Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada

Opportunities for Reduced Non-Renewable Energy Use in Canadian Prairie Agricultural Production Systems

August 2001

Canada

OPPORTUNITIES FOR REDUCED NON-RENEWABLE ENERGY USE IN CANADIAN PRAIRIE AGRICULTURAL PRODUCTION SYSTEMS

Agriculture and Agri-Food Canada

August 2001

Prepared by:

Ravinderpal S. Gill
Agriculture and Agri-Food Canada,
Research and Analysis Directorate, Strategic Policy Branch,
Building 74, Central Experimental Farm,
960 Carling Avenue, Ottawa, ON K1A OC6

Cecil N. Nagy
Canadian Agricultural Energy End-Use Data and Analysis Centre,
51 Campus Drive, University of Saskatchewan, Saskatoon, SK S7N 5A8

Robert P. Zentner
Agriculture and Agri-Food Canada, Semi-arid Prairie Agricultural Research Centre,
Box 1030, Swift Current, SK S9H 3X2

Andre Hucq
Canadian Agricultural Energy End-Use Data and Analysis Centre,
51 Campus Drive, University of Saskatchewan, Saskatoon, SK S7N 5A8

Robert J. MacGregor
Agriculture and Agri-Food Canada,
Research and Analysis Directorate, Strategic Policy Branch,
Building 74, Central Experimental Farm,
960 Carling Avenue, Ottawa, ON K1A OC6

Martin H. Entz
Department of Plant Sciences, University of Manitoba,
222 Agriculture, Winnipeg, MB R3T 2N2

John C. Giraldez
Agriculture and Agri-Food Canada, Environment Bureau, Strategic Policy Branch,
930 Carling Avenue, Ottawa, ON K1A OC5

OPPORTUNITIES FOR REDUCED NON-RENEWABLE ENERGY USE IN CANADIAN PRAIRIE AGRICULTURAL PRODUCTION SYSTEMS

Project Team:

Agriculture and Agri-Food Canada
    Policy Branch
        Research and Analysis Directorate (R&A)
        Environment Bureau (EB)
    Research Branch
Semi-arid Prairie Agriculture Research Centre
Canadian Agricultural Energy End-Use Data and Analysis Centre
Department of Plant Sciences

Edited by:

Betty Lorimer

To obtain additional copies, contact:

Information Production and Promotion Unit
Research and Analysis Directorate
Strategic Policy Branch
Agriculture and Agri-Food Canada
Building 74, C.E.F.
Ottawa, Ontario
K1A 0C6
Tel: (613) 759-1865
Fax: (613) 759-7090
E-mail: ippdist@em.agr.ca

Electronic versions of Research and Analysis Directorate publications are available on the Internet at: www.agr.ca/policy/epad

Publication 2082/B

ISBN 0-662-65881-7

Catalogue A22-225/2001

Project 01-047-r

Aussi disponible en français sous le titre de :
POSSIBILITÉS DE RÉDUCTION DE LA CONSOMMATION D'ÉNERGIE NON RENOUVELABLE DANS LES SYSTÈMES DE PRODUCTION AGRICOLE DES PRAIRIES CANADIENNES

Table of Contents

List of Tables and Figures

Tables

Tables – Appendix A

Tables – Appendix B

Tables – Appendix C

Figures

Acronyms

AAFC	Agriculture and Agri-Food Canada
BAU	Business as usual
CAEEDAC	Canadian Agricultural Energy End-Use Data and Analysis Centre
CRAM	Canadian Regional Agricultural Model
GHG	Greenhouse gas
ha	Hectare
MJ	Mega-joules
MTB	Medium Term Baseline
PCEM	Prairie Crop Energy Model
PERD	Panel on Energy Research and Development
PMP	Positive mathematical programming
TJ	Tera-joules

Executive Summary

This report identifies opportunities to reduce non-renewable energy use in Canadian prairie agriculture. Natural Resources Canada, through the Panel on Energy Research and Development (PERD) program coordinates energy research and development in co-operation with the Research Branch of Agriculture and Agri-Food Canada (AAFC). One of the objectives of the Panel's program is to increase energy use efficiency in the agri-food sector.

The main objective of this project was to develop a methodology to estimate and compare non-renewable energy inputs, energy outputs, and energy use efficiency from six crop production technologies and practices in the Canadian Prairies: enhanced nitrogen use efficiency, increased use of zero tillage, decreased use of summerfallow area, the inclusion of more forage in crop rotations, a 10% improvement in the fuel efficiency of farm machinery, and crop diversification and extension. The scope of this report was limited to estimating the macro-level impacts on energy use in the Canadian Prairies that would result from greater use of these practices. Macro-level analysis aggregated farm-level information on energy use to a regional basis (e.g. soil zone, agroecosystem, or prairie-wide).

The Canadian Regional Agricultural Model (CRAM), developed by the Policy Branch of AAFC was used to estimate the impact on energy given the changes (i.e. level and areas of adoption and economic impact) for the production technologies under study. The Prairie Crop Energy Model (PCEM) was developed as a module for CRAM to capture the regional impacts of different technologies on non-renewable energy use. The models were calibrated for the base year 1996 and subsequently used to estimate energy use, energy output and energy use efficiency levels for the year 2010 which provided the comparative business as usual (BAU) baseline.

Total energy use for the Prairies in 1996 was estimated at 171,090 tera-joules (TJ). Fertilizer use represented 51% of the total, fuel 28%, seed 10%, machinery 6% and herbicides 5%. Total energy output at the prairie level was estimated at 620,540 TJ. Energy use efficiency, which is the ratio of energy output to energy input, was 9.5 units for the Prairies.

Total energy use for the Prairies in 2010 was estimated to be 192,000 TJ—an increase of 21,000 TJ (12%) from the 1996 baseline. Total energy output at the prairie level was estimated to be 1,985,000 TJ—an increase of 364,000 TJ (23%) from 1996. The energy use efficiency ratio increased from 9.5 to 10.4 units for the Prairies. The highest energy use efficiency ratios were

for the Brown soil zones of Saskatchewan and Alberta at 12.6 and 12.0, respectively. Energy input and energy output increased for all soil zones due to the increase in cropped area and the reduced use of summerfallow.

Six scenarios were analyzed to test the possible effect of production trends, technology and policy measures on energy use in prairie agriculture relative to the 2010 BAU baseline. Nitrogen fertilizer use as influenced by the mix of crops grown and summerfallow area were the main determinants of energy use and energy use efficiency. With enhanced nitrogen use efficiency, energy input for the Prairies decreased 7,090 TJ (3.7%) from the 2010 BAU baseline. The reduction in energy use from the crop sector is due to lower nitrogen fertilizer use.

Increased use of zero tillage to double the baseline levels resulted in a reduction of energy input of 2,270 TJ (1.0%) on the Prairies. Energy input for fertilizer and herbicides increased but energy input for fuel and machinery decreased resulting in a reduction in energy input across all soil zones. Total energy output also decreased 8,060 TJ, resulting in an improvement in the energy use efficiency ratio of 0.08 units. Herbicide energy use, the highest of all the scenarios, is directly related to the use of zero tillage as herbicides are substituted for the tillage.

Decreased use of the summerfallow area resulted in an increase in energy use of 3,790 TJ (2.0%) from the 2010 BAU baseline. This increase is due to the increased use of fertilizer and pesticides, which increased in proportion to the increase in seeded area. However, the Brown soil zone had reduced energy use as more land went into forage and reduced the annual crop area and the associated crop inputs, especially nitrogen fertilizer.

The largest reduction in energy use, the largest increase in energy output and the largest increase in energy use efficiency occurred with the inclusion of more forage in crop rotations. For this scenario, total energy input for the Prairies decreased 9,830 TJ (5.1%) from the 2010 BAU baseline. Total energy output increased 251,680 TJ resulting in an improvement in the energy use efficiency ratio of 1.9 units. The decrease in energy use from the crop sector is due to the lower use of crop production inputs—such as fertilizer, fuel, machines and chemicals—as forage area is increased (a less intensive farming system).

A 10% improvement in the fuel efficiency of farm machinery would result in a savings in energy input of 4,460 TJ (2.3%) on the Prairies. Total energy output would increase slightly by 540 TJ resulting in an improvement in the energy use efficiency ratio of 0.25 units. Energy use reduction is proportionally more for the higher yield production areas—the Black soil zone—and for fossil fuel intensive management systems—conventional tillage. But overall, no significant change from the 2010 BAU baseline was detected in the area under the different tillage management practices.

The energy input for the Prairies would decrease 1,000 TJ (0.6%) from the 2010 BAU baseline under crop diversification. Energy use would be reduced for the Dark Brown, Black and Gray soil zones of Saskatchewan. The reduction in nitrogen fertilizer use tends to offset the higher herbicide, machine and fuel energy for these regions. Energy use would increase for the Brown soil zone as more stubble crops were grown, the area of summerfallow would decrease, and land would be taken out of forage production.

Increased adoption of zero tillage and a 10% increase in the fuel efficiency of farm machinery were two scenarios that would result in decreased energy use, primarily through the reduction in fuel use. These two scenarios have the potential to offset the increased energy use as the summerfallow area declines.

Policy measures and production trends did not always result in the same response or the same magnitude of response across all soil zones. These varied responses have implications for the policy development and implementation of on-farm energy-reducing strategies as soil zone characteristics are taken into consideration.

Policies that reduce summerfallow area would increase energy use if they are not combined with management practices that reduce energy use. Zero tillage and enhanced nitrogen use efficiency are two management practices that can partly offset increased energy use resulting from decreased summerfallow area. Policies that increase forage area and expand livestock production would have the largest negative effect on energy use as summerfallow area would decline and land would be taken out of annual crop production.

With improvements in the fuel efficiency of farm machinery and the expanded use of zero tillage management practices, direct fossil fuel use can be decreased. The case for zero tillage lowering fuel consumption has been documented in this report and in other studies.

Policies designed to encourage crop diversification, especially of nitrogen fixing crops, would decrease the demand for commercial nitrogen fertilizers. However, the extent to which land is taken out of forage production would dictate the net energy savings. Any change in policy or management practice that reduces nitrogen fertilizer use would have the largest impact on total energy use due to the high energy demand associated with the manufacture of nitrogen fertilizer.

This report identifies opportunities that are available to reduce non-renewable energy use in cropping systems in Canadian Prairie agriculture. Total energy use for the Prairies in the 2010 BAU scenario would increase 12.0% from the 1996 baseline. A net reduction in energy use of 12.7% would be possible by wider adoption of the practices which reduce net energy inputs.

However, policy makers should take into account the economic effects as well as the effects on soils, greenhouse gas emissions, water quality, biodiversity and rural communities that the changes in farm practices would produce. Although this report focused on energy use on the Canadian Prairies as this was the scope defined for this project, other economic and environmental indicators need to be incorporated to provide more comprehensive assessment of the impact on the agricultural sector.

Section 1: Introduction

1.1 Background

Land use practices are changing, especially on the Canadian Prairies. Changes in grain transportation policies and other government support, rising costs for farm inputs, new technologies, new markets, value-added opportunities, growing concerns about environmental degradation, and weak markets—all contribute to this change. Producers are extending and diversifying their crop rotations, thereby becoming less reliant on summerfallow and mono-culture cereal cropping. The areas planted to crops such as canola, linola, mustard, field peas, chickpeas, lentils, beans and sunflower have expanded dramatically in recent years, often into new or non-traditional production regions. There is renewed interest in legume green manure, perennial grass, and legume forage for livestock feed and forage seed production to help restore soil productivity and as a means to reduce inorganic fertilizer inputs in subsequent cereal crops. Further, the use of conservation tillage management practices, coupled with new methods of integrated pest management, improved methods of fertilizer placement, precision farming, reduced chemical input techniques, use of livestock manure, and other land management practices are becoming integral components of the changing production systems.

New cropping systems provide at least eight potential advantages:

- reduced weed infestations or reduced potential for build-up of herbicide resistant weeds through the use of a broader selection of herbicide options
- reduced incidence of diseases that are common with mono-culture cereals (e.g. common root rot, leaf spotting diseases)
- reduced requirements for nitrogen fertilizer particularly for those systems that include legumes
- improved soil fertility and quality because of less summerfallow and reduced soil tillage
- higher yields of subsequent cereal crops and improved grain quality (e.g. higher protein levels or reduced downgrading due to disease)
- lower requirements for fossil fuels and reduced emissions of greenhouse gases

- higher economic returns, lower unit costs of production, and/or reduced financial risk.

For new production systems to be sustainable in the long term, they must meet three criteria:

- be technically feasible (i.e. suited to the soil and climatic conditions of the area, practical to implement, and capable of producing an acceptable quantity and quality of grain or forage).
- ensure that the quality of the soil, water and air resources are maintained or enhanced over the long term.
- be economically viable and socially acceptable.

Considerable research has been completed, or is underway, to study the agronomic performance of new production systems. However, less is known about their environmental impacts and even less about their economic impacts.

Past research shows that up to 70% of the non-renewable energy used in mono-culture cereal cropping systems on the Prairies is attributable to inorganic fertilizers, particularly nitrogen. Furthermore, fertilizer use efficiency is often less than 50% (Campbell and Paul 1978, Gauer et al. 1992), which contributes to the growing concern about environmental contamination (e.g. the run-off losses into surface waters and the leaching of nitrates into ground water). Also, although continuous cereal cropping systems produce significantly more energy output (i.e. grain, biomass, protein, etc.) than less intensive summerfallow systems (i.e. summerfallow, wheat), these latter systems often have lower energy use efficiency ratios (energy output/energy input) (Zentner et al. 1998, Zentner et al. 1999). In addition, although conservation tillage methods (zero and minimum tillage) use less on-farm fuel and machinery inputs than conventional tillage methods, they are usually more dependent on herbicide and fertilizer inputs.

