed (0.9 - (2)	0.0	0.2	0.0	0.1	0.2	0.4
(4)	Straw Available when at least 0.9 t/ha of stubble is left	2.0	1.2	2.4	1.6	1.2	0.8

NOTES: a) Average of all soil zones as per Table 4.4

Given the rather small deficits, it seems reasonable to assume that farmers could increase combine cutting heights to provide the additional straw needed thereby reducing available straw. This would reduce the average amount of straw available on a per hectare basis from 1.7 (Table 4.5) to 1.6 (No. 4, Table 4.11) t/ha for wheat and from 1.3 to 1.0 t/ha for barley; oats remains the same at 2.0 t/ha.

Table 4.12 indicates the net effect on total straw availability in the study area. For the years 1973, 1974, 1975 and 1976 straw availability decreases to 1.224, 1.378 and 1.234 million tonnes respectively with an average of about 1.3 million tonnes. As the average in Table 4.5 is 1.4 million tonnes total straw availability is theoretically reduced up to 100,000 tonnes when the availability constraint is applied in the analysis.

4.4.2 Summerfallow

The extent to which summerfallow practices present a constraint to straw availability varies throughout the study area. Table 4.13 shows total area under crop production and summerfallow by municipality in 1976. Percentage of crop area under fallow basically reveals amount of land available for increasing cereal grain production and thus straw production if summerfallow could be eliminated as a practice. The overall average percent under fallow in 1976 for Crop Districts 3, 4 and 5 is about 10 percent.

TABLE 4.12

TOTAL AVAILABLE WHEAT, OATS AND BARLEY STRAW
WHEN STRAW NEEDED IS 0.9 t/ha IN CROP DISTRICTS 3, 4 AND 5 (1973-76)

Crop	Year	ha[a] (000)	Straw Available (t/ha) Factors			Total Straw Available (000 Tonnes)	Average
			WD	PD	AVG.		
Wheat	1973	390	2.0	1.2	1.6	624	768
	1974	546	2.0	1.2	1.6	874	
	1975	451	2.0	1.2	1.6	722	
	1976	532	2.0	1.2	1.6	851	
Oats	1973	164	2.4	1.6	2.0	328	330
	1974	145	2.4	1.6	2.0	290	
	1975	165	2.4	1.6	2.0	330	
	1976	186	2.4	1.6	2.0	372	
Barley	1973	272	1.2	0.8	1.0	272	212
	1974	214	1.2	0.8	1.0	214	
	1975	182	1.2	0.8	1.0	182	
	1976	180	1.2	0.8	1.0	180	

TABLE 4.13

PERCENTAGE SUMMERFALLOW IN CROP DISTRICTS 3, 4 AND 5 (1976)[a]

Area/ Municipality	Area in Crops (ha)	Area in Summerfallow	% Summerfallow
Central Area			
Cartier	45,270	5,130	11.3
McDonald	88,828	6,760	7.6
Morris	88,758	5,374	6.0
Rosser	31,716	4,899	15.4
Area Average			10.0
Eastern Area			
Desalaberry	41,798	2,390	5.7
Hanover	35,421	3,135	8.8
Ritchot	27,577	2,705	9.8
Ste. Anne	16,338	994	6.0
Tache	30,035	3,680	12.2
Area Average			8.5
South Central			
Montcalm	46,929	2,435	5.1
Rhineland	80,015	5,513	6.8
Roland	37,634	1,946	5.1
Area Average			5.6
Southwest			
Thompson	34,077	1,923	2.8
Stanley	68,571	3,230	9.4
Area Average			6.1
Northwest			
Portage la Prairie	105,112	19,324	18.3

SOURCE: [a]Statistics Canada. 1976. Census of Agriculture: Manitoba. Cat. No. 96-807.

CHAPTER 5

ENERGY POTENTIAL OF STRAW IN THE STUDY AREA

5.1 Introduction

The preceding straw inventory indicates that wheat, oats and barley straw are available in large quantities in the Winnipeg - central region. This analysis suggests a preliminary examination to explore the feasibility of extracting energy from this renewable resource to meet specific end-uses. Determining feasibility in this situation, however, is complicated by the fact that there are several technologies in various stages of development which have the potential to produce energy from cellulosic sources such as straw, as is shown in Table 5.1. Further, many uses are possible for biomass energy. For agricultural residues in particular, the scale of utilization ranges from "on-site" (e.g. farm) to community and industrial scale uses.

Although straw is seemingly available in large quantities in the study area, the viability of energy production from straw or any other biomass source depends ultimately on a number of interrelated factors. Of considerable importance among these factors are three in particular: the cost of the straw delivered to a central site (see Chapter 6), the quantity and quality of energy produced and energy efficiency of the technology.

Notwithstanding these constraints, however, biomass

TABLE 5.1

BIOCONVERSION ROUTES AND POTENTIAL END-USES FOR ENERGY PRODUCED FROM BIOMASS SOURCES

BIOMASS FEEDSTOCKS	POSSIBLE CONVERSION PROCESSES	ENERGY PRODUCTS	POTENTIAL END-USES
Wood and and Wood Residues	Gasification/ Methanol Synthesis Hydrolysis/Fermentation	MBG MeOH EtOH	Transportation Fuels, Turbines, Chemicals
	Liquefaction Gasification Direct Combustion	Fuel Oils LBG/MBG Heat/Steam	Process Heat Space and Water Heating
Agricultural Residues	Hydrolysis/Fermentation Gasification Direct Combustion	EtOH LBG Heat	Transportation Fuel Space, Water and Process Heat
Surplus Food Material - distressed grain - food processing waste	Fermentation/Distillation	EtOH	Transportation
Animal Manures	Anaerobic Digestion	Methane	Space Heating, Process Heat, Turbines

energy in general has a number of characteristics which favour its development and deployment as an alternative energy source. These are outlined below:

1. Biomass resources are renewable; although these sources tend to be dispersed large quantities are available.

2. Bioconversion technologies are in various stages of development and number of systems are proven and commercially available.

3. A ready market exists for certian biomass fuels such as ethanol.

4. Certain biomass technologies can be scaled to community, regional and even individual needs; others require large installations to capitalize on economies of scale.

5. Biomass resources have minimal pollution and disposal problems, due to their negligible sulphur and ash contents (Wan 1978). Biomass is a relatively clean source of fuels. This is a significant advantage over coal as an alternative to petroleum based fuels.

Based on the straw inventory data developed in the previous chapter, this chapter provides a "first-cut" analysis of the energy potential of available straw feedstocks in the study area. Energy potential of biomass resources depends to a large extent on assumptions made about the state-of-the-art of technology.

It should be recognized, however, that at this point in time many of the processes are under development and rapidly evolving. Assumptions about the energy production potential of selected processes which are used in this analysis are based on information and claims made in available current literature, much of which of course is rapidly subject to change. A second problem in this area is the dearth of solid, reliable data on these processes.

5.2 The Chemical Composition of Straw

Straw is a lignocellulosic substance which simply means cellulose and lignin are the main components. In addition, straw contains a number of other components as can be seen in Table 5.2. Although the various types of straw vary slightly in their composition, most straws contain about 40 to 50 percent cellulose, 20 to 25 percent hemicellulose and 14 to 18 percent lignin.

The following generalizations can also be made about straw: first, agricultural residues such as straw are particularly low in lignin and high in hemicellulose (Stone and Associates, 1980). Second, the lignin content of straw is generally much lower than wood, and the ash content is much higher (SRI International, 1980).

The relative amounts of straw's main constituents are of greater importance if straw is hydrolyzed than

TABLE 5.2

THE CHEMICAL COMPOSITION OF STRAW
(% DRY WEIGHT)

CHEMICAL COMPONENT	SRI INTERNATIONAL 1980[a]	ANDERSON 1979[b]	BIOMASS ENERGY INSTITUTE 1978[c]	RYKENS 1977[d]
Cellulose	41.5	50.0	50.0	36.0
Hemicellulose				
- Pentosans	20.0	25.0	22.0	25.0
- Hexosans	5.0			
Extractives				
- Fats				
- Resins	5.3	5.0	6.0	8.0
- Proteins				
- Other				6.0
Lignin	13.7	13.0	13.0	18.0
Ash	8.1	7.0	8.0	7.0
Total	100.0	100.0	100.0	100.0

a) SRI International. 1980. Biomass business opportunities program. Status Report No. 2, Part C. Project No. 1334. Menlo Park: California.
b) A. W. Anderson. 1979. Increasing the value of straw by fermentation. Corvallis: Oregon. Department of Microbiology. NSF/RA-790489.
c) Biomass Energy Institute. 1978. Straw files. Winnipeg, Manitoba.
d) B. A. Rykens. 1977. Some possibilities for multiple uses of straw. Report on Straw Utilisation Conference. Feb. 24-25, 1977. Oxford, England ADAS, MAFF.

gasified. Gasification results in mass destruction of lignocellulose materials and thus the chemical makeup is not a critical factor. The opposite is true if straw is hydrolyzed to sugars by either acid or enzyme hydrolysis as the various components of straw have different levels of resistance to acids and enzymes.

One of the chief difficulties with cellulosic substances is that it has a more complex chemical composition than sugars and starches which belong to a general class of compounds called carbohydrates ($C_2(H_2O)_n$). Sugar substances are glucose molecules or isomers[1] and fall into two categories: simple sugars or monosaccharides such as pentose ($C_5H_{10}O_5$), commonly know as five-carbon sugar, and hexoses ($C_6H_{12}O_6$), six-carbon sugars. A second class of sugars are dissaccharides ($C_{12}H_{22}O_{11}$) or complex sugars which are made up of two or more glucose units joined by glycosidic linkages.[2]

The glucose units of sugars and starches are uniformly arranged and linked in a manner which facilitates hydrolysis. Dissaccharides are easily hydrolyzed by either acid or enzyme hydrolysis back to pentose sugars such as fructose and glucose. The linkage also permits starch to be easily hydrolyzed.

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[1]Isomer - Chemical substances having the same elementary percentage composition and molecular weight but differing in structure.

[2]A sugar molecule link.

In contrast, cellulose is a high molecular weight polysaccharide made up of three chemically bonded components, two of which are carbohydrate compounds (cellulose and hemicellulose)[1] and one is a non-carbohydrate (lignin). These components are interlocked resulting in stiffer lignified fibres which are suitable as a structural material. Therefore cellulose is very difficult to hydrolyze. The reasons have been outlined in several articles (Ladisch et al, 1978; Hayes and Timbers, 1980, and Stone and Associates, 1980). The following paragraph is taken from the latter report:

> Cellulose ... has glucose chains which have been arranged in a manner which permits polymer chains to pack together in crystallites ...
>
> In addition to providing a basic polysaccharide structure with inherent strength and insolubility, the cellulose chains are laid down in the cell wall in layers and then impregnated with a three-dimensional, non-swelling phenolic polymer (lignin). Thus, there are two lines of defence against microbial attack - lignin and crystallinity - both of which must be overcome if cellulose is to be converted to ethanol.

In effect, cellulose - the glucose bearing substance - is surrounded by a resistant lignin seal; this factor and its crystalline nature makes hydrolysis of cellulose exceedingly difficult.

