


Application Of Sustainable Agriculture Metrics To Selected Western Canadian Field Crops

Final Report

PREPARED FOR

PULSE CANADA
CANADIAN CANOLA GROWERS ASSOCIATION
CANADIAN WHEAT BOARD
DUCKS UNLIMITED CANADA
FLAX COUNCIL OF CANADA AND
GENERAL MILLS

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Abstract

In January 2011, Pulse Canada, the Canadian Canola Growers Association, Ducks Unlimited Canada, the Canadian Wheat Board and the Flax Council of Canada initiated a project to replicate the Keystone Field to Market Sustainable Agriculture metrics for Western Canadian production of peas, lentils, canola, spring wheat, winter wheat and flax.

The project was a first step toward responding to customer requests for information on environmental performance with science- and evidence-based measurements, in particular those that properly account for the environmental benefits of reduced tillage and other innovations that have occurred in Western Canada. The purpose of this project was to:

a) Demonstrate the extent of progress in environmental performance made in western Canadian cropping systems over the past two decades.

b) Establish a baseline against which to monitor future improvements.

c) Create enabling conditions for stakeholders in Canadian agriculture to contribute to discussion and development of sustainable agriculture metrics for commercial use within the food industry.

In February 2011, General Mills became a member of the project, with a specific interest in Canadian oat production. In September 2011, durum wheat was added to the analysis, in response to a market request.

Field to Market, the Keystone Alliance for Sustainable Agriculture is a coalition of U.S. farm groups, agribusiness, academia, and food industry, and includes the American Farm Bureau Federation, National Corn Growers Association, University of Arkansas, Cargill, Bunge, General Mills, World Resources Institute, John Deere, Coca-Cola, Syngenta, Bayer, and several others. Field to Market's initiative focuses on evidence- and outcome-based measurements of sustainability.

Field to Market has developed five sustainability indicators to date: land use (productivity), climate impact, energy use, soil loss and irrigated water use. The key outcome from the development of the indicators is to measure change in environmental performance of a crop over time. Their focus to date has been on corn, soy, wheat and cotton.

In order to replicate the Field to Market metrics in Western Canada, a team of experts was assembled from the International Institute for Sustainable Development, Agriculture and Agri-Food Canada, the University of Saskatchewan, and the University of Manitoba. Workshops were held in order to identify the optimal approaches to replicating the Field to Market sustainability indicators with Canadian data. These workshops enabled the project team to access and consider the existing research in Canada, and utilize this data to accomplish this study.

The results show that, over a period of two decades, each crop has improved for each indicator – land use, soil loss, energy use and climate impact efficiencies. Irrigated water use was not replicated due to a lack of acreage and therefore suitable data (98.5 per cent of cropland in Western Canada is rain-fed and not irrigated). The improvement in the sustainability indicators is driven largely by a combination of yield improvements, reduced tillage, improved crop rotations and improved nutrient management which has occurred from 1986 to 2006.

In terms of next steps, the report outlines several areas where data development would be beneficial, including improved collection, validation and management. Another important area for future work relates to the functional unit of the Field to Market efficiency indicators. Communicating impacts per unit of yield produced is an incomplete approach, since if agriculture is to be sustainable, the intensity of land use must be matched to the land's capacity to produce agricultural products. Finally, additional work would be beneficial in the area of linking the effects of farm practices to specific environmental outcomes. Field to Market has developed a tool for this purpose in the U.S., and the extension of it into Canada should be considered.

Executive Summary

Project Context

The food industry has recognized that the production, processing and distribution of food affects water, greenhouse gas emissions, soil quality, and other environmental resources. As a result, the food industry and other groups focusing on sustainability are looking at the entire value chain for ways to be more environmentally responsible.

Over the past two decades, primary production in Western Canada has seen a significant increase in the adoption of direct seeding and conservation tillage. There has been a reduction in the area of summerfallow, significant improvements in nutrient management practices, increased diversity in crop rotations, and improvements in crop yield. Ultimately, these changes resulted in significant improvements in the sustainability of primary agricultural production in Canada.

To assess the magnitude of change, sustainable agriculture metrics needed to be developed and accepted. Work undertaken in this area typically has been at a very aggregate level. The situation was similar in the U.S. until a U.S.-based group of agriculture stakeholders called Field to Market: The Keystone Alliance for Sustainable Agriculture took the step of developing crop-specific indicators for the United States (Field to Market, 2009a). This work included an extensive consultation process involving multinational food companies, the science community, the conservation community, and producer organizations. Field to Market's members include the American Farm Bureau Federation, National Corn Growers Association, University of Arkansas, Cargill, Bunge, General Mills, World Resources Institute, John Deere, Coca-Cola, Syngenta, Bayer, and many others.

A group of Canadian agriculture organizations took the initiative to replicate Field to Market's approach for Canada, with a specific focus on selected western Canadian annual field crops as a first step. This group included Pulse Canada, the Canadian Canola Growers Association, the Canadian Wheat Board, Ducks Unlimited Canada, the Flax Council of Canada, as well as General Mills. The project was a first step toward responding to customer requests for information on environmental performance with science- and evidence-based measurements, in particular those that properly account for the environmental benefits of reduced tillage and other innovations that have occurred in Western Canada.

Care was taken to ensure that comparisons across crops and geography were focused on relative rather than absolute indicator findings. This is important since the level of aggregation, geographic characteristics and crop selection make direct comparisons very difficult. On the other hand, many aspects of the Field to Market approach serve as an excellent starting point for the assessment of the sustainability of Canadian primary production.

Objectives and Scope

The objective of the initiative was to implement sustainable agriculture metrics similar to those developed by Field to Market (the Field to Market Indicators), for selected western Canadian field crops and:

1. Demonstrate the extent of progress in environmental performance made in western Canadian cropping systems over the past two decades.
2. Establish a baseline against which to monitor future improvements.
3. Create enabling conditions for stakeholders in Canadian agriculture to contribute to discussion and development of sustainable agriculture metrics for commercial use within the food industry.

The study was limited to an analysis of the metrics that have been developed to date by Field to Market, which Field to Market itself acknowledges are just a starting point, and to which further metrics will be added. The five current metrics are:

1. Land Use
2. Soil Loss
3. Irrigation Water Use
4. Energy Use
5. Climate Impact

Some of the key differences in the approaches included the scope of the assessment – both geographical and crop types chosen:

1. While the Field to Market Indicators have taken a national perspective, this project has addressed a more restricted geography, and is limited to analysis of Western Canada. This decision actually improves the effectiveness of the metrics, since this smaller and more consistent geographical area allows application of algorithms that are more realistic for all locations across that geography.
2. A different selection of crops is addressed. Different agronomic realities exist between Canada and the United States, with the consequence that typical crops and crop rotations differ significantly between the two countries. The following analysis focuses on crops that are prevalent in Western Canada, specifically:
    - Spring wheat
    - Durum wheat
    - Winter wheat
    - Canola
    - Peas
    - Lentils
    - Flax
    - Oats

These crops represented 82% of western Canadian seeded acreage from 2006-2010.

Approach

The process implemented by the project team early in 2011 included the following steps:

1. The completion of detailed documentation of the Field to Market methodologies, including identification of minimum data requirements to implement the indicators.
2. The completion of an environmental scan to locate Canadian data, and characterise it as to geography covered, location-specificity, temporal frequency, and (to the extent possible) accuracy and reliability.
3. Finalize the optimal approach to implementing the Field to Market indicators in Canada.

To accomplish the third of these steps, the project team conducted a modified Delphi process. This process was applied through a series of workshops with a group of selected experts noted in the full report. This expert opinion process was a means of obtaining group consensus through an iterative process of eliciting opinions, in a workshop setting. The goal was to arrive at a relatively narrow spread of opinions within which the majority of experts agreed.

In summary, the scientific and technical input from the workshops initiated the actual analysis and selection of the best way to implement each Field to Market Indicator in Western Canada, enabling the process to access and consider the excellent research that exists in Canada – for example, Agriculture and Agri-Food Canada's Agri-Environmental Indicator Report Series – and to utilize it to accomplish the goals of this study.

One of the most important outcomes of the project was the development of a set of indicator/data selection criteria to ensure consistent selection of data and models and other decision points required in replicating Field to Market's Indicators for Western Canada. The criteria were:

1. Representative of the environmental impact area (e.g. soil loss, GHG emissions)
2. Peer-reviewed, well-developed methodology

3. Adaptable to structure of Field to Market Indicators
4. Geography – regionally representative
5. Temporal representation
6. Most accurate representation of relevant parameters, given existing models and data

Findings

Findings were reported by crop type for each of the indicators. As previously outlined, disparities in data availability and model development between Western Canada and the US make it very difficult, and potentially misleading, to compare the Western Canada indicators with the US ones. Even given directly comparable data, any comparison would have to be made within the context of the different geographic conditions of the two jurisdictions.

Important results have been achieved. The process has served to bring together individuals from different areas of expertise, with the goal of developing a basic set of indicators that can be used to engage producers and work with them to continuously improve practices. It has also identified a number of data gaps that need to be addressed if there is a serious intention to understand the sustainability of different agronomic practices at the farm level.

In terms of the project objectives:

1. Demonstrate the progress made in western Canadian cropping systems over the past two decades, with regards to environmental performance

   The results clearly indicate that Canadian producers have been successful in improving sustainability over the past two decades. The analysis shows that there has been an improvement in efficiency, in every crop, for every indicator.

2. Establish a baseline against which to monitor further improvements in the future

   The modelling and data collection process that was developed in this study involved the use of a set of indicator selection criteria that are replicable, objective and scalable to different levels of aggregation. As a result, the indicators themselves can be replicated as required. They can also be adjusted as better and more complete data becomes available. As these adjustments are made, the current algorithms can be re-established so that the baseline can be updated, allowing analysis on a go forward basis.

3. Create enabling conditions for stakeholders in Canadian agriculture to contribute to discussion and development of commercial sustainability indicators in the food industry

   The analysis provides the evidence required in order to validate claims that actions are taking place that lead to a more sustainable set of agricultural practices. While the indicators are neither perfect nor complete, they are now available and can be used as the starting point for indicator advancement, improvement, and adoption.

Attributing causation of reduced environmental impacts to specific management practices always requires a great deal of caution. At one end of the spectrum, reduced tillage is a well defined practice, with substantial research evidence to say that it leads to reduced soil erosion, reduced energy use and reduced climate impact. Details of these relationships are discussed in this report. At the other end of the spectrum, it is very difficult to rigorously quantify the environmental impacts of increasingly diverse crop rotations.

The findings do clearly demonstrate that Canadian farmers continue to be good stewards of the land, air and water. Indicators are of increasing importance as the population continues to become more urban and the average consumer's understanding of the agricultural system becomes more remote. This results in increased challenges in communicating the work being done to protect the environment in which food is produced. The indicators developed in this report could be used as one way of providing information to all Canadians about food production and its impact on the environment. While not perfect at this point in time, the sustainability indicators provide a starting point for what is likely to be an increasingly popular topic of discussion in the future.

Next Steps

An important output of this project is the identification and prioritisation of areas where further work is needed. While the project team has been able to make use of well developed data in some areas (e.g. energy use and climate impact), better data and analysis are clearly needed in other areas. For example, future indicator development relating to land use will depend on analysis and data development that are not yet in place. Given the reality of limited resources for such work, priorities must be established in these areas.

There are five main areas where the analysis has provided evidence that additional data and/or research would be strongly beneficial. These have been summarized, identifying both suggested changes as well as an indication of how additional data could be used.

1. The Land Use Indicator is an area where further work could provide substantial benefits. A key outstanding issue is that of whether the intensity of use of agricultural land is consistent with the productive capacity of the land. Data sources are already in place for Western Canada which could be developed to provide insight into this issue. These are identified in this report.
2. Field to Market has identified several areas for development of indicators in the future, including pesticide, fertilizer use and water quality.
3. Another important area for future work relates to the functional unit of the Field to Market efficiency indicators. Ultimately, it is important to go beyond expressing the relative impact on the environment, per unit of output. Aggregate environmental impacts must also be expressed, and compared to absolute environmental conditions. There is a danger that efficiency gains will lead to increased aggregate consumption of a resource when demand is strong, leading to increased pressure on the resource.
4. The time-series indicators presented in this report are the inputs required by integrated models, which can eventually enable identification of system linkages and synergies. By the nature of time-series data, significant time is needed to accumulate it. As a result, it is critical that priority be placed on identification of the process to be used to improve collection, validation and management of this data. This speaks to the urgency of data collection for time series indicators in two key areas:
    - Strengthening and further validating existing data, e.g. the soil erosion data used in this report
    - Collecting additional data, e.g. for land use indicators as proposed in this report.
5. An objective for further work is to demonstrate the aggregate effects of farm practices at the higher-level ecosystem scale. Ultimately, it is critical that correlation and causation be separated and completely understood, if there is to be a focus on motivating appropriate and/or desired behaviour. An improved understanding should be developed on how on-farm practices impact the indicators, and what can be done to improve these impacts. One approach to doing so is creating a farm-level tool that individual growers can use to assess how their decisions impact the indicators. Field to Market has developed a tool like this, and the extension of this model into Canada should be considered.

In summary, the ability to measure the sustainability of agricultural production is likely to become even more relevant in the future. Not only is sustainable production the right thing to do, but it is also becoming a significant point of comparative advantage. As a result it is in the best interests of all stakeholders to work together to refine and improve sustainability measurement. Ultimately, accurate, timely and defendable indicators will become the basis of validating the promise behind a brand related to environmentally friendly agricultural production in Canada. Given the time it takes to collect the time-series data necessary to populate these indicators, it is essential to prioritize this effort and initiate a full time commitment to indicator development and support as soon as possible. The work completed under this project offers an excellent starting point. It is consistent with the work being completed by Field to Market in the U.S., and uses the best information available for Western Canada at this time. It also serves to identify where the key weaknesses in both data and scientific knowledge are, thus providing a basis for prioritization of actions.

Table of Contents

TABLE OF CONTENTS

List of Tables and Figures

Glossary

Acronyms

ASAE	American Society of Agricultural Engineering
CEEMA	Canadian Economic and Emissions Model for Agriculture
ESTR	Ecosystems Status and Trends Report
F4E2	Fossil Fuel Farm Fieldwork Energy and Emissions simulation model
FEUS	Farm Energy Use Survey
FRIS	Farm and Ranch Irrigation Survey
FTM	Field to Market: The Keystone Alliance for Sustainable Agriculture
GHG	Greenhouse gas
IISD	International Institute for Sustainable Development
LSRS	Land Suitability Rating System
NAHARP	National Agri-Environmental Health Analysis and Reporting Program
NASS	National Agricultural Statistics Service
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
OECD	Organization for Economic Co-operation and Development
PFRA	Prairie Farm Rehabilitation Administration
RWEQ	Revised Wind Erosion Equation
RUSLE	Revised Universal Soil Loss Equation
RUSLE2	Revised Universal Soil Loss Equation 2
SCI	Soil Conditioning Index
SLC	Soil Landscapes of Canada
SOC	Soil Organic Carbon
SoilERI	Soil Erosion Risk Indicator
USLE	Universal Soil Loss Equation
USDA	United States Department of Agriculture
USDA-NRCS	United States Department of Agriculture Natural Resources Conservation Service
T	Tolerable soil loss level
WEPS 1.0	Wind Erosion Prediction System 1.0
WEQ	Wind Erosion Equation

Abbreviations

T	tonne (metric ton)
ha	hectare
CO_2e	CO_2 equivalent
T CO_2e	tonnes of CO_2 equivalent
CE	carbon equivalent
lbCE	pounds of carbon equivalent
GJ	gigajoule

Note on Terminology

Field to Market Environmental Resource Indicators (or Field to Market Indicators) refers to the sustainable agriculture metrics developed by Field to Market: The Keystone Alliance for Sustainable Agriculture, since 2007, in the United States.

Introduction

The following report provides the results of work done to apply a set of sustainable agriculture metrics (indicators) to selected western Canadian field crops. These metrics are the Field to Market Environmental Resource Indicators, or Field to Market Indicators, initially developed in the United States. Emphasis is placed on identifying critical success factors achieved, as well as the identification of issues of specific importance as they relate to the project deliverables.

Developing sustainable agriculture metrics is not new to Canada. However, work in this area has typically been at a very aggregate level. Field to Market: The Keystone Alliance for Sustainable Agriculture, a U.S.-based group of agriculture stakeholders, has taken the step of developing crop-specific indicators for the United States (Field to Market, 2009a). This work included an extensive consultation process, involving multinational food companies, the science community, the conservation community, and producer organizations.

The business of growing, processing and distributing food creates a significant environmental footprint. The activities needed to produce and distribute food have impacts on water, greenhouse gas emissions, soil characteristics, and other environmental resources. The entire value chain – retail, food manufacturing, agriculture – recognizes the need to look for ways to be more environmentally responsible.

A market intelligence report on sustainable agriculture published in early 2011 by Canadian agriculture stakeholders (Pulse Canada, 2010) demonstrated that leading companies and organizations within the food value chain have examined strategies regarding environmental sustainability. It was found that, while each sector within the value chain has focused on the set of environmental issues it knows best, the food industry has identified that the majority of the environmental impact of their products occurs in their agricultural supply chains.

Many food companies have already committed to long term goals to reduce environmental impacts. Some will only purchase ingredients from sustainable sources. In November 2010, Unilever, one of the world‘s largest food companies, committed to a long term goal of purchasing 100% of its agricultural products from sustainable sources by 2020.

Effective measurements will guide individuals, companies and governments as they move toward more sustainable approaches, by allowing for meaningful evaluations of actions and policies. The right measurement tools are the cornerstone of efforts to reduce primary agriculture‘s impact on the environment. The sustainable agriculture metrics developed by Field to Market are part of larger efforts within the food value chain to correctly and fully account for agriculture‘s impacts on natural resources. This type of accounting is viewed as the enabling condition to improve environmental footprint per unit, and reduce risk, as well as to identify potential corrective actions needed to bring agricultural systems into long-term balance.

Field to Market's sustainable agriculture metrics are an effort to begin to quantify the environmental impacts of U.S. agriculture, as well as progress made over time. The decision of Canadian stakeholders to replicate the Field to Market metrics for Western Canada will make it possible to provide credible information on the impacts of western Canadian agriculture to the food industry. It will also make it possible to quantify the extent of positive environmental impacts resulting from significant changes in farm management practices that have occurred in Canada over the past few decades.

The overall intensity of crop production in Western Canada has increased over the past few decades. At the same time, farm management practices have changed significantly, with a large amount of effort devoted to mitigating negative impacts of crop production on the environment. The following are key areas in which crop production practices have changed in recent decades.

1. **Increased adoption of no-till and conservation tillage**

   Between 1991 and 2006, the percentage of cropland area under no-till has increased from 3% to 48% in Alberta, from 10% to 60% in Saskatchewan, and from 5% to 21% in Manitoba (Eilers et al, 2010).

2. **Reduced area of summerfallow**

   Between 1981 and 2006, the share of cropland under summerfallow decreased from 12% to 4% in Alberta, from 26% to 9% in Saskatchewan, and from 8% to 2% in Manitoba. Further, on the land where summerfallow is still used, tillage is used less and chemicals are used more. Between 1981 and 2006, the share of summerfallow area under tillage only (no chemical use) decreased from 58% to 27% in Alberta, from 57% to 31% in Saskatchewan, and from 73% to 46% in Manitoba. During the same time frame, the share of summerfallow area under tillage and chemical treatment decreased from 37% to 28% in Alberta, from 39% to 31% in Saskatchewan, and increased from 24% to 40% in Manitoba, again demonstrating a significant reduction in the use of tillage across Western Canada (Eilers et al, 2010).

3. **Improvements to nutrient management**

   - Various practices relating to nutrient management are being monitored under the Farm Environmental Management Survey (FEMS), e.g. (Eilers et al, 2010):
   - A higher proportion of Canadian cropland was nutrient tested at 2-5 year frequencies (as opposed to 6 years+ frequencies) in 2006 than in 2001
   - Between 2001 and 2006, Canadian producers have reduced the time between manure application and incorporation, improving nutrient retention
   - Between 1995 and 2006, Canadian producers have increased the percentage of manure spread in the spring, when crops can best utilize it, and reduced the percentage spread in the fall.
   - Storage capacity for liquid manure has been increasing since 1995, increasing the flexibility producers have to spread manure at the optimal time
   - Injected or knifed in/subsurface fertilizer application, separate from seeding, was used on about 12% of Canadian crop farms in 2001, and on about 18% in 2006, reducing the risks of nutrient runoff and volatilization[1]
   - Post-plant/foliar/top dressing application of fertilizer was used on about 4% of Canadian crop farms in 2001, and on about 8% in 2006, showing that nutrients are increasingly being added to crops during periods of rapid growth

4. **Increasingly diverse crop rotations**

   Producers are using increasingly diverse crop rotations. In particular, the introduction of oilseeds and pulses into crop rotations provides benefits to other crops. This trend is reflected by the diversification of cropping patterns between 1981 and 2006, with the proportions of oilseeds, pulses and forages increasing at the expense of cereal grains. For example, while the share of cropland producing cereal grains decreased from 71% to 52% in Alberta, from 85% to 52% in Saskatchewan, and from 67% to 45% in Manitoba, the share of cropland producing pulses increased from <1% to 3% in Alberta, from <1% to 11% in Saskatchewan, and from 1% to 6% in Manitoba, and the share of cropland producing oilseeds increased from 8% to 18% in Alberta, from 6% to 21% in Saskatchewan, and from 15% to 25% in Manitoba (Eilers et al, 2010). Also between 1981 and 2006, the harvested area of canola increased by 96% in Alberta, by 220% in Saskatchewan, and by 191% in Manitoba (Statistics Canada, 2011a).

5. **Crop development**

Improvements in plant breeding have led to substantial increases in crop yields, contributing to greatly increased land use efficiency in crop production.

[1] Data published in NAHARP's third report (Eilers et al, 2010) indicates a slight decrease in application of fertilizer with seed, a slight decrease in banding during seeding, and a slight increase in broadcasting, between 2001 and 2006. These trends are likely not representative, and need to be monitored over a longer period.

These changes to management practices raise the question, how have the impacts of crop production on the environment changed over the past few decades? Further, since the food industry is looking for this information, how have these impacts changed with respect to production of individual crops? Documentation of improved management practices, as outlined above, is important. The additional step of measuring the actual impacts on natural resources is even more important.

As a result, the present study was commissioned in late 2010, by the Canadian agriculture interests listed below, to address the following:

- The need to verify the sustainability of crop production for the food companies purchasing the commodities
- The need to quantify natural resource impacts of the changes in crop production systems noted above, on a crop-specific basis

It is critical to understand the Field to Market Indicators and the development process behind them in order to ensure that work done in Canada is comparable. As expected, collection of data relevant to the various environmental impact areas addressed by Field to Market has followed different paths in Canada and the United States. Geography and cropping systems also differ between the two countries. Consequently, the Project Team devoted considerable effort to gathering information on the various sources of Canadian data relevant to the Field to Market Indicators. Considerable effort went into deciding how best to adapt the indicator development process for Canada.

The methodology used by the Project Team involved a significant amount of facilitated expert opinion. Canadian operating realities and data deficiencies create a different context from that in which the Field to Market Indicators were developed, and a large amount of effort was devoted to identifying the implications of these differences for replication of the Field to Market Indicators in Western Canada. Workshops were conducted, with a number of respected experts in the specific areas of focus, in order to determine how best to address the three most complex of the five indicators. Findings from these workshops fall into the three following categories:

1. How the Field to Market Alliance developed the Field to Market Indicators, and how these will evolve in the future
2. The status of relevant models, research and data in Canada
3. Results from a solicitation of expert opinion as to the best specific approach to replicating Field to Market Indicators in Western Canada.

The following report presents the results of implementation of Field to Market-equivalent sustainable agriculture metrics for Western Canada. The metrics are presented in the context of the key trends that have shaped crop production in Western Canada over the past three decades. Strengths and weaknesses of the metrics are identified and comparisons are made to other possible metrics or functional forms that could be used for the same or similar data. Data gaps, future data needs, and different metrics/forms of metric that have good potential to add information to the environmental impact area in the future are also provided.

Objectives

This project is an initiative of Canadian agriculture interests, including Pulse Canada, the Canadian Canola Growers Association, the Canadian Wheat Board, Ducks Unlimited Canada, the Flax Council of Canada and General Mills (the Project Partners). The objective of the initiative is to implement sustainable agriculture metrics similar to those developed by Field to Market (the Field to Market Indicators), for selected western Canadian field crops.

The Project Partners view the implementation of the Field to Market Indicators in Canada as an opportunity to:

1. Demonstrate the progress made in western Canadian cropping systems over the past two decades, with regards to environmental performance
2. Establish a baseline against which to monitor future improvements
3. Create enabling conditions for stakeholders in Canadian agriculture to contribute to discussion and development of sustainable agriculture metrics for commercial use within the food industry

Scope

As is outlined in the Field to Market report (Field to Market, 2009a), there are a number of sustainable agriculture metrics that could be used in an exercise of this nature. However, for reasons of consistency with the existing Field to Market Indicators, this study is limited to the following metrics:

1. Land Use
2. Soil Loss
3. Irrigation Water Use
4. Energy Use
5. Climate Impact

This is not intended to be a complete list of relevant sustainable agriculture metrics. Rather, it is a starting point. The Field to Market Alliance plans to develop additional metrics for water quality and biodiversity next.

The following differences in scope between the USA and Canadian metrics should be noted:

1. While the Field to Market Indicators have taken a national perspective, this project has addressed a more restricted geography, and is limited to analysis of Western Canada. This decision actually improves the effectiveness of the metrics, since this smaller and more consistent geographical area allows application of algorithms that are more realistic for all locations across that geography.
2. A different selection of crops is addressed. Different agronomic realities exist between Canada and the United States with the consequence that typical crops and crop rotations differ significantly between the two countries. The following analysis focuses on crops that are prevalent in Western Canada, specifically:
   - Spring wheat
   - Durum wheat
   - Winter wheat
   - Canola
   - Peas
   - Lentils
   - Flax
   - Oats

As seen in Table 1, below, the area seeded to these eight crops represented 82% of the area seeded to the principal field crops in Western Canada, on average, for the five year period from 2006 to 2010 (Statistics Canada, 2011b).

Table 1: Seeded Area of Crops Under Study vs. Total Seeded Area of Principal Field Crops, Western Canada

Crop	Seeded Area (million hectares)	% of Principal Field Crops
Spring Wheat	6.65	27.7
Durum Wheat	1.90	7.9
Winter Wheat	0.37	1.5
Canola	6.27	26.2
Peas	1.45	6.0
Lentils	0.82	3.4
Oats	1.57	6.5
Flax	0.61	2.5
Total for Crops Under Study	19.63	81.9
Total for Principal Field Crops	23.98	100.0

Source: Statistics Canada (2011b).

As stated above, the geographic scope for this work is Western Canada. For the crops under study, the relevant area essentially includes the agricultural areas of Manitoba, Saskatchewan, Alberta and the British Columbia Peace Region. This includes two of Canada's terrestrial ecozones, namely the Boreal Plains and the Prairies. While the indicators in this study are developed for Western Canada, parts of the following discussion relate primarily to the climate and ecology of the Prairie Ecozone. Where this is the case, this report refers to "the prairies" rather than to "Western Canada".

Project Context

The Project Team's Approach to Development of Indicators for Western Canada

The genesis of this project involved a previous analysis of the Field to Market approach and the potential to replicate it in Canada. Serecon completed a study to assess the feasibility of implementing sustainable agriculture metrics similar to the Field to Market Indicators developed by Field to Market, in Western Canada in 2009 (Serecon, 2009). This work was done under contract with Pulse Canada, the Canola Council of Canada and the Canadian Wheat Board. The primary objective was to review the analysis conducted for the U.S., in order to determine whether this approach could be effectively extended to Canada.

A detailed environmental scan was conducted into the availability and applicability of Canadian data. The analysis focused on determining whether there was sufficient consistency in data structure to allow the creation of effective Field to Market Indicators for Canada. Specific sources of Canadian data were examined for each of the five Field to Market Indicators.

A number of data gaps were identified. In spite of the fundamental nature of the environmental issues addressed, and the simple structure of the five Field to Market Indicators, it was found that significant differences exist between the data used for the U.S. Field to Market Indicators, and Canadian data. In several instances, it was found that the Field to Market Indicators for the U.S. were based on proxy data. On the other hand, in the United States, soil loss measurement has been based on management data from tens of thousands of sample sites, with the analysis supported by extensive databases providing site-specific data on such factors as precipitation, wind, erodibility and topography. This implies a considerably greater density of data relative to soil loss in the U.S. than in Canada.

In short, Serecon's 2009 feasibility study revealed that, in spite of the apparent simplicity of the Field to Market Indicators, the methodology is sophisticated and accompanied by significant data requirements. The crop-specific nature of the Field to Market Indicators creates unusual data requirements. As well, time-series data is necessary. It became apparent that, in the areas of soil loss, energy use and climate impact, it would be necessary to go well beyond existing data, and to make use of research and analysis in these areas to find ways of generating the data required to implement the indicators.

As a result of this analysis, the Project Team felt strongly that a key critical success factor would be the implementation of a formally-structured approach to indicator development. This was to ensure that the process would result in the development of as many of the Field to Market Indicators as possible, while also ensuring that the necessary steps are taken to initiate the process of data collection/development for those indicators for which suitable data is not readily available. In other words, where serious data limitations remain, the Project Team's effort would be shifted to identifying the steps necessary to develop the necessary data.

In line with this approach, the Project Team anticipated that the potential to replicate each of the five Field to Market Indicators for a Canadian context would fall into one of the following categories:

1. The existing Field to Market model can be populated with Canadian data
2. The Field to Market model can be adapted, or a model can be developed, and populated with Canadian data
3. A model can be developed, but Canadian data to populate it will remain incomplete within the timeframe of this study
4. A model and/or Canadian data cannot be developed within the timeframe of this study, but the necessary processes can be started.

A specific research approach was then designed to address these four situations, and to create opportunities to minimize any negative impacts on the resulting indicators.

The formally-structured process implemented by the Project Team early in 2011, included the following steps:

1. The completion of detailed documentation of the Field to Market methodologies, including identification of minimum data requirements to implement the indicators
2. Completing an environmental scan to locate Canadian data, and characterise it as to geography covered, location-specificity, temporal frequency, and (to the extent possible) accuracy and reliability
3. Finalizing the identification of the optimal approach to implementing the Field to Market Indicators in Canada.

The Use of Expert Opinion

To accomplish the third of these steps, the Project Team conducted a modified Delphi process. This process was applied through a series of workshops, with the goal of identifying the optimal approaches to developing Field to Market Indicators with Canadian data. This process of capturing expert opinion provided a means of systematically evaluating alternative approaches, subject to the need to:

1. Adhere closely to the intent of the Field to Market Indicators
2. Respond optimally to the issues raised by Field to Market's peer reviewers in July, 2008 (e.g. address issues of data aggregation and scalability)
3. Provide the best possible indicators for Canada's crop production sector, subject to data constraints
4. Facilitate communication between groups and individuals with potential to contribute to valuable Canadian indicators over time.

This expert opinion process was a means of obtaining group consensus through an iterative process of eliciting opinions, in a workshop setting. The goal was to arrive at a relatively narrow spread of opinions within which the majority of experts agreed. This process addressed the decision point, for each indicator, that required the broadest range of scientific and technical input.

Critical areas of expertise were identified for representation at the workshops, including:

1. Knowledge of how the Field to Market Indicators were constructed in the United States
2. Knowledge of the relevant Canadian data sets
3. Knowledge of relevant Canadian science and modelling
4. Modelling expertise
5. Expertise in indicator development.

With all of these areas of expertise represented at each workshop, it was possible to generate the necessary back-and-forth discussion in a face-to-face setting, so that ideas could be shared and alternative approaches explored.

The workshops were structured around seven specific objectives, and organised so as to elicit critical information and expert opinion in a sequence that was both logical and iterative, thus allowing consensus to build. These specific objectives included:

1. Definition of needs and expectations for indicator development – detailed description of Field to Market Indicator methodology and intended future directions
2. Identification of information requirements for indicator development
3. Assessment and definition of the utility of existing data for indicator development
4. Assessment of how the evolution of Canadian modelling capacity over time is impacting, and will impact,

the utility of Canadian data for indicator development (objective #3, above)

5. Assessment of alternative data sources
6. Assessment of alternative approaches/methodologies for indicator development
7. Critical assessment of the potential to develop effective indicators for Canada

In summary, these workshops initiated the actual analysis and selection of the best way to implement each Field to Market Indicator in Western Canada. They represented the decision point, for each indicator, that required the broadest range of scientific and technical input.

In more specific terms, these workshops enabled the Project Team to access and consider the excellent research that has already been initiated in Canada, and to adapt it to the goals of this study.

Specifically, this research includes:

1. The work that has been done on soil erosion on agricultural lands in Canada by the National Agri-Environmental Health Analysis and Reporting Program (NAHARP) (Eilers et al, 2010). While not immediately applicable to Field to Market Indicators for Western Canada, this provided a strong base of data and methodology from which the Field to Market Soil Loss Indicator could be developed.
2. The work feeding into Canada's reporting on agricultural greenhouse gas (GHG) emissions, under the Kyoto Protocol (Eilers et al, 2010). This included the Fossil Fuel Farm Fieldwork Energy and Emissions (F4E2) simulation model to quantify farm energy, NAHARP's work on nitrous oxide emissions, and estimates of soil carbon emissions and sequestration using the Century model. Again, these sources did not provide data immediately applicable to crop-specific metrics, but did provide the necessary building blocks.

Indicator Selection Criteria

As would be expected, several possible processes were available to the Project Team for the development of each indicator and these processes and data sources needed to be ranked in some way. The following criteria were established in order to ensure consistent selection of data and models to implement Field to Market Indicators in Western Canada. These criteria underwent refinement as the project progressed and additional information became available, and ideas put forward at the indicator workshops in March, 2011 were incorporated into the selection criteria.

In summary, it was determined that, in order to be considered, data and models should be:

1. Representative of the environmental impact area (e.g. soil loss, GHG emissions)
    - Captures the most significant elements/sources of impact
    - Outcomes-based
        - Either quantifies the environmental impact, or
        - Quantifies causative factors, with coefficients relating these to environmental impacts
2. Peer-reviewed, well-developed methodology
    - Provides a reliable baseline, upon which additional work can be built
        - Potential to add consistent data for future years
        - Potential to expand and refine data, e.g. with input of expert opinion
3. Adaptable to structure of Field to Market Indicators
    - Capable of providing crop-specific data on environmental impacts
    - Capable of providing data on environmental impacts on a per unit area basis

4. Geography – regionally representative
   - Accurate at the regional level (i.e. for Western Canada)
     - Ecoregion and provincial levels are most relevant
     - Good national-level data may not translate to good regional data
     - Good data for a smaller geography, e.g. one province, may not translate to good regional data
5. Temporal representation
   - Consistent across time – suitable for creation of time-series indicators
   - Sensitive to changes across time
6. Most accurate representation of relevant parameters, given existing models and data
   - Models, rather than existing data, may provide the best representation of parameters for which surveys are not feasible or have not been conducted

The Project Team has used these selection criteria to guide decision making throughout the project as to which of the various Canadian data sources and models should be used in the implementation of Field to Market Indicators for Western Canada.

The Field to Market approach – Overall Structure and Evolution of Indicators for the United States

It is critical to recognize the excellent work that has been conducted to date in the U.S. The Field to Market Indicators provided the starting point for this analysis, and need to be understood in the context for which they were developed.