Most studies suggest that the energy savings associated with direct seeding are highly dependent on obtaining increased yields and improvements in water and fertilizer use efficiency compared to conventional production systems. Soil carbon sequestration tends to be higher and carbon dioxide release to the atmosphere tends to be lower for extended cropping systems, particularly those that use conservation tillage.

The greatest opportunities for reducing energy inputs and greenhouse gas emissions in Canadian prairie agriculture involve cropping systems that are less dependent on inorganic nitrogen fertilizer inputs such as those that include pulses, forages or green manure legumes, those that effectively utilize livestock manure, and those that use production practices that improve water and nutrient use efficiency. There may also be an opportunity or rationale to use some of the agricultural biomass production and by-products for value-added activities that sequester carbon (e.g. strawboard where fibre straw is a substitute for wood pulp) or for the production of bio-fuels and ethanol. By further substituting primary agricultural production opportunities for non-renewable energy forms, environmental sustainability is improved.

This report provides information for prairie producers, policy analysts and the general public about the relative environmental (and economic) performance of new crop production systems and their impact on non-renewable energy use efficiency. The scope of this report and the identification of opportunities for improving energy use efficiency will be limited by considering only production practices that are currently economical. The focus of the report is on the macro-level analysis and impacts.

The report uses a multi-agency, multi-disciplinary approach and it captures existing databases and knowledge at Agriculture and Agri-Food Canada's (AAFC) Research Centres, the Department of Plant Sciences at the University of Manitoba, and the Canadian Agricultural Energy End-Use Data and Analysis Centre (CAEEDAC) at the University of Saskatchewan.

1.2 Objective

The objective of the report is to develop a methodology to estimate and to compare non-renewable energy inputs, energy outputs, and energy use efficiencies of six management practices on the Prairies:

- enhanced nitrogen use efficiency
- increased use of zero tillage
- decreased use of summerfallow area
- inclusion of more forage in crop rotations
- a 10% improvement in the fuel efficiency of farm machinery
- crop diversification.

A critical aspect of recommending management practices that reduce fossil fuel use for the Prairies is the appropriateness of extending site-specific results to different soil zones and climatic regions and predicting their micro- and macro-level impacts. Selecting these six management practices has two important advantages given the short time period of the report:

- we have existing and extensive databases covering all major agro-ecological zones within the Prairies.
- we have a good knowledge of the current cropping systems and examples of farm-level adoption of newer practices which can be used to predict the socio-economic and environmental impacts from the widespread adoption of these management practices.

Although this report focuses on energy use on the Canadian Prairies, other economic and environmental indicators would have to be incorporated to understand the full impact on the agricultural sector. The impact of these new crop production technologies on economic performance, greenhouse gas emissions, soils and other environmental or social outcomes were beyond the scope of this report.

1.3 Organization of the Report

The report has six sections. Section 2 provides an overview of the models used for the estimation of energy use. Sections 3 and 4 describe the 1996 baseline and 2010 BAU baseline to compare the proposed scenarios. Section 5 describes the scenarios and summarizes the results. Section 6 presents the key findings, the limitations of the report and the policy implications. The report concludes with a list of references and three appendices.

Section 2: Models for the Estimation of Energy Use

2.1 Micro-level Analysis

The micro-level analysis provided the economic/agronomic representative farm-level data which are exogenous to the macro-level analysis. The experimental data, which are small-plot and site-specific, were extrapolated to the farm level using representative farms for those soil-climatic regions or agro-ecosystems to which the management practices have application. These data were used as input into CRAM and to modify its structure to include additional crops.

Crop inputs, field operations (use of farm machinery) and yield data from field experiments conducted by AAFC Research Centres and the University of Manitoba were used for the micro-level analysis (Agriculture and Agri-Food Canada 1999b). Several sites and four soil zones were used in the micro-level analysis:

- Swift Current, SK for the Brown soil zone
- Lethbridge, AB and Scott, SK for the Dark Brown soil zone
- Melfort, SK, Indian Head, SK and Glenlea, MB for the Black soil zone
- Tisdale, SK and Rycroft, AB for the Gray soil zone.

A field-level process analysis was used in the micro-level energy evaluations. This analysis involved identifying all the direct and indirect non-renewable energy inputs going into the production and the on-farm transport of the saleable products for each production system or management practice (e.g. types and frequencies of field operations performed; types, amounts and application methods for fertilizers, herbicides and insecticides; and crop yields and grain protein obtained).

The physical quantities of the production inputs were converted to energy values using coefficients and parameters taken from the literature and several Canadian studies (Nagy 1999). The energy coefficients include all energy used in the materials and manufacture of the farm inputs plus transport to the farm gate. The production output was taken as the gross energy content of the grain or above-ground biomass. Energy efficiencies or intensities of the production systems were calculated as ratios of energy output to energy input, net energy produced (energy output minus energy input) and the quantities of grain and protein produced per unit of energy input. In addition, the net energy savings (i.e. imputed savings in nitrogen fertilizer, machine operations and other inputs) and increased crop yields for the alternative production systems were computed and compared to an appropriate check or benchmark system. The micro-level data were scaled to the farm level using representative farms typical of the soil zones within each province (Hoeppner 2000, Rossetti and Nagy 1999, Zentner et al. 2000).

2.2 Macro-level Analysis

The purpose of the macro-level analysis was to aggregate farm-level energy use to a regional basis (e.g. soil zone, agroecosystem, or prairie-wide). The findings from the macro-level analysis are used as the basis to formulate recommendations for three groups:

- producers regarding the adoption of particular production systems and technologies that are more environmentally and economical sustainable
- policy analysts as guidelines for development of public policies on energy use
- the general public as indicators of Canada's ability to meet its international commitments in reducing fossil fuel use and greenhouse gas emissions.

The Canadian Regional Agricultural Model (CRAM), developed by the Policy Branch of AAFC was used to estimate the impact on energy given the changes (i.e. level and areas of adoption and economic impact) for the six management practices under study. The Prairie Crop Energy Model (PCEM) was developed as a module for CRAM to capture the regional impacts of different management practices on non-renewable energy use. The economic findings and performance indicators from the micro-level analysis were used primarily to revise and to modify the production activities contained in CRAM. An overview of the integrated model is provided in Figure 1.

Canadian Regional Agricultural Model

CRAM is a sector equilibrium model for Canadian agriculture which is disaggregated across both commodities and space (Horner et al. 1992). It is static in nature—when a change is introduced, CRAM solves for the new equilibrium position but does not trace the time path required to get there. CRAM is a nonlinear, optimization model maximizing producer surplus plus consumer surplus less transport costs. It allows for both inter-provincial and international trade in primary and processed products. It covers seven basic commodities: grains, oilseeds, forage, beef, hogs, dairy and poultry (horticulture is excluded). Government policies are incorporated directly through payments and indirectly through policies such as supply management and subsidized input costs. Spatial features of the model include livestock and crop production at the provincial level, except for crop production in the three prairie provinces. They are divided into 22 regions based on the crop district boundaries of Statistics Canada (Figure 2).

Figure 1: Overview of the Integrated Model

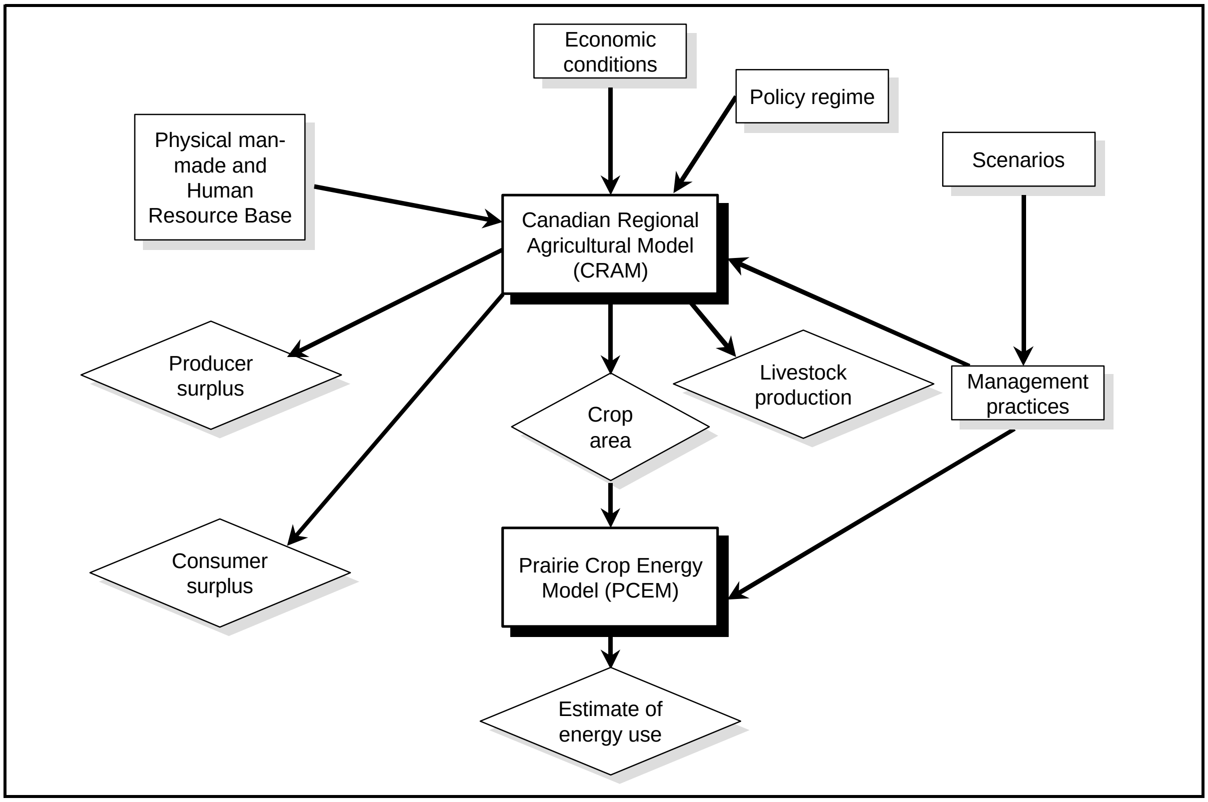
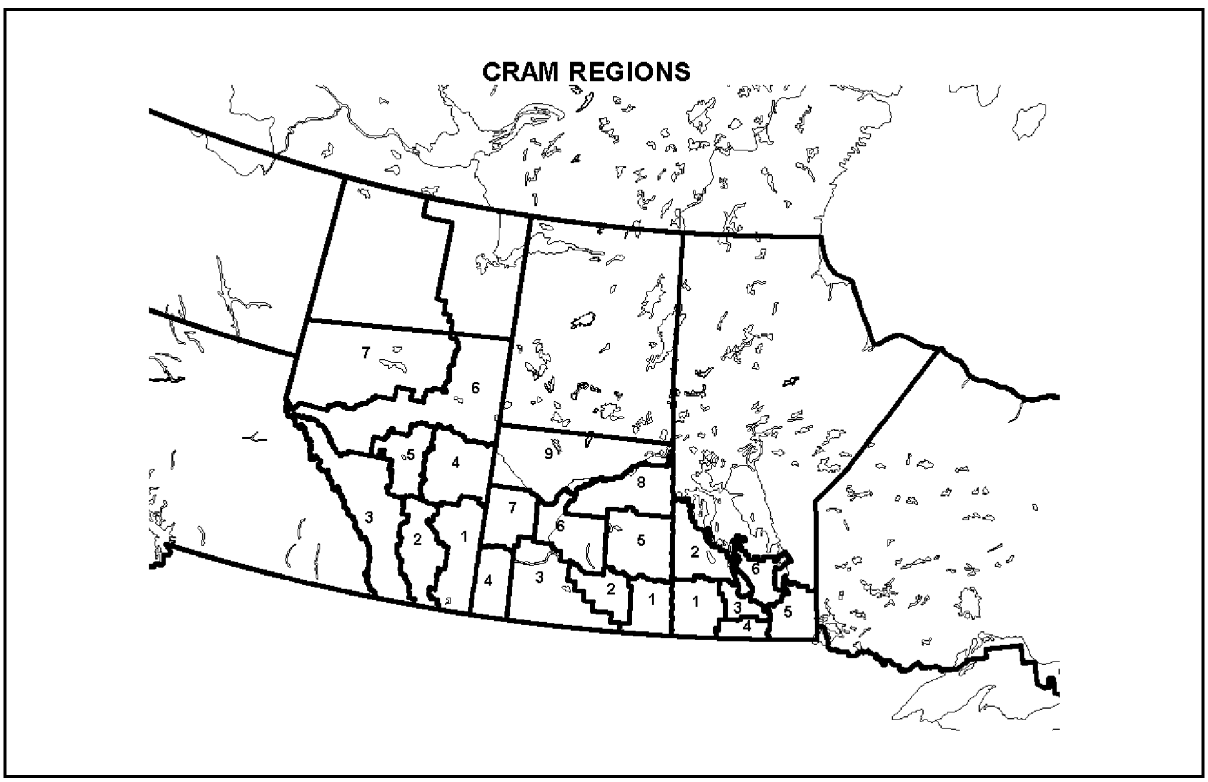


Figure 2: Prairie Crop Production Regions in CRAM



CRAM is referred to as a positive mathematical programming (PMP) model. Through a calibration process, artificial constraints are eliminated and management practices, represented by a fixed input mix, are replaced by upward-sloping supply relationships (Howitt 1995). Grain, oilseed and forage areas are determined by changes in the relative profitability of the alternative cropping options. CRAM essentially duplicates the observed allocation of a fixed and allocatable resource (land) by positioning an unobserved marginal cost curve to ensure that the classic conditions for constrained profit maximization are obtained. The marginal value product less the marginal cost for each output must equal the return to the fixed and allocatable resource (land). At the margin, the return to land for each crop produced is similar.