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[1]Hemicellulose can also be hydrolyzed to yield pentoses which can be fermented to ethanol; the technology is presently laboratory scale.

5.3 Ethanol from Cellulose

5.3.1 The Maximum Theoretical Yield of Ethanol from Straw

The previous discussion showed that ethanol can be produced from starch, sugar or cellulose substances. The maximum theoretical yield obtainable when starch is converted to glucose is 111 percent (Sydio, Inc. 1980; Stone and Associates 1980). Once glucose is obtained it can be fermented to ethanol by yeast and the maximum theoretical yield is 51 percent (Hayes and Timbers, 1980). This can be achieved with current technology and yeast micro-organisms such as Saccharomyces cerevisiae (Stone and Associates, 1980).

The calculations on Table 5.3 indicate the maximum theoretical quantity which could be obtained from a tonne of straw. Assuming 1 kilogram ethanol is equivalent to 1.26 litres of ethanol (Stone and Associates, 1980), then 1 tonne of straw contains a theoretical maximum of 293 litres of ethanol.

The actual yields which can be obtained from straw however, will depend on the type of pretreatment process used to separate the main chemical components of straw and the type of hydrolysis process (i.e., acid or enzymatic) used to convert cellulose to glucose. The fermentation/distillation stage, the last part of the cellulose to ethanol cycle, is a mature and well esta-

TABLE 5.3

The Maximum Theoretical Yield of Ethanol From Straw

Feedstock (t)	Conversion Factor(%)	Cellulose Content (kg)	Conversion Factor(%)	Glucose Content (kg)	Conversion Factor(%)	Ethanol Content (kg)
1 t Straw	41.5	410.5	111	456	51	233

Notes: The above calculations are based on the following assumptions:

1. The cellulose content of straw is 41.5 per cent (see Table 5.1); and
2. The maximum theoretical conversion yield of cellulose to glucose and glucose to ethanol are 111 and 51 per cent respectively.

blished technology. The technical viability of producing ethanol from cellulose does not depend on dramatic improvements in this area. The following sections discuss current developments in the area of cellulose pretreatment and hydrolysis technologies based on recent literature. Each section includes a "first-cut" analysis of the maximum theoretical energy yield (ethanol) obtainable with these processes when straw is used as a feedstock.

5.3.2 Acid Hydrolysis

Although extreme low and high wood cellulose to glucose yields have been reported for some acid hydrolysis processes, it appears, based on research conducted by John Stone and Associates (1980), that the state-of-the-art at present is in the range of 50 to 60 percent. For the purpose of this analysis 50 percent is used. The maximum potential yield of glucose from wood is therefore 25 - 30 percent as the cellulose content of wood is about 50 percent.

Because straw has a lower cellulose content than wood it has a correspondingly lower energy value in terms of its capability to yield ethanol. The calculations in Table 5.4 show the maximum theoretical yield of ethanol obtainable if the total surplus straw available in the study area is converted to ethanol via acid hydrolysis (148,155 tonnes). Since 1 tonne of ethanol contains 1260 litres of ethanol, the potential ethanol yield of available

TABLE 5.4

Maximum Theoretical Ethanol Yield From Available Straw Via Acid Hydrolysis

Feedstock Available (M t)	Conversion Factor(%)	Cellulose Content (t)	Conversion Factor(%)	Glucose Content (t)	Conversion Factor(%)	Ethanol Content (t)
14.	41.5	581,000	50	290,500	51	148,155

Notes: 1. The assumed rate of cellulose to glucose conversion with acid hydrolysis is 50 per cent.

straw (1.4 million tonnes) in the study area is approximately 186 million litres (148,155 x 1260 = 186,675,300 litres).

5.3.3 Enzymatic Hydrolysis

In recent years research on enzymatic hydrolysis processes has increased considerably in North America although the process has never been used commercially. The promise of higher sugar yields from both cellulose and hemicellulose and recovery of potentially valuable byproducts (e.g. lignin) are two primary reasons why this process is being actively considered by numerous research organizations.

A major difference between enzymatic hydrolysis and acid hydrolysis is the use of pretreatment of the cellulose substance to make the cellulose more accessible to enzymes such as Trichoderma reesei fungi. The chemical composition of cellulose and the selective nature of enzymes as noted in 5.2 and by numerous researchers (Wayman et al, 1979; Tsao 1978, 1979; Stone and Associates, 1980) are the major factors necessitating pretreatment of the cellulose. The various technological advances which have been reported in cellulose pretreatment are reviewed in Table 5.5.

Based on the findings presented by Stone and Associates (1980); Tsao, 1978; Wilke et al, 1978; Ladisch et al, 1978, 1979, it appears that the state-of-the-art

TABLE 5.5

MAJOR TYPES OF PROMISING CELLULOSE PRETREATMENT TECHNOLOGIES FOR ENZYMATIC HYDROLYSIS

TYPE OF PRETREATMENT	STATE OF DEVELOPMENT	ORGANIZATION	COMMENTS	LITERATURE SOURCES
Autohydrolysis (Steam Pretreatment)	-	University of Toronto Toronto, Dept. of Chemical Engineering and Applied Chemistry	- Batch process	Wayman et al (1979)
Autohydrolysis (High temperature steaming)	Commercial	Stake Technology, Ottawa	- Existing plants convert wood (e.g., poplar, cottonwood) and sugar bagasse to to animal feed - Continuous process	Stake Technology Ltd. Ontario Ministry of Energy (1980) Stone and Associates (1980)
Autohydrolysis (Steam Explosion)	Pilot plant	Iotech Corporation, Ottawa	-Not proven commercially	Stone and Associates (1980)
Chemical Pretreatment	Bench Scale	Purdue University, Laboratory of Renewable Resources Engineering	- Chemical cellulose solvent used is Cadoxen (Cadmium Oxide-Ethylene Diamine)	Ladisch et al (1978) Ladisch et al (1979) Tsao (1978) Tsao (1979)
	Bench Scale	University of Pennsylvania	- Aqueous Butanol extraction of wood chips	Pye (1978) Pye and Humphrey (1979)
	Bench Scale	University of California	- Dilute acid pretreatment	Wilke et al (1978)

in terms of the rate of glucose yields from cellulose via enzymatic hydrolysis is 80 to 90 percent of theoretical. The calculations in Table 5.6 show the theoretical ethanol content of available straw in the study area when converted via enzymatic hydrolysis processes.

If all of the available straw in the study area is converted to ethanol by state-of-the-art enzymatic hydrolysis technology, approximately 298 million litres of ethanol could be produced theoretically (237,000 x 1260 = 298,620,000 litres).

5.3.4 Petroleum Extender Potential of Straw Derived Ethanol in Manitoba

In the year of 1980, the motor gasoline consumption in Manitoba was 55800 TJ or about 1531.31 million litres (Statistics Canada, 1980). The quantities of ethanol theoretically producible from available straw in the study area via acid hydrolysis (186 million litres) and enzyme hydrolysis (298 million litres) respectively represent 12.1 percent and 19.4 percent of total motor gasoline consumption in Manitoba in 1980. Straw based ethanol could play a significant role as a petroleum extender in Manitoba if the production economics become favourable.

TABLE 5.6

Maximum Theoretical Ethanol Yield From Available Straw Via Enzyme Hydrolysis

Feedstock Available (M t)	Conversion Factor(%)	Cellulose Content (t)	Conversion Factor(%)	Glucose Content (t)	Conversion Factor(%)	Ethanol Content (t)
14.	41.5	581,000	80	465,000	51	237,000

<u>Notes</u>: 1. The assumed rate of cellulose to glucose conversion with enzyme hydrolysis is 80 per cent.

5.3.5 Production of Ethanol from Hemicellulose

In addition to cellulose, straw also contains another major class of polysaccharides know as hemicellulose. Straw has about 25 percent hemicellulose content. Hemicelluloses are basically 5-carbon sugars (pentosans) and 6-carbon sugars (hexosans) which can also be hydrolyzed to produce ethanol. The technology for doing this has not yet been perfected but research is proceeding in several places, for example, University of Purdue (Ladisch et al, 1979; Flickinger et al, 1980) and at the National Research Council of Canada, Division of Biological Sciences by H. Schneider (Energy Report Canada, 1981a). In Canada, Weston Research and the University of Waterloo are also active in this area. A major benefit of converting hemicelluloses to ethanol is that by increasing total ethanol yields process economics could be improved.

5.3.6 Economics of Ethanol from Cellulose

Because a pilot plant has not been built, existing economic analyses of ethanol from cellulose processes are not very accurate or reliable and usually out of date by the time they are published (Stone, April 1981). One of the more germaine comments on this subject may be found in John Stone and Associates' (1980) report:

> Perhaps the most useful conclusion to be drawn is that the cost of producing fuel ethanol from cellulosic feedstocks is uncertain, but appears to be not greatly different from the cost using starch. When the much lower cost of cellulosic

> feedstocks is taken into account and is combined with the rapid improvements being made in extraction technology, the prognosis for producing ethanol, at a cost which will be competitive with projected prices for oil, seems reasonably good. This is particularly true if the pentose sugars can be converted to ethanol.

5.4 The Gasification of Straw

5.4.1 Introduction

Gasification technologies have been used since the middle 18th century by the coal industry. In the 20th century this technology which originally used wood as a feedstock is being resurrected and adapted to burn biomass feedstocks once again.

Gasification and pyrolysis are virtually synonymous terms which refer to controlled thermal decomposition of carbonaceous substances in a reactor in which air or oxygen is driven to maintain combustion. The major difference is that gasification operates at temperatures in excess of 600°C and usually with the addition of air or oxygen into the reactor. The main product is a low Btu (6 MJ/m^3 - 7.5 MJ/m^3) non-condensible gas commonly known as "producer-gas". Pyrolysis on the other hand, operates below 600°C without the addition of air or oxygen and the main products are an "oil-like" liquid, char, a solid and a small amount of gas and other liquids.

This discussion concentrates on gasification technology. It should be recognized that there are at least four major types of gasifiers (Overend, 1977): updraught, downdraught, crossdraught which are usually of the fixed bed design and fluidized bed which is by definition an updraught gasifier (Graham, 1979). Table 5.7 presents an overview of major developments in wood gasification technology.