The National-Level Field to Market Indicators

To date, the Field to Market Alliance has implemented two separate sets of metrics. The first is the set of national-level indicators, published in 2009, covering five indicator areas: land use, soil loss, irrigation water use, energy use and climate impact (Field to Market, 2009a). These are outcomes-based indicators, built from the top down, and designed to show change over time at the national level. The focus of the Field to Market Alliance in developing these indicators has been on finding the best possible time-series data.

It is acknowledged that metrics are also needed for water quality and biodiversity, which are also key environmental areas of concern for agriculture. These are works in progress.

At present, the national-level Field to Market Indicators are able to provide results from 1987 to 2007, for each of the five indicators (land use, soil loss, irrigation water use, energy use, and climate impact).

The national-level Field to Market Indicators for all five indicator areas (i.e. land use, soil loss, etc.) are reported in two separate formats: a resource impact indicator and an efficiency indicator. These two indicator formats are constructed from three basic sets of data for each crop:

1. Resource use or impact per acre
2. Crop yield per acre
3. Resource use or impact per unit of crop output, indexed to a value of 100 for the year 2000 (“efficiency indicator”).

These three data sets are outlined in Table 1.

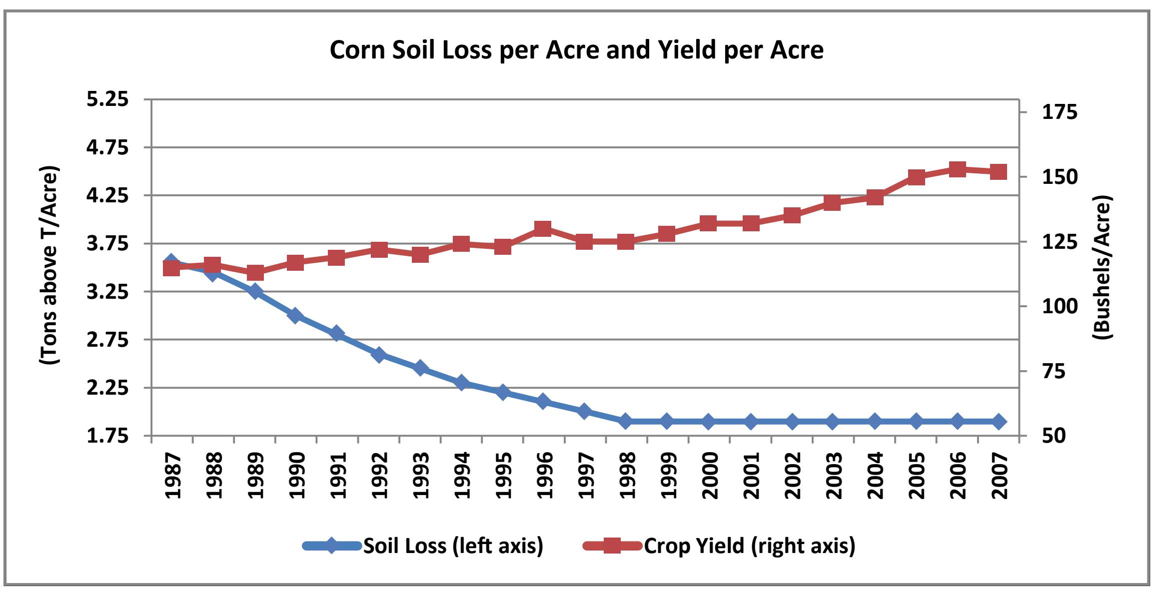
Table 2: Summary of Field to Market Alliance Indicator Units (to Illustrate Dimensions of Indicators)

	Land Use	Soil Loss	Irrigation Water Use	Energy Use	Climate Impact
Resource Use/ Impact per Acre	million acres	tons above T (tolerable level)/ acre	thousand gal/ acre	million BTU/acre	lb carbon/ acre
Crop Yield per Acre	bu/acre	bu/acre	bu/irrigated acre	bu/acre	bu/acre
Efficiency Indicator	acres/bu of crop	lb soil/bu of crop	thousand gal/ incremental bu due to irrigation	million BTU/bu of crop	lb carbon/ bu of crop

These three data sets provide the basis for two distinct approaches to assessing the sustainability of each crop. The first of these comes directly from 1, above, and provides information on changes over time in resource use, or impact on resources, independent of crop yield. This is the resource impact indicator.

The Field to Market Soil Loss Indicator for corn serves to illustrate the construction of a resource impact indicator. Figure 1 presents data for corn for both resource impact (i.e. soil loss, in tons above T per acre, left axis) and crop yield (bushels/acre, right axis). The blue curve represents the resource impact indicator for soil loss.

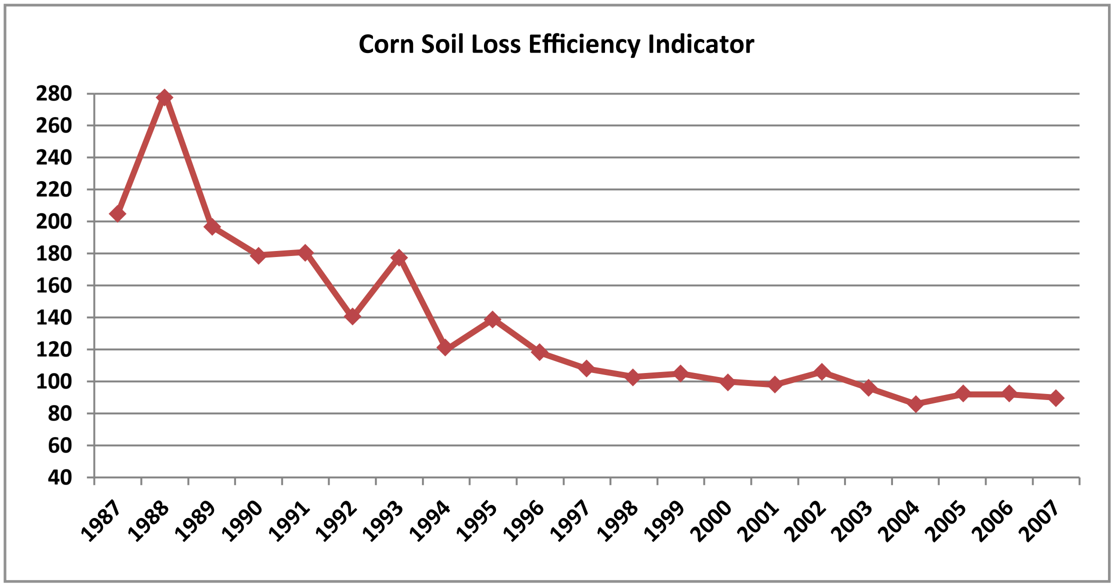
Figure 1: The Field to Market Soil Loss Indicator – Resource Impact Indicator



Source: Field to Market: Environmental Resource Indicators Report, First Report, January 2009

The second approach combines information from data sets 1 and 2, above, and constructs measures of resource impact over time, relative to crop yield. This leads to efficiency indicators. Again, the Soil Loss Indicator for corn provides an example of an efficiency indicator. Figure 2 presents the Field to Market Efficiency Indicator for Soil Loss. Soil loss (tons above T/acre), from Figure 1, has been divided through by crop yield (bushels/acre), also from Figure 1, giving the Soil Loss Efficiency Indicator, showing resource impact per unit of output. As with all the Field to Market Efficiency Indicators, this is indexed to a value of 100 for the year 2000.

Figure 2: The Field to Market Soil Loss Indicator – Efficiency Indicator



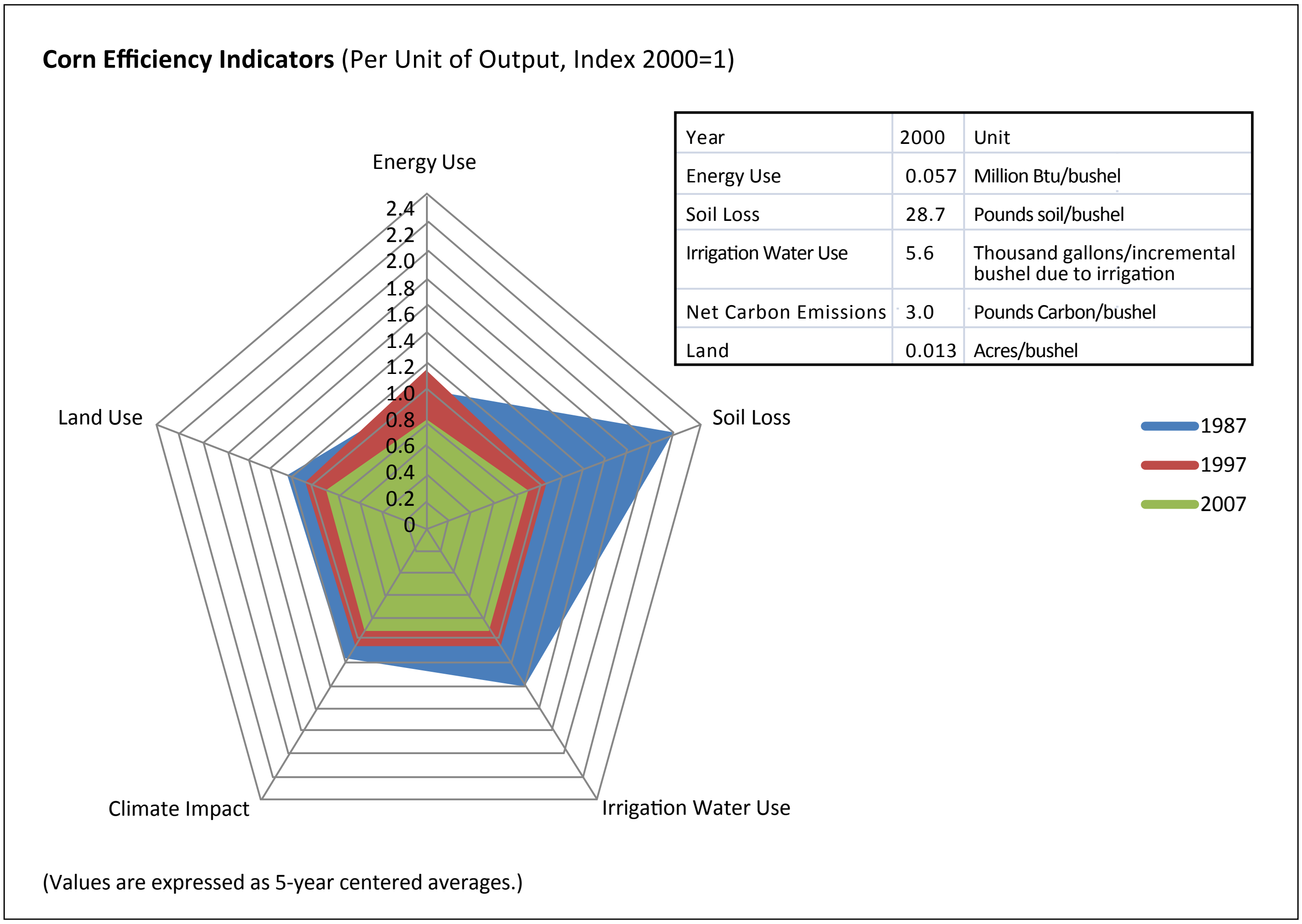
Note: The Efficiency Indicator is expressed as Soil Loss (Tons above T per acre) relative to one bushel/acre of output, indexed to 100 in the year 2000.

Source: Field to Market: Environmental Resource Indicators Report, First Report, January 2009

Thus the three data sets outlined in Table 1 provide the basis for both resource impact indicators and efficiency indicators. The intent of the two resulting indicators is to track information over time, in order to illustrate changes, and the relative magnitudes of changes. While the changes are of interest in their own right, the baselines provided by the indicators are also very important. By providing baselines, and tracking changes over time, the indicators provide information on the impacts of policy decisions, in an objective fashion.

Figure 3 illustrates all five efficiency indicators for corn. Thus land use, soil loss, irrigation water use, energy use and climate impacts are all represented.

Figure 3: Field to Market Efficiency Indicators for Corn, 1987 to 2007



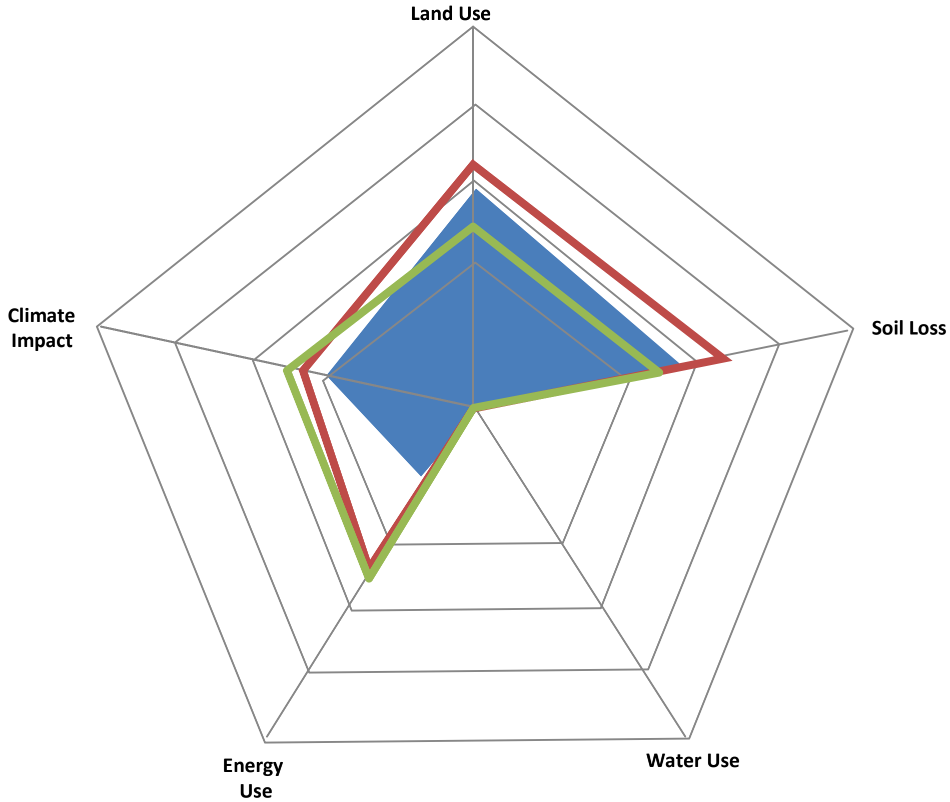
Year	2000	Unit
Energy Use	0.057	Million Btu/bushel
Soil Loss	28.7	Pounds soil/bushel
Irrigation Water Use	5.6	Thousand gallons/incremental bushel due to irrigation
Net Carbon Emissions	3.0	Pounds Carbon/bushel
Land	0.013	Acres/bushel

Source: Field to Market: Environmental Resource Indicators Report, First Report, January 2009

The Fieldprint Calculator

The Keystone Alliance's second set of metrics is contained in the "Fieldprint Calculator", also implemented in 2009 (Field to Market, 2009b). The Fieldprint Calculator enables an individual grower to input his management practices, creating a point-in-time snapshot at the field level. This enables the grower to compare environmental sustainability on his farm to national and state averages. More importantly, it lets the grower see the relationships between his practices and sustainability outcomes, and the relative impacts of different changes he might make to his management practices.

Figure 4: Sample Output from Field to Market Fieldprint Calculator (Imaginary Wheat Field, Montana)



National (U.S.A.) averages for each Indicator are shown in green, state (Montana) averages in orange, imaginary wheat field in blue.
Source: Field to Market Fieldprint Calculator

The Future Fieldprint Calculator

At present, the Field to Market Alliance is focussing its efforts on revising the Fieldprint Calculator (Field to Market, 2011). This includes the following proposed changes to the overall approach used in the Fieldprint Calculator:

1. **Crop production system.** While the present Fieldprint Calculator assumed a one-year production period, the revised Calculator will define a crop production system across multiple years. This will make it possible to include all the investments and production decisions that impact crop yield. A crop production system will be considered to start when the first practice or application is made to improve crop performance, and to end at the first point-of-sale of produce. Thus, for example, energy used to dry grain is allocated differently if the grain is dried on the farm, as opposed to being delivered wet to an elevator.
2. **Co-products and bi-products.** Related to the new definition of production system is refined accounting for co-products and bi-products. Cotton seed is an important example of a co-product. An economic allocation, based on price, will be applied to resources shared in the harvesting of cotton seed and cotton lint. Thus, for example, the energy use metric will allocate some of the energy used to harvest and dry cotton to lint, and some to seed.

3. **Production space.** The revised Fieldprint Calculator will define production space as total land area, rather than harvested area. This will provide a more appropriate accounting, for example where significant areas of crop are abandoned, due to extreme weather. Emphasis is on application of a systematic method to capture and allocate resources across abandonment, double cropping, etc. This allocation will be based on information from a full cycle of a producer's rotation.
4. **Use of government databases to provide default data specific to the farmer's location.** In the proposed Fieldprint Calculator, the grower will be able to click the location of his field on an interactive GIS map to plug into government databases containing location-specific data on climate, soil and topography. The grower will also be able to access a "Managements" database, developed by USDA's Natural Resources Conservation Service. This database contains over 26,000 "tillage systems", or prebuilt management scenarios, regionally tailored and organised by 75 crop management zones. These databases provide the soil erosion models used by the new Fieldprint Calculator with highly specific input, without creating an unmanageable data input task for the grower.

Once the revised Fieldprint Calculator is in place, it is expected that work will begin on revising the national-level indicators. Future national-level indicators will probably incorporate methodology from the revised Fieldprint Calculator. The Fieldprint Calculator is necessarily built from the bottom up, and uses different data from the national-level indicators. As a result, it is not possible to simply project numbers from the Fieldprint Calculator upward to create national-level indicators. However, it is anticipated that the Fieldprint Calculator may be used to provide some verification of future national-level indicators (Ramsey, 2011a).

Strengths and Weaknesses of the Field to Market approach

General Overview and Evaluation of the Field to Market approach

The Field to Market Indicators represent a robust approach to performance measurement that has several advantages, but also some challenges. These can be assessed based on the intended purpose and uses of the Indicators, or on the basis of best practices. The analysis below loosely builds on the criteria identified in the Bellagio Sustainability Assessment and Measurement Principles (BellagioSTAMP) developed by the OECD and IISD in an expert process that builds on multi-decade experience with sustainability measurement and assessment systems (IISD and OECD, 2009). BellagioSTAMP is a set of guiding principles for measuring progress toward sustainability. These principles respond to the need for greater harmony with the natural environment, and for measures to secure the wellbeing of both current and future generations.

The Field to Market Indicators are related to the environmental domain of sustainability, and address a wide range of environmental issues. Sustainability (and unsustainability) of agriculture of course goes beyond environmental conditions, but, as an effort focused on the environment, the themes covered are relevant and representative of key issues. As the developers also note, the list is not definitive, and additions related e.g., to agri-biodiversity can be expected. This is in line with a view of sustainability assessment and measurement systems as learning-evolving systems.

Approach Advantages

Among the advantages of the Field to Market Indicators, one must recognize the emphasis on robustness and simplicity of the indicator set. Indicator systems focused on various aspects of 'sustainability' often fall into the trap of generating excessively long lists of indicators. While these may cover a wider range of issues, they raise significant implementation challenges. The Field to Market list is a short 'headline' indicator set, focused and designed to be implementable under a wide range of conditions. In addition to their relative simplicity, the developers also considered data availability, and the web tool in particular will provide direct access to geo-referenced federal databases with primary, quality controlled data.

Although the indicators don't arithmetically aggregate up from the farm to the regional or national level, they can be meaningfully applied on multiple scales and used for cross—scale comparison. Comparison across production units, whether fields, farms or regions may also be possible, which may be important for diagnosing differences in production processes and their impacts on the environment. In addition, emphasis on longitudinal data allows the analysis of long-term patterns of change. These features could help identify structural challenges and trace the impacts of policy interventions, technical developments or changes in agro-ecological conditions that would not be visible in the absence of dynamic time series.

The Field to Market Indicator methods are clearly described, which is an essential condition for transparency and trust in the integrity and broader application of the approach. The Fieldprint Calculator takes the indicators to a new level and promises to be a practical, easy tool to use even at the level of individual farms, without technical assistance. The spidergraph is a well accepted method to communicate the performance of both individual and a collection of different indicators, although setting the scale and weighting of the indicators can represent challenges. These issues, however, are not unique to this method. At the moment the Fieldprint Calculator applies equal weighting to the indicators, and presents no aggregate other than the size and shape of the star diagram in the middle of the spidergraph, outlined by the lines connecting the current performance for each individual indicator.

A definite strength of the approach is the involvement and commitment of multiple stakeholders. This seems to go beyond the development of the tool and involves commitment to its actual use. This reflects not only an understanding of the potential power of the indicator system, but perhaps also recognition that realizing the potential of an alternative indicator system to achieve positive change requires long-term investment and building of capacity.

Approach Disadvantages

Besides their many advantages, the Field to Market Indicators also have some more challenging aspects that would be particularly important when one wants to apply them under different contexts. Some of these challenges speak to core methodological issues, specifically the emphasis on expressing environmental impact per unit of production.

The approach represents an efficiency measure, and this has been applied or proposed in broader contexts beyond agriculture. For example, measures have been developed to track changes in the carbon intensity of national economies where overall greenhouse gas emissions are expressed per unit of GDP. Essentially, these measures help track whether society is able to reduce - or decouple - the environmental impact of production and consumption from the generation of wealth, measured through GDP growth.

While there is no doubt that lower environmental impact per unit of GDP produced is more sustainable on a relative scale, critiques of the concept point out that the measure can send a misleading message about progress by failing to express the aggregate environmental impact of production and consumption, and compare it with absolute environmental conditions. The dilemma is also associated with the Jevons paradox (Alcott, 2005) according to which efficiency gains often result in increased aggregate consumption of a particular resource when demand is strong, thereby leading to a higher rather than lower pressure on a particular resource.

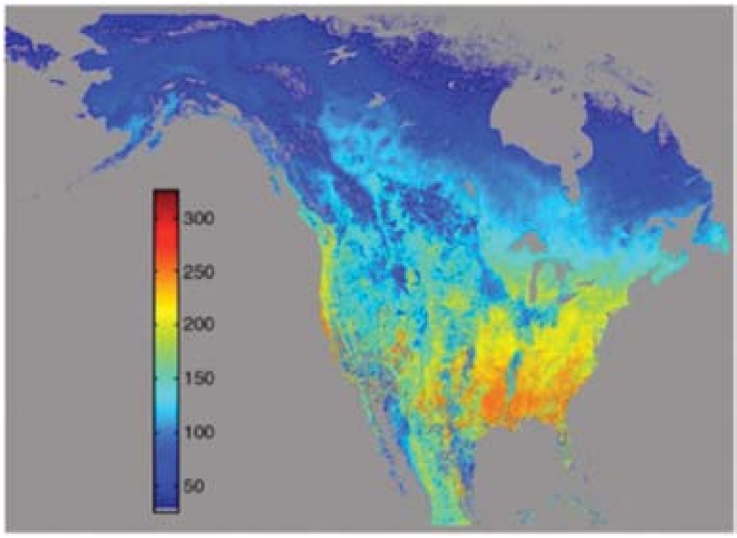
A similar argument can be used regarding Field to Market's efficiency measure, where yield-based efficiency improvements alone may mask overall environmental impact. Particularly in cases where agricultural production is pushing against agro-ecological limits, the use of only an efficiency measure may result in a false sense of progress and security, when in fact risks to the sustainability of production are increasing.

Differences between the Conditions of Crop Production in the U.S. and in Western Canada

Indicators are typically developed with specific technological, socio-economic and ecological conditions in mind, therefore their application elsewhere needs to take differences in context into account. While growing conditions in the U.S. are not all that dissimilar to Western Canada, there are some important differences that affect indicator development and use.

The growing season in the agro-ecological zones of Western Canada falls into the May to September period, up to 3-4 months shorter than in some parts of the United States (see map). Shorter growing seasons mean generally lower yields in northern latitudes, and differences in the intra-annual distribution of agricultural activities and their impacts.

Figure 5: Mean Growing Season Length for North America, in Days for 2001-2006



Source: http://landval.gsfc.nasa.gov/images/valsup/mod12q2_valsup2_fig1.jpg

Another significant difference is that a higher proportion of Western Canada's agro-ecological zones fall into lower-precipitation, drought-prone areas (Figure 6). The picture is further coloured by higher inter-annual variability of precipitation in Western Canada, particularly on the prairies. According to climate change projections for central Canada, a general warming and northward shift of agro-ecological zones will be accompanied by an increasing frequency of extreme events. These factors combined lead to a higher risk of crop failure due to extreme events, such as drought or flooding, even today.

Figure 6: Average Annual Precipitation in North America

Source: http://media-1.web.britannica.com/eb-media/10/112210-004-CAA67432.gif).

In light of the specific characteristics and sensitivity of agricultural production in Western Canada (particularly on the prairies), the use of efficiency-based metrics alone would represent a risk. For example, in areas with a periodic critical water shortage, such as Western Canada's Palliser Triangle area[2], water use efficiency improvements alone would be meaningless if, due to an overall increase in production and water withdrawal, the water supply is getting close to critical limits. Particularly in cases where a resource is quasi non-renewable (i.e. renewable only at a high cost and over longer periods of time), indicators should measure progress against an absolute limit. This approach has recently been emphasized by the concept of planetary boundaries (Rockstrom et al, 2009), but applies equally at the sub-global level of agro-ecosystems.

Efficiency-based measures are not in themselves unhelpful, but they should be used in tandem with measures that express aggregate impact. This also applies to the Fieldprint Calculator, where a version of the spidergraph could, in theory, be developed where the reference point is set according to absolute 'sustainable' values, rather than an arbitrarily-selected baseline that would help measure only relative progress.

Some of the measures in the Field to Market set bring up additional, specific challenges in the Canadian context. The land use measure, in particular, tracks only area under cultivation, but says nothing about land quality. It is recognized that land quality is more difficult to measure, yet methods to monitor it using ground-based and geospatial techniques are becoming more widely available. Especially for agro-ecosystems with more marginal conditions, such as Western Canada's prairies, a land use measure taking land quality into account would be a more realistic indicator or index of sustainability.

[2] The Palliser Triangle is a largely semi-arid region of Western Canada's prairies.

Indicator Development Process

The Project Team's approach to developing indicators for Western Canada was applied consistently across the five Field to Market Indicators. This process included:

1. Assessment of the specifics of the Field to Market Indicator
2. A review of data and information in Western Canada that could be used to replicate that indicator
3. A gap analysis
4. Incorporation of expert opinion on potential options to address GAPs
5. Application of the Indicator Selection Criteria
6. Development of the model and conducting the analysis

Communication initiated through the workshops was also crucially important to the progress of the project. This extended beyond the Project Team and the Canadian subject area experts present at the workshops. For example, Stewart Ramsey, the consultant most involved in the development of the Field to Market Indicators in the U.S., provided much crucial information on the methodologies used in the U.S. Dave Lightle, formerly of the USDA's Natural Resources Conservation Service added perspective on the development of the Field to Market Soil Loss Indicator in the U.S. This kind of communication was an essential element of identifying what approaches would work best in Canada.

Communication with the Project Steering Committee was also maintained on a structured basis. Steering Committee members participated in, and provided input to the workshops. Ongoing communication was also maintained between the Project Team and the Steering Committee through regular conference calls.

Indicator 1: Land Use

As of 2006, Canada has over 67 million hectares in agriculture, with almost 36 million hectares of this area in crops (Statistics Canada, 2008). Over 57 million hectares of Canada's agricultural land is in Western Canada, with about 30 million hectares of this in crops. In this report, the focus is on land use for crop production, specifically for production of spring wheat, durum wheat, winter wheat, oats, peas, flax, canola and lentils.

Land is a primary input for crop production. It also underlies all other economic activities, and provides rural amenities, with the consequence that agriculture must compete for land with other land uses. As development pressures on agricultural land increase over time, it is increasingly important that cropland be managed efficiently. A key component of efficient management is ensuring that loss of land with a high capacity for crop production to other land uses is minimized. Another important priority is to ensure efficient agricultural production on land in agricultural use, so that moving to less suitable land, where production is less sustainable, can be minimised.

The Field to Market Indicator

The National-Level Field to Market Land Use Indicator

The Field to Market national-level Land Use Indicator uses data from the National Agricultural Statistics Service (NASS), a division of the United States Department of Agriculture (USDA). More specifically, the data is found in the Annual Crop Production report released in February, 2008 (Field to Market, 2009a).

The focus of this national-level Land Use Indicator is on providing simple metrics for agricultural production per acre. It is intended that future versions of the metric will more explicitly capture land use components such as biodiversity and wildlife habitat.

As identified above, the national-level Field to Market Indicators for all five indicator areas (i.e. land use, soil loss, etc.) are reported in two separate formats: a resource impact indicator and an efficiency indicator. In the case of the land use indicator, the resource impact indicator is reported as planted acres and crop yield (as output per harvested acre), annually and by crop. The crop yield curve is presented as a five-year moving average. While planted acres were reported, it has been noted that to report harvested acres would have been more consistent with the intention of the indicator (Ramsey, 2011b).

The Land Use Efficiency Indicator is intended to reflect the need to minimize land use as a function of production. It is based on land use per unit of output, i.e. harvested acres per bushel or pound, annually and by crop. It is reported as an index, with the data indexed so that the year 2000 has a value of 100.

The Proposed Fieldprint Calculator Land Use Metric

Plans for the future Fieldprint Calculator Land Use Metric recognize that the present national-level metric, being based on harvested area, does not capture abandonment of planted crop area. It also does not give consideration to practices such as multi-cropping and fallow (Field to Market, 2011).

The Land Use Metric in the proposed Fieldprint Calculator will use total land area, as opposed to either harvested or planted area, giving total land area per unit of output. This is intended to capture productivity, as well as abandonment and other practices that impact land use intensity, such as double cropping and systems involving a fallow year or a green manure year. In order to appropriately capture such practices, the proposed method will use information from an entire production cycle. Since this implies the need to aggregate across several crops and several years, revenue is taken as a common unit of measurement.

The proposed method will use a five-year average annual revenue to establish a baseline, and this will be divided into the average annual revenue for each crop, so as to create the acreage allocation for that crop. A five-year average is used so that calculations are not excessively impacted by, for example, adverse weather or prices occurring in a given year.

Western Canadian Methodology and Data Sources

The Project Team has implemented a methodology that closely replicates the Field to Market national-level Land Use Indicator. While this approach is straightforward to implement, it is also simplistic, and it is debatable how useful it really is. Field to Market has recognized this fact and is currently looking at options for improving it. The Project Team has also proposed a separate methodology which it believes has potential to more meaningfully address the issues surrounding agricultural land use. However, for the purpose of this analysis we have kept the methodology consistent with Field to Market's.

The Field to Market national-level Land Use Indicator is replicated for Western Canada using data from Statistics Canada (Statistics Canada, 2011a). Harvested area, in hectares (ha), is plotted alongside crop yield, in tonnes per hectare (harvested area) (t/ha), to create the resource impact indicator. Crop yield is presented as a five-year centred moving average.

This is not completely consistent with the published national-level Field to Market Land Use Indicator, which presents planted area, and crop yield based on harvested area. However, as noted above, it is consistent with the intent of the national-level Field to Market Land Use Indicator to focus on harvested area (Ramsey, 2011b). The efficiency indicator is calculated as harvested area per unit of output (ha/t), again as a five-year centred moving average. As with the Field to Market Land Use Indicator, it is reported as an index. The data is indexed so that the year 2001 has a value of 100.

Additional Options for Consideration

The Field to Market national-level Land Use Indicator, as replicated in this project for Western Canada, provides a measure of crop productivity with respect to the area of land required for production. Presented as a time series, this provides a certain amount of information about trends in the quantity of land required to produce crops.

The Project Team has identified two key areas of concern in the context of agricultural land use which are not adequately addressed by this metric:

1. If agriculture is to be sustainable, the intensity of use of agricultural land must be matched to the capacity of the land, so that land is allocated to uses which it is able to sustain without damage (Angyan et al). This can be enabled in part by ensuring efficient production on the land best suited to agricultural production, thereby minimising the need to bring less suitable land into production.
2. Given that agricultural lands occupy large areas, it is important that they support and protect biodiversity, including wildlife habitat.

Neither of these dimensions of agricultural land use is addressed by the Field to Market Land Use Indicator. For example, the Field to Market Land Use Indicator is partly driven by land capacity, but does not explicitly address whether the specific agricultural use of the land is suited to its capacity. This section proposes potential approaches to developing land use metrics for Western Canada which would provide information relevant to these two issues. Relevant Canadian research, which might contribute data to more meaningful land use metrics, is identified.

Suitability vs. Actual Use of Agricultural Land

One option that could be used would be to assess the extent to which the capability of agricultural land is matched to its actual use in Western Canada. This consists of overlaying maps of land capability and land use (i.e. the prevalence of specific crops), and developing a system to assess the extent to which these two elements are correlated. Possible data sources are as follows:

1. The Land Suitability Rating System (LSRS) provides a peer-reviewed, biophysical assessment of what can be grown at a given location, throughout Canada (AAFC, 1995)
2. The Canadian Economic and Emissions Model for Agriculture (CEEMA) contains data on the prevalence of specific crops, at the Census District scale (Kulshreshtha et al, 2002).

Economic dimensions are not specifically addressed in this analysis. However, it is anticipated that economic factors will provide explanations for many of the discrepancies between land capability and actual land use

Biodiversity

A second consideration that needs to be explored involves using a measure of biodiversity as the basis for determining suitability of practices from a sustainability perspective.

A large amount of data describing biodiversity and ecosystem quality has been synthesized in the Wildlife Habitat Capacity on Agricultural Land indicator, included in the Ecosystems Status and Trends Report (ESTR) (Javorek and Grant, 2011). The wildlife habitat indicator provides an assessment of trends in the potential ability of Canada's agricultural landscape to provide habitat for terrestrial vertebrates. It is very data-intensive (Smith, 2011). Wildlife habitat capacity was investigated on all land within the agricultural area of Canada, for the years 1986, 1996 and 2006. Data was analyzed at the Soil Landscapes of Canada (SLC) polygon level. Wildlife capacity could also be tested for spatial correlation with agricultural land capacity and land use.

Unfortunately, neither of these approaches is well developed at this point in time, and significant work would be required before they could satisfy the Indicator Selection Criteria. However, they certainly present excellent options for future consideration and need to be explored further.

Indicator 2: Soil Loss

Soil is fundamental to efficient crop production, and excessive soil loss has negative impacts on agricultural productivity and environmental health. Movement of soil from the field not only lowers productivity, but is also detrimental to surface water quality. Soil loss is caused primarily by wind and water erosion. Tillage practices that result in exposure of soil to wind and water, without vegetative cover, can also significantly accelerate the rate of soil loss.

The Field to Market Indicator

The National-Level Field to Market Soil Loss Indicator

The Field to Market national-level Soil Loss Indicator is based on data in the National Resource Inventory (NRI), from the United States Natural Resources Conservation Service (NRCS). Data for wind and water erosion were summed to estimate total soil loss from cultivated cropland. As identified above, Field to Market's resource impact indicator for soil loss is reported as soil loss above tolerable level (T), in units of tons above T/acre/year, by crop. As for the Land Use Indicator, crop yield is presented as a five-year moving average.

The soil loss efficiency indicator is generated by dividing the soil loss resource impact indicator through by crop yield. The efficiency indicator is thus calculated from pounds of soil loss above T/bushel/year, by crop, and reported as an index with a value of 100 for the year 2000.