The critical advantage of using the PMP methodology is that it allows the removal of artificial constraints that characterize traditional linear programming optimization models. The only constraint on crop production is the total amount of land available in each region. The PMP methodology has also been incorporated into the beef and hog components of CRAM so that the production of these commodities reacts to the changes in prices, input costs (e.g. feed grains) and quantity of feedstock as impacted by the cropping mix.

Prairie Crop Energy Model

The objective of the PCEM is to estimate aggregate energy outputs, energy inputs and energy efficiencies using the representative farm-level data. The PCEM consists of an energy production vector that describes the energy output and energy input from a crop and its related production process. Net production of energy (energy output minus energy input) can be either positive or negative. The PCEM multiplies the aggregate hectares and the related production process of a specific crop by an energy coefficient. The energy coefficient is a representative measure of the energy output or the energy input per hectare for a specific crop and its related production process in a specific region. Energy efficiencies or intensities of the production system are calculated as the ratios of energy output to energy input.

The available cultivated area is allocated to 122 cropping activities for each of the 22 CRAM regions on the Prairies in the PCEM. The cropping activities include the eight major grain crops, plus summerfallow, alfalfa, hay and three “other” categories for pulses, oilseeds and other annual crops that are new or limited in area. Each cropping activity can be produced by one of three tillage management practices (conventional, minimum or zero tillage) and each can be grown after summerfallow, cereal, pulses, oilseeds, alfalfa, hay or green manure. However, not all combinations of the crop/tillage/previous activity are included as cropping activities in all CRAM regions for agronomic reasons. See Appendix A, Table A6 for a complete list of the cropping activities.

The input costs, energy used and yields per hectare that were generated from the farm-level analysis were used to develop the energy coefficients and parameters in the PCEM for the 122 cropping activities in each soil zone in each province. Where no data were available from the farm-level analysis, cropping activities were generated by taking similar activities and adjusting the coefficients to be compatible with that soil zone. Adjustments were made based on the marginal change in energy use for the machine and fuel coefficients due to a change in the yield (see Appendix A). These marginal coefficients were then multiplied by the percentage change in yield and added to the energy coefficient. Fuel cost was adjusted by adding, to the cost of the fuel, the change in energy multiplied by the dollar value of a mega-joule of energy used in conventional, minimum or zero tillage.

Crop production cost data from the provincial agriculture departments were used as guides in developing some of the cropping activities. Crop district energy coefficients and yield and input costs were developed from the percentage of soil zone type in each district. (See Appendix A, Tables A1, A2 and A3 for the soil zone percentages used to develop the crop district coefficients). Data from the 1996 Census of Agriculture and the 1995 crop area survey were used for the logical splits in the area allocated to the cropping activities for the 1996 baseline. Also, 1996 Census data were used as a consistency check for the crop expenditures on fertilizer, herbicides and fuel, which in turn were used as a consistency check on the amount of energy used at the crop district level.

Section 3: The 1996 Baseline Estimates

3.1 Micro-level Estimates

Five observations were evident from the micro-level analysis for the Prairies as a whole. The highest gross energy output were (in decreasing order) the Black, Gray, Dark Brown and Brown soil zones (Table 1). This output reflects the higher productivity as moisture is not as limiting as one moves from the Brown soil zone to the Black soil zone. Energy input tends to increase from the Brown soil zone to the Black soil zone due to the increase in nitrogen fertilizer, greater use of tillage and less summerfallow. Also, energy use increases due to the increased use of nitrogen fertilizers with Saskatchewan having the lowest nitrogen use and Manitoba the highest. Inclusion of a pulse or forage crop in the crop rotation reduces the energy input because little or no nitrogen fertilizer is used. Zero tillage increases herbicide and fertilizer energy use which tends to offset much of the savings in machine and fossil fuel use.

3.2 The Canadian Regional Agricultural Model Estimates

CRAM was calibrated to the 1996 Census of Agriculture information for the reported levels of cropping and livestock production activities. Total agricultural land on the Prairies (excluding unimproved pasture or rangeland) was 38 million hectares—31 million hectares (81%) were cropland, seven million hectares were hayland and improved pasture, and six million were summerfallow.

Tillage practices were estimated using the 1996 Census of Agriculture to determine regional distributions of conventional, minimum, and zero tillage. The areas of major crops grown on the Prairies are shown in Table 2. Cereal and oilseed crops dominate two thirds of the total cropland area. Although speciality crops such as lentils and field peas are increasing in area, they constituted a small proportion (2.4%) of the total cropland in 1996.

3.3 The Prairie Crop Energy Model Estimates

Total energy use for the Prairies in 1996 was estimated at 171,090 tera-joules (TJ) (Table 3). Fertilizer use represented 51% of the total, followed by fuel at 28%. Seed, machinery and herbicides represented 10%, 6% and 5%, respectively, of the total energy use in 1996. Total energy output was estimated at 1,620,540 TJ. Energy use efficiency, which is the ratio of energy output to energy input, was 9.5 units for the Prairies.

Table 1: Farm-Level Cropping System Energy by Crop Rotation (MJ ha^{-1})

Soil	Crop Rotation	Tillage[a]	Input[b]	Output[c]	Ratio[d]
Brown	Fallow–wheat	I	2,469	22,538	9.1
		M	2,464	21,625	8.8
		N	2,818	21,342	7.6
	Fallow–wheat–wheat	I	3,453	26,538	7.7
		N	3,833	25,708	6.7
	Green manure–wheat–wheat	I	3,804	24,944	6.6
	Continuous wheat	I	4,861	34,674	7.1
	Fallow–lentils–wheat	I	3,054	23,074	7.6
		N	3,383	23,918	7.1
Dark Brown	Fallow–wheat	I	2,290	27,519	12.0
	Fallow–wheat–wheat	I	3,267	30,321	9.3
	Fallow–canola–wheat–barley–hay–hay	I	2,818	32,854	11.7
	Fallow–wheat–wheat–alfalfa–alfalfa	I	2,312	30,512	13.2
	Fallow–canola–wheat	I	2,859	28,039	9.8
	Fallow–canola–wheat	N	3,297	22,945	7.0
	Green manure–wheat–wheat	I	2,626	20,847	8.0
Black	Canola–barley–peas–wheat	I	7,669	57,914	7.6
		M	7,486	58,348	7.8
		N	7,288	59,831	8.2
	Canola–wheat–barley–barley	I	8,887	61,817	7.0
		M	8,714	63,239	7.3
		N	8,436	60,422	7.2
	Canola–peas–flax–barley	I	6,837	49,558	7.2
		M	6,662	47,483	7.1
		N	6,465	50,306	7.8
	Wheat–flax–winter wheat–peas	I	7,543	43,435	5.8
		M	7,669	45,447	5.9
		N	7,504	44,573	5.9
	Wheat–alfalfa–alfalfa–flax	I	4,167	75,667	18.1
	Continuous wheat	N	7,336	37,591	5.1
			9,325	49,699	5.3
	Fallow–wheat–wheat–hay–hay–hay	I	3,818	88,767	23.2
Gray	Canola–barley–peas–wheat	I	8,789	52,666	6.0
		M	8,303	50,845	6.1
		N	8,168	48,000	5.9
	Canola–peas–flax–barley	I	8,118	42,969	5.3
		M	7,632	41,574	5.4
		N	7,496	38,495	5.1
	Fallow–canola–wheat–barley	I	6,191	26,100	4.2
		N	6,162	27,619	4.5

a. Tillage systems: I—conventional, M—minimum, N—zero tillage.
b. Input energy is fertilizer, herbicide, fuel and embodied machine energy averaged over the crop rotation.
c. Output energy is the yield-seed multiplied by the gross energy content of the grain as measured by laboratory bomb calorimeter tests averaged over the crop rotation.
d. Ratio is a measure of energy efficiency calculated as the output energy divided by the input energy.

Source: Agriculture and Agri-Food Canada Research Centres at Indian Head, Melfort, Scott, Swift Current and Tisdale, Saskatchewan and Lethbridge and Rycroft, Alberta; also, University of Manitoba research plots at Glenlea, Manitoba.

Table 2: 1996 Baseline: Activity Levels

1996 Baseline Activity Levels ('000' ha)										
	Alberta				Saskatchewan				Manitoba	Prairies
Soil Type	Brown	Dk Brown	Black	Gray	Brown	Dk Brown	Black	Gray	All	All
Summerfallow	492.25	435.23	271.81	233.67	1,668.31	1,506.74	923.45	296.46	322.46	6,150.38
Wheat	519.57	827.15	758.44	520.27	1,344.75	1,964.98	1,686.57	640.15	1,639.55	9,901.43
Durum	154.06	133.22	25.83	6.53	864.51	636.95	173.52	9.47	58.84	2,062.93
Barley Feed	124.01	438.19	782.23	642.15	166.53	387.71	635.05	342.49	477.36	3,995.73
Barley Malt	45.11	137.72	120.91	61.64	33.18	103.23	184.45	60.85	157.37	904.48
Oats	55.39	88.93	186.41	232.07	91.76	201.76	435.06	156.16	426.63	1,874.16
Flax	1.85	6.00	3.52	2.51	15.63	129.17	158.94	43.96	232.29	593.88
Canola	93.50	321.26	427.67	438.20	105.86	454.64	663.81	347.49	641.40	3,493.83
Lentils	4.56	2.83	0.10	0.00	77.91	156.13	35.45	2.71	15.95	295.64
Field Peas	4.65	27.82	40.81	42.78	24.61	99.89	146.60	87.41	58.63	533.19
Hay	139.56	228.98	587.39	975.65	198.82	264.07	410.71	218.04	753.48	3,776.70
Other Pulses	8.80	4.57	0.04	0.03	2.48	2.26	0.39	0.01	34.81	53.38
Other Oilseeds	14.23	17.62	8.97	0.94	49.38	99.15	64.01	13.17	30.43	297.89
Other Cereals	43.13	44.25	72.65	96.78	99.39	145.92	103.08	44.73	161.94	811.87
Improved Pasture	253.83	308.72	587.22	764.83	360.15	300.03	381.08	192.04	356.24	3,504.15
Unimproved Pasture	2,271.45	1,161.14	1,773.87	1,409.05	89.38	757.48	1,109.96	534.49	1,653.83	10,760.66

Source: CRAM

Table 3: 1996 Baseline: Energy Input, Energy Output and Energy Efficiency

1996 Baseline Energy Use Levels ('000' TJ)										
	Alberta				Saskatchewan				Manitoba	Prairies
Soil Type	Brown	Dk Brown	Black	Gray	Brown	Dk Brown	Black	Gray	All	All
Energy Input	5.38	13.23	19.17	17.93	12.76	23.52	30.80	13.68	34.62	171.09
Energy Output	57.47	123.21	188.62	195.84	140.60	225.76	274.39	119.53	295.12	1,620.54
Energy Efficiency	10.67	9.31	9.84	10.92	11.02	9.60	8.91	8.74	8.52	9.47

Source: PCEM

Section 4: The 2010 Business as Usual Baseline Estimates

4.1 The Canadian Regional Agricultural Model Estimates

The primary agriculture activity levels used in the 2010 business as usual (BAU) baseline of CRAM are based mainly on the Medium Term Baseline (MTB) as outlined in Agriculture and Agri-Food Canada 1999a. The MTB provides a policy baseline to 2007 under three assumptions:

- stable world macroeconomic and political conditions
- normal weather patterns
- the status quo in the international and domestic policy environments.

The levels of crop and livestock activities were projected to 2010 based on historical trends and the MTB. Estimates of land management practices (summerfallow use and distribution of tillage practices) were based on information from the 1981, 1986, 1991 and 1996 Census of Agriculture.

Eight assumptions were made in constructing the 2010 BAU baseline of CRAM:

- The land base for agricultural production was held constant at the 1996 level with regional distributions by crop based on the MTB.
- Yields for grain, oilseed and forage crops were increased based on the historical trends to reflect improvements in technology from research and development.
- Costs of production were increased based on the Farm Input Price Index projection.
- Transportation costs were indexed forward based on the MTB.
- Nitrogen fertilizer use in Western Canada was increased 25% over 1996 levels.
- The proportion of prairie crops under zero tillage was projected to be 30% but this proportion varies considerably across the Prairies.

- The amount of cropland in summerfallow was five million hectares.
- Commodity prices (crops and livestock) were based on the MTB.

In addition to these eight assumptions, some adjustments were made in CRAM to obtain an optimal solution with the appropriate activity levels for crop and livestock production. As the forage supply generated by CRAM was not sufficient to meet the demands of the increased beef herd, forage yields were increased an additional 10%. Also, the MTB estimates of relatively low beef and pork prices for 2010, combined with increased input costs, restricted beef and hog output below the MTB levels in CRAM. To remedy this lower level, beef and pork prices were increased 15% and 30%, respectively. Note that these changes have no impact on the estimated energy use since it is determined by the levels of crop production activities which are consistent with the MTB. A summary of the crop production activities for 2010 is presented in Table 4. Although total cropland does not increase, crop production increases significantly due to reduced summerfallow and increased yields.

4.2 The Prairie Crop Energy Model Estimates

Total energy use for the Prairies in 2010 was estimated to be 192,000 TJ—an increase of 21,000 TJ (12%) from the 1996 baseline (Table 5). Total energy output was estimated to be 1,985,000 TJ—an increase of 364,000 TJ (23%). The energy use efficiency ratio was 10.4 units—an increase of 0.9 units. The Brown soil zones of Saskatchewan at 12.6 units and Alberta at 12.0 units had the highest energy use efficiency and a higher percentage of crop area devoted to forage. Energy input and energy output increased for all soil zones due to the increase in cropped area and reduced use of summerfallow area.