5.4.2 General Operating Characteristics of Gasifiers

The main component of gasification system is a reactor vessel. Figure 5.1 illustrates schematically a vertical shaft type gasifier and its operating characteristics. Feedstocks are placed in a hopper at the top and enter the reactor chamber through an air lock feeder. Feedstocks may be shredded previously but this is not essential. Then feedstock descends through three zones and decomposes sequentially. In the heating zone any feedstock moisture is evaporated by intense heat generated in the pyrolysis and oxidation zones. This occurs at temperatures of 100 to 800^{o}C. In the pyrolysis zone in temperatures between 200 to 500^{o}C feedstock is pyrolized or thermally decomposed. Between 150 and 270^{o}C hemicellulose component is decomposed completely to produce char, CO, CO_2 and water vapour, while cellulose decomposition is initiated (Horsfield et al 1977). From 270 to 380^{o}C decomposition of cellulose and some of the lignin occurs to produce liquid distillates, hydrocarbon gases and more tars. From 380 to 470^{o}C lignin decomposes to light and

TABLE 5.7

MAJOR TYPES OF WOOD GASIFICATION TECHNOLOGIES
UNDER DEVELOPMENT IN NORTH AMERICA AND EUROPE

GASIFIER TYPE/ MANUFACTURER	STAGE OF DEVELOPMENT	FEEDSTOCK MAX. MOISTURE CONTENT %	FEEDSTOCK MAX. PARTICLE SIZE (in)	ENERGY PRODUCT	PLANTS OPERATING IN CANADA	TOTAL INSTALLED COST $\$10^3$	CAPACITY TONS PER HOUR	ENERGY OUTPUT RATING MMBtu/hr	THERMAL EFFICIENCY	COMMENTS
1. Fluid-Bed (Omnifuel)	First Commercial plant in operation	55	2	Low Btu Gas	Hearst, Ontario	830	6.5	80	75	Sand Bed
2. Fluid-Bed (B.C. Re-search)	Prototype	55	3	Low Btu Gas	Sask. Power Corp. Hudson Bay, Sask.	300	3.5	4-6	-	Charcoal and ash bed
3. Fixed-Bed (Westwood Polyglas)	Prototype	50	8	Low Btu Gas	Ainsworth Lumber Mill Clinton, B.C.	1000		20	50	Max. continuous was 10 hours; Low efficiency.
4. Down-Draft (Imbert)	Number of commercial units in operation	20	5	Low Btu Gas	Canning, N.S. (Straw is feed-stock)	78	-	5	55	Proven technology; small mobile units available
5. Down-Draft (Duvant)	Commercial	20	5	Low Btu Gas	-	84	-	2	75	Proven technology; small mobile units available.
6. Up-Draft (Mellenger-Gasodyne)	Commercial	50	3	Low Btu Gas	Vancouver Island	-	-	8-12	50 (or less)	Based on Crossley Bros. design.

Sources: 1. Levelton and Assoc. 1978. An evaluation of wood waste energy conversion systems. Prepared for the B.C. Wood Waste Energy Coordinating Committee

2. Proceedings of Energy Seminar. Timmins, January 17, 1979. Sponsored by Eastern Forest Products Laboratory and Ministry of Energy.

3. Omnifuels Company Literature.

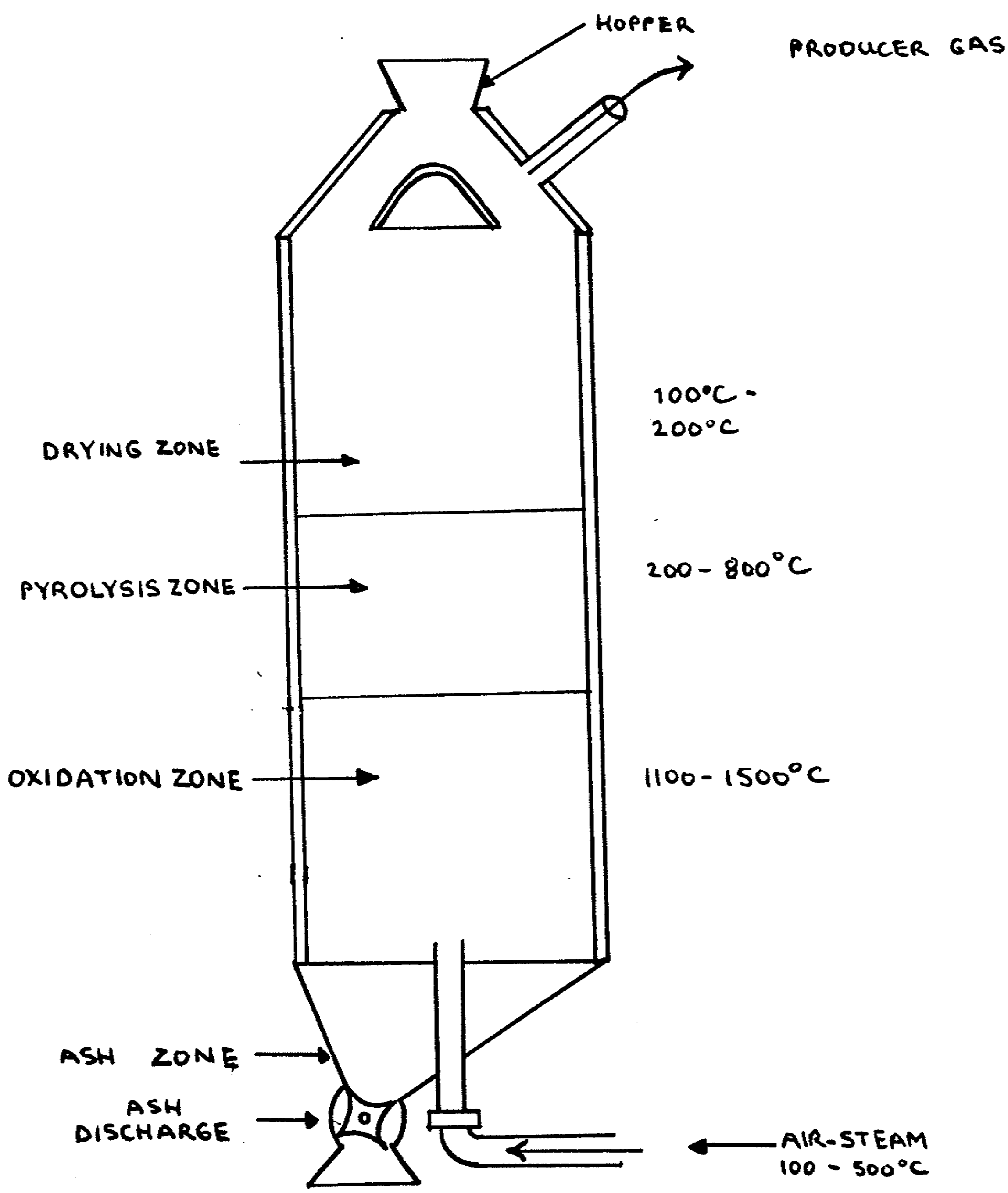

Figure 5.1

SCHEMATIC OF A GASIFIER REACTOR

heavy tars, and hydrocarbon gases. Hydrogen appears between 700 to 900°C.

Conversion of biomass feedstocks via gasification to a hot gas containing CO_2, N_2, CO, H_2 and CH_4 can occur at an efficiency rate of up to 85 percent (Baillie and Carns 1976; Horsfield and Williams 1976b). Other gaseous products include hydrocarbons, water vapours, aromatics and ash (Graham 1979). Precise proportion of above constituents depends on type of feedstock and type of gasifier. Upgrading of raw gas to a cold, clean gas with a cooler and scrubber decreases energy efficiency of the conversion process to about 65 percent (Miles 1979; Overend 1977).

Usefulness of gas depends to a large extent on gas composition and its heat value. Factors affecting type of gas produced include feedstock and gasifier type. Generally, gas produced from biomass has low to medium heat values. Low Btu gas (LBG) from biomass with heat values from about 4.8 MJ/m^3 to 7.4 MJ/m^3 (130 - 200 Btu/SCF) has limited application as it is not suitable for synthesis gas production (Ontario 1976) and its energy density is too low to economically permit upgrading to pipeline quality gas (Walkup _et al_ 1978). LBG does have promise in on-site applications in which gas quality is not an important consideration and its heat content can be utilized directly (e.g., industrial and utility gas combustion, electricity generation, on-farm users).

On the other hand, medium Btu gas (MBG) has considerably more utility. Heat values for MBG are about 9.3 MJ/m^3 to 18.6 MJ/m^3 (250 - 500 Btu/SCF). Because of its higher energy value, and the fact that MBG has a higher CO_2 and lower N_2 content than LBG (Overend 1977; Ontario 1976), it is more suitable for synthesis gas production.[1] This is a crucial distinction as methanol and other chemicals can be produced from synthesis gas.

5.4.3 Biomass Gasification: Developments and Applications

Gas producer technology advanced steadily from the middle of the nineteenth century to about 1950 when availability of "cheap" fossil fuels curtailed further development of gasifier technology. Considerable attention was given to development of stationary producers which could utilize wood and crop residues in countries where oil and gas were scarce. Development of mobile gas producers for cars, trucks and buses advanced rapidly during the 1940's as a result of oil shortages brought on by World War II. Feedstocks included whatever was locally available - coal and coke, wood, all kinds of vegetative material, straw, charcoal, sawdust, etc. A very thorough review of the history of gasifier development and its utilization in Europe and elsewhere and literature on the subject may

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[1] Production of synthesis gas from raw gas involves gas purification and reforming to obtain the proper proportions of H_2 and CO.

be found in Horsfield and Williams (1976a, b) and Overend (1977). It is interesting to note that the National Research Council of Canada was very interested in portable gas producer technology in the 1940's. As a result, extensive tests were carried out on available European models (Allcut and Patten 1943).

More recently, interest in the potential of small-scale stationary gasifier technology utilizing local agricultural or wood biomass is increasing. Its potential for MSW is also being investigated (Hammond et al 1972). Horsfield et al (1977) have been investigating the utilization of an experimental down-draught gasifier using rice straw as feedstock. They conclude that this design is probably best suited to agricultural residues as it eliminates tar from gases and thus provides a cleaner gas. Beck (1978) reports that oak sawdust fed to a counter-current fluidized bed gasifier supplied with air and steam produced a gas having a heat content of 9.3 MJ/m^3. Corn stover as a feedstock was also investigated. This research is in the pilot plant stage.

5.4.3.1 On-Farm Utilization of Straw as an Energy Source

When the farmer has the dual problem of rising energy costs and excess surplus straw which cannot be burned, the utilization of straw as an energy source becomes increasingly attractive. This section discusses an on-farm straw burning unit originally developed in Germany and installed on a farm in Canning, Nova Scotia as an interesting practical example of using straw as an alternative energy source.

Description of the System

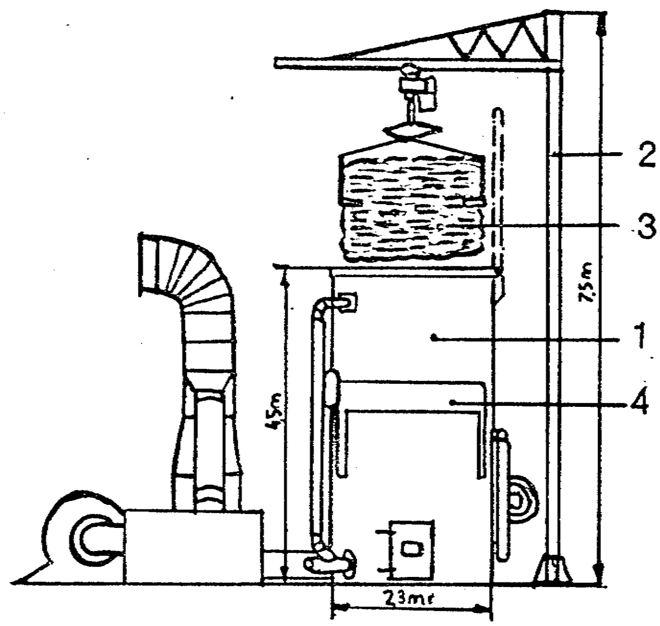
The straw is collected by a round baler which makes bales weighing 300 to 400 kilograms. Bales are stacked at the field's edge and moved to a storage building near the gasifier as needed.