NRCS data reported in the NRI from 1982 to 2003 provides the basis for the Field to Market national-level Soil Loss Indicator. The NRI uses data from several hundred thousand sample sites. Some tens of thousands of sites are visited every five years, and data is collected on the crops grown, rotations used, and management practices followed at each. This data is used as input into two models used to compute soil erosion: the Universal Soil Loss Equation (USLE) for water erosion, and the Wind Erosion Equation (WEQ) for wind erosion. Allocation of erosion to individual crops was done by NRI staff as a custom calculation for the Field to Market Alliance.

The Proposed Fieldprint Calculator Soil Conservation Metric

The proposed Soil Conservation Metric for the Fieldprint Calculator (version 2), will report total soil erosion, as opposed to soil erosion above tolerable levels (T). In this version, soil erosion data will be calculated using newer models. Water erosion will be computed using the Revised Universal Soil Loss Equation 2 (RUSLE2), and wind erosion will be computed using the Wind Erosion Prediction System 1.0 (WEPS 1.0).

A key problem faced by the Field to Market Alliance, in designing an improved Fieldprint Calculator, is that of providing enough input to RUSLE2 to take advantage of its features. A balance had to be sought between providing the model with enough input, and making it manageable for the grower to enter the model inputs. This problem was addressed in two steps:

1. Identification of databases that could be loaded as default entries for users of the Calculator, and
2. Identification of the minimum information the user still has to input.

To execute properly, RUSLE2 requires:

1. The support databases that were used to calibrate it (see Table 2, below), and
2. User input

In the proposed Fieldprint Calculator, the user will indicate the location of his field on an interactive GIS map, and the Fieldprint Calculator will go to the databases listed in Table 2, and get the information for that field. For the first four variables (r, k, L and S), this will be all the user has to do, since the location will define all the information the Calculator needs. For the fifth variable, cover management, the user will have to select a set of management practices. He will have to identify a chronological listing, by day, of all his field operations – tillage, planting and harvest. He will do this by selecting one of about 29,000 "tillage systems" – prebuilt management scenarios – residing in the Managements database, organised by 75 crop management zones across the U.S.A. (Lightle, 2011).

Table 3: RUSLE2 in the Proposed Fieldprint Calculator – Variables and Databases (a (soil loss) = rkLScp)

Variables	Input to RUSLE2 (databases)
r, Erosivity Factor	Based on PRISM precipitation database
k, Soil Erodibility Factor	Based on NASIS (derived from USDA-NRCS SSURGO soil database)
L, Slope Length Factor	Can be related to steepness, S, using a lookup table provided by USDA-NRCS
S, Slope Steepness Factor	Can be estimated from the 10m USGS Digital Elevation Model (DEM)
c, Cover-Management Factor	A USDA-NRCS "Managements" database
p, Supporting Practices Factor	USDA-NRCS provides a correspondence table relating various interceptors to a "standard" terrace

Note that the original Fieldprint Calculator offered six options for pre-plant tillage, four options for conservation practices, and twelve options for surface soil texture. For example, where "no-till" was an option, the new Calculator will offer several variations of "no-till" for selection. While RUSLE2 uses the same variables as the USLE, it will plug directly into the databases listed above, allowing for much more detailed input, and much finer calculations.

Incorporation of RUSLE2 into the Fieldprint Calculator creates the possibility of generating inputs for some of the other Field to Market Indicators. For example, if RUSLE2 is fully populated, it will create a Soil Conditioning Index (SCI). In time, it may be possible to calibrate the SCI to quantitative changes in soil carbon. Accuracy issues remain, and calibration of the Soil Conditioning Index is very location-specific. However, this is one possible route toward obtaining soil carbon data.

Wind erosion, in the revised Fieldprint Calculator, will be calculated by WEPS 1.0 (WEPS 1.0 may not be incorporated in the initial Fieldprint Calculator v.2, but the intention is to introduce WEPS 1.0 a bit later on. WEPS 1.0 is structured around a supervisory routine to accept:

1. Four kinds of user input
   - Location
   - Field geometries
   - Soil

   Management practices
2. Two weather generators
   - Daily weather data
   - Hourly wind speed data
3. Six submodels
4. Five databases (listed in Table 3, below).

The transition from the Wind Erosion Equation to WEPS 1.0 in the Fieldprint Calculator will be similar to that from the USLE to RUSLE2. As with RUSLE2, a key step in the implementation of WEPS 1.0 in the Fieldprint Calculator involves identification of databases that can be automatically loaded as default entries for users (see Table 3, below). In the case of WEPS 1.0, the databases (particularly those for climate and crop/decomposition) contain data more relevant to wind erosion. Management scenarios, as entered in RUSLE2, provide daily input to WEPS 1.0, describing vegetation cover, roughness, consolidation, root and canopy development, and decomposition of surface and buried residues.

Table 4: WEPS 1.0 in the Proposed Fieldprint Calculator – Variables and Databases

Variables	Input to WEPS 1.0 (databases)
Climate	Based on precipitation, max/min temperature, solar radiation, dew point, wind direction and speed
Soil	Surface soil properties, derived from soil survey data in the USDA SSURGO soil database
Management	Defined by "tillage systems", organized by crop/climate management zones (CMZ), in a USDA-NRCS "Managements" database
Crop and Decomposition	Daily input provided by RUSLE2 management scenarios
Barriers	A correspondence table, relating various barriers to a "standard" barrier, will be developed cooperatively with USDA-NRCS

The user will receive output on both water and wind erosion in the form of tables and/or graphs. Having done so, he will have the opportunity to change critical management practices, and run "what if" scenarios to see the impacts of possible actions on soil erosion.

The Future National-Level Field to Market Soil Loss Indicator

The Field to Market Alliance intends to resume work on the national-level indicator once version 2 of the Fieldprint Calculator has been implemented. The future national Soil Loss Indicator will make use of new NRI data, as well as existing NRI data for previous years. The NRCS has invested significant effort in retooling for use of the RUSLE2 model, including back-casting over a twenty-year time frame with RUSLE2. Thus it is expected that the future Field to Market Indicator will be based primarily on 2007 NRI data and a re-run of older NRI data, both using RUSLE2. It is possible that some calibration of this output will take place, using the methodology of the new Fieldprint Calculator.

The future national-level Soil Loss Indicator will probably not be reported as soil loss above T, tolerable soil loss. Instead, absolute soil loss will be reported, and T will be regarded as a reference level.

Table 4, below, summarizes the data, models and output of the present and future Field to Market Soil Loss metrics.

Table 5: Summary of Field to Market Soil Loss Indicator Work

		National-level Indicator	Fieldprint Calculator
Version 1	Data	NRI (1982-2003)	User input
	Models	USLE, WEQ	USLE, WEQ
	Output	Tons/acre/year, by crop, relative to T	Tons/bu, by crop (for each of water and wind erosion)
Version 2	Data	NRI (1982-2007) and RUSLE2 (and WEPS 1.0?) databases	User input and RUSLE2/WEPS 1.0 databases
	Models	RUSLE2, (WEPS 1.0?)	RUSLE2, WEPS 1.0
	Output	Tons/acre/year, by crop	Tons/bu, by crop?

Western Canadian Methodology and Data Sources

Soil Loss Indicator Workshop

The Project Team identified the Soil Loss Indicator as one of the most demanding of the five Field to Market Indicators to implement. A workshop was designed to identify alternative approaches to implementing a Canadian Field to Market Indicator for soil loss. Emphasis was placed on identifying Canadian models and data for soil loss.

Potential participants were identified in conjunction with subject experts, primarily Dr. Brian McConkey and Dr. Laszlo Pinter. Dr. McConkey is Lead Scientist for Canada's system for greenhouse gas accounting for agriculture, and conducts original research on effects of agriculture on soil health, soil carbon and greenhouse gas emissions. Dr. Pinter is an internationally noted expert on sustainable development, whose primary interest is in integrated information, indicators and future-oriented reporting systems. Response from the experts contacted to participate in the workshops was extremely positive. A workshop to discuss the Soil Loss Indicator was held in Winnipeg on March 18, 2011. The participants in this workshop are listed in Appendix A.

Summary of Workshop Findings

Canada's National Agri-Environmental Health Analysis and Reporting Program (NAHARP) has developed a Soil Erosion Risk Indicator, SoilERI. SoilERI was developed to assess the risk of soil erosion under a given land use; consequently the indicator is driven by land use. SoilERI was developed by gathering soil, topography, land use and climate data, and calculating tillage, water and wind erosion, and then total soil erosion rates, on a two-dimensional hill slope. The results were then aggregated from the two-dimensional hill slope to the SLC polygon (ranging in size from 10,000 to 1 million hectares), and to the provincial and national levels.

SoilERI calculates the sum of tillage erosion, water erosion and wind erosion, where:

- Tillage erosion is calculated as the product of tillage erosivity and landscape erodibility
- Water erosion is calculated using an equation in the form of the Universal Soil Loss Equation (USLE), with some adjustments applied on regression equations established from intensive test runs in RUSLE2
- Wind erosion is calculated using the wind erosion equation (WEQ), with adjustments based on expert knowledge concerning processes and conditions in Canada.

These three erosion rates are summed to arrive at the total soil erosion rate for each segment in each landform. The erosion rates are then area-weighted across landform, crop type and tillage system, and aggregated to the value for each segment at the SLC polygon, province and country levels.

The resulting erosion rates are reported as risk levels. Erosion rates are grouped into six risk classes, four of which represent a risk of unsustainable conditions, and call for conservation measures. Risk levels are reported on one map for each census year. The map unit is the SLC polygon, and the risk class for each polygon is taken to be that of the most eroded segment.

The differences in this approach and that taken by Field to Market were the subject of significant discussion at the workshop. A summary of the main findings can be seen in Table 5 below.

Table 6: Soil Loss Indicator Workshop Findings by Indicator Element

Element	Canadian Situation
Approach	The NAHARP soil loss indicator is based on a combination of wind, water and tillage erosion. NAHARP has water, wind and tillage erosion risk indicators. This is a more comprehensive approach to the soil erosion indicator than the one used by Field to Market. The Canadian approach focuses on soil leaving the eroding portion of the slope. It explicitly includes the concept of redistribution within the field. There is no effort to estimate how much is actually leaving the field. This leads to an indicator that is relevant to sustainable management. In terms of Canada's soil erosion indicators: • Terrain analysis of typical sites has been completed. • A two-dimensional idealized slope is built from a large matrix • Soils are allocated to these slopes – properties are allocated based on what soil is located on what slope position.
Models	Water erosion: Canada does not maintain the data sets (particularly re climate) to run RUSLE2, but AAFC has put together a combination, using some RUSLE and RUSLE2 features using a Universal Soil Loss Equation (USLE). Wind erosion: The Canadian model approaches wind erosion using the Wind Erosion Equation (WEQ). The use of this model needs to be assessed over time since it has not been validated (unlike the water and tillage ones which have). Integrated Soil Erosion Indicator (SoilERI): This is simply a summation of tillage, water and wind erosion, aggregated across landform, crop type (crop sequence, focused on the current crop) and tillage systems. This gives a value for each SLC polygon, with the ability to roll up data for each province. These values are calculated internally by landform and by crop sequence. Calculations are based on a two year production system, and the probability of it occurring within a given ecodistrict. This comes from two tables, from expert opinion and from the Census of Agriculture.
Data and Scale	Soil data: The US has more detailed information on soils, embodied in the NRI data when compared to the National Soil Database (NSDB) in Canada, which is linked to SLC polygons. The SLC polygon is the smallest scale for mapping. Topographic data is different. Canada uses representative modal hill slopes to represent the land forms. This approach handles the landscape much more effectively than in the US model which only looks at slope and grade. Topographic data includes: • Nominal information in NSDB and SLC polygon (landform type, surface form and slope class) • Terrain analyses of typical sites (nominal topographic information to two-dimensional hill slopes) Climate data: Climate data is another area where the US models will have an advantage over the Canadian models. In Canada, erosivity levels are not well defined and certainly does not exist beyond the ecodistrict level. However, these models can be operated on a field scale, given the right input, i.e. farmer's contribution, e.g. for topography. Farm management: Farm Environmental Management Survey (FEMS), run in 2001 and 2006, and to be run again in 2011. FEMS is designed to give ecoregion-scale data. FEMS 2006 has a question about crop sequence (two years only).

Element	Canadian Situation
Formats and Reporting	Reporting on erosion issues – There are data available in many different formats, but key are • average rates for the eroding portion • average rates of the two highest-eroding segments.

Specific Methodology developed for Soil Loss Indicator for Western Canada

The Project Team concluded that the Field to Market Soil Loss Indicator can be effectively replicated in Western Canada using the Soil Erosion Risk Indicator, SoilERI. In spite of the fact that Canada does not have the detailed history of agricultural land use, cropping and management practices that is represented by the NRI in the United States, estimates of soil erosion have been made by running soil erosion models with the data available in Canada. These models have been augmented with expert opinion, notably in the area of tillage erosion. The tillage and water erosion estimates have been validated, with tillage often being the dominant source of erosion.

The Soil Erosion Risk Indicator, SoilERI, is already a part of the National Agri-Environmental Health Analysis and Reporting Program (NAHARP), funded by Agriculture and Agri-Food Canada. NAHARP is aimed at providing science-based agri-environmental information that can guide policy and program design. The core component of NAHARP is the Agri-Environmental Indicators (AEI). Within the Agri-Environmental Indicators, SoilERI, is one of several soil health indicators, and combines measures of the risks of water, wind and tillage erosion.

Due to the nature of topography and tillage on Western Canada's prairies, in-field deposition of eroded soil often equals the vast majority of gross erosion. Hence, net erosion over much of Western Canada is close to zero – loss of soil from a field is often very small. However, there may be high erosion in specific parts of the field. Logically, the approach taken in Canada has been to focus on the loss of soil from these eroding portions of hills.

SoilERI is applied at the scale of the Soil Landscape Canada (SLC) polygon. SLC polygons cover the whole country, with the polygon size ranging from 10,000 to 1 million ha. Basically, the indicator development process uses data on soil, topography, climate and land use, and calculates tillage, water, and wind erosion. Total soil erosion rates, on two-dimensional hill slopes, are calculated by combining the estimates of water, wind, and tillage erosion. The results are then aggregated from the two-dimensional hillslope to the SLC polygon, the province, and the whole country of Canada, providing a detailed analysis of soil loss risk (McConkey, 2011a).

Soil and topographic data for the soil erosion models comes from the National Soil Database (NSDB), which is linked to the SLC polygons. A landform model was established based on terrain analyses of typical sites, in order to convert the nominal topographical information from the NSDB into two-dimensional hillslopes. Each SLC polygon is characterized by one or more representative landforms. The model has a total of 19 landform types, with each landform represented by hillslope segments – upper, mid and lower slopes and depressions. Each hillslope segment has a slope gradient and a slope length. There may be one to several landforms in a single SLC polygon. As a result, there are multiple hillslopes in each SLC polygon (McConkey, 2011a).

Climate data comes from long-term climate stations across the country.

Land use data, including crop type and tillage system information, is allocated to each segment in each landform. Land use data are from the Census of Agriculture, which was conducted every five years from 1981 to 2006.

To estimate water erosion, a model was developed that combines features of the Universal Soil Loss Equation (USLE) and the Revised USLE (RUSLE2). This model accounts for rainfall-runoff (from rain gauge data), crop type, crop area and erodibility. The management factor is influenced by the preceding crop in the rotation; consequently, for a given crop type in the year of analysis, the management factor varies with the probability of specific crop types being grown in a rotation sequence. The erodibility of each soil, and the slope gradient and length factors, are determined (Eilers et al, 2010).

Wind erosion is estimated using the Wind Erosion Equation (WEQ). The WEQ uses a climatic factor based on wind speed and rainfall, soil factors relating to soil texture and landform, and a vegetation factor based on crop residue levels. Surveys by the Prairie Farm Rehabilitation Administration (PFRA) of crop residue levels in Saskatchewan provided the basis for estimates of crop residue levels for different crops under different tillage systems. Wind erosion is estimated for the agricultural regions of the prairies, for April and May, when residue levels are low and wind speeds are high (Eilers et al, 2010)

Tillage erosion is calculated as the product of tillage erosivity and landscape erodibility. Landscapes with short, steep slopes are highly erodible, and frequent tillage that moves large amounts of soil across the landscape is highly erosive. Tillage erosivity values are assigned based on experimental data relating erosivity and land use, namely the cropping system and tillage system. Landscape erodibility is calculated for each landform as a function of:

- the gradient of the mid-slope (which determines the total soil loss on the landform)
- the length of the upper slope (which determines the area over which soil is lost)
- the total slope length (which determines the density of hillslopes in a given area) (Eilers et al, 2010).

Finally these three erosion estimates are summed up to give an estimate of total soil erosion, Soil ERI, for each hillslope segment in each landform. These results are then aggregated from the two-dimensional hillslope to the SLC polygon. The erosion rates are thus area-weighted across landform, crop type and tillage system and aggregated to the SLC polygon, the province and the whole of Canada (Eilers et al, 2010; McConkey, 2011a).

To arrive at a Soil Loss Indicator for Western Canada, the Project Team has used aggregated SoilERI data to estimate the average quantity of potential soil erosion on upper and mid hillslopes. This approach reflects the facts that soil losses from wind and tillage erosion are greatest on the upper slopes of a landform, and soil losses from water erosion are greatest on the mid slopes. Appropriately, potential soil loss is assessed as the aggregate loss for the slope segments where soil loss is greatest, since this is most relevant to land management decisions.

Finally, this Soil Loss Indicator for Western Canada is based on data for NAHARP's Soil Erosion Risk Indicator, SoilERI, and should be understood to indicate potential soil loss. Actual soil loss depends on the occurrence of storms and other severe weather that cause soil erosion. It should also be understood that, on Western Canada's prairies, most potential soil erosion is strictly a down-slope movement of soil, with the great majority remaining on the field.

Crop-specific soil erosion estimates are not made, due to Canada's lack of sufficient soil cover data, by crop. Rather, estimates are specific to general crop types, e.g.:

- winter cereals – winter wheat
- small grains – spring wheat, durum wheat, oats, barley
- brassicas – canola, mustard
- pulse – peas, lentils
- flax – flax

As with all the Field to Market Indicators, the Soil Loss Indicator for Western Canada is presented as both a resource impact indicator and an efficiency indicator, each showing change over time for a specific crop. The resource impact indicator presents potential soil loss, in tonnes of soil per hectare, alongside crop yield, in tonnes per hectare. Crop yield is presented as a five-year centred moving average. The efficiency indicator for soil loss is calculated as potential soil loss (tonnes/hectare) divided through by crop yield (tonnes/hectare), and thus reflects potential soil loss per unit of crop output. In common with all the efficiency indicators, it is reported as an index, with the data indexed to give a value of 100 for the year 2001.

Indicators 3 And 4: Energy Use And Climate Impact

Energy use is an important policy topic from two key standpoints. First, energy is sourced largely from non-renewable resources, particularly fossil fuels, which are in limited supply. Secondly, most energy use results in production of greenhouse gases, which in turn results in climate change.

Methodologies for the Energy Use and Climate Impact Indicators are presented together since both indicators, as developed for Western Canada, share the same methodology. Essentially, the western Canadian Energy Use Indicator comprises a subset of the terms that make up the Climate Impact Indicator. As a result, the methodologies used to generate the coefficients are the same.

The Field to Market Indicators

The National-Level Field to Market Energy Use Indicator

The Field to Market national-level Energy Use Indicator is intended to capture the major energy-intensive areas of on-farm crop production. The analysis thus includes direct energy use, such as operation of farm equipment, and indirect energy use, such as the energy used to produce fertilizers and crop protection products.

The Field to Market national-level Energy Use Indicator is reported as:

1. A resource impact indicator, in units of BTU/acre/year, by crop, and
2. An efficiency indicator, in units of BTU/bushel/year, by crop.

The estimates of energy use in the national-level Field to Market Indicator all depend on Shapouri's study of the energy requirements to produce a bushel of corn, in 2001 (Shapouri and McAloon, 2001). In this work, Shapouri provides good estimates of energy for equipment operation, production of crop protection products and fertilizer production. Consequently, the Field to Market Alliance has chosen to handle energy use in these three categories, which, together, capture about 95% of farm energy requirements (Field to Market, 2009a). A simplified description of the approach is provided below.

1. Direct energy use, i.e. fuel and electricity for equipment operation. Shapouri's study provides BTU's from fuel and electricity, averaged across nine states, in 2001, to produce a bushel of corn. The Field to Market Alliance extended this value across time and across other crops, using USDA surveys of dollars spent on on-farm energy, adjusted by price index.
2. Indirect energy use – crop protection products, i.e. energy to produce crop protection products. Shapouri's study identifies the energy required to produce the products used to produce a bushel of corn, averaged over nine states. The Field to Market Alliance extended this across the years and across the other crops, in the same way as for fuel and electricity.
3. Indirect energy use – fertilizers, i.e. energy to produce fertilizer. Shapouri's study identifies the energy to produce a pound of nitrogen fertilizer, a pound of phosphate fertilizer, and a pound of potash fertilizer. The Field to Market Alliance extended this using USDA data on acreage and % of acreage of major crops using commercial fertilizers, and fertilizer application rates.

Table 7: Data Sources and Output for the National-level Energy Use Indicator

	Data Category	Data Source
Data	**Data Category**	**Data Source**
	Direct energy	Shapouri
	Indirect energy - fertilizer	Shapouri
	Indirect energy - crop protection products	Shapouri
Output (units)	BTU/acre/year, by crop	

The Proposed Fieldprint Calculator Energy Use Metric

As described above, the overall changes to the approach used in the Fieldprint Calculator will affect how energy use is allocated, for example between cotton seed and cotton lint. As well, the Energy Use metric will include all inputs from the start point of a production system, potentially including products applied in a previous season.

In addition to these changes, incorporation of the RUSLE2 model for water erosion of soil will affect how energy use is calculated in the proposed Fieldprint Calculator. Having populated RUSLE2, as described under the Soil Loss metric, with detailed data including soil type and tillage method, we will have provided a lot of information about the draft associated with tillage. The grower may also be able to choose between, perhaps, three levels of fuel efficiency for his equipment. With that, the Calculator's default course of action will be to have RUSLE2 calculate fuel use for equipment operation. Alternatively, should the grower have exact data on fuel consumption, he will likely be able to input those values instead. In either case, the new Fieldprint Calculator will allow much more specific estimates of energy used to fuel farm equipment.

The Energy Use metric in the proposed Fieldprint Calculator will be more inclusive than the existing one. For example, areas such as grain drying and energy to produce lime will be included in the new metric. Direct energy in the following categories will be included:

1. Tillage and equipment operation
2. Manure application
3. Drying and product handling
4. Irrigation systems
5. Transportation
6. Overhead purposes.

Product-embedded energy in the following forms will be included:

1. Seed
2. Fertilizer and lime
3. Manure
4. Crop protectants
5. Equipment service products.

The National-Level Field to Market Climate Impact Indicator

Agriculture is the source of about 10% of greenhouse gas emissions in the United States. As well as energy use, covered in the previous section, soil carbon (carbon dioxide - CO_2) emissions resulting from tillage, and emissions of nitrous oxide (N_2O) from soil, can be significant sources of greenhouse gases. While tillage can cause CO_2 to be released from soils into the atmosphere, zero-till practices can lead to sequestration of carbon in the soil, under certain circumstances. Soil N_2O emissions result primarily from application of nitrogen fertilizer and manure.

The national-level Climate Impact Indicator is reported as:

1. A resource impact indicator, in units of pounds of Carbon Equivalents/acre/year, by crop, and
2. An efficiency indicator, in units of pounds of Carbon Equivalents/bushel/year, by crop.

The Climate Impact Indicator addresses four sources of climate impact:

1. emissions from energy used to power machinery
2. emissions from energy used to produce agricultural inputs (fertilizer and crop protection products)
3. carbon emissions or sequestration in soil, due to tillage
4. nitrous oxide emissions from applied fertilizer and manure.

Based on these four categories, the Field to Market Alliance constructed a carbon balance for each of the four crops under study (Field to Market, 2009a).

The values used for the first three of the four categories were based on a carbon cycle analysis by West and Marland, using 1995 data (West and Marland, 2002). West and Marland examined the effects of tillage practices, not only on soil carbon (emissions or sequestration), but also on fuel usage by farm machinery, and application rates of fertilizers and crop protection products. This analysis was conducted across three tillage systems (conventional till, reduced till, and no till), for three crops (corn, soybeans and winter wheat). The Field to Market Alliance's approach to deriving time-series climate impact data for each source of climate impact is briefly outlined below.

1. Fuel consumption (direct energy). West and Marland reported carbon emissions from fuel consumption, for each tillage system, for each crop, in kg C/ha. The Field to Market Alliance extrapolated this across time, based on changes in tillage practices over time, using CTIC data. It was assumed that fuel efficiency within each tillage system remained the same.
2. Agricultural inputs (indirect energy – crop protection products and fertilizer). West and Marland reported carbon emissions for 1995, for each tillage system, for each crop, in kg C/ha. The Field to Market Alliance extrapolated this across time using the same time-series data they used for the energy use indicator, i.e. dollars spent on crop protection products, and application rates for fertilizers.
3. Soil carbon emissions and sequestration. A three-crop rotation (corn, wheat and soybeans) was assumed, and the average for the three crops was used for each. This was assumed to be representative of average values across the U.S. Continuous no-till was assigned 337 kg C/ha/year of carbon sequestration, as an average over twenty years. Conventional till and reduced till were assigned zero. While the assumption that a rotation is being followed is not valid everywhere, it was felt that this would come close to a national average.
4. Soil nitrous oxide emissions. The Field to Market Alliance assumed that 1.33% of fertilizer nitrogen applied, and 1.79% of nitrogen from manure, is released as nitrous oxide. USDA data on application rates were used to arrive at annual, crop-specific rates of emission.

Table 8: Data Sources and Output for the National-Level Climate Impact Indicator

	Data Category	Data Source
Data	Direct energy	West and Marland
	Indirect energy - fertilizer	West and Marland
	Indirect energy	West and Marland
	Soil emissions/sequestration	West and Marland
	Soil N	IPCC, USDA
Output (units)		lb C Equivalent/acre/year, by crop

The Proposed Fieldprint Calculator Climate Impact Metric

In the proposed Climate Impact metric in the Fieldprint Calculator, direct energy and product-embedded energy are handled similarly to the Energy Use metric in the Fieldprint Calculator. Nitrous oxide emissions for fertilizer and manure are to be estimated at 1.3% of nitrogen applied. Nitrification inhibitors will be considered to reduce N_2O emissions by about 25%, for ammonium-based fertilizers.

Soil carbon sequestration will not be part of the new Climate Impact metric. Instead, there will be a separate soil carbon metric. The rationale for this is that it is difficult to quantify changes in soil carbon over time, and soil carbon has important implications for soil, as well as for greenhouse gas emissions. Note, again, that the Soil Conditioning Index created by RUSLE2 is considered to be a possible route toward obtaining soil carbon data.

Western Canadian Methodology and Data Sources

Energy Use and Climate Impact Indicator Workshop

The Project Team identified the Energy Use and Climate Impact Indicators as relatively complex, both in terms of the data required and the modelling required to implement them. Consequently, as with the Soil Loss Indicator, a workshop was convened to facilitate identification of relevant models and data sources, and to initiate the process of selection between them. Workshop findings, the rationale for the selection of Canadian data and models, and the specific methodology for both the Energy Use Indicator and the Climate Impact Indicator are presented together.

As for the soil loss workshop, potential participants were identified in conjunction with subject experts, primarily Dr. Brian McConkey and Dr. Laszlo Pinter. Again, response from individuals invited to participate was positive, and a workshop to discuss the Energy Use and Climate Impact Indicators was held in Winnipeg on March 28, 2011. The participants in this workshop are listed in Appendix A.

Summary of Workshop Findings

It became evident early on in the discussion that there are currently three key models/indicator sets in Canada, all directed by AAFC, that could be used as the basis to develop Field to Market-type indicators for energy use and climate impact:

1. The National Agri-Environmental Health Analysis and Reporting Program **(NAHARP)**. NAHARP has developed the Agricultural Greenhouse Gas Indicator, which provides an estimate of N_2O, CH_4 (methane) and CO_2 emissions from agroecosystems throughout Canada. The Agricultural GHG Indicator incorporates a soil carbon component and a component encompassing nitrous oxide emissions. Note that, in the soil carbon component, emphasis is on identifying and quantifying soil carbon emissions/sequestration resulting from major shifts in land use and land management practices. The quantification of nitrous oxide emissions generally follows International Panel for Climate Change (IPCC) Tier II methodology for estimating greenhouse gas emissions from crop/soil and animals. The Agricultural GHG Indicator is summarized by province and nationally, and its temporal frequency follows the Census of Agriculture.

2. The Farm Fieldwork and Fossil Fuel Energy and Emission Model **(F4E2)**. The F4E2 simulation model has been used to quantify the fossil energy used to conduct farm field operations in Canada. The F4E2 model is able to define the consumption of mobile fuels for 20 distinct field operations. It has estimated the total diesel fuel used for farm fieldwork in Canada to within 5% of the 1996 Farm Energy Use Survey (FEUS). F4E2 computations have been included in integrated assessments of greenhouse gas emissions from various agricultural sectors within Canada. Note that F4E2 output provides values for fossil fuel energy used in the Agricultural GHG Indicator.

3. The Canadian Economic and Emissions Model for Agriculture **(CEEMA)**. CEEMA is an outcome from AAFC's recognition of the need to estimate impacts of agricultural policies on greenhouse gas emissions. The CEEMA model consists of two sub-models:

    a. An economic optimization sub-model, which generates resource allocation levels under given economic and technological conditions; and

    b. A GHG emissions sub-model, which estimates the GHG emissions from the output of the first model

    The CEEMA model encompasses all major forward and backward linkages of primary agricultural production in Canada, and thus approaches a life cycle approach to the study of GHG-producing activities. CEEMA is based on 55 geopolitical units throughout Canada, and considers 21 crops. The model considers dryland vs. irrigated land use, as well as tillage practices. It is based on 1996 and 2001 Census data, with 2006 data still being worked on.

    Significant discussion occurred around which model and/or combination of models could be used to best represent the output of the Field to Market approach. A summary of the key elements (by GHG source) can be observed in Table 8.

Table 9: Energy Use and Climate Impact Indicator Workshop Findings by GHG Source

GHG Source	Canadian Situation
Fuel Use	**Source:** For the CEEMA model, fuel use data was developed by working backwards from the costs paid for fuel. The recreational volume of fuel was removed. Natural Resources Canada was also a source of fuel data. All the models are based on Census data. Consequently, data will have to be interpolated between Census years, and extrapolated forward from 2006 until 2011 Census data is recorded and processed. Some of the data will be available annually. **Includes:** CEEMA applies a technical coefficient, based on the size of the area and the types of crops. This has been used as a way to verify the top-down approach. **Allocation:** CEEMA assumes that the breakdown of tillage type for each crop is the same as the provincial tillage breakdown. This is used except where a crop is known not to be grown under a specific type of tillage. The CEEMA model assumes that 90% of the fuel reported for farm use is diesel and 10% is gasoline. While this is a limiting assumption, the same one has been made for the Field to Market Indicators. The F4E2 simulation model provides data for fuel used for farm fieldwork (based on agricultural engineering coefficients). The Farm Energy Use Survey, 1996, provides data on consumption of gasoline for farm-owned vehicles and heating fuel.
Energy Use - Fertilizer	**Source:** The Canadian Fertilizer Information System has the information from the fertilizer manufacturers. This is broken down by NPK values. **Includes:** Production, manufacturing, transportation and storage. From this, the models calculate the impact of the application of fertilizer at the farm. Canada uses the ratio 4.2 kg CO_2/kg of N – world recognized – even though some people feel that it should be less due to increased manufacturing efficiency in North America. This creates an interesting problem, since it is very likely that they have significantly improved these efficiencies – due to cost pressures, if nothing else. Emission coefficients have not been updated since they were developed (Jaques, 1997). These efficiencies should have improved, but we do not have the data to verify this. "Energy Based Greenhouse Gas Emissions from Canadian Agriculture" (Dyer and Desjardins, 2007)... this is one of several relevant publications by Dyer and Desjardins.
Energy Use – Crop protection products	**Source:** Much of this information comes from CAEEDAC (Canadian Agricultural Energy End-Use Data and Analysis Centre, which used to be at the U of Saskatchewan). As with fertilizers, the emission factor has not been changed in a number of years. In CEEMA, they used financial expenditures as the driving force, and then worked backwards to the volumes.
Carbon Sequestration	**Source:** This comes from work done under NAHARP, using the "Century" model, looking at changes in emission factors resulting from changes in land use and land management. **Includes**: Estimates of carbon sequestration as a function of tillage practice, summerfallow, conversion to forage crops, etc. The largest changes result from going in and out of hay, going in and out of pasture, and tillage changes. Canada has very poor information on irrigated soils, where there is a higher level of carbon sequestration. As a result, this information cannot be used with any confidence and has been omitted from the approach. Soil sequestration changes over time. This is embedded in the methodology used by NAHARP. Carbon has a long memory, and it is constantly moving toward a new equilibrium.

GHG Source	Canadian Situation
Nitrous Oxide	**Source:** The Canadian Fertilizer Information System has the information from the fertilizer manufacturers. This is broken down by NPK values. This is a big area of difference between Canada and the Field to Market national indicator. Field to Market is using a slightly modified Tier 1 approach (1.3% for everything). Using this approach would significantly bias the numbers against production in Western Canada, and would not be accurate. **Includes:** An empirically established linear relationship between fertilizer-induced N_2O emissions and the ratio of precipitation to potential evapotranspiration, P/PE, for three regions of Canada. Currently working on a model (with the US – Colorado and New Hampshire groups).

Project Team Opinion on Energy Use and Climate Impact – Potential to Replicate Field to Market Indicators in Western Canada

The Project Team concluded that there is good potential to replicate the Field to Market Indicators for Energy Use and Climate Impact in Western Canada. Overall, the workshop findings indicated that, while Canada may have less data than the United States, there is potential for us to make use of greater modelling capacity in Canada than the Field to Market Alliance did.

More specifically, in the United States, the NRCS has continually collected detailed data on cropping history, rotations and management practices, since 1982. Canada, on the other hand, lacks detailed data on crops and farm practices, on a spatially-explicit basis. Land use changes and land use management changes, for example, have to be estimated from survey data. Lack of data on tillage and crop rotations remains an issue. However, substantial work has been done in Canada to develop farm energy budgets based on a combination of farm statistics and agricultural engineering coefficients. As well, N_2O emissions have been estimated in accordance with IPCC methodologies. This allows for considerably more robust estimates in many areas than the approach used to develop the national-level Field to Market Indicators for Energy Use and Climate Impact.

In one specific example, Canadian researchers have established an empirical relationship between the ratio of precipitation to potential evapotranspiration (P/PE), and a fertilizer-induced N_2O emission factor. This makes it possible to predict N_2O emissions for a given P/PE value, leading to estimates for the prairies that are much more accurate and much lower than what would result from the Field to Market approach (i.e. 1.3% of applied fertilizer nitrogen, across the board). In this area, the approach that has been taken in Canada makes it possible to distinguish regional differences that are important for the prairies.

The United States has much better data than Canada on soil organic carbon (SOC). The U.S. uses explicit process modelling at NRI sample sites, and updates SOC data periodically, while Canada lacks current and high-quality SOC data. However, the Field to Market Alliance estimated carbon sequestration at a constant 337 kg C/ha/year for continuous no-till, based on no solid data on the actual occurrence of continuous no-till. By contrast, in Canada, modelling of soil organic carbon change using the “Century” model shows substantial increases in soil carbon on the prairies, reflecting decreased use of summerfallow, increased adoption of conservation tillage, and conversion of annual cropland to perennial cropping systems. Again, there is scope for the Project Team to make use of modelling done in Canada that will probably reflect reality on the prairies more accurately than the approach taken to developing the national-level Field to Market Indicators in the U.S.