Table 4: 2010 BAU Baseline: Activity Levels

2010 BAU Baseline Activity Levels ('000' ha)										
	Alberta				Saskatchewan				Manitoba	Prairies
Soil Type	**Brown**	**Dk Brown**	**Black**	**Gray**	**Brown**	**Dk Brown**	**Black**	**Gray**	**All**	**All**
Summerfallow	405.72	353.44	187.32	156.06	1,394.21	1,234.00	702.04	198.21	170.36	4,801.37
Wheat	515.73	793.67	742.19	491.35	1,310.31	1,871.50	1,614.42	602.89	1,553.09	9,495.14
Durum	175.71	144.22	28.32	6.91	1,016.10	707.37	187.53	10.04	63.36	2,339.56
Barley Feed	73.08	192.19	359.51	375.17	71.07	75.45	219.15	158.76	278.23	1,802.61
Barley Malt	111.47	349.78	503.28	287.71	163.38	397.95	538.35	206.19	331.14	2,889.25
Oats	46.47	69.23	146.15	183.91	78.62	160.48	340.31	120.07	329.39	1,474.62
Flax	2.69	8.42	4.88	3.41	23.54	182.16	222.71	60.33	319.28	827.42
Canola	142.72	467.96	620.59	627.33	167.42	670.93	960.05	494.33	920.15	5,071.48
Lentils	4.63	2.74	0.31	0.14	80.44	152.09	37.39	5.36	15.09	298.19
Field Peas	8.52	48.87	71.50	74.83	44.04	178.16	256.23	150.34	101.63	934.12
Hay	146.55	226.62	587.11	975.62	215.42	265.65	402.40	210.51	738.97	3,768.86
Other Pulses	6.75	4.18	0.00	0.01	2.01	2.33	0.43	0.01	30.76	46.48
Other Oilseeds	11.30	15.41	3.32	0.36	65.35	94.84	51.71	11.98	23.80	278.07
Other Cereals	32.66	22.37	24.24	59.79	49.80	96.47	57.21	24.53	131.13	498.20
Improved Pasture	247.45	300.96	572.45	745.60	351.04	292.49	371.50	187.22	347.28	3,415.98
Unimproved Pasture	2,271.45	1,161.14	1,773.87	1,409.05	773.65	975.60	1,117.59	534.49	1,653.83	11,670.67

Source: CRAM

Table 5: 2010 BAU Baseline: Energy Input, Energy Output and Energy Efficiency

2010 BAU Baseline Energy Use Levels ('000' TJ)										
	Alberta				Saskatchewan				Manitoba	Prairies
Soil Type	**Brown**	**Dk Brown**	**Black**	**Gray**	**Brown**	**Dk Brown**	**Black**	**Gray**	**All**	**All**
Energy Input	6.05	14.69	21.47	20.14	14.02	25.95	34.59	15.28	39.51	191.72
Energy Output	72.76	154.58	239.84	238.91	176.22	277.96	334.52	144.54	345.48	1,984.80
Energy Efficiency	12.03	10.52	11.17	11.86	12.57	10.71	9.67	9.46	8.74	10.35

Source: PCEM

Section 5: Scenarios – Description, CRAM and PCEM Results

5.1 Enhanced Nitrogen Use Efficiency

Description

Research scientists recommend that improved efficiency can be achieved through the better management of nitrogen fertilizer. This improvement can, but does not necessarily, involve a reduction in fertilizer use. Improved efficiency can be achieved through changes in management practices or through an "environmental reduction" that takes into account the negative externalities related to nitrogen fertilizer use. In the short term, fertilizer efficiency could be increased by proper timing, proper placement, lower rate of application and precise control of fertilizers to match the crop requirements. Fertilizer efficiency will also increase as soil organic matter increases. Soil organic matter has a large capacity to store nutrients in available forms and to reduce the potential for nutrient losses due to leaching and erosion. Long-term gains in fertilizer efficiency should be associated with cropping systems, such as minimum tillage and direct seeding, that tend to increase soil organic matter over time.

Assumptions for this scenario are summarized in Table 6. Only one nitrogen fertilizer management practice is altered in this scenario from the 2010 BAU baseline—the elimination of the fall application of nitrogen.

Table 6: Assumptions for Enhanced Nitrogen Use Efficiency Scenario

Adoption Rate	Assume 100% adoption in 2010
Productivity	No crop yield impacts from increased nitrogen use efficiency
Input Use	Reduce fertilizer use by prescribed amounts (see Appendix B)
Cost of Production	Nitrogen fertilizer is 12% more costly in spring versus fall

In CRAM, fertilizer application on the Prairies is not separated into fall and spring applications. The imposed shock assumes that fertilizer application is currently split between the fall and the spring (i.e. 30/70) and with the elimination of the fall application, total fertilizer use can be reduced by the efficiency loss related to the fall application. In the CRAM 2010 BAU baseline, the quantity of nitrogen fertilizer use on the Prairies was increased 25% over 1996 levels to reflect that the nitrogen deficit situation cannot continue indefinitely. The reductions by crop district are indicated in Appendix B. The forecasted growth in nitrogen utilization for this scenario will be slightly lower with the elimination of the fall application than in the BAU baseline. To reflect that the cost of the spring fertilization is about 12% more expensive, the cost of fertilizer was adjusted (Appendix B) to indicate that all the fertilizer was purchased at the more expensive spring price (or in the fall but extra costs were incurred with storing the fertilizer over the winter).

CRAM Results

The scenario assumes a reduction in fertilizer use through the improved management of nitrogen fertilizer applied to the crops being grown on the Prairies. The impact of reducing nitrogen fertilizer use results in a slight shift in the crop mix in the different soil zones (Table 7). The real cost of fertilizer increases for the Dark Brown and Brown soil zones in Alberta and Saskatchewan as the increased cost of fertilizer is not offset by the increase in fertilizer use efficiency. The result is a shift away from cereal and oilseed crops to hay, field peas and summerfallow. Fertilizer use efficiency gains offset the cost increase in fertilizer for the Black and Gray soil zones. The areas for lentils, field peas, hay and summerfallow decrease while the areas planted to most cereal and oilseed crops increase. These results are as expected given the soil zone and climatic differences. For the Prairies, the areas for wheat, malting barley and canola increased 26,000, 16,000 and 14,200 hectares (0.3%, 0.5% and 0.3%), respectively, whereas the area for hay decreased 51,700 hectares (1.4%).

PCEM Results

Under the enhanced nitrogen efficiency scenario, the energy input for the Prairies decreased 7,090 TJ (3.7%) from the 2010 BAU baseline (Table 8). The reduction from the crop sector was due to the lower use of nitrogen fertilizer. The savings in energy input were in the Black soil zones of Manitoba, Saskatchewan and Alberta at 1,930, 1,440 and 840 TJ, respectively. Energy input decreased slightly for the Brown soil zone due to increased area for hay and field peas with less area for cereal. Also, more crops would be grown on summerfallow, reducing nitrogen energy use. However, increased summerfallow area results in slightly lower energy output. The net effect was a slight increase in energy use efficiency of 0.14 and 0.08 units for Alberta and Saskatchewan Brown soil zones, respectively. The largest improvement in energy use efficiency was for the Alberta and Saskatchewan Black and Gray soil zones as the nitrogen fertilizer use was higher resulting in greater gains as nitrogen use efficiency increased. The decrease in summerfallow area in the Dark Brown, Black and Gray soil zones, all in Saskatchewan, resulted in increased energy output as more area was cropped. The total energy output increased 4,030 TJ for the Prairies, which resulted in an improvement in energy use efficiency of 0.4 units.

Table 7: Enhanced Nitrogen Use Efficiency: Activity Levels

	Difference from 2010 BAU ('000' ha)										*Scenario*
	Alberta				Saskatchewan				Manitoba	Prairies	Prairies
Soil Type	**Brown**	**Dk Brown**	**Black**	**Gray**	**Brown**	**Dk Brown**	**Black**	**Gray**	**All**	**All**	**All**
Summerfallow	0.34	-0.22	-0.19	0.05	1.72	-1.34	-7.78	-2.91	-1.20	-11.53	4.80 mha
Wheat	-0.15	-0.80	1.15	8.46	-0.53	0.93	5.44	2.92	8.64	26.04	9.49 mha
Durum	-0.09	0.00	0.05	0.04	-2.05	-0.62	0.45	0.03	0.01	-2.18	2.34 mha
Barley Feed	-0.25	-0.35	-0.08	1.10	-0.33	-0.24	-0.37	-0.37	0.00	-0.89	1.80 mha
Barley Malt	-0.27	0.13	2.59	5.75	-0.11	0.41	4.31	1.40	1.80	16.01	2.89 mha
Oats	-1.24	-1.31	-0.42	6.42	-0.94	-0.78	2.66	1.50	0.01	5.89	1.47 mha
Flax	0.00	0.00	0.03	0.09	-0.09	0.01	1.08	0.51	0.29	1.92	0.83 mha
Canola	-0.20	-0.23	1.51	6.00	-0.56	-0.44	2.57	3.02	2.49	14.16	5.07 mha
Lentils	0.02	0.01	0.00	0.00	-0.03	0.24	-0.27	-0.12	-0.22	-0.38	0.30 mha
Field Peas	0.08	0.69	0.82	0.34	0.27	0.59	-1.36	-1.49	-0.78	-0.84	0.93 mha
Hay	1.96	2.20	-6.29	-31.26	3.53	2.34	-7.84	-5.06	-11.27	-51.70	3.77 mha
Other Pulses	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	-0.57	-0.55	0.05 mha
Other Oilseeds	-0.01	0.00	0.01	0.00	-0.10	0.01	0.09	0.03	0.02	0.05	0.28 mha
Other Cereals	-0.18	-0.11	0.78	2.77	-0.74	-0.94	0.98	0.53	0.80	3.88	0.50 mha

Source: CRAM

Table 8: Enhanced Nitrogen Use Efficiency: Energy Input, Energy Output and Energy Efficiency

	Difference from 2010 BAU ('000' TJ)										*Scenario*
	Alberta				Saskatchewan				Manitoba	Prairies	Prairies
Soil Type	**Brown**	**Dk Brown**	**Black**	**Gray**	**Brown**	**Dk Brown**	**Black**	**Gray**	**All**	**All**	**All**
Energy Input	-0.07	-0.33	-0.84	-1.16	-0.09	-0.53	-1.44	-0.70	-1.93	-7.09	184.63
Energy Output	-0.03	0.07	0.50	1.41	-0.03	0.18	0.83	0.32	0.77	4.03	1,988.84
Energy Efficiency	0.14	0.25	0.48	0.80	0.08	0.23	0.45	0.47	0.47	0.42	10.77

Source: PCEM

5.2 Increased Use of Zero Tillage

Description

In this scenario, the adoption of zero tillage was increased from 31% in the 2010 BAU baseline to 52% of the cultivated area (Table 9). The increase in zero tillage area reduces the area for conventional and minimum tillage about one third. The shift of land from conventional tillage to zero tillage changes the mix of cropping inputs. Zero tillage relies on the use of herbicides rather than tillage for weed control. Therefore, as the area under zero tillage increases relative to conventional tillage, the use of herbicides increases, but machinery and fossil fuel use decline. Nitrogen fertilizer use was increased 5% over the 2010 BAU baseline to ensure that the crop biomass production was not constrained by a nitrogen limitation.

Table 9: Assumptions for Increased Utilization of Zero Tillage Scenario

		2010 BAU	Scenario
Adoption Rate	Zero tillage Minimum tillage Conventional tillage	31% 37% 32%	52% 25% 23%
Productivity	No changes in crop yields		
Input Use	• CRAM cost structure varies by tillage regime; zero tillage tends to have lower machine expenses but requires more chemical inputs. • Nitrogen fertilizer was increased 5% over the 2010 BAU baseline for new zero tillage land.		
Cost of Production	No change from the 2010 BAU baseline, except for the 5% increase in nitrogen fertilizer as noted above		
Land Allocation	Held constant		

CRAM results

The impact of increasing the area under zero tillage was a reduction of summerfallow area of 35,700 hectares on the Prairies. By assumption, the area under all crops was kept constant across all soil zones. The area of crops grown under zero tillage was increased whereas the area of crops grown under minimum tillage and conventional tillage was allowed to adjust downward.

PCEM results

An increase in the adoption of zero tillage to double the baseline levels resulted in a reduction of energy input of 2,270 TJ (1.0%) on the Prairies (Table 10). Energy input for fertilizer and herbicides increased, but energy input for fuel and machinery decreased resulting in a reduction in energy input across all soil zones. Total energy output also decreased 8,060 TJ with an improvement of 0.08 units in energy use efficiency. The decrease in energy output was a result of more stubble cropping under zero tillage, however, lower energy input results in a net gain in energy use efficiency.

Table 10: Increased Use of Zero Tillage: Energy Input, Energy Output and Energy Efficiency

	Difference from 2010 BAU ('000' TJ)										*Scenario*
	Alberta				Saskatchewan				Manitoba	Prairies	Prairies
Soil Type	Brown	Dk Brown	Black	Gray	Brown	Dk Brown	Black	Gray	All	All	All
Energy Input	-0.05	-0.17	-0.30	-0.28	-0.08	-0.13	-0.54	-0.25	-0.48	-2.27	189.45
Energy Output	-0.16	-1.14	-2.04	-1.82	-0.06	-0.08	-1.00	-0.66	-1.10	-8.06	1,976.78
Energy Efficiency	0.07	0.05	0.06	0.07	0.07	0.05	0.12	0.11	0.08	0.08	10.43

Source: PCEM

Herbicide energy use was the highest for this scenario and the increase was directly related to the substitution of herbicides for tillage. The rate of the increase was highest for the Brown soil zone (28%) and lowest for the Black soil zone (12%), both in Saskatchewan. The higher amount of summerfallow area in the Brown soil zone compared to the Black soil zone was the main reason for the difference.