The gasifier consists of three components as shown in Figure 5.2 (ADI, 1980; Peill, 1980):

1. an overhead rail hoist system for feeding 2 meter diameter bales to the burner,
2. a burner with primary and secondary combustion chambers, and a gas to air heat exchanger which can feed the hot gas either to a grain dryer or to the space heat system. The burner is fed by a primary air fan; and
3. a gas to water heat exchanger connected to a 60,000 litres hot water storage tank.

Characteristics of Straw Feedstock

Laboratory tests on wheat straw bales collected on the Lyndhurst Farm revealed that bale weights are usually 360 to 380 kilograms and have a moisture content of between 12 and 17 percent on a wet basis (ADI, 1980).



Description:
1 = Combustion Plant
(Producer of energy)
2 = Loading crane
3 = Big bale
4 = Lock

Figure 5.2

SCHEMATIC OF ROUND-BALE GASIFIER

SOURCE: Biomass Combustion Ltd. Canning, Nova Scotia

Thermal Output

Three hot runs were performed and the maximum (averaged) gross output for a complete test run was 5.16 x 10^6 kJ/hr (4.9 x 10^6 Btu/hr).

Thermal Efficiency

Due to air infiltration at the burner and losses due to absence of insulation, thermal recovery at the heat exchanger was 20 percent of the gross output. Theoretically, 55 percent efficiency is possible if the system is optimized by reducing air infiltration and heat losses.

Preliminary Economics

In 1978 and 1979 a total of about 3900 tonnes of grain and corn were dried and the 250 sow barn heated as well with the burner using approximately 400 tonnes of straw (Peill, 1979).

In 1979 straw procurement costs were about $23.00 per tonne. A preliminary economic evaluation indicates that straw costs $1.62/GJ when propane costs about $5.88/GJ. Thus the saving is in the order of about $4.00/GJ for a tonne of straw (Peill, 1980).

5.5 Constraints on Utilization of Biomass Fuels

As can be seen from Table 5.8, potential end-uses for biomass exist in all demand sectors. Biomass fuels are potentially compatible with a wide range of sta-

TABLE 5.8

POTENTIAL APPLICATIONS FOR BIOMASS FUELS
BY DEMAND SECTOR AND ENERGY TYPE

DEMAND SECTOR	ENERGY TYPE	APPLICATIONS	BIOMASS FUEL
Residential/ Commercial	Low-temp. thermal energy	Space and water heating	LBG, MeOH
	Electricity	Peak power demands for small communities	
Industrial	Process heat and steam	Fuel supply for retrofit utility boilers and turbines[a]	MBG, HBG, MeHO, oil
		Petro-chemical feedstocks	MBG, HBG, MeOH, EtOH
		Methanol feedstocks	MBG, HBG
Agriculture	Low temp. thermal energy	Space and water heating for farms	LBG
	Process-heat	Crop drying	LBG
Utilities	Steam	Electricity generation Fuel cells[a]	LBG, MBG, HBG, MeOH
Transportation	Liquid fuels	Internal combustion engines Diesel engines	EtOH, MeOH, oil

SOURCE: a) Schooley, F. et al. 1978. Mission analysis for the federal fuels for biomass program. Proceedings: Second Annual Symposium on Fuels from Biomass; June 20-22, 1978. Troy, New York.

tionary and mobile end-uses. This section concentrates on the utilization of alcohol fuels.

The extent to which alcohol fuels can widely displace conventional fuels in any given end-use depends largely on the number of technical, economic, political and social obstacles which must be overcome. Specific end-uses with potential for utilization of alcohol fuels in the near term (5 - 10 years) in Canada include internal combustion engines and gas turbines. Longer term applications include use of alcohol fuels in diesel engines and industrial boilers (Osler 1977). Diesel applications would require engine and fuel systems modifications and boilers would require burner system changes. Although use of alcohol fuels in stationary gas turbines has not been extensively tested, it is expected that their utilization would require only minor technical changes (Barr and Parker 1976). A major barrier to this change is the competitive price of conventional fuels.

Utilization of alcohol fuels in internal combustion engines was first recognized by Niklaus Otto in 1876. During World War II ethanol produced from sugar beets and synthetic methanol was used extensively in Europe when oil supplies were scarce. The advent of "cheap" gasoline after World War II rendered automotive grade alcohol production uneconomical. Now, however, alcohols are viewed as viable means of substitution for expensive, imported and non-renewable energy supplies.

Due to a rapid increase in gasoline sales in the United States, the production and utilization of ethanol has increased. The commercialization of ethanol, as opposed to methanol, is due to the fact that gasohol requires, at most, only very minor materials and engine modifications (United States 1979).

The following section provides a summary of factors affecting demand for alcohol/gasoline fuel blends in the transportation sector. Each fuel blend has advantages and disadvantages, which can only be evaluated in comparison with each other, and against conventional liquid fuels. Factors reviewed include important fuel characteristics (compatibility, driveability, and mileage) and socio-economic factors (price, availability, consumer preference and environmental impacts).

5.5.1 Gasohol

5.5.1.1 Octane Rating

Octane rating (number) of a fuel is an important aspect of vehicle performance. Octane number is a measure of a fuel's ability to prevent engine knock and deliver power to the engine. Octane enhancers produced from petroleum include MMT (methyl cyclopentadienyl manganese tricarbonyl), TBA (tertiary butyl alcohol), MTBE (methyl tertiary butyl ether) and TEL (tetraethyl lead).

Addition of ethanol with average octane numbers of 98 - 100[1] to regular unleaded gasolines with average octane numbers of 88 results in average octane number for gasohol of 90, an increase of 2 - 3 points over regular gasoline (United States 1979).

5.5.1.2 Mileage

A litre of ethanol has two-thirds of the energy contained in a litre of regular gasoline (Osler 1977). There are 34.9×10^6 J/L of gasoline as compared to 23.1×10^6 J/L of ethanol. Addition of ethanol to gasoline lowers the energy content of gasoline but available evidence indicates that fuel economy does not necessarily decline 3.5 percent as would be expected. Data from several state fleet tests in the United States suggests that gas mileage is at least equal or better to that obtained from gasoline (United States 1979). Actual increases or decreases in km/L depends on age, size and condition of vehicle, base gasoline used, weather conditions and measurement technique. Available mileage data are inconclusive and not necessarily applicable to Canadian conditions.

5.5.1.3 Driveability

Driveability refers to aspects of a vehicle's

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[1]Average octane number = RON + MON/2. Research Octane Number (RON) is always greater than Motor Octane Number (MON). MON is measured under actual driving conditions. The RON of ethanol is 106 - 108.

performance such as starting, hesitation and rough running. In this regard, there is general acceptance that the addition of alcohol to gasoline decreased driveability but these problems properly pertain more to methanol than ethanol for reasons outlined below:

1. Ethanol is more similar chemically to gasoline than methanol. Thus ethanol shows a higher tolerance for traces of water and does not exhibit phase separation[1] tendencies unless excess water is present in cold weather conditions. Scheller (1973) notes that phase separation was not encountered with gasohol in Nebraska tests in temperatures as low as -34°C. One report claims gasohol will separate into layers when water is in excess of .2 percent[2] in -18°C temperatures (United States Senate 1977). Even 0.1 percent water in regular gasoline can cause driving difficulties (Lincoln 1976) and this tolerance level is normally not exceeded with current fuel handling methods, so that a permissible water content twice that of gasoline can easily be maintained to avoid driveability problems.

2. When the ethanol component in gasoline does not exceed 10 percent, carburetor adjustments are not necessary (United States 1977; 1979). Because ethanol has a lower

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[1]Phase separation refers to layering of alcohol and gasoline in the fuel tank. When it occurs, alcohol forms the lower layer and gasoline the upper layer. This causes rough running and starting difficulties.

[2]0.2 percent means 5 ounces in a 20 gallon (U.S.) tank.

oxygen to carbon ratio than methanol, it does not exhibit the poor driving characteristics associated with leaning-out effects.

3. Nebraska road test data showed no starting difficulties with gasohol in temperatures as high as 37.8°C (United States Senate 1977). Thus vapour lock[1] is not a problem with gasohol.

5.5.2 Methanol/Gasoline Blends (Methaline)[2]

5.5.2.1 Octane Rating

The RON and MON measurements of straight methanol are 106 and 92 respectively (Barr and Parker 1976). RON and MON of unleaded regular base gasoline are 92.7 and 84.3 (Ontario 1978). A review of research on octane numbers of methaline indicates that RON is increased more than MON when methanol is added to gasoline (Ontario 1978). Precise increase depends on base gasoline and percentage concentration of methanol.

5.5.2.2 Mileage

As with ethanol, methanol has less energy per unit volume than gasoline. The difference is approximately 50 percent (Osler 1977). Methanol has 18.8 million J/L; gasoline has 34.9 million J/L. However, methaline has

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[1]Vapour lock refers to an increase of vapour pressure in the fuel line which may block fuel flow.

[2]A blend of 10 - 15% methanol plus 85 - 90% gasoline.

approximately 95 percent of the energy content of the base gasoline. A review of research indicates that fuel economy with methaline declines 2 - 5 percent (Ontario 1978). On the other hand, due to the fact that methanol has a lower air/fuel ratio the energy efficiency of methaline is equal or better than gasoline. Since the trend is toward engines which are set to run leaner, fuel economy will tend to decrease if methanol is used in new cars but energy efficiency should not change. Thus the expected overall net effect is very little change from mileage obtained currently.

5.5.2.3 Driveability

Methaline has two problems which adversely affect smooth performance of a standard North American vehicle. The first is vapour lock. The addition of methanol which has a higher heat of vaporization to gasoline tends to cause an increase in vapour pressure in warm weather (Alexander 1975; Ontario 1976, 1978; Lincoln 1976; Barr and Parker 1976). Presence of vapour in the fuel line blocks fuel flow and can cause starting and driving difficulties. However, vapour lock may not be a serious problem in Canada. Volkswagen-Audi fleet tests indicate that vapour lock occurred above 32°C during stop and go driving (Lee et al 1976). This problem can be overcome to some extent by increasing the aromatic content of gasoline or adding higher alcohols (e.g., isobutanol). Engineering changes in the fuel line may be required to effectively eliminate this problem.

Because methanol is immiscible, even very small quantities of water may cause stratification of methanol and gasoline in the fuel tank in cold weather conditions. Phase separation is therefore an aspect of importance in Canada, although it is not a significant limitation. Blending aromatics (e.g., pentane and butane) and higher alcohols with methaline increases water solubility but increases its cost (Ontario 1976). More research is required to determine what blends are appropriate for Canadian conditions. It is felt by many researchers that an increase in precautions used to minimize water content in gasoline in transportation, distribution and storage of methanol can be an effective means of controlling phase separation (Ontario 1978; Barr and Parker 1976).