Rationale for Selection of Data and Models for Energy Use and Climate Change Impact in Western Canada

It is clear from the preceding that the Project Team was faced with several options for sourcing data for the Energy Use and Climate Impact Indicators for Western Canada. Two possible data sets with coverage of Western Canada are available:

1. Data used to construct the NAHARP Agricultural Greenhouse Gas Indicator, incorporating
    - data from the F4E2 model on fuel used for field operations
    - data from the Century model on soil carbon emissions/sequestration
2. Data from the CEEMA model's database of GHG emissions.

Table 9 summarizes the coverage of various sources of agricultural GHG emissions, including the various forms of energy use, by the key Canadian data sources and by the various Field to Market Indicators. This comparison clearly shows that the coverage of GHG sources by the CEEMA model is very broad, with significantly more GHG sources covered than either the existing Field to Market national-level indicators or the proposed Fieldprint Calculator. The combination of the F4E2 model (and its related literature) and the NAHARP Agricultural GHG Indicator also compares well with the coverage of both the existing Field to Market national-level indicators and the proposed Fieldprint Calculator.

Table 10: Comparison Chart – Coverage of GHG Sources in Existing Energy Use and Climate Impact Indicators

GHG Source (categories from CEEMA documentation)	CEEMA	F4E2/Dyer/ Desjardins Literature	NAHARP Agricultural GHG Indicator	Field to Market Energy Use (national indicator)	Field to Market Climate Impact (national indicator)	Field to Market Fieldprint Calculator v2, Energy Use (proposed)	Field to Market Fieldprint Calculator v2, Climate Impact (proposed)
Emissions from Crop Production Related Activities (CEEMA Module A)							
N_2O Emissions from Crop Residues (8.2)				N/A		N/A	GHG emissions from burning crop residues only
N_2O Emissions from Fertilizer Use (8.3)				N/A		N/A	
N_2O Emissions from Production of N-Fixing Crops (8.4)				N/A		N/A	
Soil Organic Matter (Emission/ Sequestration of CO_2 by Soil) (8.5)			Does not include CO_2 emissions from land conversion (e.g. forest to cropland)	N/A		N/A	Future soil carbon indicator
On-Farm Fuel Use (non-stationary combustion) (8.6)							
N_2O Emissions from Manure Application (8.7)	Data gap, assumed 0, but included under livestock			N/A		N/A	
Farm Input Production (CEEMA Module D)							
Fertilizer Production (14.2)							
Fuel Production (14.3)							
Pesticide Production (14.4)							
Machinery and Equipment Manufacturing (14.5)							
Seed Production					Seems to be included in West and Marland		
On-Farm Energy Use – Non-Farm Machinery (CEEMA Module C)							
On-Farm Crop Transportation (12.2)	All business use of motor vehicles	On-farm only	On-farm only	(included under 8.6)	Seems to be included in West and Marland		On-farm and to storage/ point of sale
Non-Farm Machinery Stationary Combustion (crop storage and drying) (12.4)		Heating fuel (includes heating greenhouses)	Heating fuel (includes heating greenhouses)	? included under 8.6 if done on-farm?	Seems to be included in West and Marland		Drying and product handling and irrigation systems

GHG Source (categories from CEEMA documentation)	CEEMA	F4E2/Dyer/ Desjardins Literature	NAHARP Agricultural GHG Indicator	Field to Market Energy Use (national indicator)	Field to Market Climate Impact (national indicator)	Field to Market Fieldprint Calculator v2, Energy Use (proposed)	Field to Market Fieldprint Calculator v2, Climate Impact (proposed)
Electricity							
Atmospheric Deposition from Nitrogen Applied to Soil (NH3, NOx -> N_2O)(10.2)				N/A		N/A	
Nitrogen Leaching and Runoff (10.3)				N/A		N/A	
Histosols (10.4)				N/A		N/A	
Human Sewage (10.5)				N/A		N/A	
Emissions from Other Agroecosystems (CEEMA Module I)							
Methane Sequestered by Cultivated Lands (11.2)				N/A		N/A	
Methane Emissions from Wetlands (11.3)				N/A		N/A	
CO_2 Sequestration Due to Planting of Shelterbelts (11.4)				N/A		N/A	
CO_2 Sequestration Due to Agroforestry				N/A		N/A	

KEY:
Included
Not included

The Project Team decided to use data from the F4E2 model and NAHARP Agricultural GHG Indicator, and related research. This decision was based on the Indicator Selection Criteria listed in the initial section of this report. The following considerations were identified as being key[3]:

- **Time-series vs. cross-sectional design.** CEEMA is a cross-sectional, data-based model. While a few runs have been made since 1990, this has the implication that substantial data would have to be provided to the model to create additional results over time. NAHARP Indicator research, while depending on many of the same data sources as CEEMA, has been designed to provide time-series data, at 5-year intervals (based on Census years), since 1981.
- **GHG emissions for individual crops.** NAHARP Indicator research has included a 2010 study to quantify fossil fuel CO_2 and soil N_2O emissions associated with production of each of 21 major field crops in Canada. Consequently, the GHG emissions associated with each crop are more readily accessible in this data set than in CEEMA's database. This is of critical importance, given that the Field to Market Indicators are explicitly crop-specific, and necessarily built on crop-specific data. The reporting of each indicator by crop is an element that has not necessarily been addressed by Canadian models in the past. See Dyer et al, 2010.

[3] Please note that, in this discussion, the term "NAHARP Indicator research" is used to include the body of research, coordinated by AAFC, and including F4E2 simulations, associated with and feeding into the creation of the NAHARP Agricultural GHG Indicator and Environment Canada's reporting under the Kyoto Protocol.

- **Separation of energy use terms from climate impact terms.** Terms relating to farm energy use appear to be more readily separable from other climate impact terms in the NAHARP Indicator research than in CEEMA.
- **Recent calibration of CEEMA using F4E2 coefficients.** F4E2 coefficients for farm energy have been integrated into CEEMA, following a recent project to upgrade data on fossil CO_2 emissions from farm fieldwork, using the F4E2 model. Prior to this, the two models differed significantly in their estimates at the regional level. Given the Project Team's focus on Western Canada, this is considered a significant refinement to CEEMA. However, the F4E2 coefficients for farm energy have not been applied to historical data in CEEMA.

Specific Methodology for Energy Use and Climate Impact Indicators for Western Canada

The data described above was incorporated into a complex modelling process in order to develop the Energy Use and Climate Impact indicators. This process included a number of specific elements of relevance which have been outlined in detail below. Energy use is presented in units of gigajoule per hectare (GJ/ha), and climate impact is presented in units of tonnes of CO_2 equivalent per hectare (T CO_2e/ha).

In this analysis, energy use includes energy used to complete field work; energy used for transport, heating and electricity; energy used to produce fertilizer; and energy used to produce machinery.[2]

Climate impact includes all these components of energy use, in addition to the following sources of nitrous oxide: fertilizer nitrogen, crop residue decomposition, leaching and volatilization (see Table 10).

Table 11: Energy and GHG Sources included in the Energy Use and Climate Impact Indicators

	Energy Use Indicator – Energy Sources Included	Climate Impact Indicator – Energy/GHG Sources Included
Sources of CO_2 (farm energy)	Energy used to complete field work	Energy used to complete field work
	Energy used for transport, heating and electricity	Energy used for transport, heating and electricity
	Energy used to produce fertilizer	Energy used to produce fertilizer
	Energy used to produce machinery	Energy used to produce machinery
Sources of N_20		Fertilizer nitrogen
		Crop residue decomposition
		Leaching
		Volatilization

Soil carbon sequestration/emission can also be a source of greenhouse gases (CO_2). This analysis excludes soil carbon. Soil carbon is not given any direct attention in this analysis for two reasons. First, soil carbon in Canadian agricultural soils is generally considered to be in equilibrium, having undergone some recharge after the adoption of reduced tillage (Desjardins et al., 2005). This tends to counteract losses of soil carbon resulting from initial cultivation. The second reason is that soil carbon does not represent an ongoing emission flux, but rather a carbon sink. Fluxes to or from this sink would only happen at a significant rate after a land use shift such as after replacement of annual crops with perennial forage, or the reverse. Hence, soil carbon is not a factor in crop-specific emission coefficients.[3]

It should be emphasized that the Climate Impact Indicators developed in this study do not consider the carbon sequestration attributed by NAHARP to reduced tillage and summerfallow. This suggests that climate impact is somewhat overestimated by these indicators, given that NAHARP data indicates that carbon sequestration by prairie soils is not negligible in comparison to the Climate Impact Indicators.

[2] To date, energy used in the production of machinery and equipment has NOT been considered in the Field to Market approach.

[3] From "Greenhouse gas emission intensities for seven selected crops in western Canada," by Xavier Verge and Jim Dyer, 2011.

Soil organic carbon (SOC) is generally increasing on Western Canada's prairies. This is mainly a result of reduced tillage and summerfallow. Soil organic carbon change on the Prairies has increased from 12 kg/ha/year of sequestered carbon in 1981 to 86 kg/ha/year in 2006 (Eilers et al, 2010).

Allocation of soil carbon change to individual commodities, as required by the structure of the Field to Market Indicators, would be very difficult in the context of the quality of data used to estimate soil carbon changes in Canada. Canada lacks high-quality data on soil carbon, as well as detailed, location-specific data on crops and farm management practices (McConkey, 2011b). Consequently, only soil carbon changes resulting from relatively major land management changes (changes in summerfallow and tillage, conversion of land between annual crops and perennial hay or pasture) and land use changes (conversion of forestland to cropland, conversion of native grassland to cropland) have been modelled.

Note that the U.S. has a very different soil carbon change inventory system from Canada's. The U.S. system relies on explicit process modelling at NRI sites, for which detailed histories of land use and management are maintained. This results in better SOC data, in that it is more detailed, and it is periodically updated (McConkey, 2011b).

It can be seen in Table 10 that the methodologies for the Energy Use and Climate Impact indicators split naturally into the methodology for farm energy and that for nitrous oxide. Consequently, these are presented separately below.

Specific Methodology for Nitrous Oxide

This section gives a brief overview of the method used in the calculation of N_2O emissions. More details on the methodology can be found in the references in this paragraph and in Vergé et al. (2007, 2008, 2009a, 2009b). Nitrous oxide emissions were calculated using the Intergovernmental Panel on Climate Change (IPCC) Tier 2 methodology (IPCC, 2000, 2006; Hutchinson et al., 2007), which estimates nitrous oxide emissions as the product of nitrogen inputs (kg N) and an emission factor (kg N_2O-N/kg N). The methodology was adapted for Canadian conditions by Rochette et al. (2008a,b). These modifications include a new estimation of the N_2O emission factor based on soil water availability, which is approximated by the ratio of precipitation to potential evapotranspiration during the growing season (May to October). The modifications also incorporate the influence of tillage practices, position in the landscape, irrigation and soil texture on the N_2O emission factors (Huffman et al. 2006). Nitrous oxide emissions from fallow soils and a variable leaching fraction for indirect emissions were also estimated based on the ratio of precipitation to potential evapotranspiration.[6]

Weather data are based on Environment Canada (2011). Both above- and below-ground crop residue contributions to nitrous oxide emissions were estimated using crop-specific N contents and residue/ crop product ratios (Janzen et al., 2003). The N_2O sources considered were nitrogen fertilizer application (commercial or natural), crop residues, leaching, and volatilization[7]. The crop-specific applications of nitrogen fertilizer were based on the recommended rates (kg N ha−1) for the most common field crops of Canada (Yang et al., 2007). Yield data comes from Statistics Canada (2011 – N°8).[8]

The N_2O emissions are broken down in two categories (direct and indirect sources) according to the IPCC recommendations presented in the GHG methodology guidelines (IPCC, 2006). For this project four sub-categories are then considered:

- direct emissions from nitrogen applications to field and from the crop residue decomposition,
- indirect emissions from leaching and volatilization.[9]

6 From "Greenhouse gas emission intensities for seven selected crops in western Canada," by Xavier Verge and Jim Dyer, 2011.
7 In this report, "commercial fertilizer" refers to inorganic fertilizer, and "natural fertilizer" refers to manure.
8 Ibid.
9 Ibid.

Table 12: N_2O Emission Intensities (tonne CO_2e/ha) by Crop, Year and Source of Nitrogen[10]

(T CO2e ha-1)	1981	1986	1991	1996	2001	2006
Nitrogen fertilizer - Commercial						
Wheat, Spring	0.56	0.56	0.56	0.60	0.56	0.57
Wheat, Durum	0.57	0.57	0.56	0.57	0.50	0.55
Wheat, Winter	0.60	0.60	0.59	0.59	0.61	0.63
Canola	0.81	0.80	0.79	0.85	0.80	0.82
Dry Peas	0.68	0.67	0.67	0.71	0.62	0.68
Lentils	0.41	0.41	0.40	0.38	0.34	0.38
Flaxseed	0.59	0.58	0.58	0.60	0.56	0.58
Oats	0.58	0.57	0.57	0.59	0.57	0.59
Nitrogen fertilizer - Natural						
Wheat, Spring	0.54	0.54	0.54	0.58	0.54	0.56
Wheat, Durum	0.54	0.54	0.54	0.55	0.49	0.53
Wheat, Winter	0.57	0.57	0.57	0.57	0.59	0.62
Canola	0.77	0.77	0.76	0.82	0.77	0.80
Dry Peas	0.66	0.66	0.66	0.70	0.62	0.67
Lentils	0.40	0.40	0.40	0.38	0.34	0.37
Flaxseed	0.56	0.56	0.56	0.58	0.54	0.56
Oats	0.55	0.55	0.55	0.57	0.55	0.57

The contributions of pulse crop residues to N_2O emissions may have been overestimated by the methodology used for this project. As noted in "Results – Considerations for Energy Use and Climate Impact – Differences by Crop", below, peas have the highest estimated crop residue nitrogen of the crops studied, and this results in a relatively high estimate of N_2O emission intensity for peas. Recent research has been conducted by Zhong et al (2011) comparing crop residues from grain legumes (lentils and peas) to crop residues from a cereal crop (spring wheat). This work suggests that N_2O emissions are not directly related to biological N_2 fixation by grain legumes such as peas and lentils. It was found that, in the short term, nitrogen rich residues of N_2-fixing crops have a limited impact on N_2O emissions. Consequently, the results in Table 11 should be interpreted in the context that N_2O emissions for peas and lentils may have been overestimated.

In this analysis, since no data were available for identifying the source of nitrogen (commercial vs. natural) used for specific crop cultivation, we calculated two sets of emission intensities, assuming that all nitrogen fertilizer is either commercial or natural. Then, given an estimate of the percentage of each of these applied to the crops, a weighted emission factor can be calculated[11].

Note that two sets of emission intensities were also calculated for farm energy (see the following section), one for commercial fertilizer and one for natural. This led to calculation of different values for the field work and fertilizer manufacture components of farm energy.

Development of Indicators from N_2O Emissions Intensity Data

The Project Team weighted the resulting emissions intensities for both nitrous oxide and farm energy according to the assumed distribution of commercial vs. natural fertilizer use presented in Table 12.

10 Ibid.

11 From "Greenhouse gas emission intensities for seven selected crops in western Canada," by Xavier Verge and Jim Dyer, 2011.

Table 13: Assumed Distribution of Commercial vs. Natural Fertilizer Use, by Province

	% Commercial Fertilizer	% Natural Fertilizer
Manitoba	95%	5%
Saskatchewan	98%	2%
Alberta	90%	10%
British Columbia	90%	10%

Note that there is potential to apply a more sophisticated methodology to arrive at a more accurate distribution. Quantities of commercial fertilizer, including N/P/K breakdown, are available from the Canadian Fertilizer Institute. Natural fertilizer quantities can be derived from livestock numbers, which are available from Statistics Canada. Other relevant data has been generated by Alberta Agriculture and Rural Development (Wallace, 2011).

For each crop, the nitrous oxide emissions intensity for each province was weighted by the province's share of the area of that crop in Western Canada, then the area-weighted emissions intensities were combined to generate the N_2O portion of the Climate Impact Indicator for that crop.

Specific Methodology for Farm Energy

Introduction

The farm energy section of this methodology assesses the fossil CO_2 that can be attributed to the seven selected field crops in Western Canada. It relies on methodologies that are generally not crop specific. The drivers of these methodologies (discussed in more detail below) are, however, largely crop specific. Nevertheless, there is very little in this analysis that was done specifically for any one crop type. Although this approach is, to some extent, limited by not being able to exploit any hands-on knowledge of commodity experts, it provides a more objective comparison because the drivers of those crops are common statistics that are available historically. Through this approach, all crops and provinces could be given the same objective unbiased treatment.[12]

Background

Two methodologies have contributed to the estimation of fossil CO_2 emissions from farm energy use in Canada. The estimates in this report will reflect some updates and re-organization of output from these two methodologies, particularly for farm field operations (Dyer et al., 2010a).[13]

The more simplistic method was the indexing of farm energy terms to agricultural statistics and related databases. This indexing approach allows estimates of farm energy terms to respond to temporal, spatial and crop-specific drivers such as crop yields and fertilization rates. The most important database is the Farm Energy Use Survey (FEUS) from 1996 (CAEEDAC, 2001). The non-fieldwork-related energy terms, including farm-owned transport, heating fuels (LPG, heating oil and natural gas), farm electricity, fertilizer and machinery supply, were based on the national calculations presented by Dyer and Desjardins (2009). The two principle terms subject to this indexing approach were farm use of heating fuels and gasoline consumption by farm-owned transport vehicles.[14]

[12] Ibid.
[13] From "Greenhouse gas emission intensities for seven selected crops in western Canada," by Xavier Verge and Jim Dyer, 2011.
[14] Ibid.

The most complex of these methods involves the Farm Fieldwork and Fossil Fuel Emissions and Energy (F4E2) model. F4E2 simulations are driven by farm machinery management and mechanical principles, using coefficients from ASAE to determine various resistances and fuel consumption rates, plus other operational and efficiency factors, to calculate work and energy requirements to till, seed, cultivate and harvest typical field crops (Dyer and Desjardins, 2003; 2005). The principle driver for F4E2 on a temporal basis has been the shifting tillage practices in Canada, namely, the adoption of reduced and no tillage approaches to spring seeding. On a nationally integrated scale, F4E2 estimates have been verified against the FEUS diesel fuel consumption data. Details of the F4E2 simulations for annual field crops are available elsewhere (Dyer and Desjardins, 2003). In addition to field operations, the F4E2 tractor power calculations also provided a theoretical basis for estimating the energy required for farm machinery manufacture and supply (Dyer and Desjardins, 2006a).[15]

Farm electrical energy was an intermediate farm energy term with respect to the mechanistic and indexing approaches. A simple, semi-empirical model was developed from the related literature that was commodity specific and on a sector-wide basis. This index model compared well with other sources on sector-specific electrical energy consumption in Canada (Dyer and Desjardins, 2006b). Farm electrical energy is, however, a relatively small term in the energy balance of grains and oil seed production in Canada. The remaining indirect term for farm inputs, the energy to manufacture and supply fertilizer (Dyer and Desjardins, 2007), used an empirical coefficient developed by Nagy (2001).[16]

List of Specific Assumptions for This Study

The basic calculations in the farm energy balance are for fossil CO_2 emissions. Farm energy consumption estimates were based on conversions from these fossil CO_2 estimates using the GJ/t(CO_2) coefficients from the 1990 GHG Emissions report from Environment Canada (Jaques, 1992). The fossil fuels involved in these conversions include diesel, gasoline, heating oil, natural gas and LPG (the last three of which make up the heating fuel). Conversions to electrical and farm machinery energy are as described by Dyer and Desjardins (2006a,b).[17]

In keeping with the above N_2O emissions assessment, the amounts and impacts from nitrogen fertilizer were derived from two sources: natural and commercial fertilizer. Because the use of natural fertilizer in fields is hard to determine, separate estimates that relied on complete dependence on each source were made. This assumption is realistic for commercial fertilizer for crops such as spring wheat that are extensive in Western Canada and go to market as a food commodity, rather than as animal feed. But assuming complete reliance on natural fertilizer is less realistic because the quantity of required animal manure is simply not available. However, the second assumption is useful to this analysis because it defines a boundary condition for examining the impact of commercial nitrogen fertilizer on energy consumption as well as N_2O emissions.[18]

For natural fertilizer application systems, solid, rather than liquid, manure application systems were assumed. This is because the dominant livestock in Western Canada is beef, for which almost all manure is stored dry (Marinier, 2004). Where liquid manure is applied (such as on large hog farms), the fuel energy to apply natural fertilizer in this form would be higher because of the added bulk of water and the need to inject this material beneath the soil surface.[19]

Both farm-owned transport fuel use (gasoline) and heating fuel terms were based on the 1996 FEUS. In both cases they were indexed to crop-specific provincial crop yield data from each census year.[20]

15 Ibid.
16 Ibid.
17 From "Greenhouse gas emission intensities for seven selected crops in western Canada," by Xavier Verge and Jim Dyer, 2011.
18 Ibid.
19 Ibid.
20 Ibid.

Farm Field Operations (Applying the F4E2 Model)

Three F4E2 model runs were made per province, mainly to accommodate the three tillage systems. However, this also accounts for slightly more draft power for seeding when no prior tillage is done, plus a similar allowance for secondary tillage when no primary tillage is done. All of the F4E2 model farms were three-tractor systems. Although F4E2 can simulate single and two-tractor operations, by allowing a tractor for each spring operation, there were no penalties for implement-tractor mis-matching.[21]

Farm field work operations were grouped as 1) spring tillage and seeding, and weed control; 2) fertilizer application (both sources); 3) harvest operations (combine, swathing and carting grain from the field). In group 1, the tillage and seeding simulation was done in triplicate with each successive simulation allowing for elimination of a tillage pass. These simulations were re-combined into a single estimate based on the respective shares of each tillage system (conventional tillage, minimum tillage and no tillage) in each province and census year. In the combined estimate for all spring tillage and planting operations, each year-province estimate is the weighted average of the three tillage systems based on the provincial statistics for the popularity/use of each of these tillage systems in each year and province.[22]

For the field work to apply fertilizer (group 2), the actual fertilizer for each crop was expressed as a ratio with the average recommendation for the five non-legume crops selected for this study, which was 61 t/ha. The either/or approach to sources of nitrogen had an impact on fuel use for farm fieldwork because of the different weights of material to be spread - the bulk weight per unit of N would be higher for natural fertilizer than for commercial fertilizer. Therefore, a special simulation from F4E2 was made where the areas to receive nitrogen fertilizer was set equal to the seeded area. This allowed the area-based CO_2 emission intensity for all farm operations to have a common area basis.[23]

Fuel energy estimates from F4E2 for harvest-related operations were modulated by (indexed to) annual provincial yields for each crop, expressed as a percent of the provincial crop yields from 1996 (the year against which the F4E2 model was verified). This indexing converted the mechanical work estimate from F4E2 sensitive to crop and year differences. The combining fuel estimates assumed that all annuals were small grains. Grain swathing was assumed to be a separate operation from combining (which is more typical of Western Canada). Carting of grain from the combine to the on-farm storage site was attributed to the diesel consumption.[24]

Tow tractors for spraying, spreading manure and applying fertilizer were the same machines as the simulated spring seeding tractors. All weed control was by spraying, regardless of the tillage system. For the energy used in the three harvest operations, the F4E2 simulation was assumed to be for 1996, since 1996 was the year of the last FEUS upon which F4E2 was calibrated.[25]

Development of Indicators from CO_2 Emissions Intensity Data

The Project Team weighted the resulting emissions intensities for farm energy in the same way as for N_2O emissions, i.e. according to the assumed distribution of commercial vs. natural fertilizer use presented in Table 12.

For each crop, the farm energy emissions intensity for each province was weighted by the province's share of the area of that crop in Western Canada, Then the area-weighted emissions intensities were combined to generate the Energy Use Indicator, and the farm energy/CO_2 portion of the Climate Impact Indicator for that crop.

[21] Ibid.
[22] Ibid.
[23] From "Greenhouse gas emission intensities for seven selected crops in western Canada," by Xavier Verge and Jim Dyer, 2011.
[24] Ibid.
[25] Ibid.

Structure of the Energy Use and Climate Impact Indicators

As with all the Field to Market Indicators, the Energy Use and Climate Impact Indicators for Western Canada are presented as both resource impact indicators and efficiency indicators, each showing change over time for a specific crop. In the case of energy use, the resource impact indicator presents energy use, in gigajoules per hectare, alongside crop yield, in tonnes per hectare. Crop yield is presented as a five-year centred moving average. The efficiency indicator is calculated as energy use (gigajoules/hectare) divided through by crop yield (tonnes/hectare), and thus reflects energy use per unit of crop output. In common with all the efficiency indicators, it is reported as an index, with the data indexed to give a value of 100 for the year 2001.

For climate impact, the resource impact indicator presents climate impact, in tonnes of CO_2 equivalent per hectare, beside crop yield, in tonnes per hectare. Again, crop yield is presented as a five-year centred moving average. The efficiency indicator is calculated as climate impact (TCO_2e/ha) divided through by crop yield (T/ha), reflecting climate impact per unit of crop output. Again, the efficiency indicator is reported as an index, giving a value of 100 for the year 2001.

Indicator 5: Irrigation Water Use Indicator

Irrigation water use refers to the application of water to land to facilitate crop growth. Irrigation is an important management tool in areas where precipitation is inadequate to maintain suitable soil moisture for crop development. Crop production depends on adequate and timely water availability. In the United States, agriculture is responsible for 80% of the nation's water consumption, and 16% of U.S. agricultural land is irrigated (Field to Market, 2009a). Canadian agriculture is considerably less dependent on irrigation, with about 540,000 hectares (about 1% of cultivated land) irrigated in Canada in 2006 (Statistics Canada, 2009; Hofmann et al, 2005). In Canada, agriculture accounts for about 9% of water withdrawals, with most of this being used for irrigation (Eilers et al, 2010).

Due to population growth, water is an increasingly scarce resource. Increasing population drives greater food requirements, as well as water requirements for other purposes. Irrigated land produces 2.5 times as much as non-irrigated land, with the implication that demand for irrigation water will continue to increase (Field to Market, 2009a).

The Field to Market Indicator

The National-Level Field to Market Irrigation Water Use Indicator

Data for the national-level Field to Market Irrigation Water Use Indicator is taken from the Farm and Ranch Irrigation Survey (FRIS), which is part of the U.S. Census of Agriculture (USDA, 2008). The Field to Market Indicator is based on data for the FRIS reference years 1988, 1994, 1998 and 2003. The FRIS collects data with a mail-out survey to a sample of almost 20,000 operators who had identified irrigation use in previous census years.

The national-level Field to Market Irrigation Water Use Indicator focuses on the additional productivity provided by irrigation. It uses data from the FRIS on

- Quantity of water applied, by crop
- Acres of irrigated crop
- Yield for irrigated crop
- Yield for non-irrigated crop, on farms that irrigate.

Since the data in the FRIS describes farms that irrigate, the decision was made to compare irrigated and non-irrigated yields on these farms, thus estimating the productivity differential due to irrigation at comparable locations (Field to Market, 2009a).

The resource use indicator for irrigation water use reports irrigation water applied, in gallons per acre, alongside the yield for the irrigated crop, in bushels per acre, by crop. The efficiency indicator is calculated as the irrigation water applied per unit of output attributable to irrigation, indexed to 100 in the year 2000.

The Proposed Fieldprint Calculator Irrigation Water Use Metric

The proposed Irrigation Water Use Metric also intends to capture the yield impact of applied irrigation water. It differs from the national-level indicator in that it includes water applied prior to the season (and contributing to the development of the reported crop), and it allocates applied water to bi-products and co-products (e.g. cotton lint and cotton seed). Irrigation water applied to failed crops is captured. As well, irrigation water applied to a green manure crop in the prior season, and water stored in the soil just prior to planting is captured. Finally, for consistency with the proposed Land Use Metric, the difference between irrigated and non-irrigated yields will be calculated on the basis of total land area, rather than harvested area (Field to Market, 2011).

Western Canadian Methodology and Data Sources

The extent of irrigation in Western Canada is much less than in the U.S. As a result, little peer reviewed work has been done to quantify the impact of irrigation on crop production efficiency. Due to the lack of work addressing this issue, the decision to this point has been to ignore the irrigation water use metric.

Recent research by Rod Bennett and Ted Harms of Alberta Agriculture and Rural Development should be noted in the context of the Irrigation Water Use Indicator, and the potential to reproduce it for Western Canada. Bennett and Harms (2011) conducted a study to establish the relationships between evapotranspiration and crop yield for major irrigated crops in southern Alberta. The authors went on to establish empirical production functions relating crop yield and field water supply (comprising irrigation at 80% efficiency, effective precipitation, and stored soil moisture depletion. Of direct interest to the current project, the crops investigated by Bennett and Harms include canola, hard spring wheat and soft spring wheat. Further analysis is planned, utilising historical weather data (Bennett, 2011).

Also relevant to the possibility of developing an Irrigation Water Use Indicator for Western Canada is a pilot study conducted by L. Tollefson, G. Dyck and J. Harrington in south-central Saskatchewan (Eilers et al, 2010). This study calculated first-generation indicators to quantify:

- Water use technical efficiency (WUTE), estimating the mass of agricultural production per unit of irrigation water used on selected crops
- Water use economic efficiency (WUEE), estimating the value of agricultural production per unit of irrigation water used for irrigated crops.

The study showed that WUTE and WUEE indicators can be calculated at the scale of the irrigation district. However, Eilers et al (2010) note that there is limited scope to develop these indicators at a national scale, due to a lack of accurate and comprehensive irrigation data, including irrigated acres, crop yields and water volumes. Nonetheless, development of a regionally sensitive national indicator of Irrigation Water Use Efficiency is still under way. This indicator is intended to reflect changes in crop selection, irrigation technology and management practices.

Summary of Western Canadian Indicator Development And Comparison with Field to Market

While there are significant similarities between the data sources used in the Field to Market (U.S.) Indicators and those used for Western Canada, there are also significant differences. Further differences in geography and crop selection make it very difficult to make direct comparisons between the U.S. and Western Canada. Any comparison of environmental performance in the U.S. and Western Canada must be informed by a thorough understanding of the context of the data and models used to generate the results, and of different geographies in the two jurisdictions.

Land Use Indicator

The Field to Market national-level Land Use Indicator developed for the U.S. is closely replicated for Western Canada. While it is arguable that planted acres would give a more relevant measure of land use, harvested acres were used for consistency with the intent of the Land Use Indicator for the U.S. (Ramsey, 2011). The data used in the two indicators comes from the respective national agricultural statistical organizations, and is considered comparable.

A suggested improvement to the process has also been proposed. Incorporation of land use efficiency parameters and/or biodiversity considerations would provide a more representative indication of sustainability.

In summary, the Land Use Indicators developed here for western Canadian crops are considered to be based on sound data. Where there are limitations, these are the same as those found in the Field to Market U.S.A. Land Use Indicators, i.e. they fail to capture key dimensions of land use intensity. For example, issues surrounding agricultural land use will be better addressed by indicators that assess the extent to which the actual use of agricultural land is matched to its capacity. A need remains for indicators designed to quantify additional dimensions of agricultural land use issues.

Soil Loss Indicator

The NRI data used to develop the Field to Market Soil Loss Indicator for the U.S. is significantly more detailed than the data available for Canada. For example, Canada lacks the density of data contained in the databases listed in Table 2, above, and has not been able to fully implement RUSLE2 modelling of water erosion, as proposed for future Field to Market Soil Loss Indicators. In one important example, climate data is stronger for the U.S. than for Canada, with the consequence that soil erosivity is less well defined for Canada. Modelling of wind erosion is somewhat more consistent between the present Field to Market U.S.A. and the western Canadian Indicator, with both using the Wind Erosion Equation (WEQ). However, again, a greater density of data is available for the U.S. Ultimately, these differences have led to Canada's implementation of indicators focused on the risk of soil erosion.

On the other hand, the U.S. only considers wind and water erosion, and does not explicitly address tillage erosion. Canada has adopted a more comprehensive approach to estimating soil erosion, including a more rational approach to estimating soil movement within the field. Loss of soil from the eroding portion of the hill is explicitly addressed, while the net loss of soil from the field, on the prairies, is close to zero. Closely related to this, Canada uses different topographic data. By using four representative, modal hillslope segments to represent landforms, Canada is characterising the landscape more intensively than the U.S. (Lobb, 2011).

In summary, data and models have developed with somewhat different areas of emphasis in Canada and the U.S. While less data-intensive, Canada's modelling provides a very comprehensive analysis of soil loss for Western Canada's prairies. The impacts of topography and land use, including crop sequence and tillage systems, are explicitly addressed.

As a result, although not directly comparable, both the U.S. and western Canadian Soil Loss Indicators enable us to observe changes in the potential for soil loss over time. These estimates of change over time both provide excellent indications of progress in making cropping systems more sustainable. The models are also detailed enough to support the establishment of a baseline against which further improvements can be observed over time.

Energy Use Indicator

The Project Team took a different approach to developing the Energy Use Indicator for Western Canada, as compared to that taken by Field to Market Field to Market in the United States (Field to Market, 2009a). The Project Team was able to utilize modelling and data for farm energy that has undergone many years of research and refinement through Canada's National Inventory reporting under the Kyoto Protocol.

The F4E2 model has undergone around ten years of continual refinement and calibration against databases such as the Farm Energy Use Survey and CEEMA. This has resulted in a data set for farm energy that is both inclusive and regionally specific in comparison to that used to develop the U.S. Energy Use Indicator. The inclusion of energy to manufacture machinery and equipment in the Western Canada indicator is a case in point. A further strength of data developed for Western Canada is that the F4E2 model has been explicitly applied to the generation of crop-specific farm energy data (Dyer et al, 2010c). The ability of the Project Team to make use of the modelling capacity of F4E2 is a key strength of the Energy Use Indicator.

The U.S. Energy Use Indicator is based on Shapouri's study of the energy required to produce a bushel of corn (Shapouri and McAloon, 2001), averaged across nine states. The weakness of this approach is that this data for fuel, electricity and crop protection products had to be extended across time and across other crops, using time-series data for expenditures on energy. Also implicit in this approach is the extension of the data from nine states across the varied geography of the entire United States, with the loss of some regional distinctions. By contrast, the Project Team was able use analysis comparing the energy needed to produce a number of individual crops, on a regionally-specific basis.

As a result, the energy use indicator developed for Western Canada is believed to be considerably more robust than that developed for the US. Different methodologies create significant difficulties in making comparisons. Owing to differences in scope alone, only relative change over time can be meaningfully compared between the Western Canada and US Energy Use Indicators.

In summary, the Project Team has been able to utilise analysis of the energy used to produce each of a range of individual crops, on a regionally specific basis. A custom run was made on the eight crops under study, providing a detailed breakdown of the energy requirements to produce each. In this way, the Project Team was able to develop the Energy Use Indicator from data developed specifically for each crop, and for each of the four western Canadian provinces.

Climate Impact Indicator

As with the Energy Use Indicator, the Project Team's approach to developing the Climate Impact Indicator for Western Canada is significantly different from that used by Field to Market in the US. Again, as discussed above in the context of the Energy Use Indicator, the F4E2 model provided strong crop-specific, region-specific data on farm energy.