5.3 Decreased Use of Summerfallow Area

Description

Summerfallow is a common practice on the Prairies although its use has been declining as reflected in the 2010 BAU baseline of 5.0 million hectares compared to 7.8 million hectares in 1996. The rate of summerfallow use in this scenario is further reduced 50% in the Black and Gray soil zones, 40% in the Dark Brown soil zone and 30% in the Brown soil zone for an average reduction of 38% for the Prairies (Table 11). The 1996 census data show that the summerfallow area in the Prairies declined 22% in Saskatchewan and 19% in Alberta since 1991 (Statistics Canada 1997). However, the summerfallow area increased 9% in Manitoba over this period. The area of summerfallow is expected to continue to decline as producers move toward longer and more diverse rotations.

Table 11: Assumptions for Decreased Use of Summerfallow Area Scenario

Adoption Rate	**Soil Zone (M ha)**	**2010 BAU**	**Scenario**	**% Change**
	Black/Gray	1.4	0.7	-50%
	Dark Brown	1.4	0.8	-40%
	Brown	2.7	1.5	-30%
	Prairies	4.9	3.0	-38%
Productivity	No crop yield impacts from an increase in soil organic carbon			
Input Use	In CRAM, the cost structure differs for crops grown on stubble or fallow. No change from the BAU baseline			
Cost of Production	No change from the BAU baseline			

CRAM Results

The CRAM output indicated that reducing the summerfallow area caused other changes. It reduces the amount of canola grown in all soil zones and wheat and durum in the Brown soil zone. These crops have traditionally been grown on summerfallow. Reducing the summerfallow area increased the amount of crop produced on stubble. Although crop yields on stubble are lower than on summerfallow, total grain production increases in proportion to the increase in seeded area compared to the 2010 BAU baseline. Also, the use of crop production inputs such as fertilizers and pesticides increases in proportion to the increase in seeded area. The area seeded to most field crops and hay increased over the 2010 BAU baseline due to the reduction of land under summerfallow (Table 12).

PCEM Results

Under the decreased use of summerfallow area scenario, the energy input for the Prairies increased 3,790 TJ (2.0%) from the 2010 BAU baseline (Table 13). The increase in the energy use from the crop sector is due to the increased use of fertilizers and pesticides, which increased in proportion to the increase in seeded area. Most of the increase in energy input occurs in the Dark Brown and Black soil zones in Saskatchewan, 1,520 and 1,200 TJ, respectively. Energy use declines in the Brown soil zone as less area is seeded to annual crops offsetting the increase in fertilizer energy use as the proportion of annual crops seeded on stubble increases. In Manitoba, energy input increases slightly and energy output decreases slightly as more land is devoted to annual crops rather than summerfallow and hay. The net result is a decrease in energy use efficiency of 0.06 units for Manitoba. There is also a decrease in energy use efficiency for the Dark Brown soil zone in Saskatchewan as the increased use of nitrogen fertilizer is not offset by increased production. Total energy output increased 41,220 TJ resulting in a slight improvement in energy use efficiency of 0.01 units for the Prairies.

The decreased use of summerfallow area scenario has the highest fertilizer energy use for all soil zones except the Gray soil zones in Alberta. The highest rates of increase in fertilizer energy use over the 2010 BAU baseline are in the Dark Brown soil zone of Saskatchewan (9.9%) and the Brown soil zones of Saskatchewan (8.7%) and Alberta (7.1%). The increase in the amount of area that is stubble cropped is proportionally greater for the Brown and Dark Brown soil zones and also the amount of fertilizer used is less than for the Black soil zones. Thus the highest rates of increase in fertilizer energy use would occur in the Brown and Dark Brown soil zones.

5.4 The Inclusion of More Forage in Crop Rotations

Description

In this scenario, the area of land devoted to forage production is increased 2.6 million hectares in the Prairies (Table 14). Forage production in the Brown soil zone was assumed to occur only as long-term permanent cover crops. The rapid expansion of the livestock industry will create a market for forage that can accommodate an increase in forage production within annual crop rotations for the other soil zones.

Legume forage that converts atmospheric nitrogen into forms available for plant uptake reduce the amount of fertilizer nitrogen required by subsequent cereal and oilseed crops. To reflect the benefits of forage in rotation, grain and oilseed yields were increased based on the amount of forage production in each crop district in 1996 (see Appendix C). Grain and oilseed yields were assumed to increase 10% in crop districts that had only a small area devoted to forage in 1996. In crop districts where forage and hayland production accounted for more than 25% of the cropland in 1996, it was assumed that most of the yield benefits from the inclusion of forage in the rotation would have already been achieved and further yield increases were limited to 2%.

The ratio of hayland to cropland was calculated for each crop district based on 1996 data (see Appendix C). Productivity changes are based on the relative amount of land currently used to produce hay in each crop district. Because the increase in forage will be uniform, the smaller the current hay area, the bigger the impact of shifting land into forage. For example in crop district SA4 in southwestern Saskatchewan, the ratio of hayland to cropland is only 5%. Shifting 10% of cropland to forage production each year will have a large relative impact.

Table 12: Decreased Use of Summerfallow Area: Activity Levels

	Difference from 2010 BAU ('000' ha)										*Scenario*
	Alberta				Saskatchewan				Manitoba	Prairies	Prairies
Soil Type	Brown	Dk Brown	Black	Gray	Brown	Dk Brown	Black	Gray	All	All	All
Summerfallow	-153.68	-146.93	-83.86	-89.62	-384.99	-445.20	-307.13	-97.61	-85.18	-1 794.20	3 mha
Wheat	-34.89	67.21	41.14	12.35	-59.90	109.42	61.03	0.34	37.79	234.50	9.37 mha
Durum	-10.72	5.20	0.38	-0.11	-52.17	6.08	7.48	-0.01	0.27	-43.60	2.30 mha
Barley Feed	7.87	8.86	2.86	0.76	9.20	8.53	10.07	5.34	2.77	56.25	1.86 mha
Barley Malt	18.21	37.12	24.15	13.96	30.41	70.85	67.74	18.59	12.95	293.98	3.18 mha
Oats	25.34	9.86	13.72	14.84	39.97	55.06	57.15	17.24	13.43	246.62	1.72 mha
Flax	0.28	0.60	0.26	0.32	4.06	22.13	24.29	5.11	6.39	63.45	0.89 mha
Canola	-37.81	-90.38	-51.76	-47.61	-24.81	-128.90	-128.06	-32.69	-53.22	-595.23	4.48 mha
Lentils	1.41	0.53	0.02	0.02	26.32	36.70	6.39	0.55	0.27	72.21	0.37 mha
Field Peas	3.38	10.54	10.49	10.52	23.36	67.68	62.02	27.56	9.11	224.66	1.16 mha
Hay	9.86	12.55	34.77	87.93	26.39	29.41	26.25	7.36	-3.84	230.67	3.99 mha
Other Pulses	1.99	0.78	0.00	0.00	0.59	0.42	0.05	0.00	-0.39	3.44	0.05 mha
Other Oilseeds	0.22	0.20	0.02	0.00	1.38	1.39	0.55	0.09	0.02	3.87	0.28 mha
Other Cereals	7.64	3.15	1.59	4.14	15.50	25.15	7.45	1.75	2.97	69.35	0.57 mha

Source: CRAM

Table 13: Decreased Use of Summerfallow Area: Energy Input, Energy Output and Energy Efficiency

	Difference from 2010 BAU ('000' TJ)										*Scenario*
	Alberta				Saskatchewan				Manitoba	Prairies	Prairies
Soil Type	Brown	Dk Brown	Black	Gray	Brown	Dk Brown	Black	Gray	All	All	All
Energy Input	-0.04	0.36	0.34	-0.04	-0.09	1.52	1.20	0.29	0.25	3.79	195.51
Energy Output	-0.49	4.47	4.63	3.58	-0.67	14.43	12.33	3.08	-0.13	41.22	2,026.03
Energy Efficiency	-0.01	0.05	0.04	0.20	0.03	-0.07	0.02	0.02	-0.06	0.01	10.36

Source: PCEM

Table 14: Assumptions for the Inclusion of More Forage in Crop Rotations Scenario

Adoption Rate	2.6 million hectares (9% of current cropland)			
Productivity	Yield increase	Hayland to Cropland (%)		
		<10%	10-25%	>25%
	Grains and oilseeds	10%	5%	2%
	Hay	10%	5%	2%
Cost of Production	Costs are for 2010 BAU baseline			

CRAM Results

A shift of 2.6 million hectares of prairie land into forage production would decrease the cropland and crop production and increase hayland and hay production 68% and livestock numbers more than 50% (Table 15). The only annual crop to show a significant increase in area across all soil zones was feed barley due to the increase in livestock numbers.

PCEM Results

The energy input for the Prairies decreased 9,830 TJ (5.1%) from the 2010 BAU baseline (Table 16). Total energy output increased 251,680 TJ resulting in an improvement in energy use efficiency of 1.9 units. The decrease in energy use from the crop sector is due to the lower use of crop production inputs—such as fertilizers, fuel, machines and chemicals—as hay area increases. The reduction in nitrogen fertilizer accounts for most of the decreased energy use for the Dark Brown, Black and Gray soil zones. Most of the decrease in Alberta's energy input are in the Black and Gray soil zones at 1,280 and 1,100 TJ, respectively. Saskatchewan's energy input decline is from the Dark Brown and Black soil zones at 1,170 and 1,660 TJ, respectively. Manitoba's decrease in energy use was 2,440 TJ. Energy output increases significantly across the Prairies as the harvestable biomass of hay production is greater than the grain output of annual crops (refer to Table 1 for the impact of forage on energy output). Energy use efficiency increases for all soil zones with the Gray soil zone in Saskatchewan having the largest increase of 3.7 units.

The inclusion of more forage in crop rotations scenario has the lowest herbicide and fertilizer energy use. Fertilizer energy use is reduced the greatest amount in Manitoba (7.1%). Alberta's fertilizer energy use decreased 4.5%, 6.5%, 6.9% and 6.3% for the Brown, Dark Brown, Black and Gray soil zones, respectively. Saskatchewan's fertilizer energy use decreased 5% for the Dark Brown, Black and Gray soil zones and 3.5% for the Brown soil zone. These results are all consistent with the traditionally higher fertilizer use observed in Manitoba and Alberta when compared to Saskatchewan. Also, the lower fertilizer use in the Brown soil zone is reflected in the smaller decrease in fertilizer use.

Table 15: Inclusion of More Forage in Crop Rotations: Activity Levels

	Difference from 2010 BAU ('000' ha)										*Scenario*
	Alberta				Saskatchewan				Manitoba	Prairies	Prairies
Soil Type	Brown	Dk Brown	Black	Gray	Brown	Dk Brown	Black	Gray	All	All	All
Summerfallow	-38.95	-33.29	-16.42	-18.30	-120.22	-113.74	-67.84	-20.79	-13.36	-442.91	4.36 mha
Wheat	-51.54	-98.92	-104.77	-75.14	-135.52	-215.19	-177.35	-62.73	-149.75	-1,070.90	8.42 mha
Durum	-7.41	-5.51	-1.44	-0.22	-40.96	-21.52	-4.92	-0.10	-2.39	-84.45	2.25 mha
Barley Feed	4.06	11.15	15.40	16.97	2.65	7.58	26.69	19.68	9.15	113.34	1.91 mha
Barley Malt	-7.76	-28.37	-55.46	-39.33	-7.40	-22.49	-44.98	-17.74	-37.99	-261.51	2.63 mha
Oats	-3.92	-3.64	-12.75	-24.44	-12.00	-6.37	-19.61	-16.69	-37.99	-137.42	1.34 mha
Flax	-0.07	-0.28	-0.34	-0.43	-0.36	-2.35	-8.96	-3.87	-27.69	-44.34	0.78 mha
Canola	-10.04	-28.04	-24.16	-18.83	-7.05	-28.98	-24.21	-7.55	-32.74	-181.61	4.89 mha
Lentils	-0.38	-0.24	-0.06	-0.03	-4.52	-6.47	-2.60	-0.69	-2.10	-17.08	0.28 mha
Field Peas	-2.06	-13.00	-21.27	-23.33	-9.91	-43.95	-93.28	-54.74	-42.86	-304.41	0.63 mha
Hay	127.60	206.89	226.17	190.23	363.89	484.10	432.56	170.34	362.76	2,564.54	6.33 mha
Other Pulses	-0.52	-0.35	0.00	0.00	-0.06	-0.05	-0.02	0.00	-5.05	-6.05	0.04 mha
Other Oilseeds	0.38	0.47	0.01	-0.01	2.37	3.48	1.86	0.38	0.41	9.35	0.29 mha
Other Cereals	-2.79	-1.84	-2.42	-4.39	-3.68	-5.43	-3.25	-1.37	-18.26	-43.44	0.45 mha
Beef Cows (million head)										2.27	6.30 mhd

Source: CRAM

Table 16: Inclusion of More Forage in Crop Rotations: Energy Input, Energy Output and Energy Efficiency

	Difference from 2010 BAU ('000' TJ)										*Scenario*
	Alberta				Saskatchewan				Manitoba	Prairies	Prairies
Soil Type	Brown	Dk Brown	Black	Gray	Brown	Dk Brown	Black	Gray	All	All	All
Energy Input	-0.24	-0.80	-1.28	-1.10	-0.47	-1.17	-1.64	-0.69	-2.44	-9.83	181.89
Energy Output	11.61	20.77	19.74	13.95	27.42	47.30	53.14	20.60	37.15	251.68	2,236.49
Energy Efficiency	2.49	2.10	1.69	1.42	2.46	2.41	2.10	3.75	1.58	1.94	12.30

Source: PCEM

5.5 A 10% Improvement in the Fuel Efficiency of Farm Machinery

Description

Energy use for fuel and machinery was about 34% of the total energy use for prairie agriculture in 1996. Since most of the direct fossil fuel use in crop production occurs through the use of farm machinery, any fuel efficiency gains could significantly reduce energy use associated with crop production. In this scenario, it was assumed that trends toward lower fuel use would continue into the future with a 10% reduction by 2010. The cost of fuel was decreased 10% for all cropping activities.