In addition, a major problem affecting driveability in the longer term is that methanol corrodes aluminum and its alloys, magnesium and its alloys, brass, zinc, some plastics and neoprene (American Petroleum Institute 1976). Replacement of fuel line components with non-corrosive materials solves this problem.

5.5.3 Alcohol Fuels: Environmental Impact

The addition of alcohol to gasoline causes a leaning effect which improves combustion efficiency. Research to date indicates that gasohol blends burn cleaner than gasoline. The United States Environmental Protection Agency conducted emission tests on gasohol, and reports that CO and HC emissions decreased, slight increases in NO_x emissions and substantial increases in evaporative hydrocarbons occurred (United States 1979).

Adding methanol to gasoline generally has the same effect as adding ethanol. A review of research on methaline, however, indicates that NO_x emissions decrease when methanol is added to gasoline (Ontario 1978; Barr and Parker 1976). Decreases in NO_x have also been reported by the American Petroleum Institute (1976). Conversely, Shell reports increases in NO_x with small European cars (1975). As there is a tendency towards leaner air-fuel ratios in late model cars, the most reliable assumption is that NO_x emission levels will not change dramatically.

In addition to reducing air pollutants, the use of alcohol fuel blends provides other environmental benefits. Because alcohols are effective anti-knock compounds, their addition to gasoline could decrease the demand for petroleum based anti-knock compounds such as TEL. This would mean an energy savings at the refinery level, an extension of petroleum supplies, and an increase in the capacity of refineries to produce other fuels (Ontario 1976). Further utilization of waste materials for alcohol production can reduce disposal problems and improve the environment.

5.5.4 Food and Fuel

The current practice for obtaining ethanol for gasohol is to utilize food process side-stream products (cheese whey, corn processing wastes), distressed grains and foodstuffs, or sulfate waste liquor. Three small-scale plants are in operation in midwestern United States as of November, 1978 (United States 1979). In Canada, the government of Manitoba and the Mohawk Oil Company are establishing an ethanol production plant utilizing surplus low grade grains (Winnipeg Free Press, August 23, 1980; Energy Report Canada, 1981b). Advantages associated with regional small-scale facilities include: a) reduction of transportation costs; b) opportunities for local involvement by a community or farmers cooperatives; and c) better utilization of surplus food crops.

As long as ethanol production utilizes surplus food products, food versus fuel priorities will not conflict. The trend toward increasing demand for gasohol, however, could create a situation where required amounts of gasohol could not be met from surplus and distressed food products alone (Scheller 1974). At this point, gasohol producers would be competing with food processors for foodstuffs which could result in food shortages and higher food prices. In the long run, this alternative for reducing petroleum consumption may not be very attractive.

The absence of food-fuel conflicts is one important advantage of utilizing non-food cellulosic materials for energy.

CHAPTER 6

STRAW COLLECTION LOGISTICS AND COSTS

6.1 System Flow Model: Description

Figure 6.1 shows the sequence of activities which are required to recover straw from the field and deliver it to a central collection site. Nine possible operations were identified, grouped into three sectors. To operate effectively on a large commercial scale (100,000 tonnes collected per year) such a system requires a management framework to coordinate participation of farmers, custom collectors and straw contractors. This chapter discusses general management and infrastructure requirements, straw collection systems and costs, system restraints, and areas of improvement for a hypothetical straw collection system for energy utilization.

6.2 Flax Collection System Characteristics

Obtaining straw for energy on a large scale has not been demonstrated before although large scale collection for single industrial purposes like pulp are common in France (Gaudier 1977), Italy (Triolo 1977), Turkey (Triolo 1977), England (Wilson *et al* 1976), Netherlands (Dean 1976), and Eastern Europe (Dean 1976). In Manitoba, two paper manufacturers have been involved in large scale flax collection for approximately 11 years. Discussions with management personnel provided the opportunity to obtain information about: a) procurement logistics; b) hand-

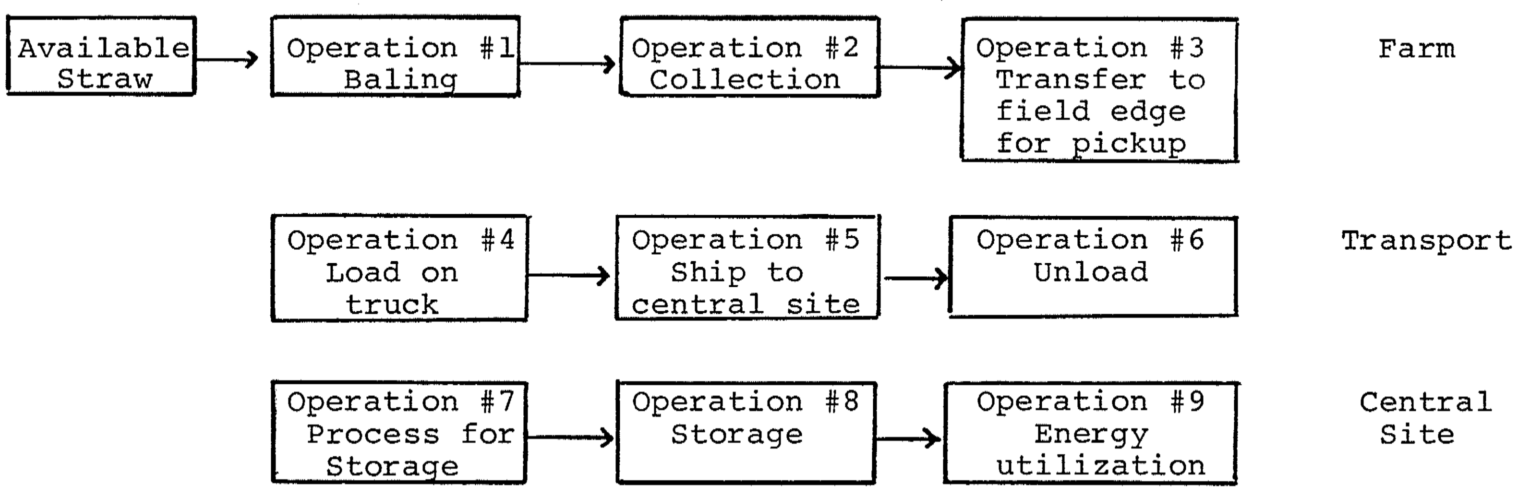

Figure 6.1

SYSTEM FLOW MODEL FOR COLLECTION
OF CEREAL GRAIN STRAW

ling methods; and c) storage. The following points are noteworthy:

Companies involved in procuring flax straw are Domtar and Kimberley-Clark (Flax Fibre Division). Kimberley-Clark is the largest operation and it obtains flax straw from growers throughout southern Manitoba and southeastern Saskatchewan. Annual straw requirements range from 40,000 to 60,000 tonnes and straw availability does not seem to be a problem. The study area is a primary source of flax straw. Carman is the central storage site but many regional collection sites have been established to reduce transportation distances and costs. Domtar's main collection site is at Morden. The primary catchment area for a site is usually within a 32 to 48 kilometre radius.

Several options are available for procuring straw when a farmer agrees to sell his flax straw. He may contract to bale, collect and bring the straw to a collection site himself. In this case he receives a predetermined payment for the straw plus a payment for each operation. On the other hand, the farmer has the option of sub-contracting to a custom collector for any one or all of the above operations. This three tier payment schedule allows farmers to adjust their participation to time availability and equipment capabilities.

Farmers' primary concerns are to: a) clear the field as early as possible in the fall so that post-harvest tillage can proceed; b) minimize interference with tillage operations; and c) obtain an economic return. The organization of this collection system is effective in that the company has a reliable straw supply and flax farmers are willing to participate.

Several unique machines called decorticators have been developed by Kimberley-Clark engineers to process flax straw at collection sites. Flax straw is not hollow like cereal grain straw. It consists of an outer straw shell (shive) surrounding flax fibres (tow) needed for cigarette paper making. To separate these two components, two types of decorticators were developed: a large stationary unit with a throughput of 12.6 t/hr which is used only at the main collection site in winter and a mobile-mini-decorticator unit which is designed to fit on a specially designed flat-bed trailer pulled by a diesel truck. Mobile units have a throughput of 6.3 t/hr and travel to regional collection sites from June to September.

Separation of shive from tow reduces the bulk of straw by 50 percent. Decorticators have a high-density baling unit which prepares large bales (136 kilograms) for shipment by truck to railway. Because procurement of flax straw for industrial purposes is economically viable, straw processing and handling facilities required for the unique characteristics of flax were developed as they became necessary.

Flax straw brought to a collection site is usually stored in open-air stacks. Each stack contains approximately 250 - 270 tonnes of straw. As a precaution against weathering losses, each stack is covered with heavy-guage plastic sheets which are kept in place by weights.

Straw quality is a major concern to the company. Generally, flax straw having a weed content exceeding 8 to 10 percent is not acceptable. Flax containing certain types of weeds such as cockleburr is totally unacceptable.

6.3 Systems Available for Field Recovery of Straw

After harvest, collection of available straw can be achieved by the use of:

1. Small bale equipment to make conventional rectangular 2 or 3 wire bales measuring approximately 1 x 0.36 x 0.46 metres and weighing between 18 and 27 kilograms.
2. Large round baling equipment to produce large cylinders 1.5 metres long and 1.8 metres in diameter and weighing about 350 kilograms.

Although these systems are widely used, other systems available include giant square balers and forage harvesting equipment.

Friesen (1980) performed tests on collection equipment under Manitoba conditions and reviewed operational characteristics. Advantages of using conventional small bale equipment include flexibility in terms of using manual and/or automatic bale making and handling methods, higher density of bale which means economical transport for longer distances, and lower machinery costs (this does not apply to self-propelled mechanical bale wagons) relative to the average cost of round balers. Advantages of round balers are higher harvesting rates per hour and lower collection costs per unit. Handling large round bales requires a front-end loader equipped with a loader attachment that can handle large round bales.

6.4 Straw Collection Costs

The starting point for assessing costs associated with bringing straw to a central site is straw left in the field after harvest. This approach assumes that costs incurred for growing the cash crop producing straw are charged to the grain crop. The effect of this assumption is that costs of straw to the farmer are essentially zero. The total cost of a tonne of straw brought to the company's central storage site consists of four components: purchase cost; baling cost; collection cost; and transportation cost (Table 6.1). Opportunity cost is also an important consideration. The opportunity cost is the cost of replacing nutrients in the collected straw. On the basis of average annual straw available for wheat, oats and barley as per Table 4.9, average opportunity cost per hectare is \$7.68 for wheat, \$11.80 for oats and \$8.87 for barley.[1]

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[1]These values assume the following cost per kilogram for fertilizer, as reported by Partridge and Hodgkinson (1977): K, 19¢; P, 72¢; N, 40¢.