Data on nitrous oxide emissions, as well as farm energy, has been developed and refined over almost two decades of evolution of the NAHARP. Both of these data sets feed into Canada's National Inventory reporting under the Kyoto Protocol, a fact that adds to their importance, and likely to the resources devoted to them. The extensive research underlying both the NAHARP Agricultural Greenhouse Gas Indicator and National Inventory reporting under the Kyoto Protocol, is reflected in the inclusion of terms for N_2O emissions due to crop residue decomposition, leaching and volatilization. These terms are not included in the Field to Market US Climate Impact Indicator. Rather, the US Climate Impact Indicator includes N_2O emissions from applied fertilizer and manure only. Also, as described for farm energy data above, crop-specific, region-specific N_2O emissions data has been developed for Canada (Dyer et al, 2010c), and the resulting emissions intensities are the basis for the N_2O portion of the Western Canada Climate Impact Indicator.

The extent of the research underlying the N_2O data is exemplified by the establishment by Canadian researchers of an empirical relationship between the ratio of precipitation to potential evapotranspiration (P/PE) and a fertilizer-induced N_2O emission factor. This allows prediction of N_2O emissions for a given P/PE value, leading to much more accurate estimates than the 1.3% of applied fertilizer nitrogen used for the U.S. Climate Impact Indicator. The difference is highly significant for the prairie region of Western Canada.

An important implication of these differences is that, as with the energy use indicator, the Climate Impact Indicator for Western Canada is substantially different from that developed by Field to Market for the US. Comparisons of Canada and the US could only be made in terms of relative changes across time. Comparisons of actual emissions intensities would be meaningless.

As with the Energy Use Indicator, the Climate Impact Indicator for Western Canada was built from a custom run providing a detailed breakdown of GHG emissions, specific to each crop, and specific to each of the four western provinces. This analysis is based on a large volume of research feeding into Canada's National Inventory reporting under the Kyoto Protocol.

Irrigation Water Use Indicator

An irrigation water use indicator has not been developed to this point. This is a result of the fact that there are really no peer reviewed approaches to measuring irrigation water use effectiveness in Canada, combined with the reality that irrigation acres are not significant in Western Canada. There is some work being completed in Lethbridge that may offer some insights.

Summary

It is clear from the above discussion that many differences remain between the Field to Market US indicators and those developed here for Western Canada. These differences are summarized in Table 13, below. Due to differences in both scope and methodology, direct comparisons are not feasible between the US and Western Canada. This results from the absence of comparable data, not from any lack of desire or effort on the part of either indicator development team. Even in the case of the Land Use Indicator, where the scope and methodology are similar for both jurisdictions, any comparison must recognize the different agronomic realities of the US and Western Canada: Western Canada is a growing environment with low moisture and a short growing season.

Table 14: Field to Market Indicators for Western Canada – Strengths and Weaknesses

Indicator	Indicator Attribute	Strengths/Weaknesses	Possible Improvements
Land Use	Scope	Same as Field to Market US	
	Data Development	Similar to Field to Market US	
	Other	Like the US indicator, fails to reflect key land use issues, e.g.: • the extent to which actual land use is matched to land capacity • loss of high quality agricultural land • protection of biodiversity	Analysis of spatial correlation between land use and land capacity Assessment of biodiversity (e.g. using ESTR)
	Comparability to Field to Market US	Comparable	
Soil Loss	Scope	Includes tillage erosion, in addition to water and wind erosion	
	Data Development	Canada has less detailed soil data; less detailed historical data on land use, cropping practices and management practices; less complete climate data.	
	Other	Canada represents the landscape more effectively, using modal hill slopes. For Canada's prairies, soil lost from the eroding portions of hills and redistributed within the field, is explicitly modelled (this represents the great majority of gross erosion, and is more relevant to sustainable management).	Improved geospecific data on areas under each crop. Improved landform tables (planned). Further field validation of wind erosion, evaluation of WEPS, RWEQ (in progress). Crop productivity model to estimate effects of erosion on productivity (in progress).
	Comparability to Field to Market US	Canada does not report soil loss relative to T. Comparison of trends over time is possible.	
Energy Use	Scope	Canadian analysis includes energy used for heating and machinery manufacture (excluded from US analysis), but excludes energy to produce crop protection products (included in US analysis).	Energy to produce crop protection products for Western Canada can be estimated.
	Data Development	Canadian data based on National Inventory quantification methods, consequently utilising a large volume of relevant research, including analysis of individual crops, by region and province.	
	Other		
	Comparability to Field to Market US	Comparison of trends over time is possible.	

Indicator	Indicator Attribute	Strengths/Weaknesses	Possible Improvements
Climate Impact	Scope	Canadian analysis includes energy used for heating and machinery manufacture and N_2O from crop residues, leaching and volatilisation (excluded from US analysis); but excludes soil carbon changes due to tillage (assumed to be in equilibrium) and energy to manufacture crop protection products (included in US analysis).	
	Data Development	Canadian data based on National Inventory quantification methods, consequently utilising a large volume of relevant research, including analysis of individual crops, by region and province. N_2O emissions for Canada are based on a more sophisticated Tier 2 approach, vs. a slightly modified Tier 1 approach used by Field to Market.	Adjustment of contribution of pulse crop residues to N_2O emissions, which may be overestimated. Some emission coefficients probably need to be updated.
	Other	Empirical relationship established across Canada to predict fertilizer-induced N_2O emission rates based on ratio of precipitation to potential evapotranspiration.	
	Comparability to Field to Market US	Comparison of trends over time is possible.	

If direct comparisons between the US and Western Canada are ever to be made, the data gaps identified need to be addressed. Development of these initial western Canadian sustainable agriculture metrics is simply the first step in the process.

On the other hand, all the indicators developed and the data used for the western Canadian models have been based on a consistent set of Indicator Selection Criteria. While not perfect, the approach does provide a method of using the best information currently available in order to demonstrate the impact of changes in cropping systems in Canada over the past two decades. They also initiate the process of baseline development, are replicable and objective, and serve as an excellent starting point for the monitoring of progress over time.

Results

The focus of the analysis in this document is the development of indicators for specific crops aggregated at the level of Western Canada, for each of the five indicators. In conducting the analysis, the models worked at a much smaller level of aggregation. This allows the data to be grouped in a number of ways, resulting in some very interesting findings, specifically in the impact areas of soil loss, energy use and climate impact. These findings, in addition to a number of specific issues around the appropriate interpretation of results, are provided before the summary of indicators by crop type. The intent is to ensure that the results are understood in the appropriate context.

Considerations For Soil Loss

As would be expected, there are data issues even with the most accurate and complete data sets. In the context of the Soil Loss Indicator for Western Canada, the issue of data density has already been identified. A related issue in this modelling exercise relates to the estimation of acres under each cropping system. Since the areas recorded in the Census of Agriculture data do not necessarily add up to the area of the corresponding SLC, the Census data is used to estimate the relative areas under each crop. Crop areas modelled are thus reflections of the relative areas of each crop reported as likely to be produced in the Census period. These are then applied to the soil areas within the SLC polygon. Because areas under each crop are estimated, soil loss cannot be analyzed on an acres-harvested basis.

Clearly, collection of more detailed, location-specific data on crops and farm management practices would benefit assessment of both soil carbon changes and soil erosion.

As well, landforms are estimates, and may not correspond exactly to actual seeded or harvested acres. This discrepancy is partly due to slopes being defined in terms of distance – a proportional length of the slope - rather than area. NAHARP is presently undertaking work to allow adjustment of these calculations to the proportional area of the slope, rather than proportional length (Krug, 2011). Thus various data limitations dictate that there is no exact one-to-one correspondence between the areas for the different erosion variables. However, once data is rolled up to the geographic levels of provinces and ecoregions, and to general crop types rather than individual crops, the impacts of these discrepancies are felt to be negligible.

Unfortunately, these data limitations have the consequence that the same soil loss values are assigned to spring wheat, durum wheat and oats, and to peas and lentils. Thus, based on existing data for Western Canada, potential soil loss cannot be distinguished between spring wheat, durum wheat and oats, and between peas and lentils. This illustrates a case where improvements in data collection could significantly improve indicator development.

While, for this project, it would be ideal to have soil loss estimates specific to individual crops, NAHARP's process has the advantage of providing information on crop types beyond those covered in this exercise. This data would support an analysis of shifts in crop mixes over time. This type of analysis could provide valuable insight, and should be considered for future work.

The present (but not future) Field to Market Soil Loss Indicator for the U.S. is reported as soil loss in excess of the tolerable soil loss level, T. For Western Canada, the concept of tolerable soil loss is disregarded, and the Soil Loss Indicator is based on unadjusted estimates of soil loss.

The concept of tolerable soil loss, T is based on the assumption that new soil formation is sufficient to replace soil losses, as long as soil losses are less than T. Thus it is assumed that soil losses of T or less do not represent a decline in soil quality or productivity. However, the actual rate of soil formation varies considerably with differences in soil-forming factors, such as climate, biota, parent material, topography. As well, for some soils, e.g. shallow soils overlying relatively impermeable bedrock or hardpan, even minimal soil loss will lead to reduced productivity. In theory, every soil situation would have a different T value.

In reality, however, there has been little focused research to determine appropriate T values for different soil situations, particularly in the context of Canada's generally cold soil temperature regime. As a result, a standard T value of 11 tonne/ha is often assumed to apply everywhere. Where this is much higher than the actual soil formation rate, soil loss rates reported relative to T, like the present Field to Market Indicator, are not an adequate reflection of how soil quality is being affected. The spatial scale at which T is applied also has implications: soil loss averaged over a landform may be less than T, but greater than T at certain locations. This raises the issue of masking the issue at those locations. For these reasons, the practice adopted by NAHARP, for Canada, is to report soil loss for those slope positions where most soil is lost, without reference to T (McConkey, 2011c).

In theory, SoilERI can work at field scale, given appropriate inputs. This would depend on user input, given that no national soils and landform data are available in Canada for a specific field, in the sense of the databases associated with RUSLE2 in the proposed new Field to Market Fieldprint Calculator. In the long term, Environmental Farm Plans are a potential source of this field–scale data. Potential therefore exists to develop tools to enable land managers to estimate erosion for specific fields and management practices (McConkey, 2011c).

Discussion of Results for Soil Loss

Overall, dramatic reductions in soil loss potential were seen for all the crops studied, in the period from 1981 to 2006.

The major driver of reduced potential soil loss in Western Canada, between 1981 and 2006, has been the widespread adoption of conservation tillage, particularly no-till. Most crops have seen a reduction in tillage intensity. The adoption of no-till in cereal production has had the greatest impact on soil erosion across Canada, owing to the large share of cropland producing cereals (Eilers et al, 2010).

The improvements in soil erosion risk across Western Canada reflect reductions in all three forms of soil erosion – water, wind and tillage. However, the reductions in tillage erosion risk have exceeded those in water and wind erosion. The nature of topography and tillage practices on the prairies are such that in-field deposition of eroded soil often equals most of gross erosion, with tillage erosion often dominating (McConkey, 2011a). Reducing tillage intensity on hilly land with short, steep slopes is an effective practice for reduction of all forms of erosion. On flatter landscapes, tillage erosion is less of a factor, and soil texture and structure become more important (Eilers et al, 2010).

A secondary driver of reduced potential soil loss on the prairies is changes in crop mixes.

Considerations For Energy Use And Climate Impact

Discussion of Results for Nitrous Oxide

Differences by N_2O-Source (Direct-Indirect)

Two types of N_2O emissions were identified and estimated: direct and indirect. The indirect emissions (leaching and volatilisation) are directly linked and positively correlated to the direct emissions (nitrogen fertilizer –N-Fert– and crop residue –CR). Among the indirect emissions, the leaching component has by far the highest impact. This is due to the fact that both N-Fert and CR are used to calculate the leaching factor whereas only N-Fert is involved in the volatilisation factor. This is for example very important for understanding the result for peas and lentils (see next section). This also explains why leaching is generally the second highest emission source after N-Fert. The third one is then CR and the last one is always volatilization.[26]

[26] From "Greenhouse gas emission intensities for seven selected crops in western Canada," by Xavier Verge and Jim Dyer, 2011.

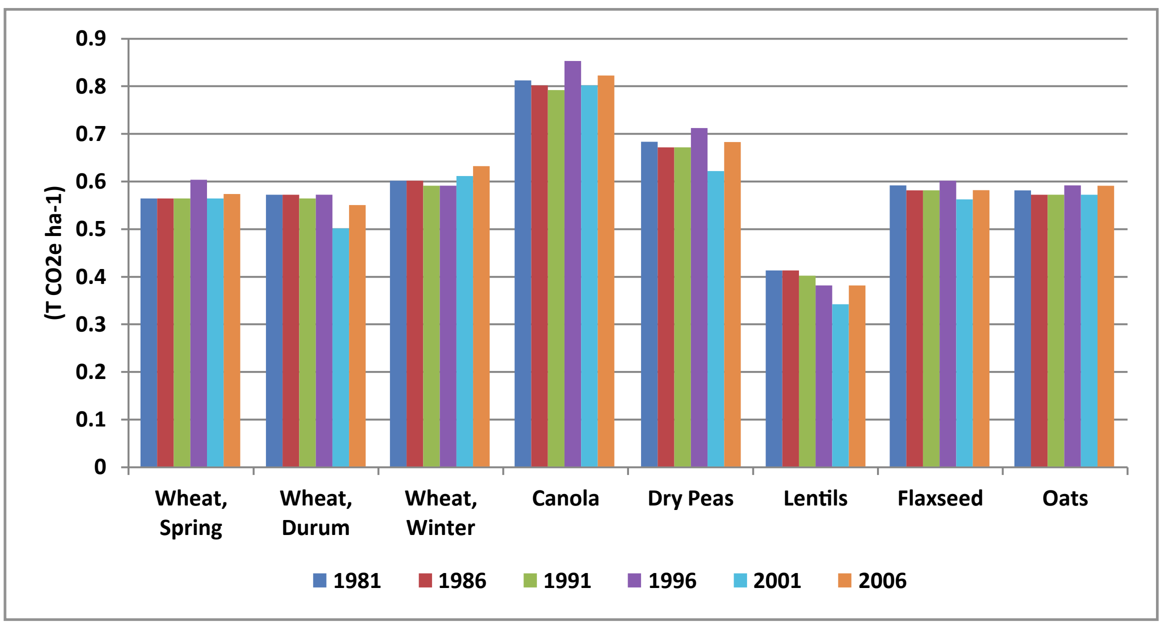
Differences by Type of Fertilizer

The use of natural fertilizer instead of commercial fertilizer has an impact on the N-Fert and volatilization terms. Leaching is not affected because the total quantity of nitrogen does not change and also the factor used to convert the nitrogen pool into N_2O does not change either. The N-Fert and volatilization terms are also based on the same quantity of nitrogen but the nitrogen conversion factor changes: higher volatilization rate with natural fertilizer application and lower emission rates from commercial fertilizer application (N-Fert). Overall we observed a slight decrease of the emission intensities when natural fertilizer is used instead of commercial fertilizers.[27]

Differences by Crop

Among all crops studied, canola has the highest N-fertilizer needs and the second highest crop residue production. Therefore, the emission factor calculated for this crop is the highest. Peas and lentils have the same N-fertilizer application rates which corresponds to the lowest one compared to all other crops. However, results are different with peas having the second highest GHG emission per hectare and lentils the lowest. This is due to the fact that peas have the highest estimated crop residue nitrogen whereas it is much lower for lentils. Comparing the two types of wheat, winter wheat has higher emission intensities than spring wheat. This is because yields, which have strong impacts on the CR source, are higher for winter wheat. This is particularly visible in the BC province.[28]

Figure 7: N_2O Emission Intensity (TCO_2e/ha) by Crop and Year Based on the Use of Commercial Nitrogen [29]



27 From "Greenhouse gas emission intensities for seven selected crops in western Canada," by Xavier Verge and Jim Dyer, 2011.
28 Ibid.
29 Ibid.

Again we refer to the work of Zhong et al (2011), which provides evidence to suggest that the methodology used in this study may overestimate the contributions of pulse (peas and lentil) crop residues to N_2O emissions.

Differences by Year

The differences observed from year to year are mainly linked to the changes in yield and tillage practices. The latter affects the emission factors used to convert nitrogen to N_2O for all direct sources and for leaching (volatilization keeps the same factor). The adoption of reduced tillage and no-till practices reduces N_2O emissions, and since these practices were constantly increasing over the time covered by this study, the resulting effect was a general decrease in the N_2O emission factors used. The second important factor is yield. Over the period considered, the changes in yields are mainly related to weather and not to farm management, because it is the year-specific data that has been used and not an average for a specific period. This factor has an impact on the CR term and therefore on the two indirect terms (which are associated with CR). In 2001 yields were generally very low because it was a dry year as compared to 1996 and 2006. Between 1981 and 1991 there was a slight decrease in yield, which explains the small decrease observed in the intensity indicators.[30]

Discussion of Results for Farm Energy

The results provided for farm energy CO_2 emissions include emissions values for each crop, by Census year (1981-2006), for each of the four western provinces. The energy terms presented in these tables include farm fieldwork, farm-owned transport, heating fuels, and the input supply terms. A summary of these results is presented in Tables 14 and 15.[31]

Table 15: Fossil CO_2 Emission Intensity by Crop, Year and Nitrogen Source[32]

$t(CO_2)$ ha-1	1981	1986	1991	1996	2001	2006
CO_2 - All Commercial Fertilizer						
Wheat, Spring	0.456	0.434	0.459	0.452	0.434	0.431
Wheat, Durum	0.418	0.414	0.428	0.405	0.361	0.369
Wheat, Winter	0.550	0.580	0.473	0.450	0.486	0.509
Canola	0.614	0.612	0.599	0.586	0.575	0.568
Dry Peas	0.335	0.329	0.363	0.353	0.310	0.317
Lentils	0.360	0.312	0.304	0.295	0.263	0.261
Flaxseed	0.478	0.476	0.466	0.454	0.418	0.411
Oats	0.452	0.457	0.439	0.425	0.413	0.401
CO_2 - All Natural Fertilizer						
Wheat, Spring	0.298	0.292	0.295	0.289	0.267	0.265
Wheat, Durum	0.282	0.284	0.289	0.270	0.227	0.239
Wheat, Winter	0.360	0.338	0.304	0.288	0.300	0.312
Canola	0.330	0.329	0.318	0.307	0.296	0.290
Dry Peas	0.270	0.257	0.270	0.258	0.214	0.223
Lentils	0.255	0.232	0.225	0.210	0.177	0.175
Flaxseed	0.283	0.285	0.275	0.269	0.237	0.229
Oats	0.270	0.274	0.259	0.248	0.234	0.225

30 From "Greenhouse gas emission intensities for seven selected crops in western Canada," by Xavier Verge and Jim Dyer, 2011.
31 Ibid.
32 Ibid.

The manure sensitivity test showed that if natural fertilizer could be used instead of the more energy-rich commercial fertilizer, fossil CO_2 emissions could be reduced by close to half. It must be cautioned that there would be an additional CO_2 emission cost associated with the animals from which the natural fertilizer was obtained. Quantifying that cost was beyond the scope of this analysis.[33]

The carbon footprint of the two legumes was appreciably lower than those of the five non-legume crops due to not having to apply as much nitrogen fertilizer. The highest energy balance was for canola because of the high amount of nitrogen fertilizer required for this crop. The CO_2 emission intensity of canola is worthy of note because this is a rapidly expanding crop and, as a feedstock for biodiesel, it will attract scrutiny for its required energy inputs (Dyer et al., 2010b).[34] The high energy inputs required to produce canola should be seen in the context that oilseeds such as canola and flax also contain a relatively large amount of energy.

Except for winter wheat, and to a lesser degree, spring wheat, the CO_2 and energy balances of these field crops have declined over the period defined by the six census years. However, this decline is rather modest because the dramatic decrease in pre-seeding tillage in the Prairie Provinces was counter-acted by slow increases in nitrogen fertilizer application. This increase resulted in higher CO_2 emissions being attributed to the fertilizer manufacturing term.[35]

The two indirect farm energy terms, transport and heating fuel, played a very small role in these field crop carbon footprints. However, with the aggregation of western farms into larger enterprises, basing the estimates of this term on the 1996 FEUS, even with indexing to increased crop yields, may not accurately reflect the transport requirements of modern farms.[36]

Table 16: The Intensity of Fossil Energy by Crop, Year and the Nitrogen Source[37]

GJ ha^{-1}	1981	1986	1991	1996	2001	2006
Energy – All Commercial Fertilizer						
Wheat, Spring	7.63	7.20	7.72	7.63	7.38	7.35
Wheat, Durum	5.91	5.86	6.05	5.73	5.11	5.22
Wheat, Winter	9.21	9.99	7.95	7.59	8.27	8.69
Canola	10.72	10.70	10.49	10.31	10.14	10.05
Dry Peas	5.26	5.22	5.85	5.74	5.11	5.22
Lentils	5.85	5.03	4.90	4.82	4.36	4.34
Flaxseed	8.19	8.14	7.99	7.79	7.24	7.14
Oats	7.74	7.83	7.56	7.35	7.18	7.00
Energy – All Natural Fertilizer						
Wheat, Spring	4.27	4.20	4.25	4.16	3.83	3.82
Wheat, Durum	3.98	4.02	4.08	3.82	3.22	3.38
Wheat, Winter	5.19	4.85	4.37	4.14	4.32	4.50
Canola	4.70	4.70	4.54	4.39	4.23	4.15
Dry Peas	3.88	3.69	3.88	3.72	3.08	3.23
Lentils	3.65	3.33	3.22	3.01	2.53	2.51
Flaxseed	4.03	4.07	3.94	3.85	3.38	3.28
Oats	3.89	3.95	3.73	3.58	3.38	3.26

33 Ibid.
34 From "Greenhouse gas emission intensities for seven selected crops in western Canada," by Xavier Verge and Jim Dyer, 2011.
35 Ibid.
36 Ibid.
37 Ibid.

Indicators By Crop Type

In this section, the analysis is presented by crop, for each indicator. This presentation is in line with the structure of the Field to Market US indicators. A summary of the results for each crop, for all indicator areas, for three separate years (1986, 1996 and 2006), is presented in a spider diagram at the end of each section. This presentation summarizes the changes for the crop in all resource impact areas, over the 20 year period.

Introduction to Indicator Charts

As already described, the indicators developed in this project comprise a resource impact indicator and an efficiency indicator for each impact area. Thus, for each crop, we present two indicators for each of land use, soil loss, energy use and climate impact.

The yield for each crop, calculated as a five-year centred moving average, is presented on the charts of the resource impact indicators. In general, a reduction of the resource impact over time reflects an improvement. The land use resource impact indicator presents harvested area, in hectares, by year, as a five-year centred moving average. The resource impact indicators for soil loss, energy use and climate impact present the respective impacts on a per hectare basis. In line with the underlying NAHARP data, soil loss, energy use and climate impact are reported for Census years, i.e. once every five years.

The efficiency indicator for each impact area is calculated by dividing the corresponding resource impact indicator through by the crop yield, and indexing the resulting time series to 100 in the year 2001. The efficiency indicator is thus an expression of relative resource impact, for each unit of crop produced. Again, if the efficiency indicator falls over time, this reflects an improvement, since less environmental impact is associated with each unit of crop produced.

Note that some caution is necessary when reading the indicator charts, since the scales on the axes differ from one crop to the next, for the same indicator. Thus, for example, the y-axis in the chart for land use for spring wheat differs from that for winter wheat, and any comparison must account for this. As well, on some charts, the y-axis does not start at zero, to ensure that changes over time can be readily seen in the charts.

All four efficiency indicators for each crop are summarized in a spider diagram, summarizing change over the time period from 1986 to 2006. Efficiency indicators for the years 1986, 1996 and 2006 are presented. This makes it possible to see at a glance the changes in all four impact areas for each crop.

Percent changes identified in the text in this section are based on linear trend lines. Unless otherwise stated, these are linear trend lines for the time period for which data is presented in the chart.

Note that the yields of all the crops studied increased substantially over the study period. Between 1981 and 2006, the yield increases ranged from 22% (flax) to 39% (canola). Due to these increases in yield, we see greater improvements in the efficiency indicators (calculated as resource impact per tonne of crop output) than in the resource impact indicators (resource impact per hectare). In fact improvement was seen in all efficiency indicators for all crops.

It is worth noting that data for earlier years may be weaker than that for more recent years, particularly for crops with small acreages, e.g. peas and lentils. Yield variability may tend to reduce the reliability of the efficiency indicators somewhat, in these circumstances.

Spring Wheat

Land Use Indicator

The trend in the efficiency of land use in the production of spring wheat is clearly seen in Figures 8 and 9, which allow us to observe the changes over a period of 45 years. Agronomic developments have led to substantial yield improvements, resulting in a much more effective and efficient use of the production land base.

In the period from 1965 to 2010 there has been a 23% reduction in the harvested area of spring wheat (Figure 8). Expressed per unit of spring wheat produced, land use efficiency has improved by 38% (Figure 9), owing to a yield increase of 66% over the same period.

Figure 8: Spring Wheat Land Use and Yield

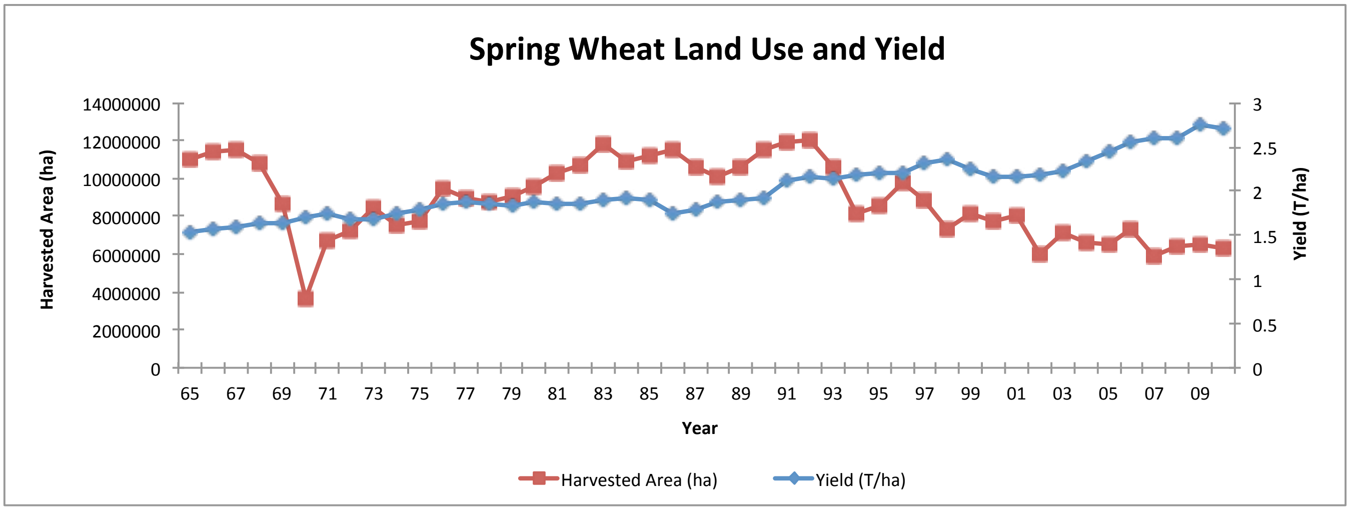
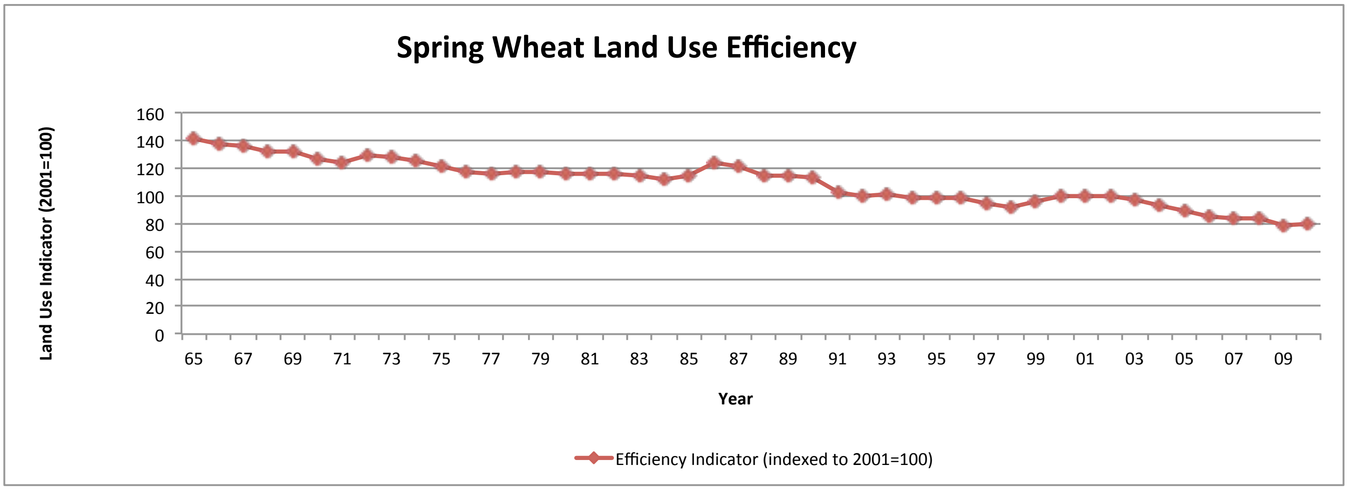


Figure 9: Spring Wheat Land Use Efficiency



Soil Loss Indicator

While improvements in land use have been dramatic, the reduction in soil loss has been even more so. The resource impact indicator (Figure 10) shows a 46% reduction in potential soil loss per acre between 1981 and 2006. Expressed on a per unit of output basis, the soil loss efficiency indicator suggests an improvement of 62% between 1981 and 2006 (Figure 11). Spring wheat yields increased by 37% during this period (Figure 10). Much of the reduction of soil loss has been achieved through decreased tillage.

Figure 10: Spring Wheat Soil Loss and Yield

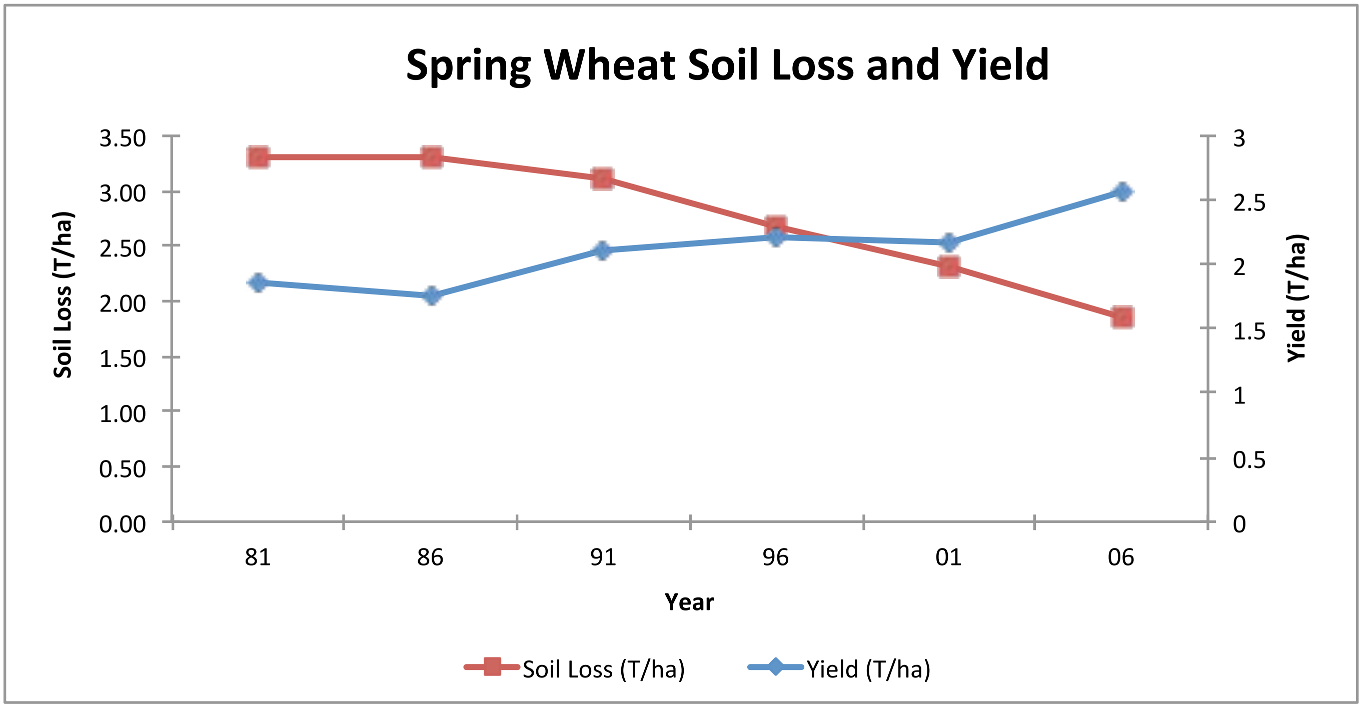
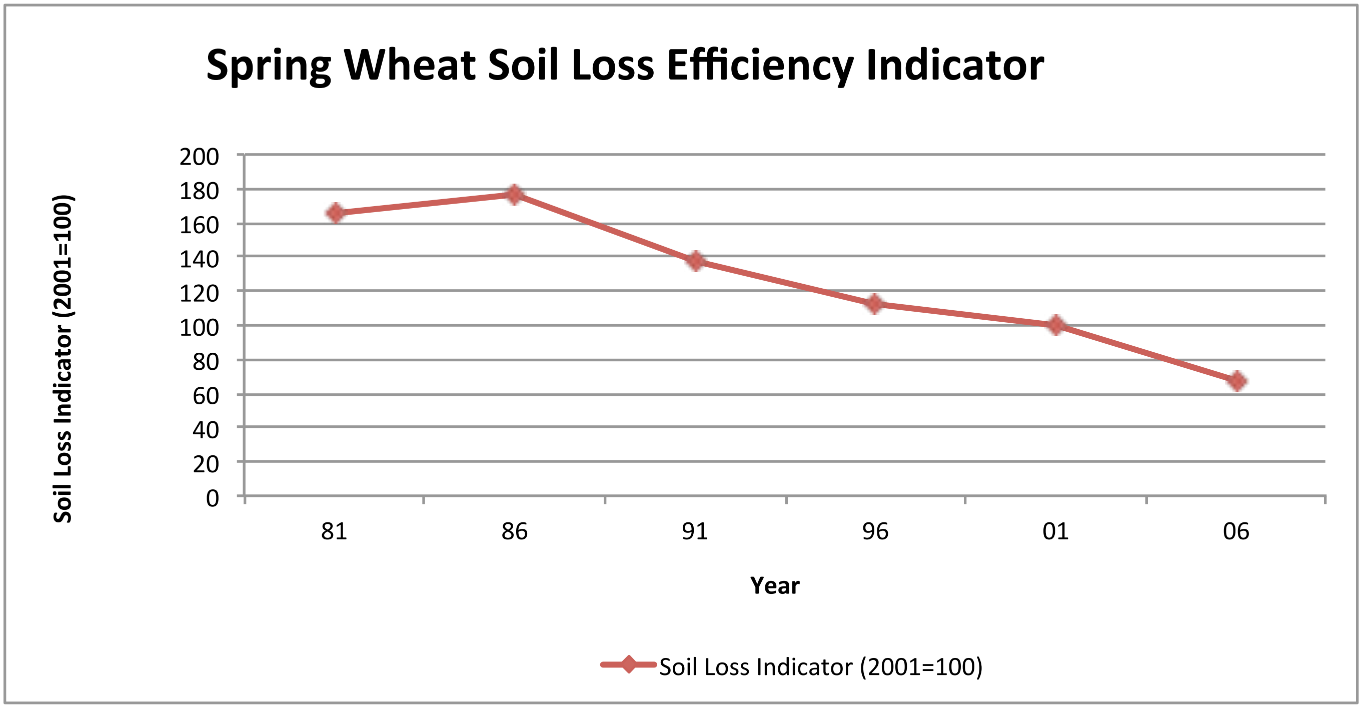


Figure 11: Spring Wheat Soil Loss Efficiency Indicator



Energy Use Indicator[38]

Improvements in energy use have been less dramatic. Energy use in production of spring wheat decreased by 4% between 1981 and 2006, on a per hectare basis (Figure 12). On a per unit of output basis (efficiency indicator, Figure 13), energy use was reduced by 32% during the same time period. The yield of spring wheat increased by 37% during this period. These trends suggest that further improvements can be expected.