CRAM Results

The CRAM output indicated that a 10% improvement in the fuel efficiency of farm machinery caused a very small change in the cropping mix and production levels on the Prairies (Table 17). Areas of hay and summerfallow decreased 5,290 and 1,280 hectares as the relative returns to annual crops increased slightly. Areas of malting barley and field peas increased 2,860 and 1,610 hectares, respectively. There were very small shifts in areas for all other crops for the different soil zones.

PCEM Results

A 10% improvement in the fuel efficiency of farm machinery resulted in a savings in energy input of 4,460 TJ (2.3%) for the Prairies (Table 18). Total energy output increased slightly by 540 TJ resulting in an improvement in the energy use efficiency of 0.25 units. The slight reduction in summerfallow area increased energy output. Energy use reduction was proportionally more for the higher yield production areas—the Black soil zone—and for fossil fuel intensive management systems—conventional tillage. But overall, no significant change from the 2010 BAU baseline was detected in the area under the different tillage management practices.

Fuel energy use was the second largest energy use component in the production systems, although it is dependent on the soil zone. Fuel energy use makes up 17% of the total energy use in Manitoba and 37% in the Brown soil zone of Saskatchewan. The lower fertilizer energy use in the drier regions of the Prairies accounts for this difference.

5.6 Crop Diversification

Description

Crop diversification toward more pulses, oilseeds and other minor annual crops has increased dramatically since 1996. The area for chickpeas increased from 2,400 hectares in 1996 to 150,000 hectares in 1999, while the area for dry beans is expected to increase to 200,000 hectares in 2000 (Saskatchewan Agriculture and Food 2000). Although a small seeded area relative to the total seeded area on the Prairies, these crops can be significant at the crop district level as the area suitable to produce these crops is limited. The purpose of this scenario is to model this diversification in crop production as the 2010 BAU baseline does not capture this diversification (Table 19).

Table 17: A 10% Improvement in the Fuel Efficiency of Farm Machinery: Activity Levels

	Difference from 2010 BAU ('000' ha)										Scenario
	Alberta				Saskatchewan				Manitoba	Prairies	Prairies
Soil Type	Brown	Dk Brown	Black	Gray	Brown	Dk Brown	Black	Gray	All	All	All
Summerfallow	-0.01	-0.13	-0.09	-0.01	0.02	-0.53	-0.36	-0.10	-0.09	-1.28	4.80 m ha
Wheat	0.01	0.04	0.10	0.24	0.11	0.07	0.08	0.03	0.30	0.99	9.50 m ha
Durum	0.01	0.00	-0.01	0.00	0.08	0.02	0.02	0.00	0.00	0.12	2.34 m ha
Barley Feed	0.02	0.04	-0.02	-0.18	0.06	0.01	0.06	0.04	0.00	0.04	1.80 m ha
Barley Malt	0.14	0.33	0.42	0.47	0.18	0.33	0.36	0.19	0.45	2.86	2.89 m ha
Oats	0.06	-0.02	0.03	0.27	0.03	0.04	0.02	-0.01	0.12	0.53	1.47 m ha
Flax	0.00	0.00	0.00	-0.01	0.00	0.00	0.03	-0.01	0.26	0.27	0.83 m ha
Canola	0.02	-0.04	0.02	0.19	-0.03	-0.21	0.00	0.05	0.08	0.10	5.07 m ha
Lentils	0.01	0.00	0.00	0.00	0.02	0.02	0.00	-0.01	0.01	0.05	0.30 m ha
Field Peas	0.03	0.08	0.08	0.00	0.23	0.83	0.20	0.00	0.16	1.61	0.93 m ha
Hay	-0.27	-0.28	-0.53	-1.00	-0.68	-0.59	-0.43	-0.19	-1.32	-5.29	3.76 m ha
Other Pulses	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.05 m ha
Other Oilseeds	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	-0.01	0.28 m ha
Other Cereals	0.00	0.00	0.00	0.01	-0.01	0.00	-0.01	0.00	0.01	0.00	0.50 m ha

Source: CRAM

Table 18: A 10% Improvement in the Fuel Efficiency of Farm Machinery: Energy Input, Energy Output and Energy Efficiency

	Difference from 2010 BAU ('000' PJ)										Scenario
	Alberta				Saskatchewan				Manitoba	Prairies	Prairies
Soil Type	Brown	Dk Brown	Black	Gray	Brown	Dk Brown	Black	Gray	All	All	All
Energy Input	-0.20	-0.36	-0.44	-0.42	-0.55	-0.74	-0.73	-0.30	-0.73	-4.46	187.27
Energy Output	0.02	0.04	0.06	0.08	0.03	0.07	0.08	0.04	0.12	0.54	1985.40
Energy Efficiency	0.42	0.27	0.24	0.26	0.51	0.32	0.21	0.19	0.17	0.25	10.60

Source: PCEM

CRAM Results

The area under oilseeds, pulses and other minor crops was increased by putting lower bounds in CRAM based on historical trends while the area under cereals and hay was allowed to adjust downward. The change in crop areas for this scenario is shown in Table 20 by soil zone and province. For example, in the Brown soil zone in Alberta, the area devoted to field peas, other oilseeds and lentils increased 29,540 hectares (347%), 19,420 hectares (172%) and 15,040 hectares (325%), respectively. Areas for wheat, summerfallow and hay decreased 28,070 hectares (5.4%), 20,620 hectares (5.0%) and 12,550 hectares (8.6%), respectively. The area in canola did not increase significantly for the Brown and Dark Brown soil zones in Alberta and even decreased in the Dark Brown soil zone in Saskatchewan. The relatively higher profitability of field peas, lentils and other pulses relative to canola seeded on stubble in these soil zones produces these changes.

PCEM Results

The energy input for the Prairies decreased 1,000 TJ (0.6%) from the 2010 BAU baseline under this scenario (Table 21). Energy use was reduced for the Dark Brown, Black and Gray soil zones, all in Saskatchewan. The reduction in nitrogen fertilizer use tends to offset the higher herbicide, machine and fuel energy for these regions. Energy use increased for the Brown soil zone as more stubble crops are grown, the area of summerfallow decreased and land was taken out of hay production. The Gray soil zone in Alberta has increased energy use (240 TJ) as less area was suitable for pulses and a large proportion of the area used to increase crop diversification was from a reduction in hay area. The large increase in field pea area (219%) and a decrease in hay area (10%) in Manitoba resulted in lower energy input and lower energy output even though the canola area increased significantly (24%). The total energy output decreased 35,000 TJ for the Prairies resulting in a reduction in energy use efficiency of 0.13 units. Energy use efficiency decreased because the area in hay decreased significantly in all regions reducing energy output even though the area devoted to annual crops increased.

Table 19: Assumptions for Crop Diversification Scenario

Adoption Rate	Lower bounds set on pulses, oilseeds and other minor crops for each crop district
Productivity	No change in oilseed or cereal crop yields
Cost of Production	Costs as for the 2010 BAU baseline

Table 20: Crop Diversification: Activity Levels

	Difference from 2010 BAU ('000' ha)										*Scenario*
	Alberta				Saskatchewan				Manitoba	Prairies	Prairies
Soil Type	**Brown**	**Dk Brown**	**Black**	**Gray**	**Brown**	**Dk Brown**	**Black**	**Gray**	**All**	**All**	**All**
Summerfallow	-20.62	-17.61	-13.70	-8.60	-196.10	-153.83	-60.93	-13.90	-16.77	-502.05	4.30 mha
Wheat	-28.07	-69.37	-92.10	-36.59	-215.95	-289.59	-181.08	-51.98	-311.19	-1275.93	8.22 mha
Durum	-6.06	-4.58	-1.48	-0.18	-98.30	-69.15	-14.51	-0.39	-5.03	-199.67	2.14 mha
Barley Feed	-1.16	-5.47	-14.56	-8.76	-7.47	-4.66	-9.22	-6.16	-25.88	-83.34	1.72 mha
Barley Malt	-5.33	-23.26	-48.70	-25.64	-18.61	-43.12	-54.63	-16.78	-68.67	-304.74	2.58 mha
Oats	-4.99	-13.37	-27.83	-20.88	-23.30	-31.77	-48.11	-17.59	-87.38	-275.22	1.20 mha
Flax	2.64	6.80	4.15	9.98	27.43	57.84	35.06	3.20	27.54	174.65	1 mha
Canola	1.96	6.83	36.72	49.99	1.36	-10.68	31.80	7.75	119.41	245.16	5.32 mha
Lentils	15.04	9.05	1.91	0.13	134.77	203.45	46.19	4.12	0.33	415.00	0.71 mha
Field Peas	29.54	83.92	148.59	73.29	156.80	112.93	161.59	82.23	224.28	1,073.19	2.01 mha
Hay	-12.55	-9.98	-35.29	-51.27	-55.34	-34.57	-18.13	-4.56	-73.40	-295.10	3.47 mha
Other Pulses	2.43	9.94	2.40	0.01	170.62	162.81	30.00	3.52	129.98	511.70	0.56 mha
Other Oilseeds	19.42	16.32	21.54	0.36	71.65	47.48	30.22	2.76	43.25	252.99	0.53 mha
Other Cereals	7.24	9.06	16.88	16.23	49.70	45.63	43.02	6.71	40.26	234.72	0.73 mha

Source: CRAM

Table 21: Crop Diversification: Energy Input, Energy Output and Energy Efficiency

	Difference from 2010 BAU ('000' PJ)										*Scenario*
	Alberta				Saskatchewan				Manitoba	Prairies	Prairies
Soil Type	**Brown**	**Dk Brown**	**Black**	**Gray**	**Brown**	**Dk Brown**	**Black**	**Gray**	**All**	**All**	**All**
Energy Input	0.09	-0.16	-0.15	0.24	0.52	-0.10	-0.19	-0.19	-1.11	-1.05	190.67
Energy Output	0.24	-1.85	-4.22	-0.68	-0.84	-5.25	-5.96	-2.04	-14.39	-35.00	1,949.81
Energy Efficiency	-0.14	-0.01	-0.12	-0.17	-0.50	-0.16	-0.12	-0.02	-0.12	-0.13	10.23

Source: PCEM

Section 6: Summary

6.1 Key Findings

The inclusion of more forage in crop rotations would have the greatest impact on reducing energy use on the Canadian Prairies. Annual crop production and summerfallow areas would be reduced resulting in the use of fewer crop inputs especially nitrogen fertilizer. Increasing forage area resulted in the highest increase in energy output and also the highest energy use efficiency ratio.

Enhanced nitrogen use efficiency would have the largest impact on the Black and Gray soil zones as these zones have the highest use of nitrogen fertilizer. The energy cost of fertilizer in the Brown and Dark Brown soil zones would be slightly reduced. Enhanced nitrogen use efficiency is the second best scenario for reducing energy use and for improving energy use efficiency. Energy output would not increase substantially, even though the cropped area would increase and the forage area would decrease (and forage produces more energy per hectare).

A 10% improvement in the fuel efficiency of farm machinery and increased use of zero tillage are scenarios that would reduce energy input with modest gains in energy use efficiency.

Crop diversification would reduce energy input and energy output resulting in a slightly lower energy use efficiency ratio. Although, more area was cropped, forage area was reduced resulting in lower energy output.

Decreased use of summerfallow area would increase energy use for the Dark Brown, Black and Gray soil zones as land went into annual crop production. Decreased use of summerfallow area in the Brown soil zone resulted in land being taken out of annual crop production and put into forage thus reducing energy use. The net result though is the energy use efficiency ratio increases slightly over the 2010 BAU baseline because output energy use increased.

6.2 Limitations of the Report

There were limited data available on some of the new emerging crop types and production systems (e.g. chick peas, dry beans, Roundup Ready®, Pursuit Smart® and Liberty Link®

canola production) and are not represented in this report. Some of the micro-level data used in the analysis had only four years of observations which may not be representative of the long-term yield patterns and input usage. The long term impact of including these emerging crop types and production systems is unknown at this time.

The static nature of CRAM limits the inclusion of synergies that appear at the research and farm levels. The extension of CRAM to specify prior cropping activities would help in capturing some of these synergies. Some of the benefits of including a crop in a rotation are showing up in the crops planted two and three years after. Also, longer term impacts of tillage and rotation on soil properties were not captured.

Although this report focused on energy use on the Canadian Prairies as this was the scope defined for this project, other economic and environmental indicators are required to understand the full impact on the agricultural sector. For example, commercial farm level data on yields and costs of production on the new crop production activities added to CRAM were not available. The experimental data, which came from small research plots and are site-specific, were extrapolated to the farm level using representative farms for those soil-climatic regions or agroecosystems to which the management practices have application. These data were used as input into CRAM. As actual farm level data become available in future, CRAM could be enhanced and used to generate information on economic indicators such as regional and provincial net margins for crops.

Another example of environmental indicators are greenhouse gas emissions and soil erosion estimates. The capacity exists now to generate this type of output but it was beyond the scope of this project.