TABLE 6.1

FLAX STRAW COSTS PER TONNE AT A CENTRAL COLLECTION SITE

System	Payment for Straw[a]	Baling[b]	Collection[c]	Transportation[a]	Total/$t
Conventional Bales	7.70	5.30	5.93[d]	8.80/t (1-16 km)	27.73
	"	"	"	9.90/t (17-32 km)	28.83
	"	"	"	11.00/t (33-48 km)	29.93
	"	"	"	12.10/t (49-64 km)	31.03
Giant Round Bales	7.70	4.15	2.95	8.80/t (1-16 km)[e]	23.60
	"	"	"	9.90/t (17-32 km)	24.70
	"	"	"	11.00/t (33-48 km)	25.80
	"	"	"	12.10/t (49-64 km)	26.90

SOURCES: [a] Domtar personnel, pers. comm.; Kimberley-Clark personnel, pers. comm.

[b] J. R. D. Partridge and D. G. Hodgkinson. Manitoba crop residues as a biomass energy source. T. and S. papers. Man. Agron. Ann. Conf. Dec. 13-14, 1977. Winnipeg, Manitoba.

[c] Intergroup Consulting Economists. 1978. Liquid Fuels from Renewable Resources: Feasibility Study. Vol. D. Agricultural Studies.

NOTES: [d] Collection costs are based on moving straw to the edge of the field -- 0.4 km average distance.

[e] Assumes transportation costs per tonne equal to conventional bales.

The first element of straw costs is payment to the farmer. The amount shown in Table 6.1 is based on payments for flax straw made by Domtar and Kimberley-Clark Ltd. to purchase straw from flax growers. Farmers are generally amenable to selling straw if it is not otherwise inconvenient for them. Flax straw on the field presents a tillage because it does not decompose readily.

Baling and collection costs are shown for two straw packaging systems. Baling costs in each case assumes a pto (power take-off) driven baler, one tractor matched to conventional/round baler in terms of power requirements, fuel, operator and twine costs. Collection of conventional bales assumes a pto driven bale-pickup wagon, tractor, fuel and operator costs. Collection of round bales assumes a tractor with front-end loader, two 6 metre flat-bed wagons, operator and fuel costs. All costs reflect custom rental charges based on a consideration of depreciation, interest on investment, maintenance, repairs, and a 25 percent mark-up. Additional details may be found in the sources shown in Table 6.1.

Total collection costs for rectangular bales are about $4.00 higher per tonne than round bales for the same distance. Costs for rectangular bales increase from $27.73 per tonne to $31.03 per tonne as the transportation distance increases. Similarly, total cost of collecting round bales increases from $23.60 to $26.90 as transportation distance increases.

6.5 Restraints for Cereal Grain Straw

Whether or not cereal grain straw will be collected in the future as an energy source depends on several factors. These include:

1. Development of a market for straw and the subsequent establishment of a procurement system and management structure for coordinating procurement of a guaranteed annual supply of straw.

2. Increasing awareness of producers toward the benefits of straw collection. Timeliness of operation is an important concern.

3. Development of methods to increase collection efficiency.

6.5.1 Management System

Development of flax collection in the study area suggests that necessary management expertise, collection system infrastructure, and technical developments necessary to reduce straw volumes and reduce handling costs would evolve as the market for straw develops. A major concern of straw buyers/contractors is procurement of necessary annual straw requirements as supply disruptions could curtail production and result in financial losses. Long-term supply contracts are one possible method for assuring continuous supply and developing inventories to sustain supply in low straw production years. This approach entails storage methods which would minimize deterioration. As the straw biomass analysis indicates, it would seem highly likely that annual straw requirements for energy production could be met from the 1,000,000 tonnes available annually in the study area.

6.5.2 Attitudes of Growers

For many years cereal grain growers harvested grain and burned straw. In heavy straw years, extent of burning increases substantially. Burning is viewed by many farmers simply as an easy method of disposing of straw and this factor often overrides the fact that returning straw to soil is a beneficial soil management practice.

Flax collection in the study area is evidence of the willingness of producers and custom collectors to participate in alternative straw disposal operations which are practical, flexible and economically beneficial. Additional indications of willingness to participate are the many straw collection cooperatives operating in European countries, where the economics of paper-making from straw are favourable. A survey of rice growers in California by Horsfield et al (1977) revealed that farmers were interested in participating in alternative methods of utilizing straw. Taking account of producer concerns and identifying areas of possible resistance is an important aspect of straw utilization.

6.5.3 Straw Handling Methods: Potential Improvements

In the short-term it is unlikely that conventional balers will be displaced by innovative technology. Because light weight rectangular bales can be handled manually by one man, demand for these packages should continue. Improvements in size and shape of bale and its transportation are oriented primarily to farm needs. Collection methods which are optimal for farm conditions may not necessarily be optimal for commercial collection schemes which often involve longer transportation distances. Further, baled straw may not be the best feedstock form for energy utilization. Suggested alternatives and improvements to conventional baling systems include:

1. Whole harvest system concept (Horsfield and Williams 1976b).
2. Straw briquetting and pelletizing machines (LaRue 1977).
3. Combine attachments for increasing straw output like the chaff saver (Miles 1976).

CHAPTER 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary and Conclusions

The primary objective of this research was to determine quantities of available wheat, oats and barley straw in Crop Districts 3, 4 and 5 in Manitoba. This was accomplished by analysis of long-term (15 - 18 year) yields. Key findings are outlined below:

7.1.1 Average Annual Straw Yields, Straw Available and Straw Needed

1. Determination of straw needed as a soil amendment on clay soils in the study area (Red River Valley) is based on several factors: physical characteristics of soils, soil management problems, a consideration of soil fertility and erosional susceptibility, climatic characteristics and agricultural practices. These factors together with soil amendment guidelines in recent literature suggest that about 0.9 t/ha per annum of straw is required as a soil mulch on study area soils. More would be required on lighter soils.

2. Oats has the highest average annual straw yield and therefore the highest amount of average annual straw available on a per hectare basis; the average for well drained and poorly drained soils is 2.0 t/ha.

3. Wheat has the next highest average annual straw yield; average annual straw available per hectare for well

drained and poorly drained soils is 1.7 t/ha.

4. Barley has the lowest average annual straw yields; the average annual straw available yield per hectare is 1.3 t/ha.

5. Wheat, oats and barley straw in Crop Districts 3, 4 and 5 are available in large quantities. On a total tonnage basis, an average of 815,000 tonnes of wheat straw are available annually in the study area. The availability of oats is about 330,000 tonnes, followed by barley which produces about 276,000 tonnes of available straw annually. Thus total average annual wheat, oats and barley straw available is about 1.4 million tonnes.

6. Wheat, oats and barley crop yields and straw yields in municipalities in the southwest part of the study area (Roland, Rhineland, Stanley) and in the municipality of Portage la Prairie are higher than in the central (McDonald) and eastern parts of the study area (Richot).

7. If it is assumed that an average of 0.9 t/ha/yr (minimum recommended annual soil amendment) of straw is uniformly left on the land throughout the study area, total straw availability would be reduced to 1.3 million tonnes, a reduction of 100,000 tonnes.

8. Straw availability would be increased by an average of 10 percent in the study area if the fallowing is not practised at all.

7.1.2 Theoretical Energy Potential

1. The total quantity of available straw produced annually (1.4 million tonnes) in Crop Districts 3, 4 and 5 could theoretically yield between 186 to 298 million litres of ethanol, depending on cellulose to ethanol conversion technology used.

2. These quantities of ethanol (i.e., 186 and 298 million litres) respectively represent 12.1 and 19.4 percent of total motor gasoline consumption in Manitoba in 1980. Thus ethanol fuels produced from straw have significant potential as petroleum extenders in Manitoba.

3. The production of hot gases (LBG) via gasification of straw for small scale on-site use is the most promising near term energy use of straw. The production of ethanol from cellulose is technically possible at present but most of the research and development in this area has concentrated on wood as feedstock. Straw as a source of ethanol fuels is a long-term possibility.

7.1.3 Collection Logistics and Costs

1. Major restraints affecting development of straw collection system include possible grower resistance and transportation distances. Transportation is a factor in that straw is a bulky commodity which is costly to move long distances. Collection and transportation constraints associated with the bulkiness of flax straw were overcome

by unique technical solutions. Grower participation is to a large extent a function of a flexible collection system which allows the grower to match level of collection involvement to his machinery capabilities and time requirements. The primary catchment area for a collection site is generally an area within a 32 to 48 kilometre radius. Collection costs vary between $23.00 and $31.00 per tonne, depending on baling system and transportation distances.

7.2 Recommendations

The foregoing has demonstrated sufficient evidence to support the view that straw has much potential as an on-site, local and regional energy source, recognizing there are technical, economic and social constraints. It may be assumed that by the time there is sufficient incentive to extract energy from biomass and straw in particular on a commercial scale, the technical difficulties will be resolved. Further, it is likely efficiency improvements in the collection, transportation and handling of straw will evolve as production of energy from straw comes on stream. The main question then will be what supply levels are necessary to produce energy, and how to produce it.

The recommendations produced from this background report are based on the assumption that straw will become a commercial energy source at some future date when its use is practicable and justifiable in technical, economic and political terms. In social and environmental terms, greater utilization of renewables is already an urgent necessity. In the intervening period, it will be necessary for the federal government and provincial governments to assist in laying the ground work in order to be properly prepared for such developments. To that end, the following recommendations for further research are suggested:

1. Investigate the development of conversion projects which have the potential to utilize different types of biomass materials (e.g., MSW, wood, food processing wastes, agricultural residues) and produce biomass fuels. Advantages of co-feedstock plants include minimization of supply effects due to seasonal availability, and economies of scale. As an example, there is an excellent opportunity in Manitoba to demonstrate the feasibility of producing fuel grade ethanol from cellulose. The opportunity arises as a result of Mohawk Oil Company's of Calgary plan to convert a beverage distillery at Minnedosa, Manitoba to produce fuel grade ethanol from barley feedstocks. The installation of a pilot pretreatment and hydrolysis plant to convert locally available cellulosic material to ethanol would reduce the capital cost of demonstrating that the cellulose to ethanol route based on Canadian technology is technically viable as the fermentation and distillation are already. An ethanol from cellulose pilot plant is an important step in terms of Canada maintaining its technological lead in this field.

2. Encourage, promote and investigate opportunities for development and utilization of non-energy products in addition to fuels such as feed, fibre, fertilizer and chemical applications. Such end-use products would allow fuller utilization of straw biomass.

3. Expand research and development efforts designed to improve the feasibility of producing energy directly from straw on the farm. This eliminates costly transportation charges and provides direct benefits to the farmer. An integral component of such an effort is development of appropriate incentives to encourage wider adoption of small-scale on-farm energy producers.

4. Closely monitor research efforts aimed at increasing the feasibility of producing ethanol fuel from cellulosic materials. More needs to be known about the feasibility of advanced cellulose conversion facilities such as simultaneous saccharification and fermentation processes under Canadian operating conditions. Further research efforts in this area ought to be aimed at bringing this technology on-stream in the near term.

5. Conduct environmental impact assessments and technology assessments of alcohol fuel supplies, production and use.

6. Develop ways to resolve institutional barriers and constraints which may impede development and utilization of alcohol fuels.