Figure 12: Spring Wheat Energy Use and Yield

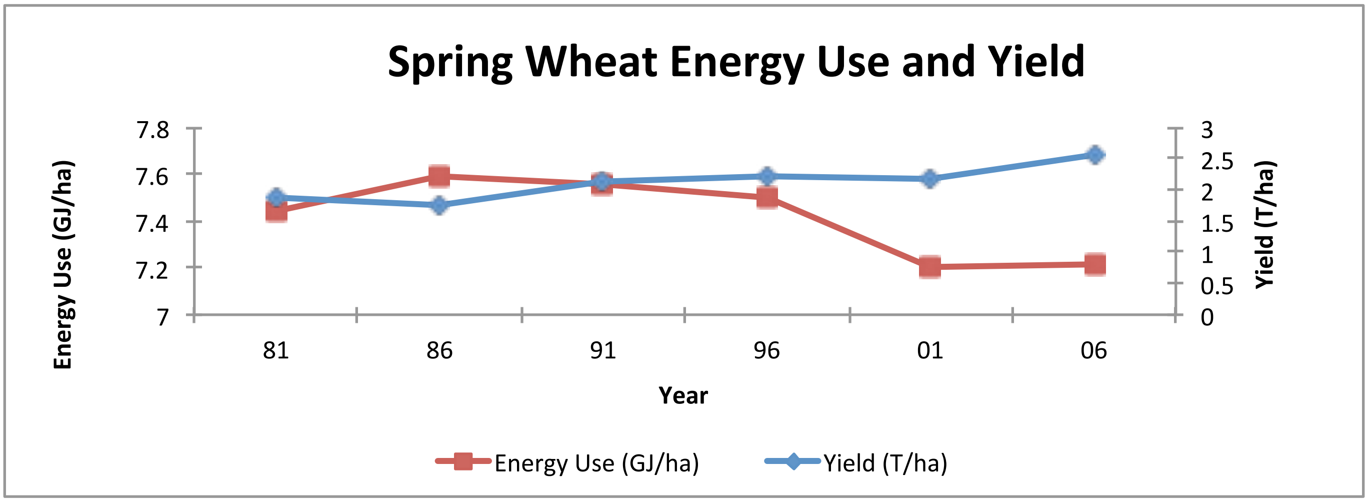
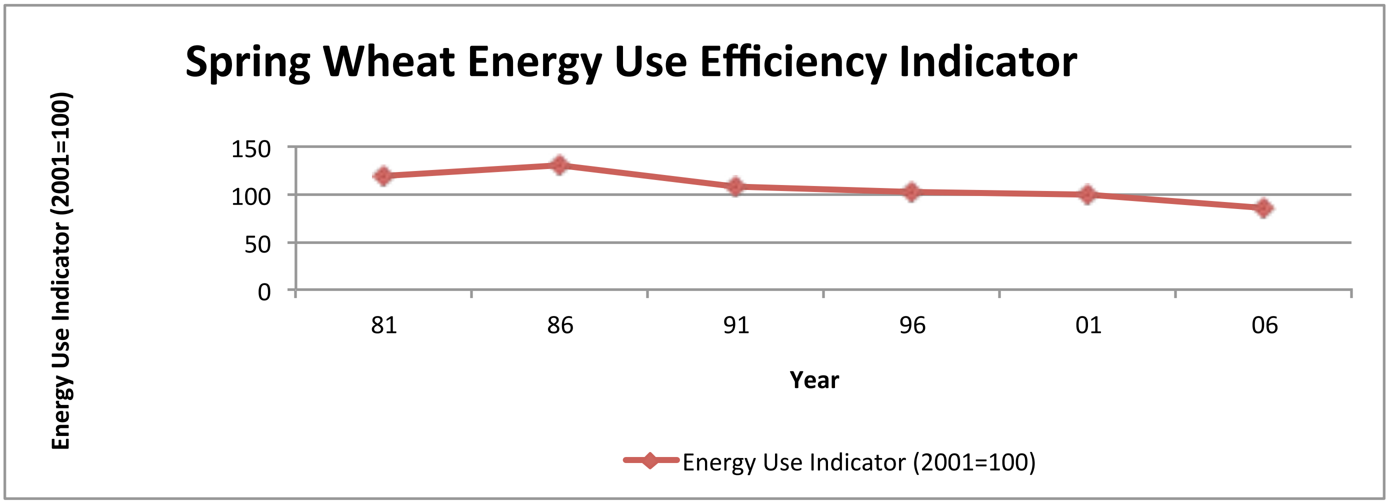


Figure 13: Spring Wheat Energy Use Efficiency Indicator



Climate Impact Indicato[39]

Not surprisingly, the climate impact indicators for spring wheat follow similar trends to the energy use indicators. The model suggests an improvement of 2% on an absolute, per hectare basis (Figure 14), between 1981 and 2006. On a per unit of output basis, the improvement was 30%, over the same period of time (Figure 15). Again, yields improved by 37%.

[38] Conversion between Western Canada Energy Use Indicator and Field to Market (USA) Energy Use Indicator: 1 GJ/ha = 3.82 x 105 Btu/acre.

[39] Conversion between Western Canada Climate Impact Indicator and Field to Market (USA) Climate Impact Indicator: 1 TCOze/ha = 243 lbCE/acre

Figure 14: Spring Wheat Climate Impact and Yield

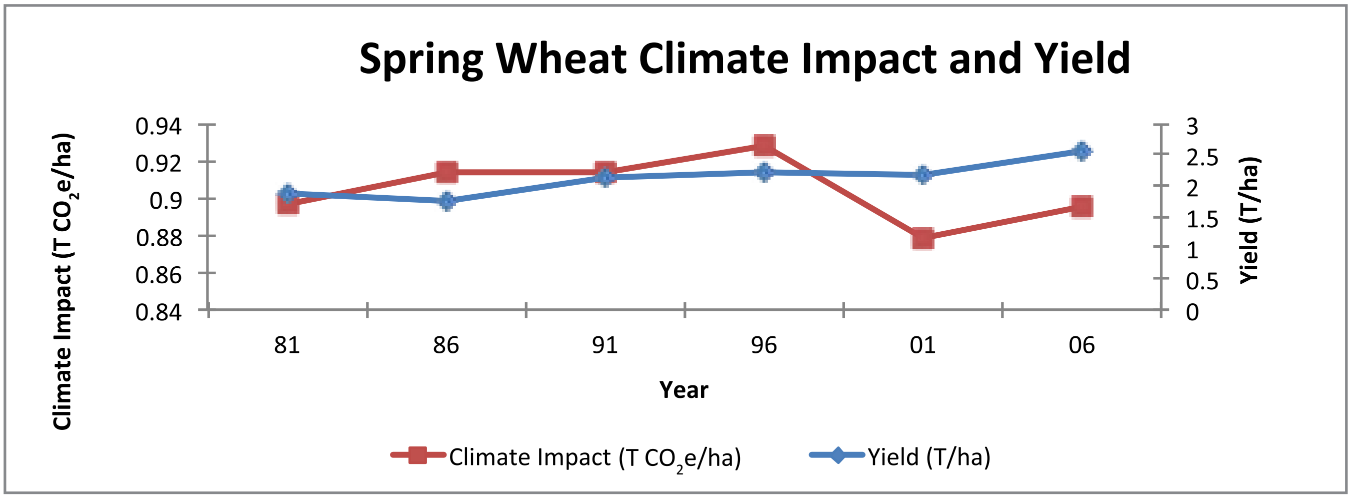
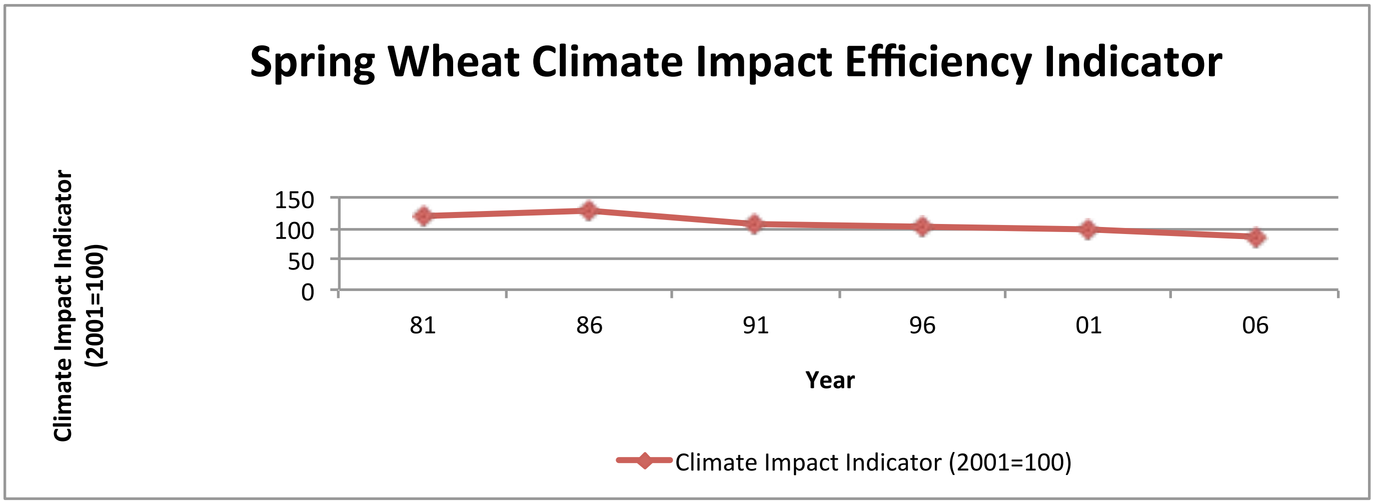


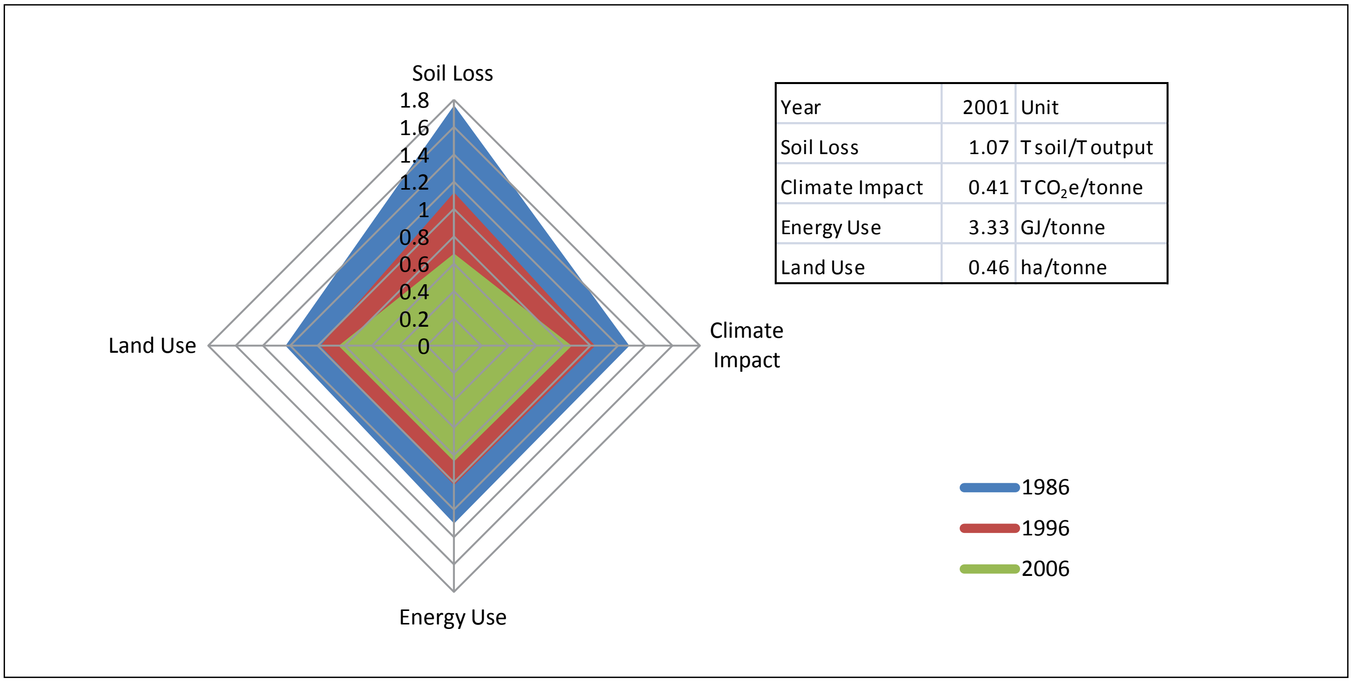
Figure 15: Spring Wheat Climate Impact Efficiency Indicator



Indicator Summary – Spring Wheat

In summary, the story for spring wheat is a very good one. As can be observed in Figure 16, all of the efficiency indicators improved consistently between 1986 and 2006. Figure 16 shows clearly that the improvement in soil loss efficiency is the most significant on a percentage basis. Between 1986 and 2006, soil loss efficiency improved by 62%, energy use efficiency by 35%, climate impact efficiency by 33%, and land use efficiency by 31%.

Figure 16: Spring Wheat Efficiency Indicators Over Time



Winter Wheat

Land Use Indicator

While harvested acres of spring wheat decreased between 1965 and the present, harvested acres of winter wheat increased significantly. Harvested acres of winter wheat increased from only 128,000 hectares in 1981, by 38% (based on a linear trend line) from 1981 to 2010 (Figure 17). Over the same time period, land use per unit of output decreased by 78%, indicating a substantial improvement in land use efficiency (Figure 18). This improvement is driven by consistent yield increases over the past 20 years, following decreases in the early 1980's (Figure 17). Over the entire study period for winter wheat, from 1981 to 2006, yields increased by 37%.

Figure 17: Winter Wheat Land Use and Yield

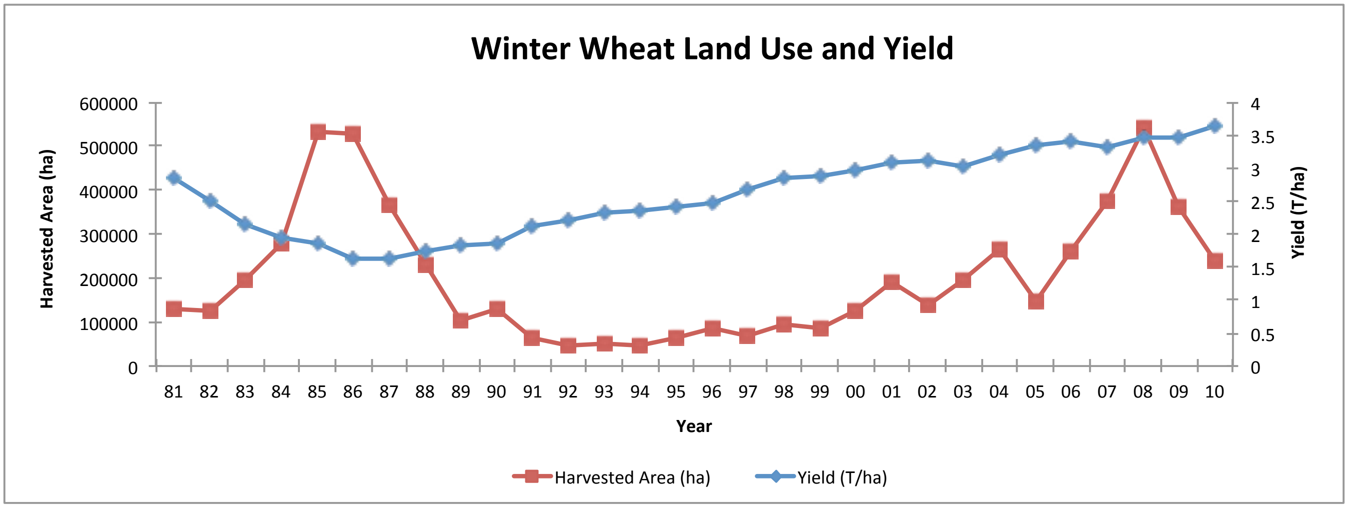
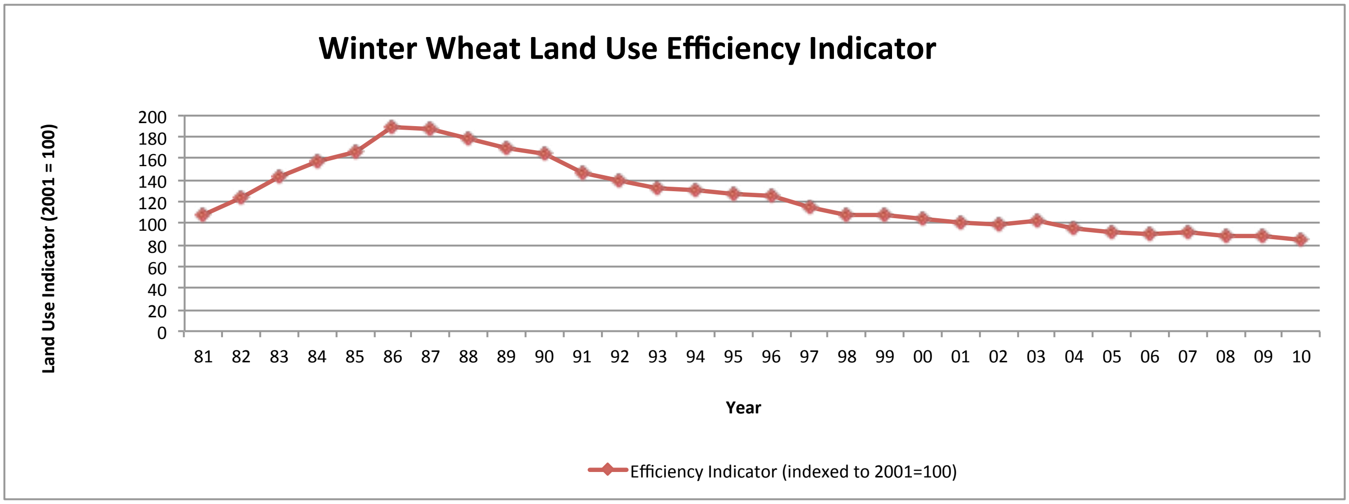


Figure 18: Winter Wheat Land Use Efficiency Indicator



Soil Loss Indicator

In spite of an increase between 1981 and 1986, the soil loss indicator for winter wheat shows overall improvement over the period from 1981 to 2006. Potential soil loss decreased by 54% during this period (Figure 19). During the same period, the soil loss efficiency indicator improved by 107% (Figure 20). Yields for winter wheat increased by 37% during this period (Figure 19). Importantly, the improvement has been quite dramatic over the past four Census periods.

Figure 19: Winter Wheat Soil Loss and Yield

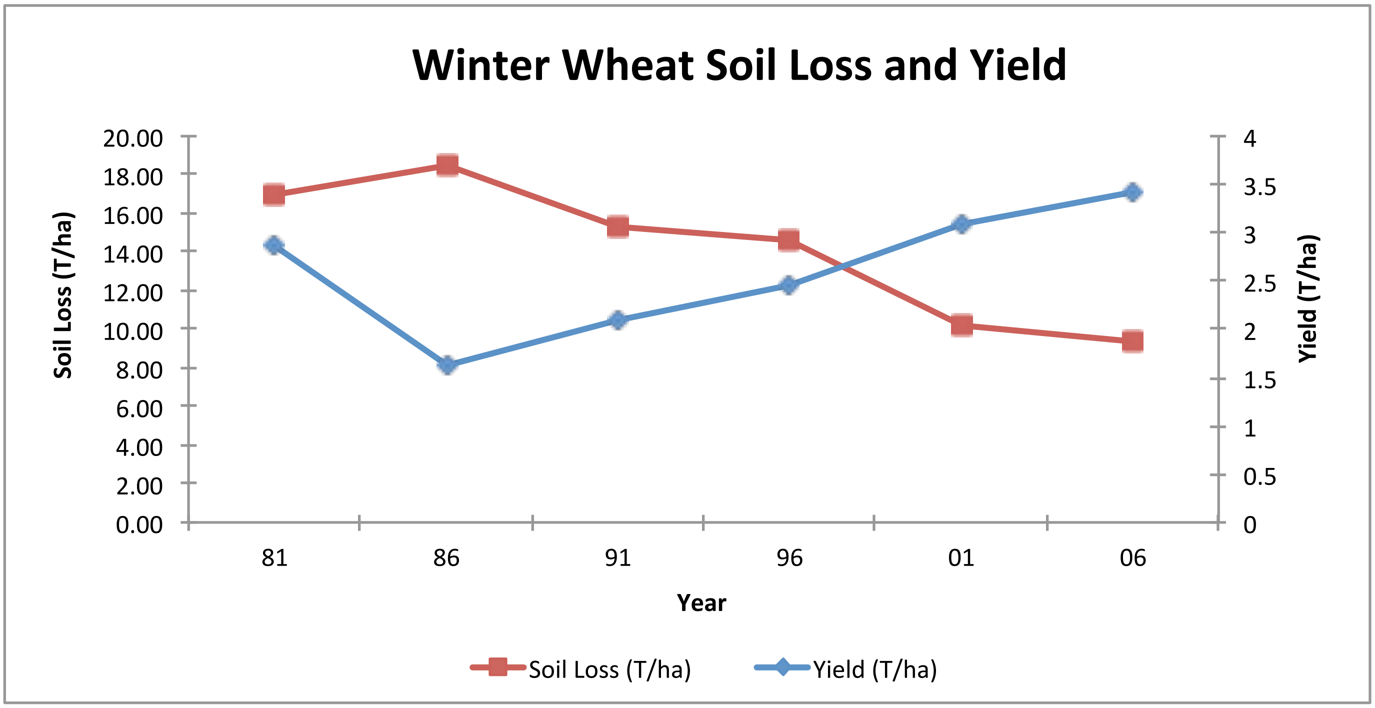
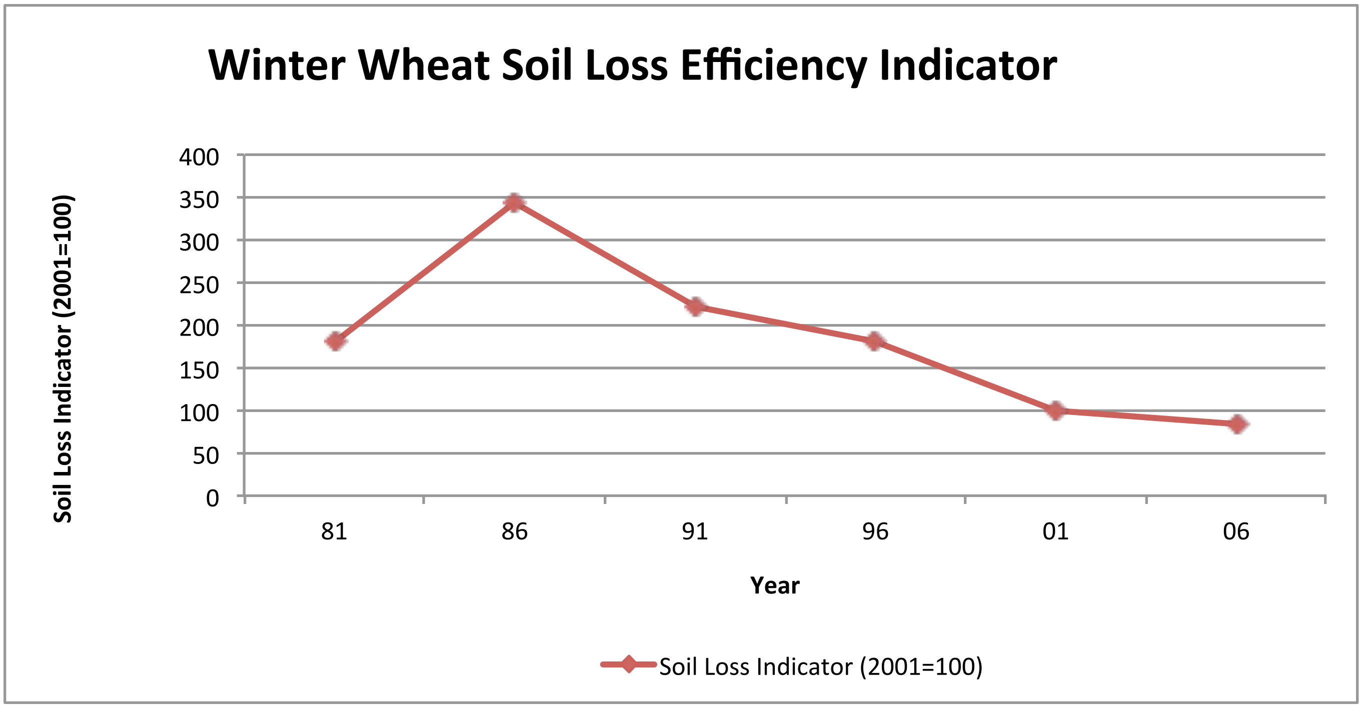


Figure 20: Winter Wheat Soil Loss Efficiency Indicator



Energy Use Indicator

The use of energy in winter wheat production has increased by 1% from 1981 to 2006, on a per hectare basis (Figure 21). Over the same period, energy use per unit of output has improved by 41% (Figure 22). As with the soil loss indicator, the efficiency actually declined between 1981 and 1986, but then has improved dramatically since that period of time.

Figure 21: Winter Wheat Energy Use and Yield

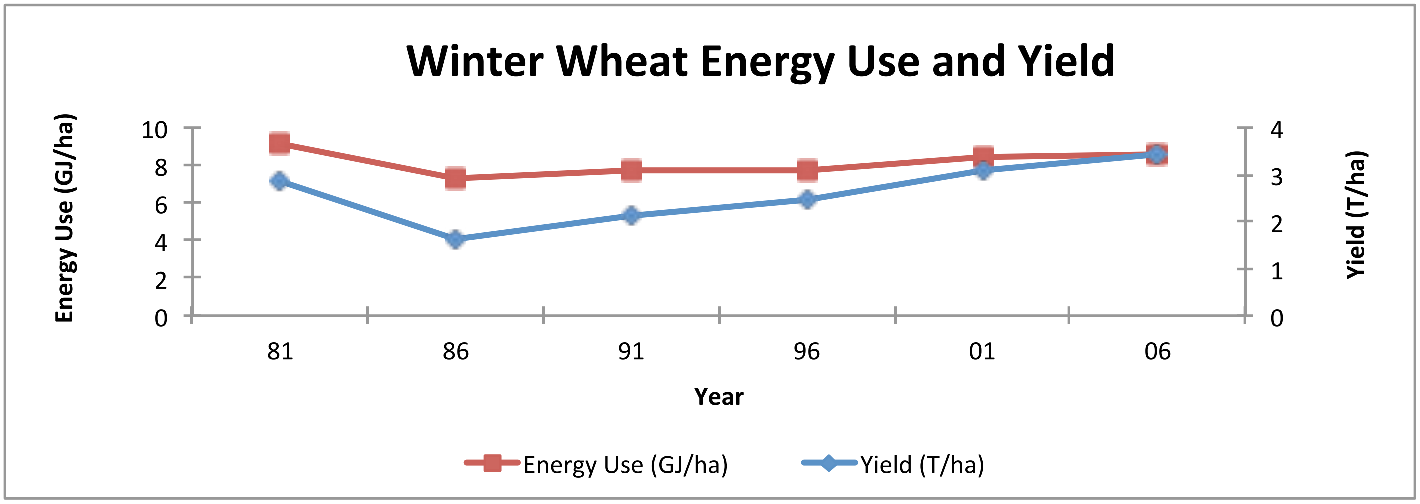
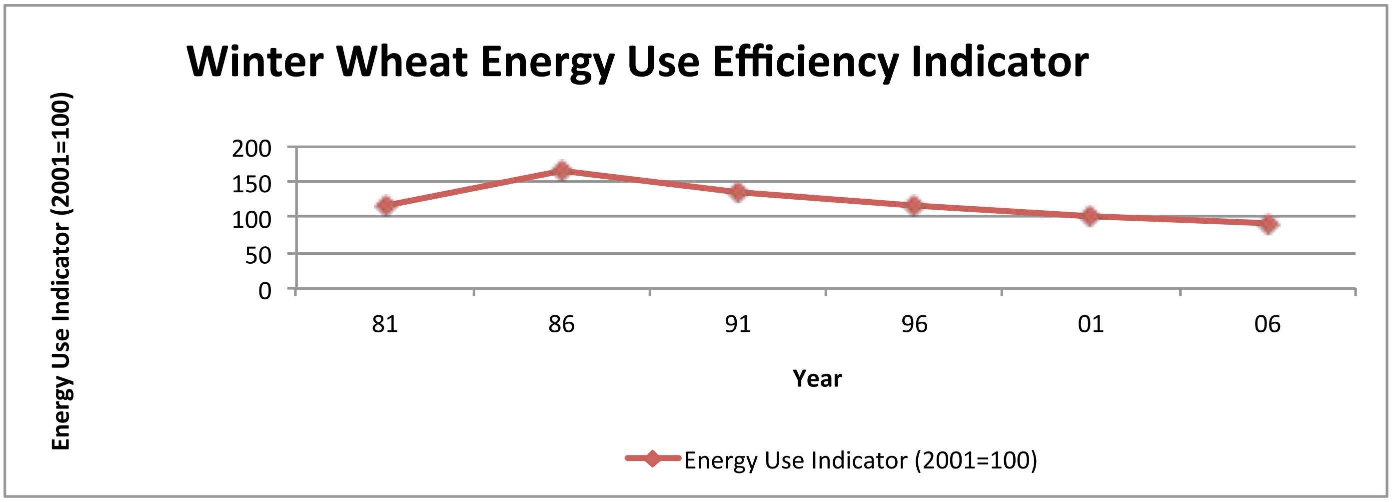


Figure 22: Winter Wheat Energy Use Efficiency Indicator



Climate Impact Indicator

The indicators of climate impact for winter wheat follow the same pattern as those for energy use. Climate impact per hectare increased by 7% between 1981 and 2006 (Figure 23), but decreased by 37% on a per unit of output basis (Figure 24). The issues around the yield in 1986 certainly impacted the efficiency indicator, but the trends have improved substantially from that point forward.

Figure 23: Winter Wheat Climate Impact and Yield

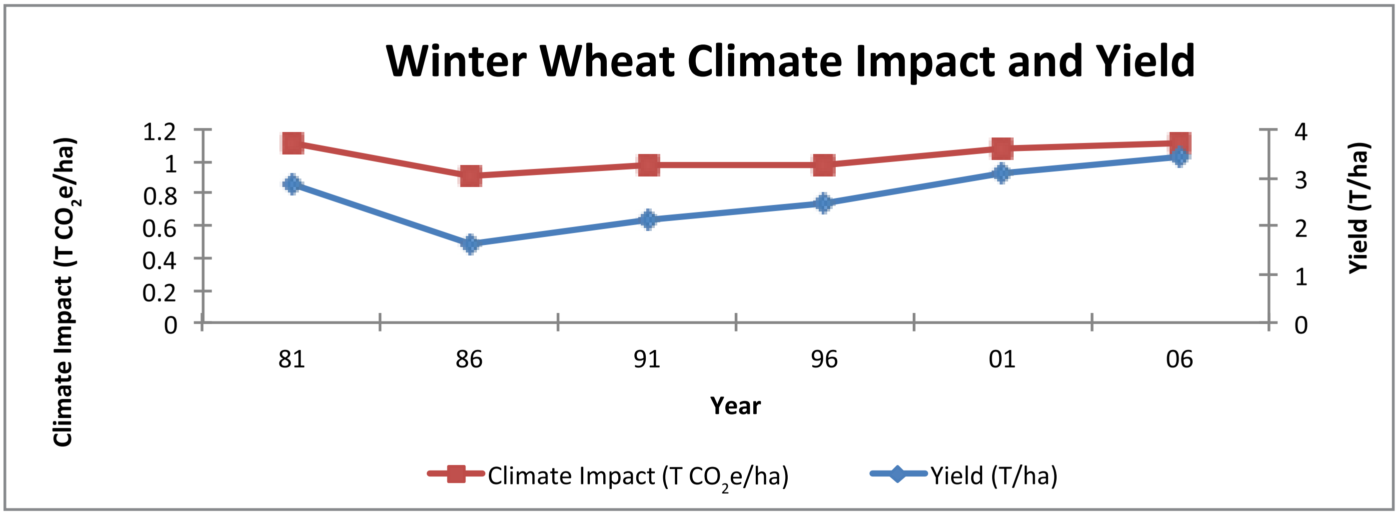
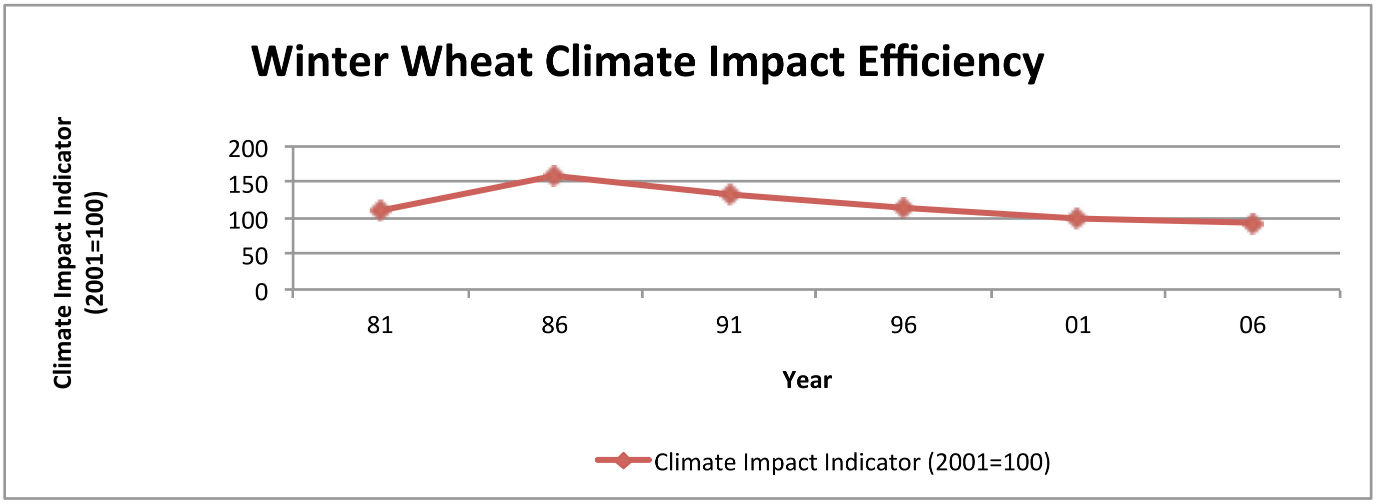


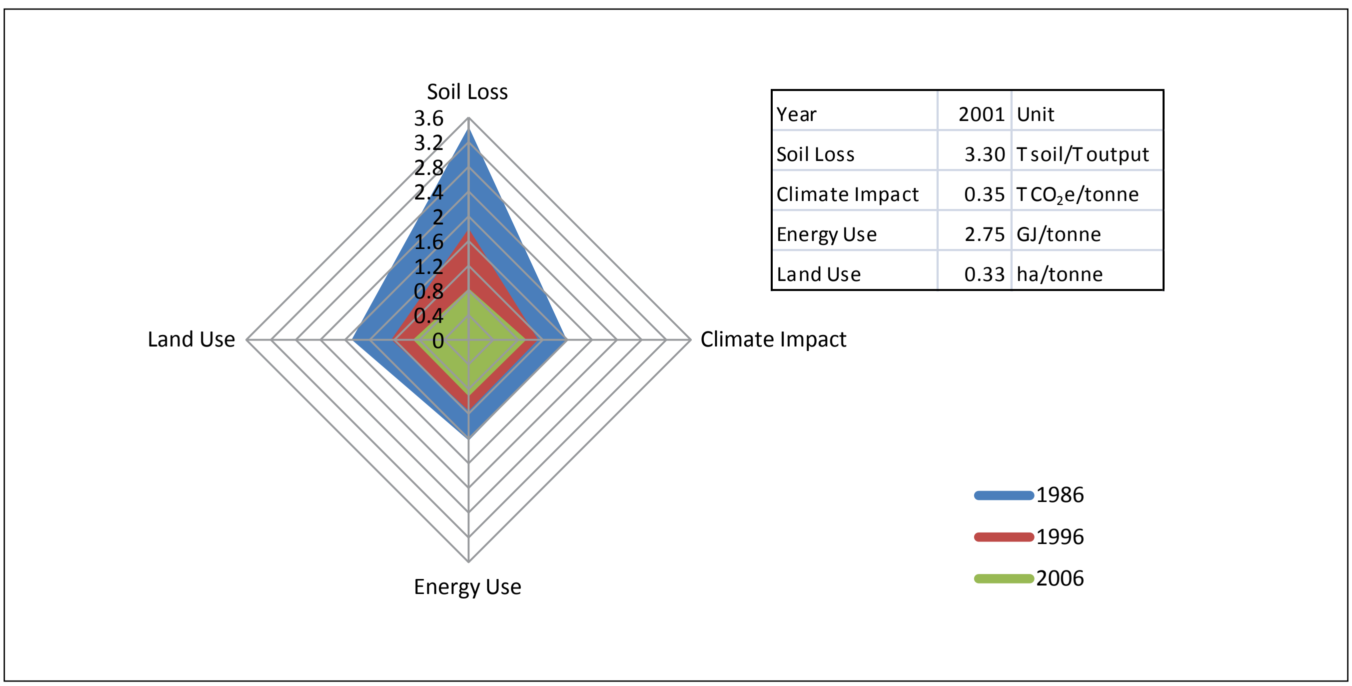
Figure 24: Winter Wheat Climate Impact Efficiency



Indicator Summary – Winter Wheat

As with spring wheat, the most dramatic improvement was in soil loss efficiency. The improvement in soil loss efficiency between 1986 and 1996 is clearly seen in Figure 25. While soil loss efficiency improved by 76% between 1986 and 2006, land use efficiency improved by 52%, energy use efficiency improved by 44%, and climate impact efficiency improved by 41%.