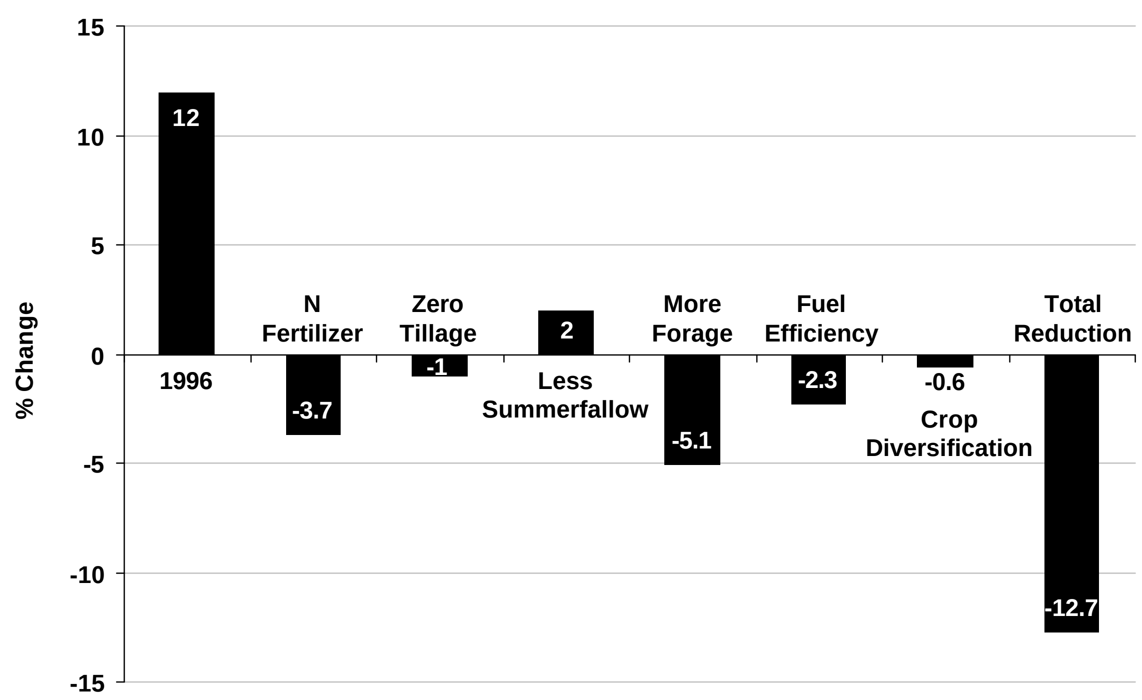
6.3 Policy Implications

Prairie level results for energy input for all the scenarios are summarized in Figure 3. Two scenarios would be most effective in reducing total energy use—the inclusion of more forage in crop rotations (5.1%) and enhanced nitrogen use efficiency (3.7%). A 10% improvement in fuel efficiency of farm machinery and increased use of zero tillage result in reducing energy input 2.3% and 1.0%, respectively. The crop diversification scenario would result in a slight decrease in energy use but the decreased use of summerfallow area would result in increase of 2.0% in energy use.

The results of reduction in energy use were evaluated for individual scenarios. If the effects are additive, then a net reduction in energy use of 12.7% would be possible by adopting all five scenarios which reduce energy use. A combination scenario of these five scenarios was not tried because some of the effects might be canceled due to the interactions between livestock and crop production activity levels.

The net results are not the same across all soil zones on the Prairies. The soil and climatic differences of the Brown soil zone in particular would produce results quite different from other soil zones. Thus, a blanket approach to policy development and implementation for reducing energy use will not produce the desired result in all regions. Appropriate management practices to limit future energy use would have to consider soil zone characteristics in determining the best method. This consideration of the soil zone is particularly true with nitrogen fertilizer reduction scenarios. For example, the lower amounts of nitrogen fertilizer used in the Brown soil zone compared to the Black soil zone would be the least costly management practice.

Figure 3: Percent Change in Energy Use Relative to 2010 BAU Baseline



Policies that reduce summerfallow area would increase energy use if not combined with management practices or other production options that reduce energy use. Zero tillage and increased nitrogen use efficiency are two management practices that would partly offset the increased energy use resulting from a decrease in the summerfallow area. Policies that increase forage area would have a negative effect on energy use as the area of summerfallow declines and land is taken out of crop production.

With an improvement in the fuel efficiency of farm machinery and expanded use of zero tillage, direct use of fossil fuel would decrease. The case for zero tillage as a means of lowering fuel consumption has been documented in this report and in other studies. Efficiency gains due to improvements in tractive power and implement design are dependent on the research and development expenditure by equipment manufacturers.

Policies designed to encourage crop diversification, especially of nitrogen fixing crops, would decrease the demand for commercial nitrogen fertilizers. However, the extent to which land is taken out of forage production would dictate the net energy savings. Any policy or management practice change that reduces nitrogen fertilizer use would have the largest negative impact on total energy use due to the high energy demand associated with the manufacture of nitrogen fertilizer.

References

Agriculture and Agri-Food Canada. 1999a. "Medium Term Policy Baseline." Ottawa: AAFC, April.

Agriculture and Agri-Food Canada. 1999b. Data from Research Centres at Swift Current, Indian Head, Melfort, Tisdale, Lethbridge, and Rycroft. Unpublished.

Campbell, C.A., and E.A. Paul. 1978. "Effects of N Fertilizer and Soil Moisture on Mineralization, N recovery and A-values, under Spring Wheat Grown in Small Lysimeters." Canadian Journal of Soil Science 58 (February 1978): 39–51.

Gauer, L.E., C.A. Grant, D.T. Gehl, and L.D. Bailey. 1992. "Effects of Nitrogen Fertilization on Grain Protein Content, Nitrogen Uptake and Nitrogen Use Efficiency of Six Spring Wheat Cultivars, in Relation to Estimated Moisture Supply." Canadian Journal of Plant Science 72 (January 1992): 235–241.

Hoeppner, J. 2000. The Effects of Legume Green Manures, Perennial Forages, and Cover Crops on Non-renewable Energy Use in Western Canadian Cropping Systems. Unpublished Master's thesis. Winnipeg: University of Manitoba.

Horner, G.L., J. Corman, R.E. Howitt, C.A. Carter, and R.J. MacGregor. 1992. "The Canadian Regional Agriculture Model: Structure, Operations and Development." Technical Report 1/92. Policy Branch. Ottawa: AAFC.

Howitt, R.E. 1995. "Positive Mathematical Programming." American Journal of Agricultural Economics 77,2 (May 1995): 329–342.

Nagy, C.N. 1999. "Energy Coefficients for Agriculture Inputs in Western Canada." Working Paper Series #2. Saskatoon: Centre for Studies in Agriculture, Law and the Environment, University of Saskatchewan, May.

Rossetti, M., and C.N. Nagy. 1999. "The Economic Performance of Tillage Systems and Diversified Crop Rotations in the Black Soil Zone of Saskatchewan." In the Proceedings of the Soils and Crops Workshop, University of Saskatchewan, Saskatoon, Saskatchewan, February 25–26, 1999: p. 131.

Saskatchewan Agriculture and Food. 2000. "1999 Specialty Crop Report." January.

Statistics Canada. 1997. "1996 Census of Agriculture Survey." Ottawa: Statistics Canada.

Zentner, R.P., B.G. McConkey, M.A. Stumborg, C.A. Campbell, and F. Selles. 1998. "Energy Performance of Conservation Tillage Management for Spring Wheat Production in the Brown Soil Zone." Canadian Journal of Plant Science 78 (October 1998): 553–563.

Zentner, R.P., D.D. Wall, C.N. Nagy, E.G. Smith, D.L. Young, P.R. Miller, C.A. Campbell, B.G. McConkey, S.A. Brandt, G.P. Lafond, A.M. Johnston, and D.A. Derksen. 1999. "Economics of Crop Diversification and Soil Tillage Opportunities in the Canadian Prairies." Presented at the annual conference of the American Society of Agronomy, November 1999.

Zentner, R.P., G.P. Lafond, D.A. Derksen, B.J. Blomert, and C.N. Nagy. 2000. "Effects of Tillage Method and Crop Rotation on Non-renewable Energy Use Efficiency in the Thin Black Soil Zone." In the Proceedings of the Soils and Crops Workshop, University of Saskatchewan, Saskatoon, Saskatchewan, February 24–25, 2000: p. 681–687.

Appendix A: The Prairie Crop Energy Model (PCEM)

Fuel and Machine Energy Coefficient Adjustment Formula

The following formula is used to adjust fuel and machine energy coefficients for cropping activities where no coefficient was generated from the farm-level analysis:

(Energy coefficient) * (1- marginal coefficient * ((1- % yield difference)*10))

Marginal Coefficients (Mj/Percentage Change in Crop Yield)

Tillage system	Machine	Fuel
Conventional tillage	.038	.038
Minimum tillage	.042	.044
Zero tillage	.047	.058

Allocation of Cultivated Area to Crop Categories

The cost of producing a crop on stubble is assumed to be the same as summerfallow crop production in CRAM for five crops: barley, oat, flax, lentils and field peas. This assumption will be used for the first year of alfalfa/grass and grass, other pulse, other oilseed and other cereal.

Table A1: Alberta Soil Zone Percentage by Crop District

Crop District	Brown	Dark Brown	Thin Black	Thick Black	Gray
AL1	100%				
AL2	20%	80%			
AL3		10%	70%	20%	
AL4		44%	46%	10%	
AL5			10%	80%	10%
AL6				20%	80%
AL7					100%

Table A2: Saskatchewan Soil Zone Percentage by Crop District

Crop District	Brown	Dark Brown	Thin Black	Thick Black	Gray
SA1		33%	67%		
SA2	3%	86%	11%		
SA3	84%	16%			
SA4	100%				
SA5		1%	30%	56%	14%
SA6		84%	16%		
SA7	43%	54%	3%		
SA8		9%		38%	53%
SA9		1%		52%	47%

Table A3: Manitoba Soil Zone Percentage by Crop District

Crop District	Dark Brown	Thin Black	Thick Black	Gray
MA1		90%	10%	
MA2	5%	35%	40%	20%
MA3			100%	
MA4		10%	90%	
MA5			100%	
MA6			70%	30%

Assumptions Used in Allocating the 1995 Area to Crop Categories for the PCEM

As there were no data available on the cropping sequence, the following methodology was used to allocate crop area for the 1996 baseline.

Statistics Canada's 1996 Census of Agriculture and 1995 crop hectares are used as the sources for seeded area for each crop. Land practice data from the 1996 Census are used to calculate conventional, minimum and zero tillage area (Table A4) and for tillage, tillage/chemical and chemical summerfallow area (Table A5).

The area in summerfallow in 1995 is allocated to the 1996 planting of canola, spring wheat and durum. Canola area is allocated first from the 1995 summerfallow area up to 95% of the 1996 canola area, with any remaining area going to spring wheat and durum based on the percentage seeded to those crops.

The crop area in 1995 of cereals, pulses and oilseeds is then allocated to the 1996 seeded area of spring wheat, durum, barley, oats, canola, flax, lentils, field peas, alfalfa/grass, grass, other pulse, other oilseed, other cereal, green manure and summerfallow. The allocation is based on the percentage of 1996 area for each activity. All the 1995 pulse area is recropped in 1996 to cereal crops. The oilseed area from 1995 is planted to cereal crops or field peas in 1996 unless they are used as a companion crop for forage establishment. The cereal area from 1995 is allocated to the 1996 summerfallow and seeded area of oilseed, pulse, cereal and forage establishment.

It was assumed that one eighth of the 1996 area in alfalfa/grass and grass is in the establishment year. The forage area in 1995 is allocated to remaining in forage, summerfallow, spring wheat or flax. Recropping to spring wheat or flax is based on the relative area in each crop for 1996 except for Alberta crop district 1 and Saskatchewan crop districts 3, 4 and 7 where the allocation of alfalfa/grass and grass area are limited to 10% of the area that would have been allocated to wheat, the remaining area going to 1996 summerfallow.

Green manure area was assumed to be one percent of the summerfallow area allocated to tillage, tillage/chemical and chemical summerfallow for each of the tillage systems. The 1995 green manure area is allocated to spring wheat, durum and canola. The cereal stubble area in 1995 is the residual area for each crop category so that the area seeded in 1996 to a crop is consistent with Statistics Canada's 1996 Census of Agriculture data.

Table A4: Area by Tillage Method (hectares)

		Total Seeded		Conventional Tillage		Reduced Tillage		Zero Tillage	
		ha	%	ha	%	ha	%	ha	%
Alberta									
Crop Districts	**1**	762,912	100	400,677	52.5	234,795	30.8	127,440	16.7
	2	1,547,221	100	734,535	47.5	609,173	39.4	203,513	13.2
	3	863,509	100	436,247	50.5	360,499	41.7	66,763	7.7
	4	1,894,611	100	1,033,628	54.6	654,060	34.5	206,923	10.9
	5	804,240	100	583,494	72.6	174,679	21.7	46,068	5.7
	6	594,188	100	426,596	71.8	131,396	22.1	36,197	6.1
	7	1,128,913	100	699,732	62.0	332,128	29.4	97,052	8.6
	Total	7,595,594	100	4,314,909	56.8	2,496,730	32.9	783,955	10.3
Saskatchewan									
Crop Districts	**1**	1,196,997	100	522,666	43.7	413,094	34.5	261,236	21.8
	2	1,324,900	100	433,258	32.7	330,252	24.9	561,389	42.4
	3	2,145,965	100	954,762	44.5	658,815	30.7	532,387	24.8
	4	598,236	100	311,696	52.1	160,052	26.8	126,488	21.1
	5	1,965,078	100	1,053,784	53.6	656,353	33.4	254,942	13.0
	6	1,942,179	100	763,956	39.3	775,967	40.0	402,255	20.7
	7	1,298,009	100	508,717	39.2	342,730	26.4	446,563	34.4
	8	1,364,883	100	763,758	56.0	492,587	36.1	108,538	8.0
	9	1,605,994	100	775,000	48.3	589,350	36.7	241,644	15.0
	Total	13,442,241	100	6,087,598	45.3	4,419,200	32.9	2,935,443	21.8
Adjusted[a]	**CD2**			523,335	39.5	491,538	37.1	310,027	23.4
Adjusted[a]	**CD7**			519,361	39.2	488,888	36.9	316,651	23.9
Manitoba									
Crop Districts	**1**	1,381,014	100	724,939	52.5	457,351	33.1	198,723	14.4
	2	608,349	100	397,156	65.3	175,550	28.9	35,643	5.9
	3	589,302	100	418,146	71.0	132,891	22.6	38,266	6.5
	4	729,687	100	502,800	68.9	185,479	25.4	41,409	5.7
	5	333,881	100	240,270	72.0	69,752	20.9	23,859	7.1
	6	317,953	100	225,412	70.9	68,805	21.6	23,736	7.5
	Total	3,960,187	100	2,508,722	63.3	1,089,828	27.5	361,636	9.1

a. Adjusted due to the response to the census question that overstated the amount of zero tillage seeded hectares. The way the question was worded the response is a reflection of direct seeded hectares with no spring tillage that includes all one-way disc and high disturbance airseeders.