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APPENDIX 1

A SUMMARY OF MAJOR RESEARCH SOURCES

Abstracts, Indexes, Libraries of Technical Centres, etc., Scanned by Computer Search for the Years 1970-1978

Canada

- Canadian Plains Research Center Can-Plains Research Inventory
- National Research Council - Canadian Institute for Scientific and Technical Information (CISTI) Library

United States

- National Technical Information Centre (NTIS)
- Engineering Index, monthly and author index
- Engineering Index - Energy Abstracts
- Agricola Index

Obtained Through CISTI but Contains International Sources

- Biological Abstracts, Inc.
- American Chemical Society Abstracts

Library Searches

- Canada Department of Agriculture publishes an index of articles published in the Canadian Journal of Soil Science based on research at C.D.A. research stations. Research on soil management for the following stations was abstracted: Lethbridge, Swift Current, Melfort, Indian Head, Brandon and Winnipeg.
- Manitoba Department of Agriculture publications:
  - Manitoba Soil Science meetings
  - Manitoba Agronomists' Annual Conference Proceedings
  - Yearbooks and agricultural handbooks
- Biomass Energy Institute Library

APPENDIX 2.1

STANDARD AND METRIC WHEAT VOLUME AND WEIGHT EQUIVALENTS FOR GRAIN AND STRAW

Yield Range of Crop	Grain	Straw		Stubble		Grain	Straw		Stubble
	1	2	3	4	5	6	7	8	9
bu/ac	lbs/ac	lbs/ac	tons/ac (2/2,000)	lbs/ac (2x33%)	tons/ac (4/2,000)	kg/ha	kg/ha	t/ha (7/1,000)	t/ha (8x33%)
10	600	900	0.45	300	0.15	672	1,000	1.0	0.33
12	720	1,080	0.54	356	0.17	807	1,210	1.2	0.39
14	840	1,260	0.63	416	0.20	941	1,412	1.4	0.46
16	960	1,440	0.72	475	0.23	1,075	1,612	1.6	0.53
18	1,080	1,620	0.81	535	0.26	1,210	1,813	1.8	0.59
20	1,200	1,800	0.90	594	0.29	1,345	2,017	2.0	0.66
22	1,320	1,980	0.99	653	0.32	1,479	2,219	2.2	0.73
24	1,440	2,160	1.08	713	0.35	1,612	2,419	2.4	0.79
26	1,560	2,340	1.17	772	0.38	1,747	2,620	2.6	0.86
28	1,680	2,520	1.26	832	0.41	1,883	2,824	2.8	0.93
30	1,800	2,700	1.35	891	0.44	2,017	2,923	2.9	0.96
32	1,920	2,880	1.44	950	0.47	2,150	3,225	3.2	1.07
34	2,040	3,060	1.53	1,010	0.50	2,286	3,429	3.4	1.13
36	2,160	3,240	1.62	1,069	0.53	2,419	3,628	3.6	1.19
38	2,280	3,420	1.71	1,128	0.56	2,553	3,830	3.8	1.26
40	2,400	3,600	1.8	1,188	0.59	2,688	4,032	4.0	1.33
42	2,520	3,780	1.89	1,247	0.62	2,822	4,233	4.2	1.39
44	2,640	3,960	1.98	1,307	0.65	2,957	4,435	4.4	1.46
46	2,760	4,140	2.07	1,366	0.68	3,091	4,637	4.6	1.53
48	2,880	4,320	2.16	1,425	0.71	3,225	4,838	4.8	1.59
50	3,000	4,500	2.25	1,485	0.74	3,360	5,040	5.0	1.66

APPENDIX 2.2

STANDARD AND METRIC OATS VOLUME AND WEIGHT EQUIVALENTS FOR GRAIN AND STRAW

Yield Range of Crop bu/ac	Grain 1 lbs/ac	Straw 2 lbs/ac	Straw 3 tons/ac (2/2,000)	Stubble 4 lbs/ac (2x33%)	Stubble 5 tons/ac (4/2,000)	Grain 6 kg/ha	Straw 7 kg/ha	Straw 8 t/ha (7/1,000)	Stubble 9 t/ha (8x33%)
10	340	476	0.23	157	0.07	381	533	0.53	0.17
12	408	571	0.28	188	0.09	457	640	0.64	0.20
14	476	666	0.33	220	0.10	533	746	0.74	0.24
16	544	761	0.38	251	0.12	610	854	0.85	0.28
18	612	857	0.42	283	0.14	685	959	0.95	0.31
20	680	952	0.47	314	0.15	762	1,067	1.06	0.34
22	748	1,047	0.52	345	0.17	838	1,173	1.17	0.38
24	816	1,142	0.57	377	0.18	914	1,280	1.27	0.42
26	884	1,238	0.61	292	0.14	990	1,386	1.38	0.45
28	952	1,332	0.66	440	0.21	1,067	1,494	1.49	0.49
30	1,020	1,428	0.71	471	0.23	1,143	1,600	1.6	0.52
32	1,088	1,523	0.76	502	0.25	1,219	1,706	1.7	0.56
34	1,156	1,618	0.80	534	0.26	1,295	1,813	1.8	0.59
36	1,224	1,714	0.85	566	0.28	1,371	1,919	1.9	0.63
38	1,292	1,809	0.90	597	0.29	1,447	2,026	2.0	0.66
40	1,360	1,904	0.95	628	0.31	1,524	2,133	2.1	0.70
42	1,428	1,999	0.99	660	0.32	1,600	2,240	2.2	0.73
44	1,496	2,094	1.04	691	0.34	1,676	2,346	2.3	0.77
46	1,564	2,190	1.09	723	0.36	1,752	2,453	2.4	0.80
48	1,632	2,285	1.14	754	0.37	1,828	2,559	2.5	0.84

APPENDIX 2.2 (cont'd)

Yield Range of Crop bu/ac	Grain	Straw		Stubble		Grain	Straw		Stubble
	1	2	3	4	5	6	7	8	9
	lbs/ac	lbs/ac	tons/ac (2/2,000)	lbs/ac (2x33%)	tons/ac (4/2,000)	kg/ha	kg/ha	t/ha (7/1,000)	t/ha (8x33%)
50	1,700	2,380	1.19	785	0.39	1,905	2,667	2.6	0.88
52	1,768	2,475	1.23	817	0.40	1,981	2,773	2.7	0.91
54	1,836	2,570	1.28	848	0.42	2,057	2,880	2.8	0.95
56	1,904	2,666	1.33	880	0.43	2,133	2,986	2.9	0.98
58	1,972	2,761	1.38	911	0.45	2,209	3,092	3.0	0.99
60	2,040	2,856	1.42	942	0.47	2,286	3,200	3.2	1.05
62	2,108	2,951	1.4	974	0.48	2,362	3,306	3.3	1.09
64	2,176	3,046	1.5	1,005	0.50	2,438	3,413	3.4	1.12
66	2,244	3,142	1.57	1,036	0.51	2,515	3,521	3.5	1.15
68	2,312	3,237	1.61	1,068	0.53	2,591	3,627	3.6	1.19
70	2,380	3,332	1.66	1,099	0.54	2,667	3,734	3.7	1.23
72	2,448	3,427	1.71	1,131	0.56	2,743	3,840	3.8	1.26
74	2,516	3,522	1.76	1,162	0.58	2,819	3,946	3.9	1.3
76	2,584	3,618	1.8	1,194	0.59	2,896	4,054	4.0	1.32
78	2,652	3,712	1.85	1,225	0.61	2,972	4,161	4.1	1.37
80	2,720	3,808	1.9	1,256	0.62	3,048	4,267	4.2	1.40
82	2,788	3,903	1.95	1,288	0.64	3,124	4,374	4.3	1.44
84	2,856	3,998	1.99	1,319	0.65	3,200	4,480	4.4	1.47
86	2,924	4,093	2.04	1,351	0.67	3,277	4,588	4.5	1.51
88	2,992	4,188	2.09	1,382	0.69	3,353	4,694	4.6	1.54
90	3,060	4,284	2.14	1,414	0.70	3,429	4,800	4.8	1.58

APPENDIX 2.3

STANDARD AND METRIC BARLEY VOLUME AND WEIGHT EQUIVALENTS FOR GRAIN AND STRAW

Yield Range of Crop bu/ac	Grain 1 lbs/ac	Straw 2 lbs/ac	3 tons/ac (2/2,000)	Stubble 4 lbs/ac (2x33%)	5 tons/ac (4/2,000)	Grain 6 kg/ha	Straw 7 kg/ha	8 t/ha (7/1,000)	Stubble 9 t/ha (8x33%)
10	480	480	0.24	158	0.07	538	538	0.53	0.16
12	576	576	0.28	190	0.09	645	645	0.64	0.21
14	672	672	0.33	222	0.11	753	753	0.75	0.24
16	768	768	0.38	253	0.12	860	860	0.86	0.28
18	864	864	0.43	285	0.14	968	968	0.98	0.32
20	960	960	0.48	317	0.15	1,076	1,076	1.0	0.33
22	1,056	1,056	0.52	349	0.17	1,183	1,183	1.18	0.36
24	1,152	1,152	0.57	380	0.19	1,291	1,291	1.29	0.42
26	1,248	1,248	0.62	412	0.20	1,398	1,398	1.39	0.45
28	1,344	1,344	0.67	443	0.22	1,506	1,506	1.56	0.51
30	1,440	1,440	0.72	475	0.23	1,614	1,614	1.61	0.53
32	1,536	1,536	0.76	507	0.25	1,721	1,721	1.72	0.56
34	1,632	1,632	0.81	538	0.26	1,829	1,829	1.82	0.60
36	1,728	1,728	0.86	570	0.28	1,936	1,936	1.93	0.63
38	1,824	1,824	0.91	602	0.30	2,044	2,044	2.0	0.67
40	1,920	1,920	0.96	634	0.31	2,152	2,152	2.15	0.69
42	2,016	2,016	1.00	665	0.33	2,259	2,259	2.25	0.74
44	2,112	2,112	1.05	697	0.34	2,367	2,367	2.36	0.77
46	2,208	2,208	1.10	728	0.36	2,474	2,474	2.47	0.81
48	2,304	2,304	1.15	760	0.38	2,582	2,582	2.58	0.85

APPENDIX 2.3 (cont'd)