Figure 25: Winter Wheat Efficiency Indicators Over Time



Year	2001	Unit
Soil Loss	3.30	T soil/T output
Climate Impact	0.35	T CO_2e/tonne
Energy Use	2.75	GJ/tonne
Land Use	0.33	ha/tonne

Durum Wheat

Land Use Indicator

Harvested acres of durum wheat have increased from only 323,000 hectares in 1965, by 450% from 1965 to 2011 (based on a linear trend line) (Figure 26). Over the same time period, land use on a per unit of output basis has decreased by 35%, indicating improved land use efficiency (Figure 27). This improved land use efficiency is driven by a 66% increase in yield over the same time period.

Figure 26: Durum Wheat Land Use and Yield

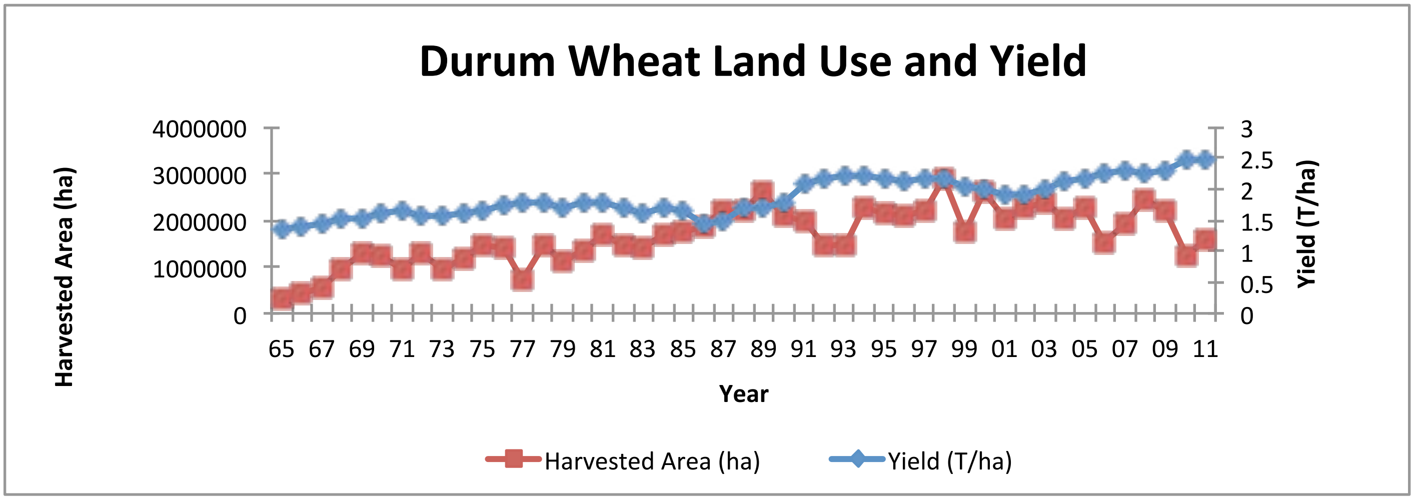
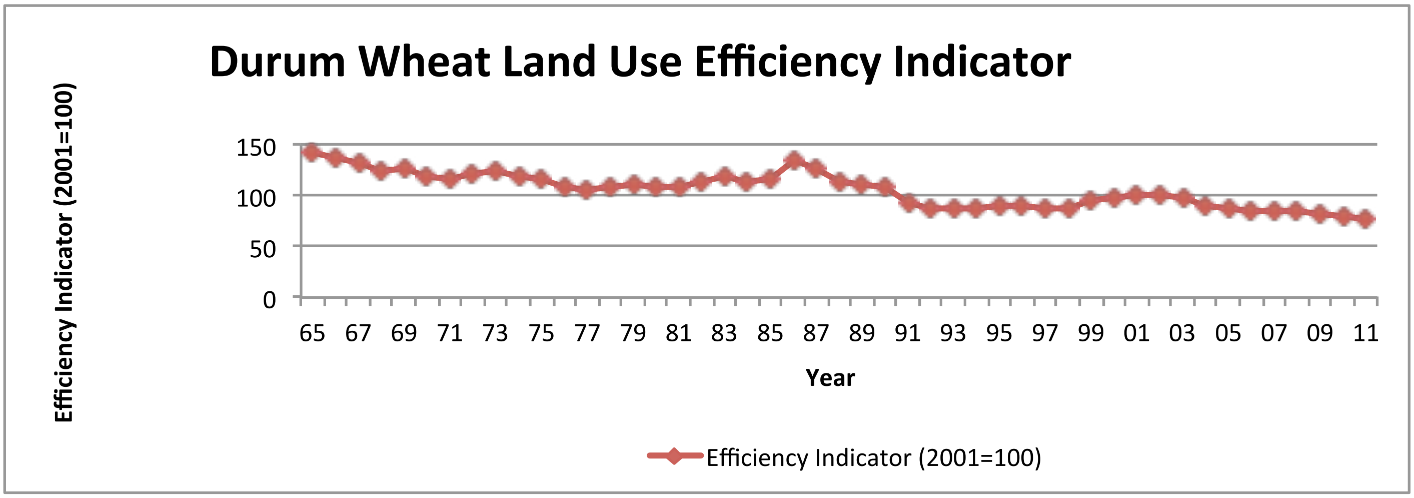


Figure 27: Durum Wheat Land Use Efficiency



Soil Loss Indicator

Potential soil loss for durum wheat, on a per hectare basis, has improved consistently – by 46% between 1981 and 2006 (Figure 28). Soil loss efficiency for durum wheat improved by 61% over the same time period (Figure 29). This trend has been strongest during the later part of the period documented, i.e. since 1991.

Figure 28: Durum Wheat Soil Loss and Yield

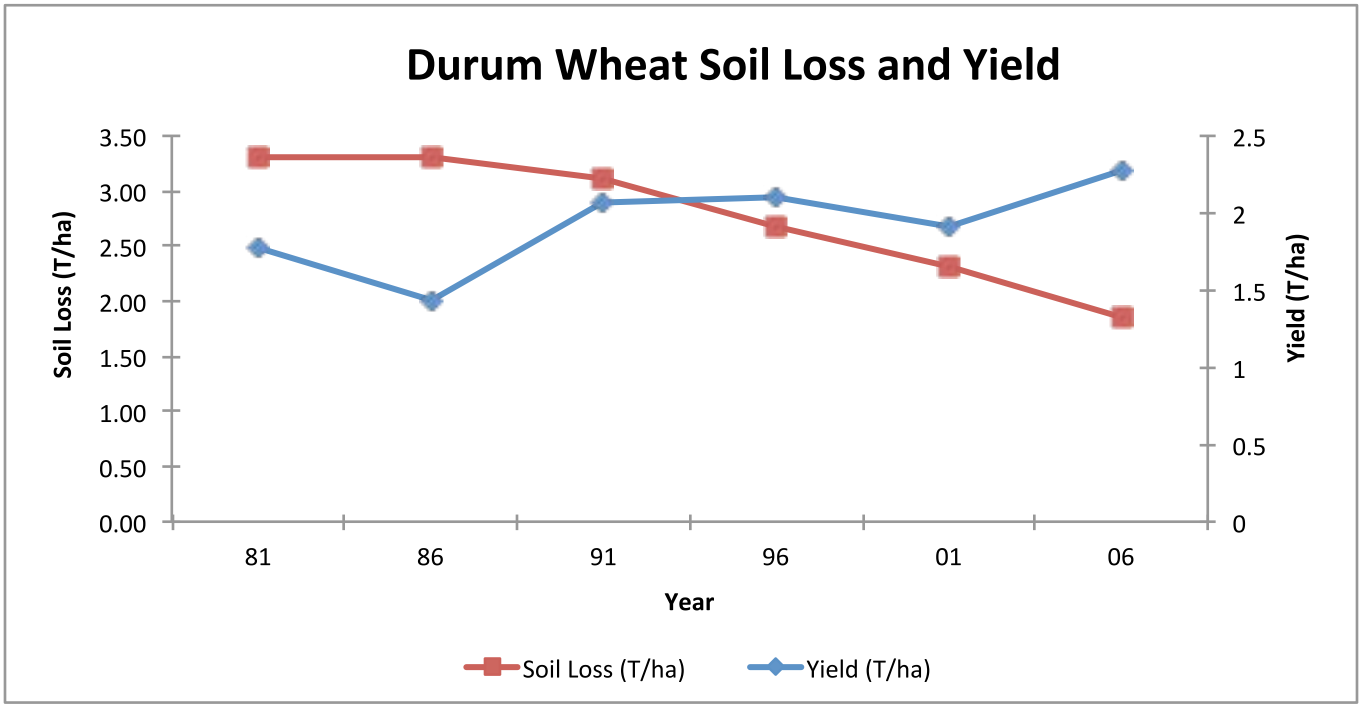
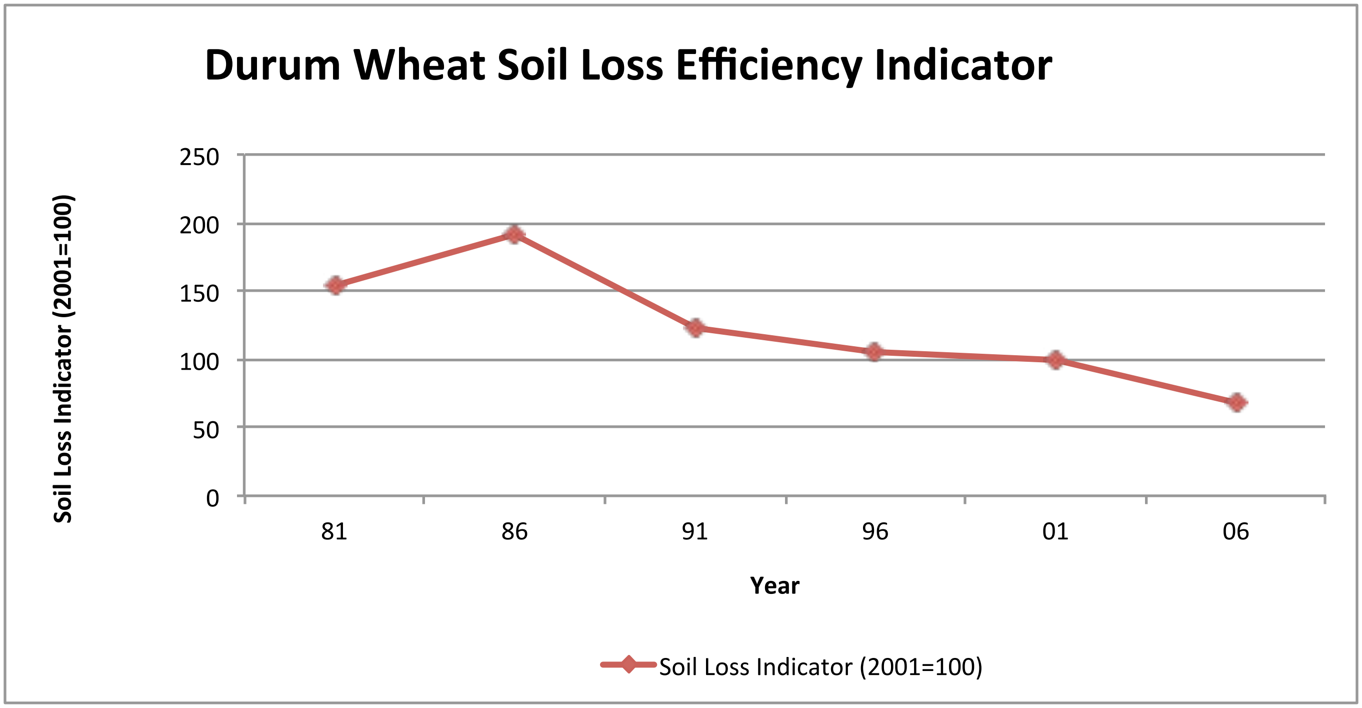


Figure 29: Durum Wheat Soil Loss Efficiency



Energy Use Indicator

From 1981 to 2006, energy use for production of durum wheat showed an increase of 10% on an absolute per hectare basis, largely due to increasing yields (Figure 30). Durum wheat yields increased by 32% over this period (Figure 30). Also driven by this yield increase, energy use efficiency improved by 21% from 1981 to 2006 (Figure 31).

Figure 30: Durum Wheat Energy Use and Yield

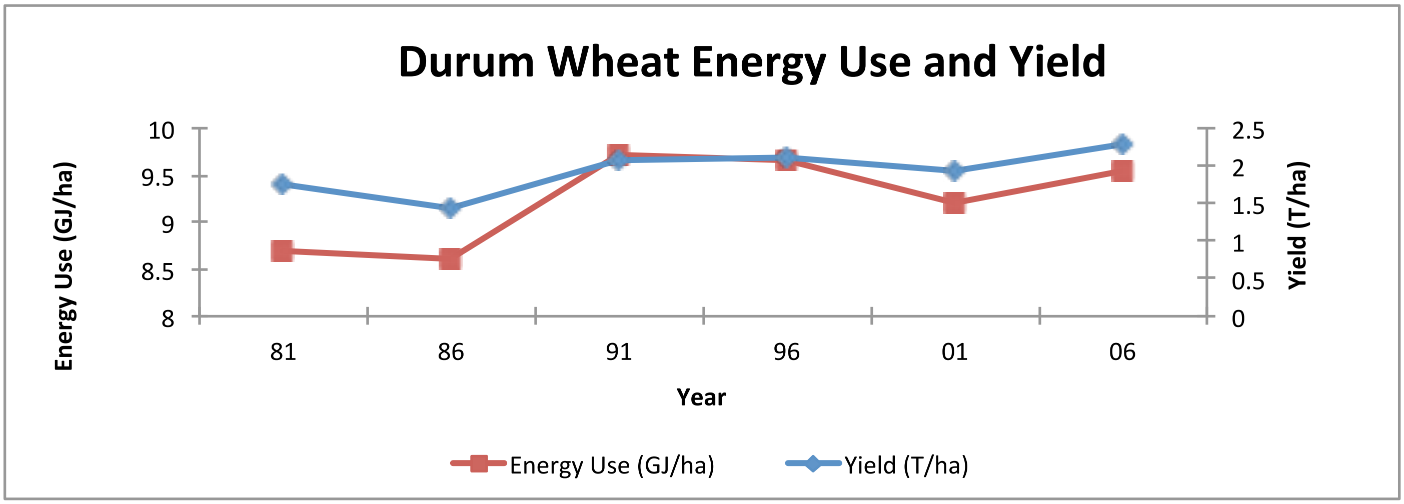
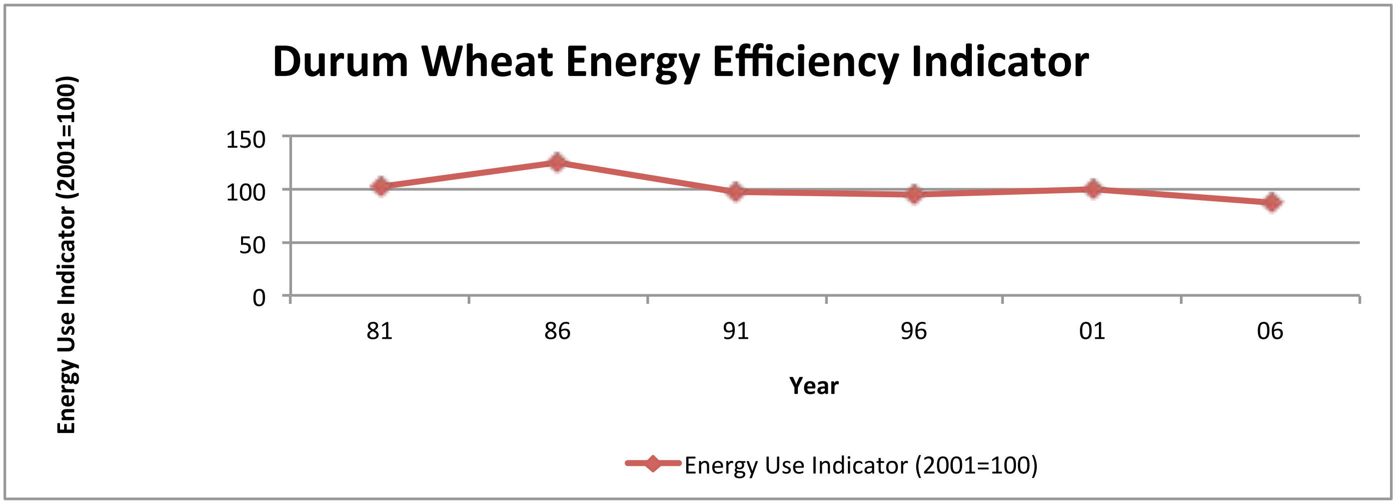


Figure 31: Durum Wheat Energy Use Efficiency Indicator



Climate Impact Indicator

Climate impact from production of durum wheat decreased by 16% between 1981 and 2006 (Figure 32). During this period, yields of durum wheat increased by 32% (Figure 32). Driven by this increase in yield, climate impact on a per unit of output basis improved by 43% (Figure 33).

Figure 32: Durum Wheat Climate Impact and Yield

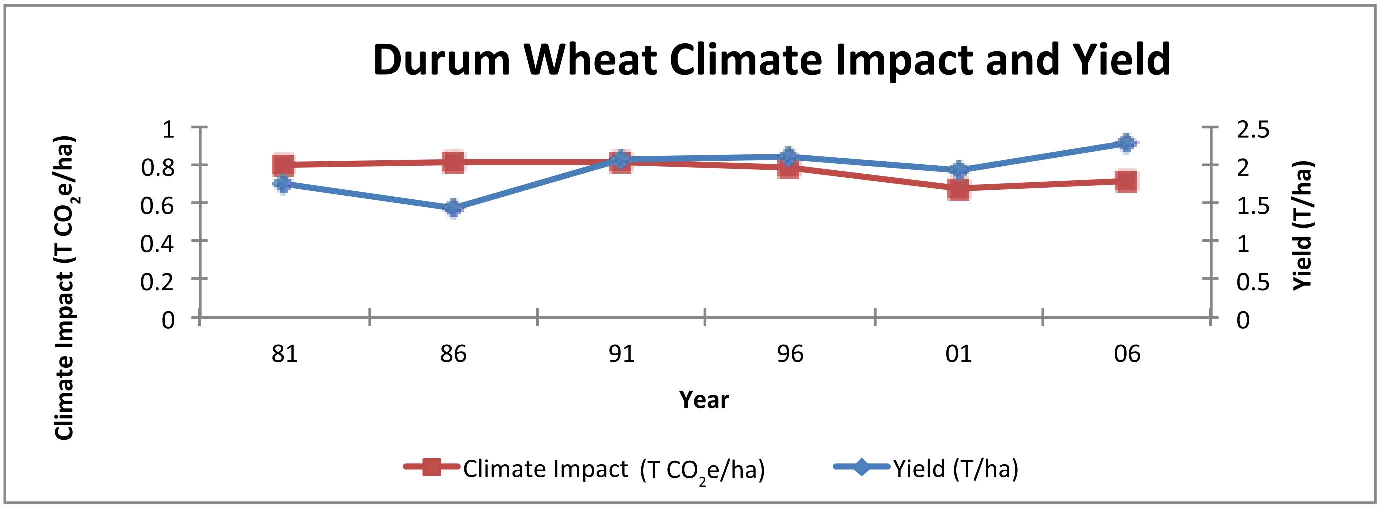
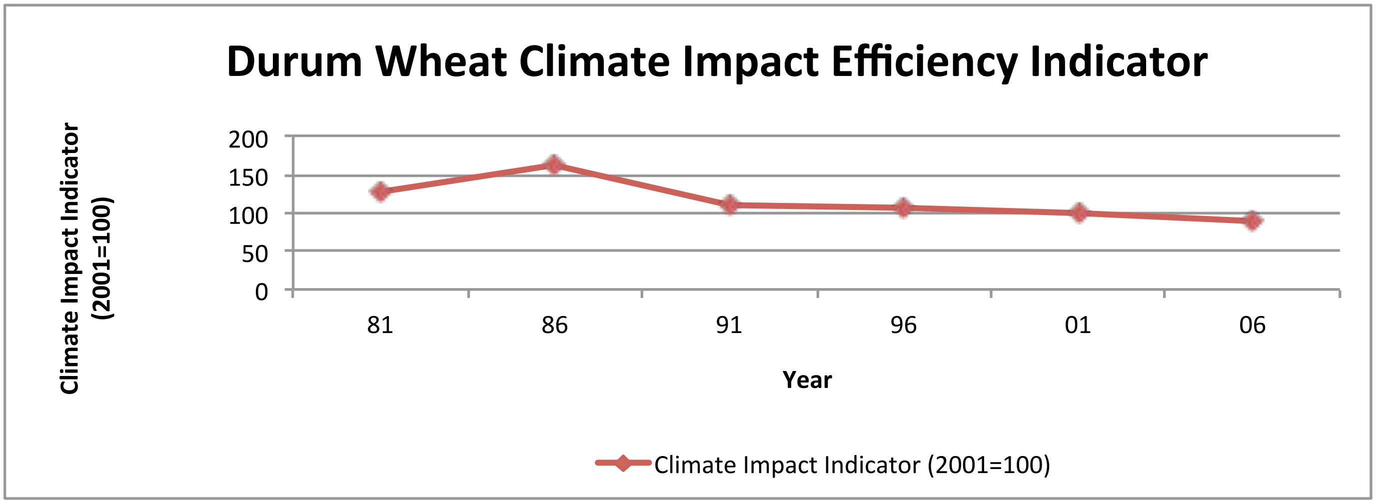


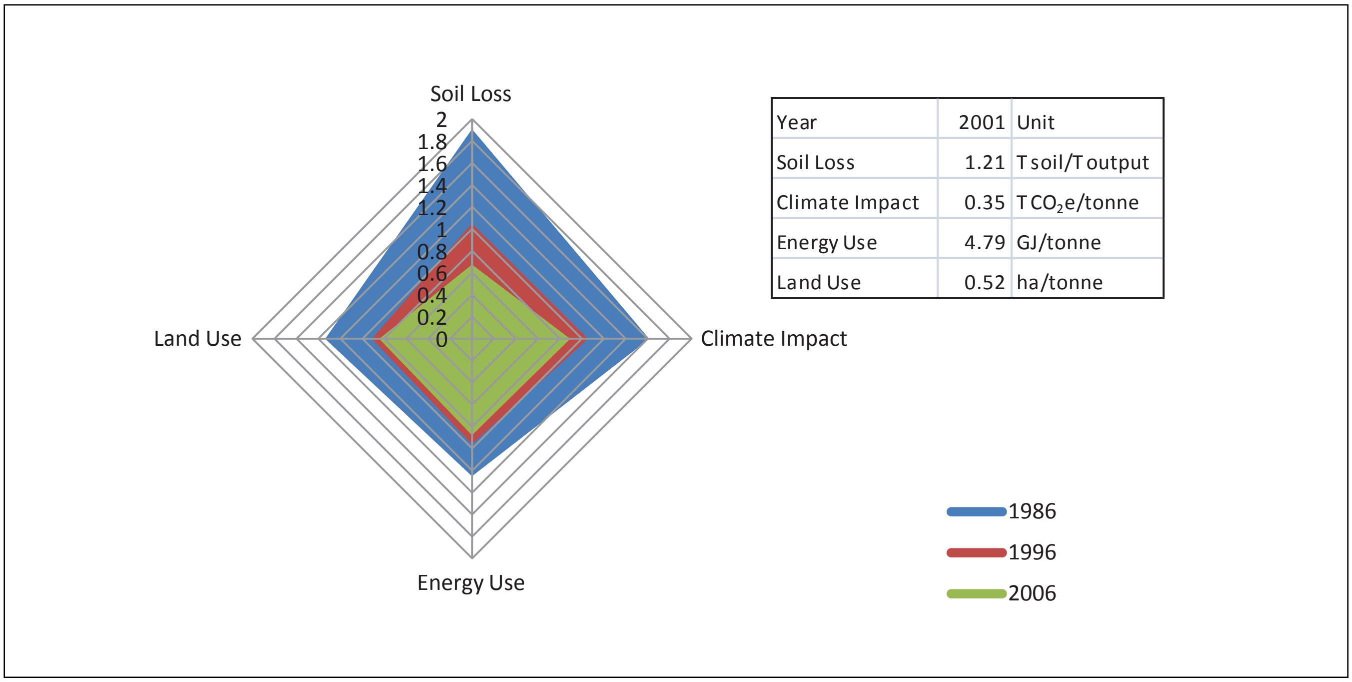
Figure 33: Durum Wheat Climate Impact Efficiency Indicator



Indicator Summary – Durum Wheat

As with the spring and winter wheat categories, all four efficiency indicators for durum wheat showed improvement between 1986 and 2006 (Figure 34). Again, for durum wheat, the efficiency indicator showing the most improvement is that for soil loss, particularly between 1986 and 1996. For durum wheat, between 1986 and 2006, soil loss efficiency improved by 65%, climate impact efficiency by 45%, land use efficiency by 37%, and energy use efficiency by 30%.

Figure 34: Durum Wheat Efficiency Indicators Over Time



Oats

Land Use Indicator

Overall improvements in yield have resulted in significant improvements in the land use indicators for oats. While harvested acres have varied over the period studied, the area harvested has decreased by 47% between 1965 and 2010, based on a linear trendline (Figure 35). During this period, land use efficiency (Figure 36) has improved by 37%, driven by consistent yield increases totalling 54% (Figure 35).

Figure 35: Oats Land Use and Yield

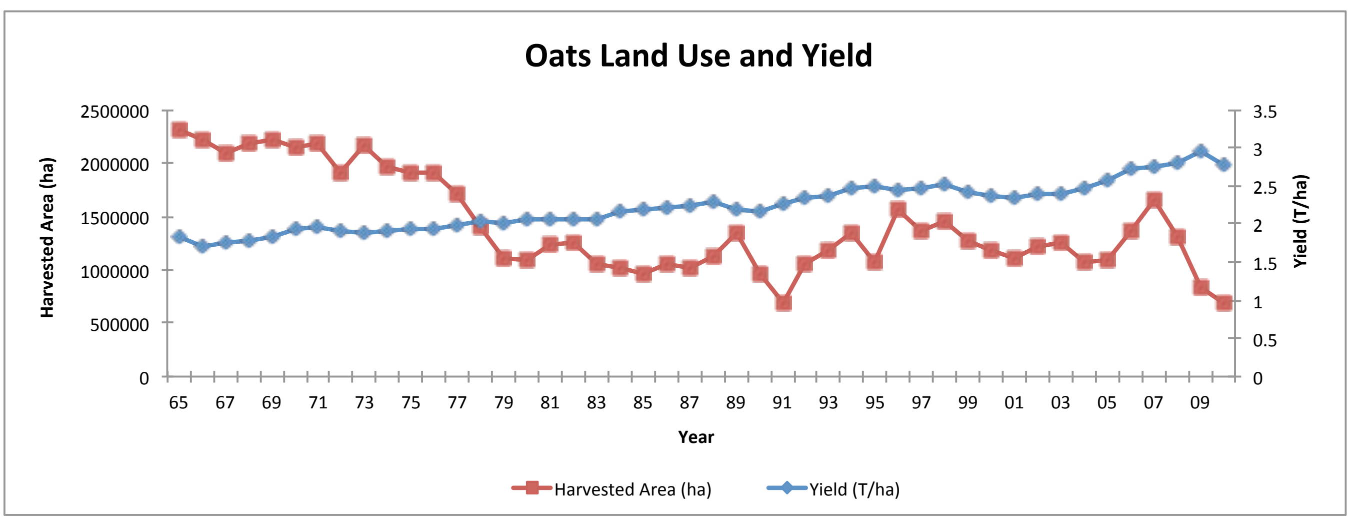
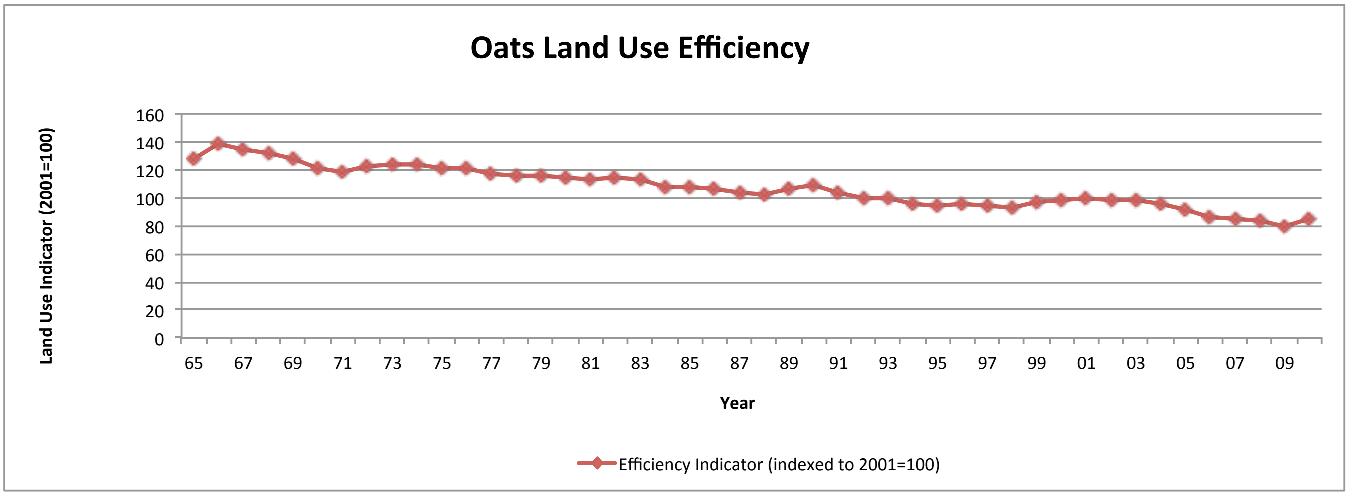


Figure 36: Oats Land Use Efficiency



Soil Loss Indicator

Potential soil loss for oats, on a per hectare basis, decreased by 46% between 1981 and 2006 (Figure 37). Soil loss efficiency improved by 54% over the same time (Figure 38). This improvement in soil loss per unit of output (soil loss efficiency) is the most significant improvement for oats of all four indicator areas. Yields have improved by 26% for oats between 1981 and 2006. The trend in both Figure s 37 and 38 suggests continuing improvement.