Source: Statistics Canada’s 1996 Census of Agriculture.

Table A5: Summerfallow by Tillage Method

Crop District	Tillage		Tillage/Chemical		Chemical		Total	
	ha	%	ha	%	ha	%	ha	%
Alberta								
1	255,551	62	107,113	26	46,340	11	409,178	255,551
2	193,930	47	171,929	41	49,624	12	415,660	193,930
3	35,724	43	36,468	44	11,251	13	83,479	35,724
4A	56,334	44	58,116	46	12,956	10	127,461	56,334
4B	47,639	43	54,913	50	8,193	7	110,793	47,639
5	26,064	57	16,198	35	3,818	8	46,099	26,064
6	44,411	58	25,870	34	6,341	8	76,655	44,411
7	78,576	47	73,560	44	15,822	9	168,030	78,576
Total	738,229	51	544,167	38	154,345	11	1,437,354	738,229
Saskatchewan								
1	156,798	54	110,462	38	20,896	7	288,279	156,798
2	253,691	64	113,579	29	26,811	7	394,249	253,691
3	680,021	57	398,231	33	124,636	10	1,203,401	680,021
4	276,527	62	128,860	29	43,637	10	449,215	276,527
5	227,164	53	172,152	40	30,236	7	429,736	227,164
6	308,192	56	206,986	37	38,863	7	554,277	308,192
7	318,354	50	249,781	39	66,984	11	635,390	318,354
8	98,609	46	103,271	48	14,720	7	216,692	98,609
9	108,820	42	136,925	52	16,244	6	262,102	108,820
Total	2,428,176	55	1,620,248	37	383,026	9	4,433,341	2,428,176
Manitoba								
1	75,581	60	43,745	35	6,909	5	126,288	75,581
2	46,703	62	24,294	32	3,946	5	74,976	46,703
3	20,831	62	10,910	33	1,715	5	33,470	20,831
4	16,399	55	11,417	39	1,743	6	29,571	16,399
5	14,581	62	7,677	32	1,396	6	23,664	14,581
6	21,926	61	11,423	32	2,456	7	35,821	21,926
Total	196,021	61	109,466	34	18,165	6	323,789	196,021

Source: Statistics Canada’s 1996 Census of Agriculture.

Table A6: Cropping Activities

Number	Abbreviation	Description
1	SUMFALI	Summerfallow intensive tillage
2	SUMFALM	Summerfallow moderate tillage
3	SUMFALN	Summerfallow zero tillage
4	GMI	Green manure intensive tillage
5	GMM	Green manure moderate tillage
6	GMN	Green manure zero tillage
7	WHTSFI	Wheat on intensive summerfallow
8	WHTSFM	Wheat on moderate summerfallow
9	WHTSFN	Wheat on zero tillage summerfallow
10	WHTPI	Wheat after pulse intensive tillage
11	WHTPM	Wheat after pulse moderate tillage
12	WHTPN	Wheat after pulse zero tillage
13	WHTCI	Wheat after cereal intensive tillage
14	WHTCM	Wheat after cereal moderate tillage
15	WHTCN	Wheat after cereal zero tillage
16	WHTOI	Wheat after oilseed intensive tillage
17	WHTOM	Wheat after oilseed moderate tillage
18	WHTON	Wheat after oilseed zero tillage
19	WHTAGI	Wheat after alfalfa/grass intensive tillage
20	WHTAGM	Wheat after alfalfa/grass moderate tillage
21	WHTAGN	Wheat after alfalfa/grass zero tillage
22	WHTGI	Wheat after grass intensive tillage
23	WHTGM	Wheat after grass moderate tillage
24	WHTGN	Wheat after grass zero tillage
25	WHTGMI	Wheat after green manure intensive tillage
26	WHTGMM	Wheat after green manure moderate tillage
27	WHTGMN	Wheat after green manure zero tillage
28	DURUMSFI	Durum on intensive summerfallow
29	DURUMSFM	Durum on moderate summerfallow
30	DURUMSFN	Durum on zero tillage summerfallow
31	DURUMPI	Durum after pulse intensive tillage
32	DURUMPM	Durum after pulse moderate tillage
33	DURUMPN	Durum after pulse zero tillage
34	DURUMCI	Durum after cereal intensive tillage
35	DURUMCM	Durum after cereal moderate tillage
36	DURUMCN	Durum after cereal zero tillage
37	DURUMOI	Durum after oilseed intensive tillage
38	DURUMOM	Durum after oilseed moderate tillage
39	DURUMON	Durum after oilseed zero tillage
40	DURUMGMI	Durum after green manure intensive tillage
41	DURUMGMM	Durum after green manure moderate tillage
42	DURUMGMN	Durum after green manure zero tillage
43	BARFDPI	Feed barley after pulse intensive tillage
44	BARFDPM	Feed barley after pulse moderate tillage
45	BARFDPN	Feed barley after pulse zero tillage
46	BARFDCI	Feed barley after cereal intensive tillage
47	BARFDCM	Feed barley after cereal moderate tillage
48	BARFDCN	Feed barley after cereal zero tillage

Table A6: Cropping Activities (Continued)

Number	Abbreviation	Description
49	BARFDOI	Feed barley after oilseed intensive tillage
50	BARFDOM	Feed barley after oilseed moderate tillage
51	BARFDON	Feed barley after oilseed zero tillage
52	BARMTPI	Malt barley after pulse intensive tillage
53	BARMTPM	Malt barley after pulse moderate tillage
54	BARMTPN	Malt barley after pulse zero tillage
55	BARMTCI	Malt barley after cereal intensive tillage
56	BARMTCM	Malt barley after cereal moderate tillage
57	BARMTCN	Malt barley after cereal zero tillage
58	BARMTOI	Malt barley after oilseed intensive tillage
59	BARMTOM	Malt barley after oilseed moderate tillage
60	BARMTON	Malt barley after oilseed zero tillage
61	OATSCI	Oats after cereal intensive tillage
62	OATSCM	Oats after cereal moderate tillage
63	OATSCN	Oats after cereal zero tillage
64	FLAXCI	Flax after cereal intensive tillage
65	FLAXCM	Flax after cereal moderate tillage
66	FLAXCN	Flax after cereal zero tillage
67	FLAXPI	Flax after pulse intensive tillage
68	FLAXPM	Flax after pulse moderate tillage
69	FLAXPN	Flax after pulse zero tillage
70	FLAXAGI	Flax after alfalfa/grass intensive tillage
71	FLAXAGM	Flax after alfalfa/grass moderate tillage
72	FLAXAGN	Flax after alfalfa/grass zero tillage
73	FLAXHI	Flax after grass intensive tillage
74	FLAXHM	Flax after grass moderate tillage
75	FLAXHN	Flax after grass zero tillage
76	CANSFI	Canola on intensive summerfallow
77	CANSFM	Canola on moderate summerfallow
78	CANSFN	Canola on zero tillage summerfallow
79	CANCI	Canola after cereal intensive tillage
80	CANCM	Canola after cereal moderate tillage
81	CANCN	Canola after cereal zero tillage
82	CANGMI	Canola after green manure intensive tillage
83	CANGMM	Canola after green manure moderate tillage
84	CANGMN	Canola after green manure zero tillage
85	LENTCI	Lentils after cereal intensive tillage
86	LENTCM	Lentils after cereal moderate tillage
87	LENTCN	Lentils after cereal zero tillage
88	FLDPCI	Field peas after cereal intensive tillage
89	FLDPCM	Field peas after cereal moderate tillage
90	FLDPCN	Field peas after cereal zero tillage
91	FLDPOI	Field peas after oilseed intensive tillage
92	FLDPOM	Field peas after oilseed moderate tillage
93	FLDPON	Field peas after oilseed zero tillage

Table A6: Cropping Activities (Continued)

Number	Abbreviation	Description
94	ALFGRCI	Alfalfa/grass after cereal intensive tillage
95	ALFGRCM	Alfalfa/grass after cereal moderate tillage
96	ALFGRCN	Alfalfa/grass after cereal zero tillage
97	ALFGROI	Alfalfa/grass after oilseed intensive tillage
98	ALFGROM	Alfalfa/grass after oilseed moderate tillage
99	ALFGRON	Alfalfa/grass after oilseed zero tillage
100	ALFGRALGR	Alfalfa/grass after alfalfa/grass
101	GRASSCI	Grass after cereal intensive tillage
102	GRASSCM	Grass after cereal moderate tillage
103	GRASSCN	Grass after cereal zero tillage
104	GRASSOI	Grass after oilseed intensive tillage
105	GRASSOM	Grass after oilseed moderate tillage
106	GRASSON	Grass after oilseed zero tillage
107	GRASSGRASS	Grass after grass
108	OTHPULCI	Other pulse after cereal intensive tillage
109	OTHPULCM	Other pulse after cereal moderate tillage
110	OTHPULCN	Other pulse after cereal zero tillage
111	OTHOILCI	Other oilseed after cereal intensive tillage
112	OTHOILCM	Other oilseed after cereal moderate tillage
113	OTHOILCN	Other oilseed after cereal zero tillage
114	OTHCERLCI	Other cereal after cereal intensive tillage
115	OTHCERLCM	Other cereal after cereal moderate tillage
116	OTHCERLCN	Other cereal after cereal zero tillage
117	OTHCERLOI	Other cereal after oilseed intensive tillage
118	OTHCERLOM	Other cereal after oilseed moderate tillage
119	OTHCERLON	Other cereal after oilseed zero tillage
120	OTHCERLPI	Other cereal after pulse intensive tillage
121	OTHCERLPM	Other cereal after pulse moderate tillage
122	OTHCERLPN	Other cereal after pulse zero tillage

Appendix B:

Table B1: Fertilizer Use and Costs for CRAM Census Regions on the Prairies for the Enhanced Nitrogen Use Efficiency Scenario

Fall Application of N 30%

Soil Zones	Black	Dark Brown	Brown	Gray	Fertilizer use with only Spring	Cost Adjust.
Eff. of Fall vs. Spring	**73%**	**86%**	**97%**	**63%**		
Crop District						
AL1			1.0		0.99	1.03
AL2		0.8	0.2		0.96	1.00
AL3	0.9	0.1			0.92	0.95
AL4		0.5	0.5		0.97	1.01
AL5	0.5			0.5	0.90	0.93
AL6				1.0	0.89	0.91
AL7				1.0	0.89	0.91
SA1	0.8	0.1	0.1		0.93	0.96
SA2	0.15	0.15	0.7		0.98	1.01
SA3			1.0		0.99	1.03
SA4		0.1	0.9		0.92	1.02
SA5	1.0				0.95	0.95
SA6	0.1	0.9			0.97	0.98
SA7		0.6	0.4		0.92	1.00
SA8	1.0				0.92	0.95
SA9	0.9	0.1			0.92	0.95
MA1	1.0				0.92	0.95
MA2	0.9	0.1			0.92	0.95
MA3	1.0				0.92	0.95
MA4	1.0				0.92	0.95
MA5	0.8	0.2			0.93	0.95
MA6	0.8			0.2	0.91	0.94

Example: MA4 is 100% Black soil zone

Fall application	30% @ 73% efficiency => 21.9%	Cost 21.9% @ 112% => 25%
Spring application	70% @ 100% efficiency => 70.0%	Cost 70% @ 100% => 70%
Only spring application	**=> 91.9%**	Total cost **=> 95%**

Appendix C:

Table C1: Agriculture Area by Crop District (000 ha) and Productivity Impacts for the Inclusion of More Forage in Crop Rotations Scenario

Crop District	Cropland	Hayland	Total Cropland and Hayland	Pasture Land	Unimproved Pasture Land	Hayland/ Cropland
BC1	227.22	347.97	575.19	240.24	1,172.59	153%
AL1	1,179.90	111.07		218.12	2,090.66	9%
AL2	1,941.89	135.25		178.54	903.95	7%
AL3	939.82	216.45		194.05	1,039.61	23%
AL4	2,115.10	244.28		367.05	836.96	12%
AL5	842.87	435.67		360.78	557.37	52%
AL6	667.66	446.67		351.05	685.57	67%
AL7	1,360.68	334.14		245.01	501.39	25%
Total Alberta	**9,047.92**	**1,923.53**	**10,971.45**	**1,914.60**	**6,615.51**	**21%**
SA1	1,468.70	89.20		87.77	305.37	6%
SA2	1,704.11	58.79		55.23	217.80	3%
SA3	3,327.20	155.38		243.86	1,350.55	5%
SA4	1,041.15	55.57		131.73	1,013.25	5%
SA5	2,374.69	153.52		141.01	360.84	6%
SA6	2,469.18	134.63		125.55	401.68	5%
SA7	1,916.56	42.51		92.67	434.08	2%
SA8	1,582.85	128.13		82.88	147.06	8%
SA9	1,854.69	271.58		272.61	862.96	15%
Total Saskatchewan	**17,739.13**	**1,089.31**	**18,828.44**	**1,233.31**	**5,093.59**	**6%**
MA1	1,493.34	186.28		107.10	406.52	12%
MA2	679.55	175.02		105.30	461.16	26%
MA3	616.88	77.35		39.72	121.84	13%
MA4	753.03	46.98		20.50	73.40	6%
MA5	362.79	89.35		21.92	114.10	25%
MA6	362.92	174.34		61.70	476.81	48%
Total Manitoba	**4,268.51**	**749.32**	**5,017.83**	**356.24**	**1,653.83**	**18%**
Prairies	**31,282.78**	**4,110.13**	**35,392.91**	**3,744.39**	**14,535.52**	**13%**