Yield Range of Crop bu/ac	Grain Straw 1 lbs/ac	2 lbs/ac	3 tons/ac (2/2,000)	Stubble 4 lbs/ac (2x33%)	5 tons/ac (4/2,000)	Grain Straw Stubble 6 kg/ha	7 kg/ha	8 t/ha (7/1,000)	9 t/ha (8x33%)
50	2,400	2,400	1.20	792	0.39	2,690	2,690	2.69	0.88
52	2,496	2,496	1.24	824	0.41	2,798	2,798	2.79	0.92
54	2,592	2,592	1.29	855	0.42	2,905	2,905	2.90	0.95
56	2,688	2,688	1.34	887	0.44	3,012	3,012	3.01	0.99
58	2,784	2,784	1.39	919	0.45	3,120	3,120	3.12	1.02
60	2,880	2,880	1.44	950	0.47	3,228	3,228	3.22	1.06
62	2,976	2,976	1.48	982	0.49	3,335	3,335	3.3	1.08
64	3,072	3,072	1.53	1,013	0.50	3,443	3,443	3.4	1.12
66	3,168	3,168	1.58	1,045	0.52	3,550	3,550	3.5	1.17
68	3,264	3,264	1.63	1,077	0.53	3,658	3,658	3.6	1.18
70	3,360	3,360	1.68	1,109	0.55	3,766	3,766	3.7	1.22
72	3,456	3,456	1.72	1,140	0.57	3,873	3,873	3.8	1.25
74	3,552	3,552	1.77	1,172	0.58	3,981	3,981	3.9	1.28
76	3,648	3,648	1.82	1,203	0.60	4,088	4,088	4.0	1.32
78	3,744	3,744	1.87	1,235	0.61	4,196	4,196	4.1	1.35
80	3,840	3,840	1.92	1,267	0.63	4,304	4,304	4.3	1.41
82	3,936	3,936	1.96	1,290	0.64	4,411	4,411	4.4	1.45
84	4,032	4,032	2.01	1,330	0.66	4,519	4,519	4.5	1.48
86	4,128	4,128	2.06	1,362	0.68	4,626	4,626	4.6	1.51
88	4,224	4,224	2.11	1,394	0.69	4,734	4,734	4.7	1.55
90	4,320	4,320	2.16	1,425	0.71	4,842	4,842	4.8	1.58

APPENDIX 3.1

MINIMUM AND MAXIMUM WHEAT
STRAW YIELDS (t/ha) IN RISK AREA 12

Soil Zone		Well Drained FF	Well Drained SF	Well Drained FU	Well Drained SU	Poorly Drained FF	Poorly Drained SF	Poorly Drained FU	Poorly Drained SU
B	MIN	2.1	2.1	1.2	1.0				
	MAX	4.8	4.0	4.2	4.5				
C	MIN	1.3	1.8	1.5	0.8	1.2	1.2	1.1	0.8
	MAX	4.0	3.6	4.0	3.4	3.6	3.6	3.0	2.4
D	MIN	1.5	1.8	1.3	0.6	1.1	1.2	1.0	1.0
	MAX	4.0	3.6	3.6	2.9	3.3	3.0	3.1	2.6
E	MIN	1.8	1.8	1.1	0.6	1.2	1.2	1.0	0.6
	MAX	3.9	3.4	3.4	2.6	3.8	3.1	3.6	2.1

Fallow fertilized (FF) and stubble fertilized (SF) 15 years (1963-77)
Fallow unfertilized (FU) and stubble unfertilized (SU) 18 years (1960-77)
Blank spaces indicate data are not available.

APPENDIX 3.2

MINIMUM AND MAXIMUM OAT STRAW YIELDS (t/ha) IN RISK AREA 12

Soil Zone		Well Drained FF	Well Drained SF	Well Drained FU	Well Drained SU	Poorly Drained FF	Poorly Drained SF	Poorly Drained FU	Poorly Drained SU
B	MIN		2.8						
	MAX		5.3						
C	MIN		2.3		1.3		1.8		0.8
	MAX		4.8		3.9		3.0		2.5
D	MIN		2.2		1.3	1.1	1.6	0.9	1.1
	MAX		4.4		2.7	3.4	3.0	3.3	2.8
E	MIN		0.8		2.1	1.3	1.6		0.9
	MAX		2.7		3.3	4.4	3.0		2.2

APPENDIX 3.3

MINIMUM AND MAXIMUM BARLEY STRAW YIELDS (t/ha) IN RISK AREA 12

Soil Zone		Well Drained				Poorly Drained			
		FF	SF	FU	SU	FF	SF	FU	SU
B	MIN		1.6						
	MAX		3.0						
C	MIN	1.5	1.3	1.1	0.9	0.9	1.0	0.6	0.4
	MAX	3.8	3.2	3.5	2.2	2.9	2.5	2.5	1.5
D	MIN	1.0	1.3		0.5	0.9	1.2	0.4	0.3
	MAX	4.0	3.2		1.6	2.8	2.3	1.7	1.2
E	MIN		1.5		0.5	0.9	0.8		0.3
	MAX		2.9		2.6	2.8	2.6		1.5

APPENDIX 4.1

MINIMUM AND MAXIMUM WHEAT, STRAW YIELDS[a] (t/ha) IN THE MUNICIPALITIES OF CARTIER, McDONALD, MORRIS AND ROSSER

Soil Zone		CARTIER		McDONALD		MORRIS		ROSSER	
		FF	SF	FF	SF	FF	SF	FF	SF
C	MIN	1.0	0.4	1.3	0.8	1.2	1.0	1.0	1.2
	MAX	3.9	3.0	3.3	3.0	3.6	2.7	3.9	3.6
D	MIN	0.2	0.8	0.8	0.8	1.3	1.2	0.4	0.8
	MAX	3.3	3.0	3.3	2.8	3.6	3.0	3.9	3.1
E	MIN	0.6	0.8	0.8	0.4	1.2	1.1	1.5	1.0
	MAX	3.6	2.7	3.4	3.0	3.6	3.0	4.0	3.7

[a]Wheat yields on poorly drained clays for a 15 year period (1963-77)

APPENDIX 4.1.1.

MINIMUM AND MAXIMUM OAT AND BARLEY STRAW YIELDS (t/ha)[a] IN THE MUNICIPALITIES OF CARTIER, McDONALD, MORRIS AND ROSSER

SOIL ZONE		OATS				BARLEY			
		CARTIER	McDONALD	MORRIS	ROSSER	CARTIER	McDONALD	MORRIS	ROSSER
C	MIN	1.1	1.5	1.8	1.1		0.5	0.6	0.4
	MAX	4.3	3.0	3.6	2.9		2.8	2.6	2.5
D	MIN	0.9	1.1	1.4	0.9		0.5	0.8	0.5
	MAX	3.1	3.0	2.9	3.1		2.8	2.2	2.5
E	MIN		0.8	1.4	1.2		0.8	0.8	0.5
	MAX		3.0	2.9	3.8		2.8	2.5	2.6

[a]Stubble fertilized yields (1963-77) on poorly drained clays

APPENDIX 4.2

MINIMUM AND MAXIMUM WHEAT STRAW YIELDS[a]
(t/ha) IN THE MUNICIPALITIES OF DESALABERRY,
HANOVER, RITCHOT AND STE. ANNE

SOIL ZONE		DESALABERRY		HANOVER		RITCHOT		STE. ANNE	
		FF	SF	FF	SF	FF	SF	FF	SF
C	MIN	1.8	1.0			1.3	0.6		
	MAX	3.4	3.3			3.6	3.3		
D	MIN	1.5	1.1	1.8	1.5	1.9		1.2	
	MAX	3.9	2.9	3.9	3.9	3.9		3.3	
E	MIN	1.1	0.6	0.2	0.2	1.2		1.1	
	MAX	4.5	3.0	3.9	3.6	3.7		3.6	

[a]Yields for 13 years (1965-77)

APPENDIX 4.2.1

MINIMUM AND MAXIMUM OATS AND BARLEY STRAW YIELDS[a] (t/ha) IN THE MUNICIPALITIES OF DESALABERRY, HANOVER, RITCHOT AND TACHE

SOIL ZONE		OATS				BARLEY			
		DESALABERRY	HANOVER	RITCHOT	TACHE	DESALABERRY	HANOVER	RITCHOT	TACHE
C	MIN	2.2		1.4		1.1		0.7	
	MAX	3.6		3.1		3.1		2.7	
D	MIN	1.6	1.6		0.5	0.9	0.9	0.9	0.4
	MAX	3.7	3.3		3.0	2.8	2.5	2.7	2.0
E	MIN	1.5	1.6	0.5	1.1	0.6	0.8	0.6	
	MAX	3.1	3.3	2.9	2.8	2.6	2.7	2.6	

[a]Stubble fertilized 13 years (1965-77)

APPENDIX 4.3

MINIMUM AND MAXIMUM WHEAT STRAW YIELDS[a] (t/ha) IN THE MUNICIPALITIES OF MONTCALM, RHINELAND AND ROLAND

SOIL ZONE		MONTCALM		RHINELAND		ROLAND	
		FF	SF	FF	SF	FF	SF
C	MIN	1.8	1.7	2.4	1.8	1.2	1.2
	MAX	4.8	3.6	4.3	3.9	4.2	3.9
D	MIN	1.7	1.7	2.1	2.1	1.2	1.5
	MAX	4.3	3.6	4.8	3.6	4.3	3.3
E	MIN	1.2	1.1	1.5	1.8	1.2	1.0
	MAX	4.9	3.7	4.5	3.3	4.0	3.1

[a] 15 year yield data (1963-77)

APPENDIX 4.3.1

MINIMUM AND MAXIMUM OAT AND BARLEY STRAW YIELDS[a] (t/ha) IN THE MUNICIPALITIES OF MONTCALM, RHINELAND AND ROLAND

SOIL ZONE		OATS			BARLEY		
		MONTCALM	RHINELAND	ROLAND	MONTCALM	RHINELAND	ROLAND
C	MIN	1.8	2.1	2.3	1.1	1.6	1.2
	MAX	3.7	3.9	3.4	3.1	3.4	3.1
D	MIN	1.6	2.2	2.0	1.2	1.5	1.0
	MAX	3.4	3.7	3.4	3.4	3.4	2.7
E	MIN	1.6	2.3	1.6		1.0	0.4
	MAX	3.4	3.7	3.3		3.0	2.7

[a]Stubble fertilized 15 years (1963-77)

APPENDIX 4.4

MINIMUM AND MAXIMUM WHEAT, OATS AND BARLEY STRAW YIELDS (t/ha) IN THE MUNICIPALITIES OF STANLEY AND THOMPSON

SOIL ZONE		WHEAT				OATS[a]		BARLEY[a]	
		STANLEY		THOMPSON		STANLEY	THOMPSON	STANLEY	THOMPSON
		FF	SF	FF	SF				
C	MIN	1.5	2.1			2.2		1.6	
	MAX	4.0	3.4			3.9		3.2	
D	MIN	2.3	2.1	1.5	1.2	2.1	2.1	1.6	1.2
	MAX	3.9	3.6	3.9	3.7	3.6	3.1	3.0	2.9
E	MIN	2.2	2.1	2.1	1.7	2.1	1.8	1.9	0.7
	MAX	3.9	3.6	3.9	3.6	3.3	3.1	3.3	2.7

[a] Stubble fertilized 15 years (1963-1977)

APPENDIX 4.5

MINIMUM AND MAXIMUM WHEAT, OATS AND BARLEY STRAW YIELDS[a] (t/ha) IN THE MUNICIPALITY OF PORTAGE LA PRAIRIE

SOIL ZONE		WHEAT		OATS	BARLEY
		FF	SF	SF	SF
A	MIN	3.1	2.4	2.5	1.4
	MAX	4.2	3.9	3.9	2.0
B	MIN	2.6	1.8	2.1	1.1
	MAX	4.3	3.9	3.7	2.0
C	MIN	2.2	1.9	2.0	1.0
	MAX	4.2	3.7	3.4	2.2

[a]Yields for 1963-77