Figure 37: Oats Soil Loss and Yield

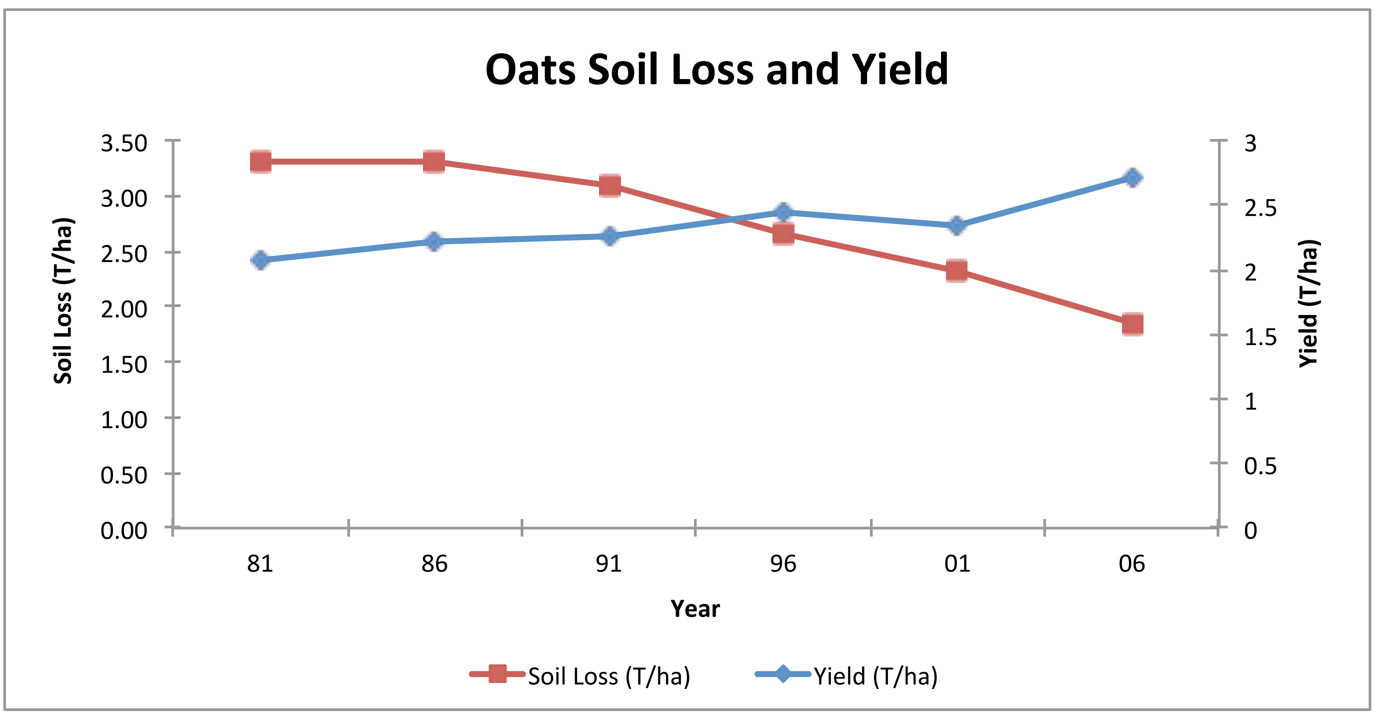
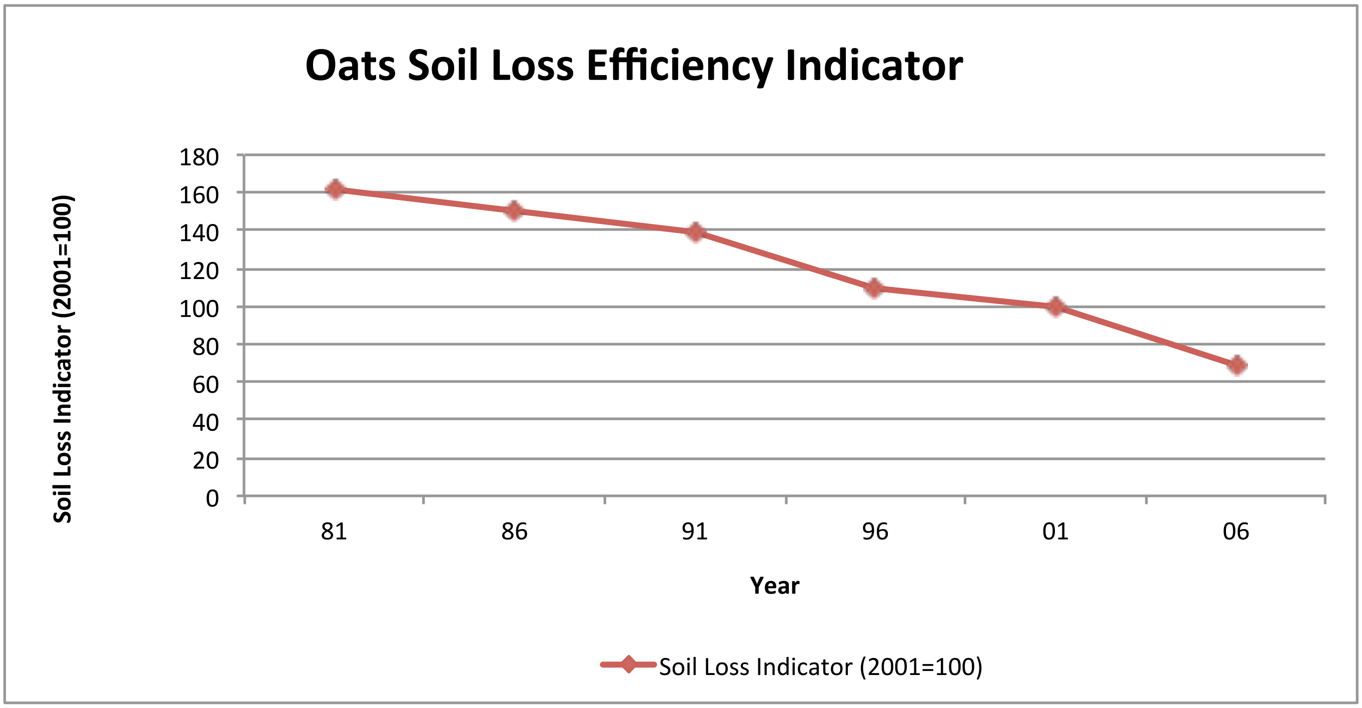


Figure 38: Oats Soil Loss Efficiency Indicator



Energy Use Indicator

Energy use for oats improved by 12% between 1981 and 2006, on a per hectare basis (Figure 39). Energy use efficiency (i.e. per unit of output) for oats improved by 30% between 1981 and 2006 (Figure 40). Yield increases of 26% account for the difference between the two indicators (Figure 39). In addition, it is important to note that the percent improvement has been relatively consistent form one period to the next. While it would be unrealistic to suggest that this trend will continue, it certainly suggests that farmers have been working hard to ensure their production makes effective use of energy inputs.

Figure 39: Oats Energy Use and Yield

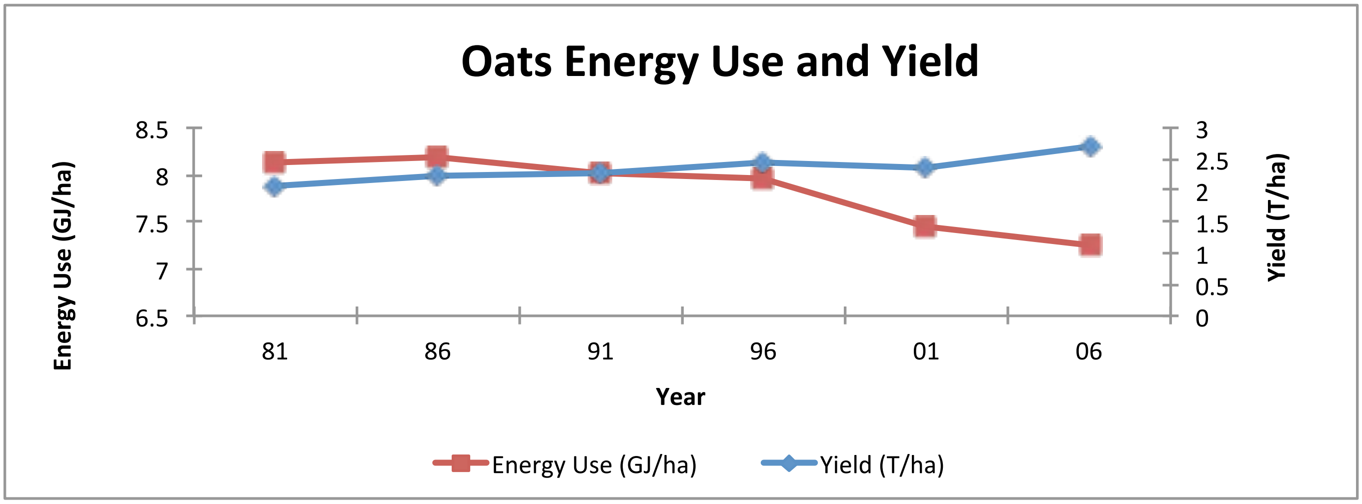
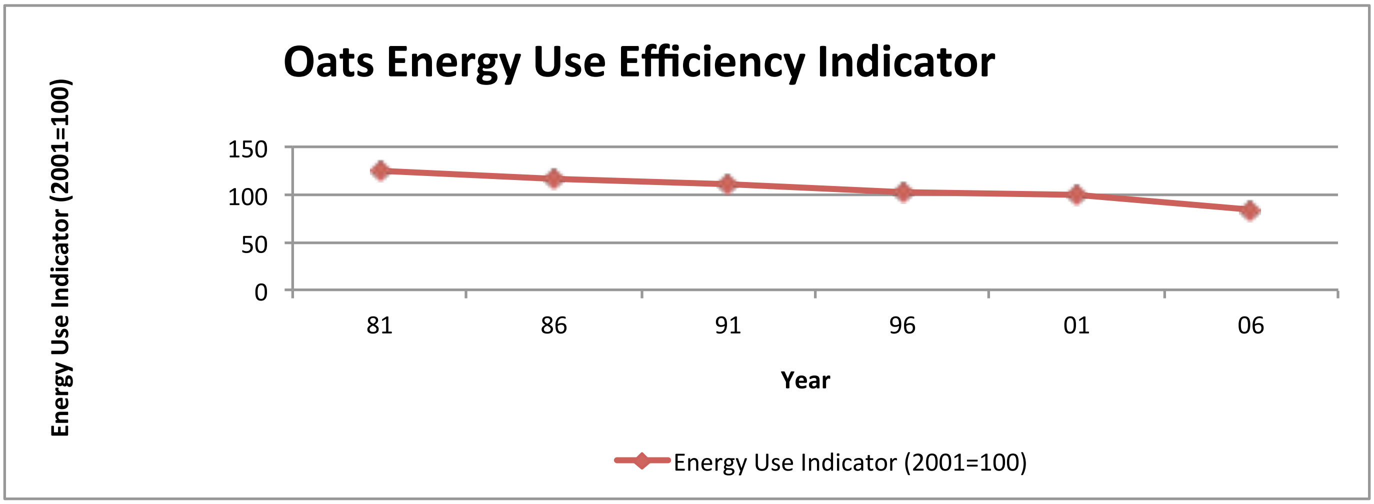


Figure 40: Oats Energy Use Efficiency Indicator



Climate Impact Indicator

The changes in the climate impact indicators for oats mirror those in the ones for energy use. On an absolute, per hectare basis, climate impact from production of oats dropped by 9% between 1981 and 2006 (Figure 41). On a per unit of output basis, climate impact efficiency improved by 27% over the same time (Figure 42). This improvement in climate impact efficiency is driven by the yield increases of 26%. (Figure 41).

Figure 41: Oats Climate Impact and Yield

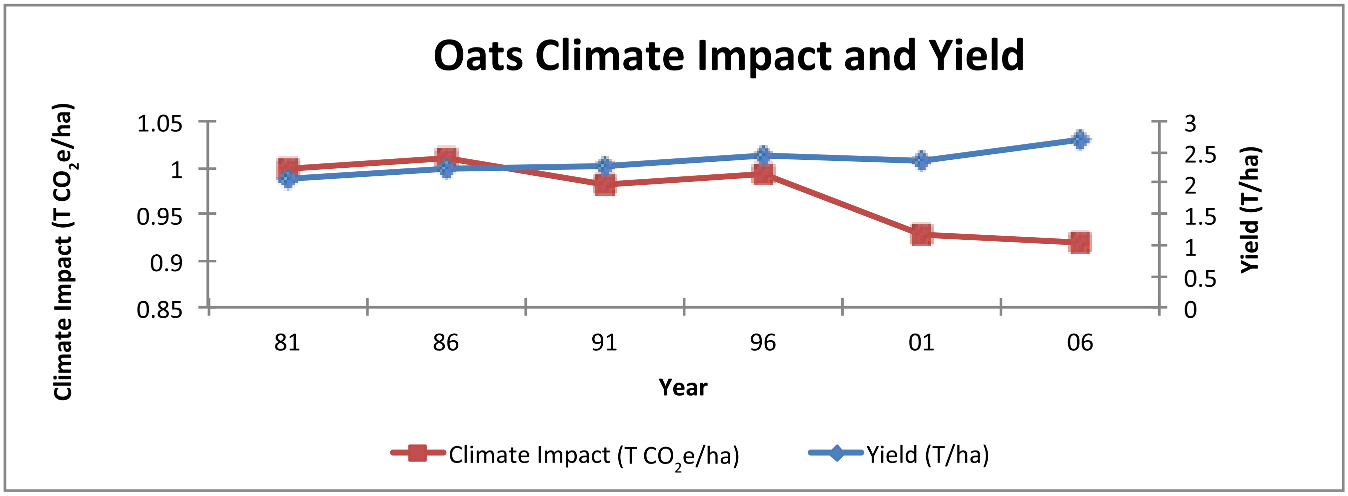
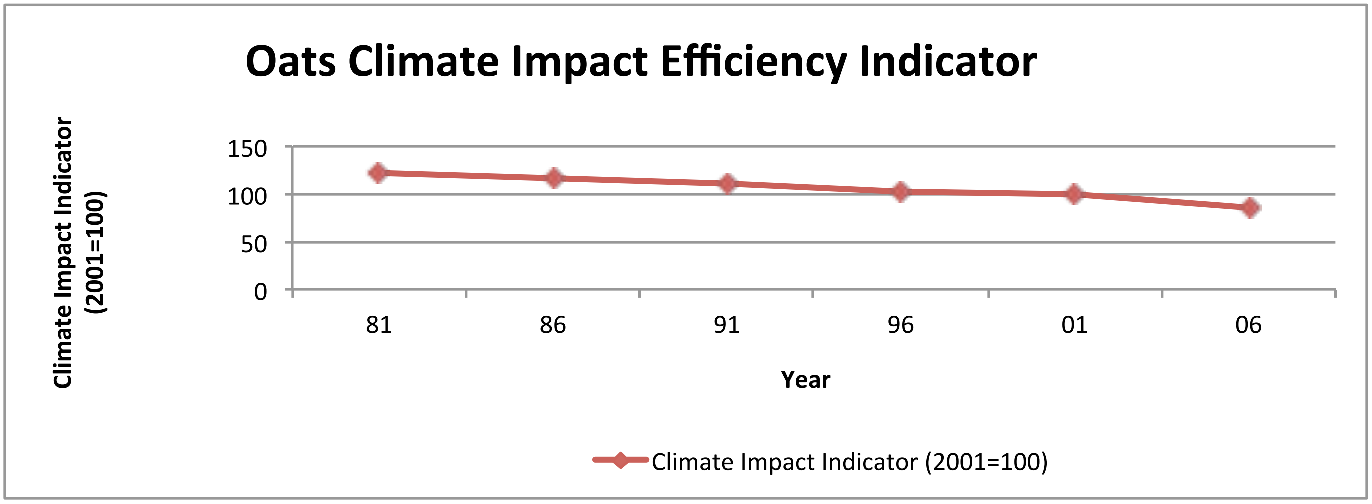


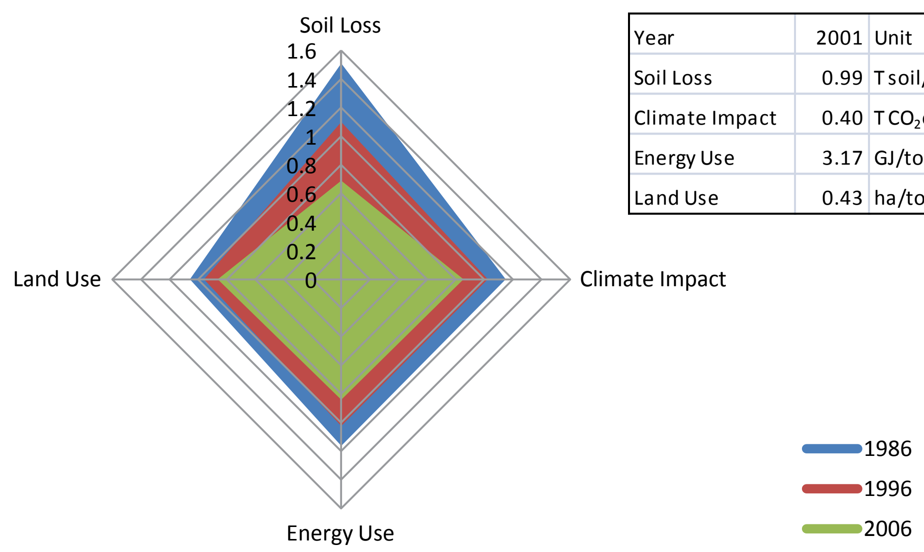
Figure 42: Oats Climate Impact Efficiency Indicator



Indicator Summary - Oats

The overall efficiency of oat production improved for each of the four indicators measured, over the period covered by the spider diagram (1986 to 2006) (Figure 43). As for the other crops, the improvement in soil erosion stands out for oats (Figure 43). This is largely a reflection of reduced tillage, the impact of which is also seen in improved energy use and climate impact. For oats, between 1986 and 2006, soil loss efficiency improved by 54%, energy use efficiency by 28%, climate impact efficiency by 26%, and land use efficiency by 18%.

Figure 43: Oats Efficiency Indicators Over Time



Year	2001	Unit
Soil Loss	0.99	T soil/T output
Climate Impact	0.40	T CO_2e/tonne
Energy Use	3.17	GJ/tonne
Land Use	0.43	ha/tonne

Peas

Land Use Indicator

A dramatic increase in the harvested area is seen in Figure 44, from very small areas until 1985 to well over a million hectares across Western Canada in the last ten years.

Land use efficiency for peas has improved by 39% in the period between 1965 and 2010 (Figure 45). This reflects consistent improvement. Yields for peas have improved by 53% between 1965 and 2010 (Figure 44). Note that the yield improvement for peas between 1981 and 2006 was 23%, significantly lower than that for most of the other crops (flax had a smaller yield increase). This relatively small increase in yield strongly impacts the land use efficiency indicator.

One factor that may have affected this indicator is the large increase in area (Figure 30), which suggests that production may be moving into areas where yield potential is not as high. If so, this would affect the increase in yield observed, and thus the land use efficiency indicator.

Figure 44: Peas Land Use and Yield

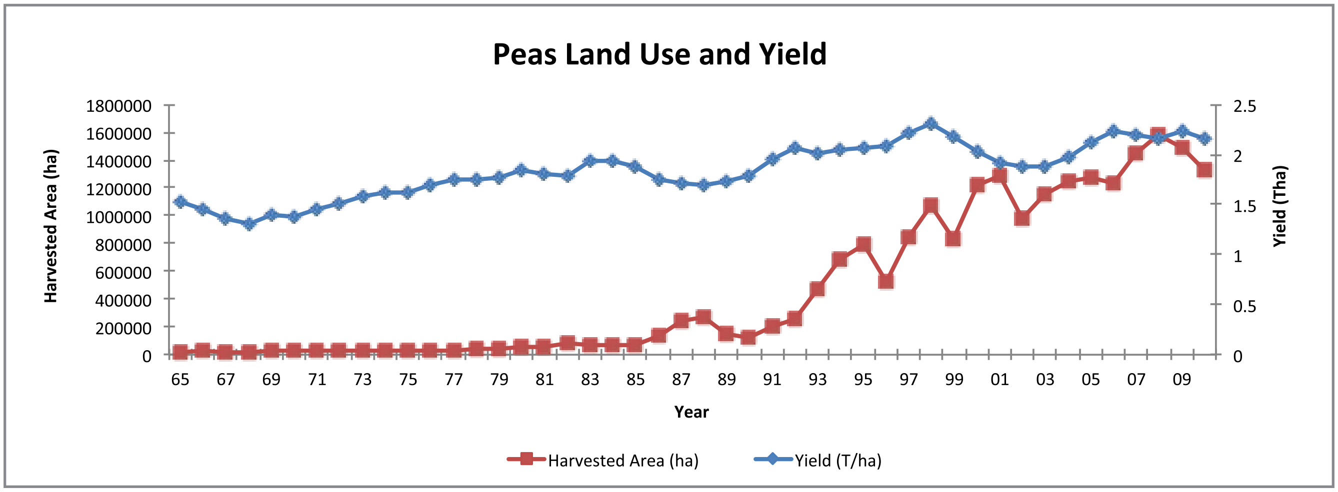
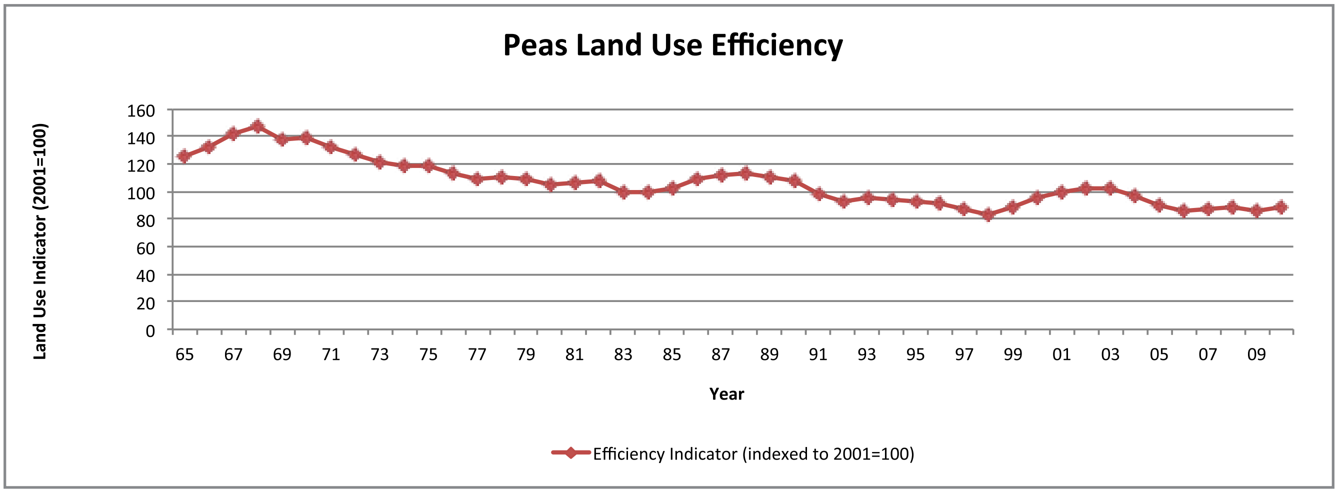


Figure 45: Peas Land Use Efficiency



Soil Loss Indicator

While improvement in land use has not been as dramatic as for many of the other crops, the results for the soil loss indicator suggest that peas have improved on a level consistent with some of the other crops. On a per hectare basis, potential soil loss for peas improved by 49% between 1981 and 2006 (Figure 46). The soil loss efficiency indicator improved by 53% between 1981 and 2006 (Figure 47). Yield increased by 23% between 1981 and 2006 (Figure 46). Much of the improvement in soil loss efficiency took place between 1981 and 1996, as can be observed in Figure 47.

Figure 46: Peas Soil Loss and Yield

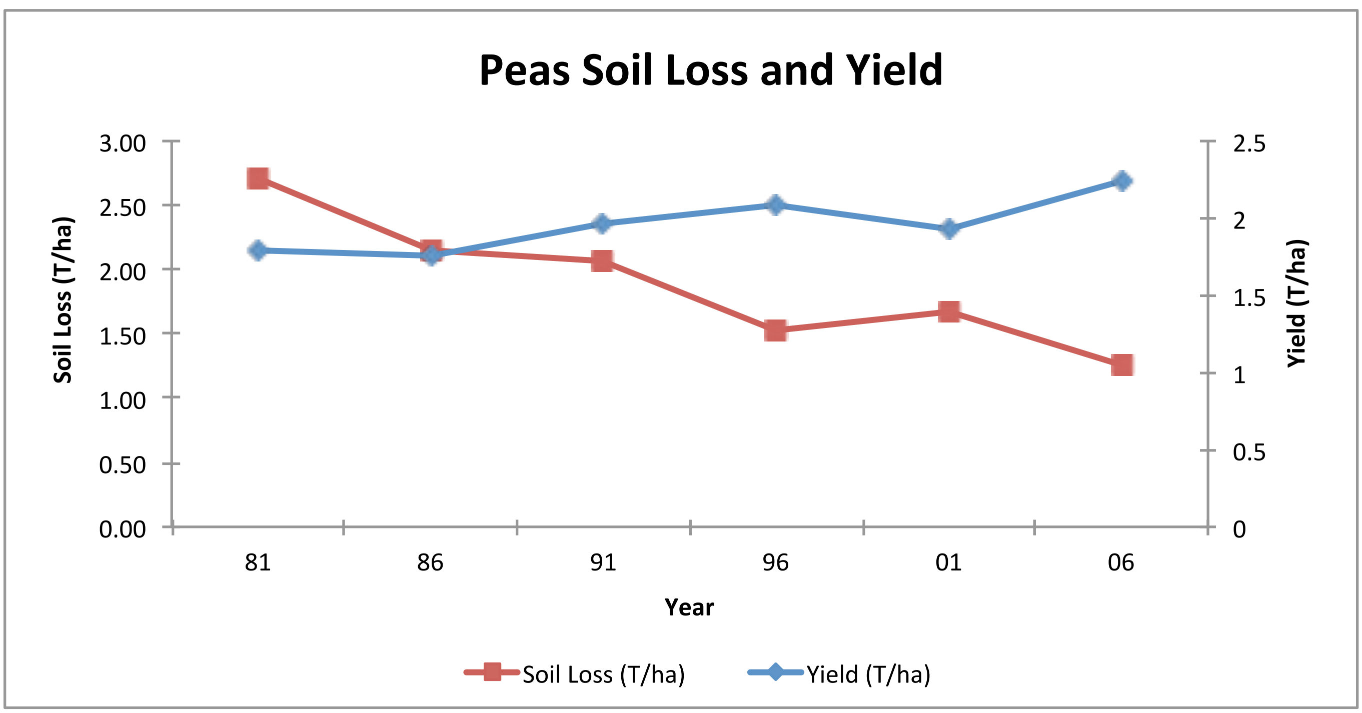
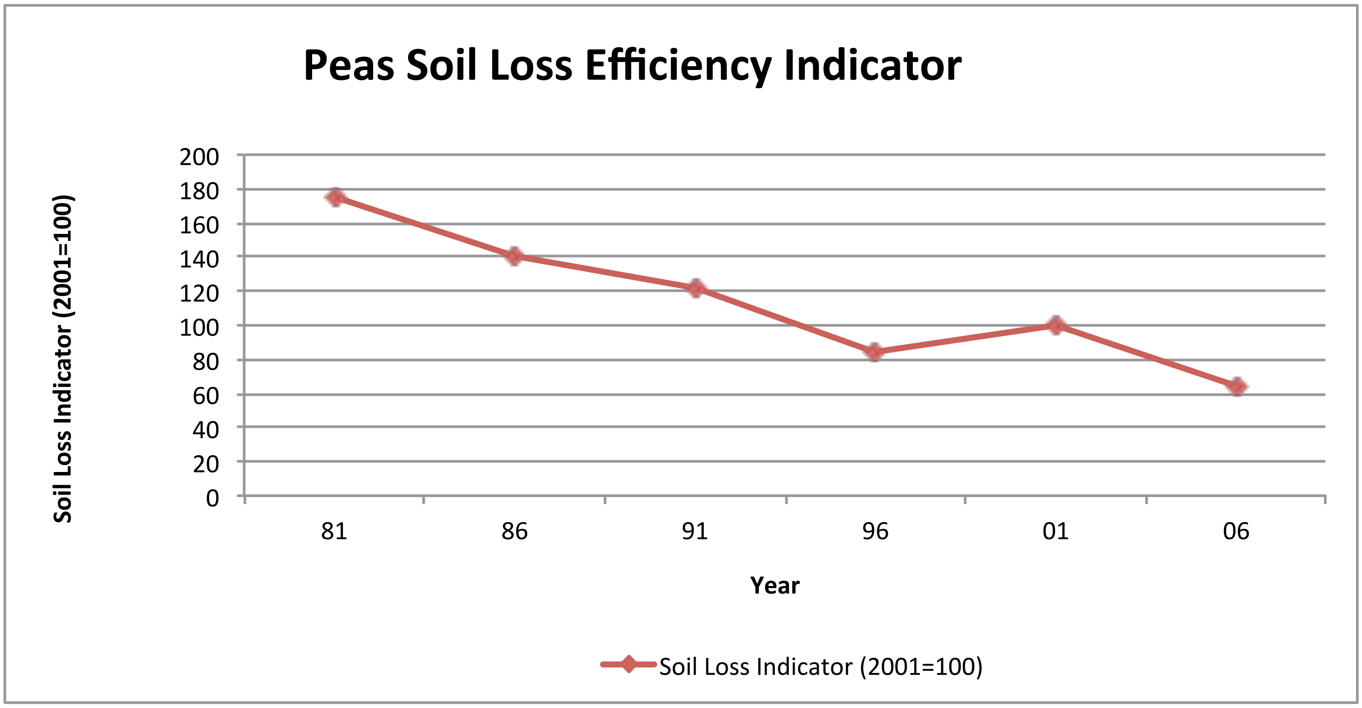


Figure 47: Peas Soil Loss Efficiency Indicator



Energy Use Indicator

On a per hectare basis, energy use for pea production increased significantly between 1981 and 1991, before falling dramatically from 1991 through 2001 (Figure 48). Based on a linear trendline for this period, energy use improved by 3% overall (Figure 48). When indexed with yield, the efficiency indicator actually declined by 22% from 1981 to 2006 (Figure 36). The main improvement actually occurred between 2001 and 2006, after total energy use bottomed out and yield continued to improve.

Figure 48: Peas Energy Use and Yield

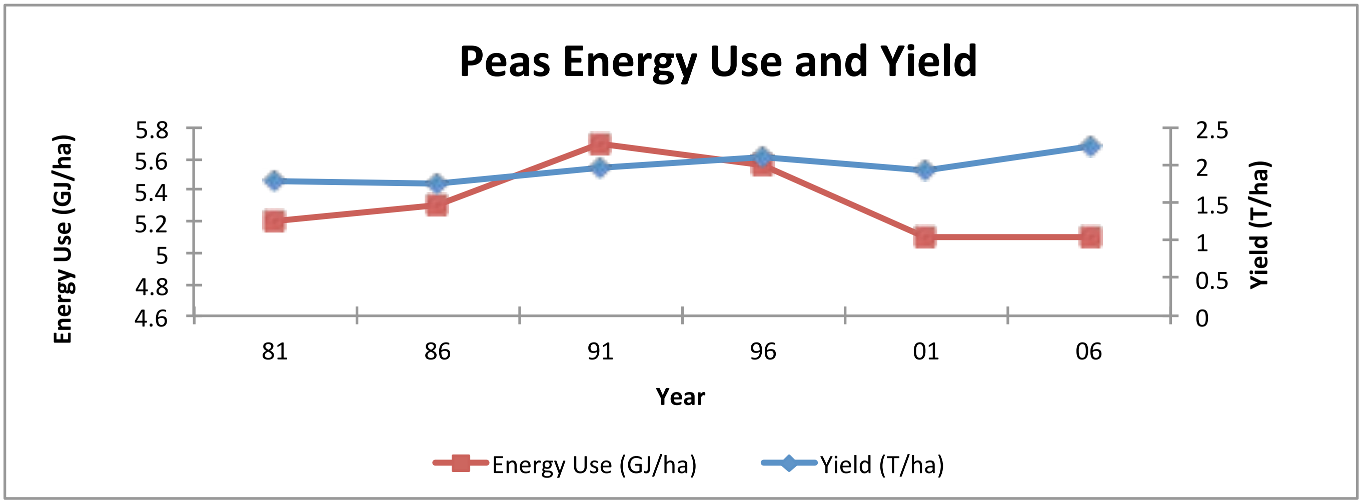
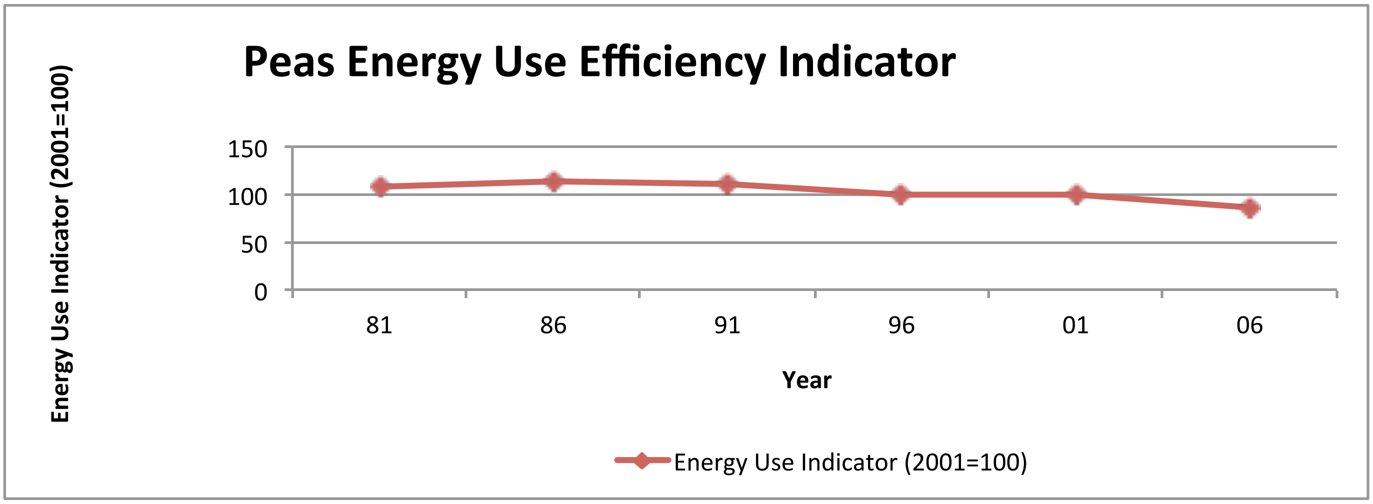


Figure 49: Peas Energy Use Efficiency Indicator



Climate Impact Indicator

While following similar patterns to the energy use indicators, the climate impact indicators for peas actually improved more between 1981 and 2006. On a per hectare basis, climate impact for peas improved by 9% over this period (Figure 50). The climate impact efficiency indicator improved by 27% (Figure 51), with yield increasing by 23% (Figure 50).

Figure 50: Peas Climate Impact and Yield

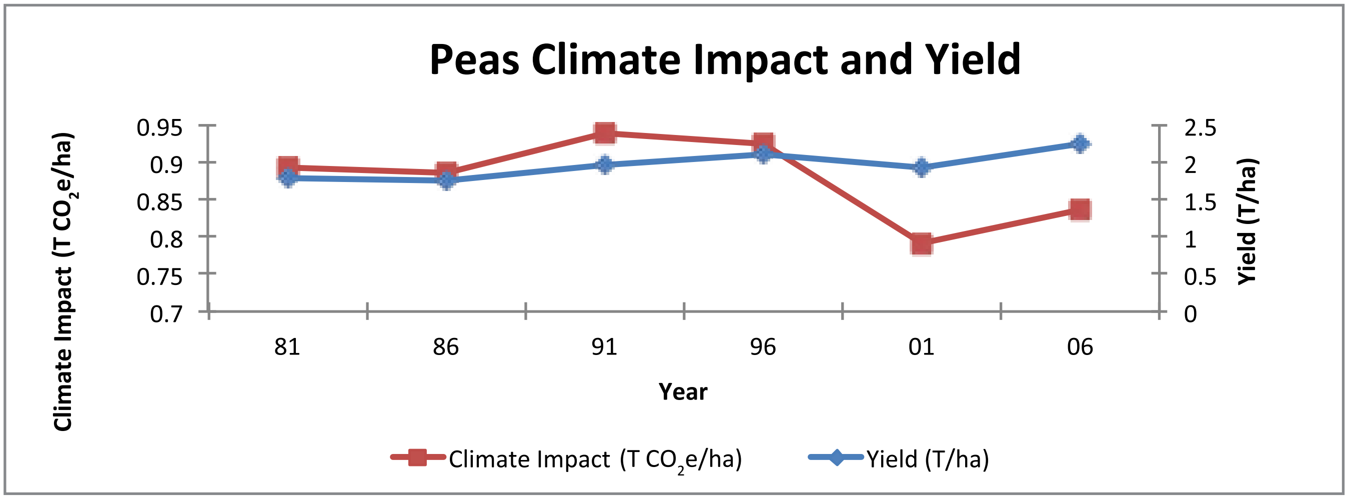
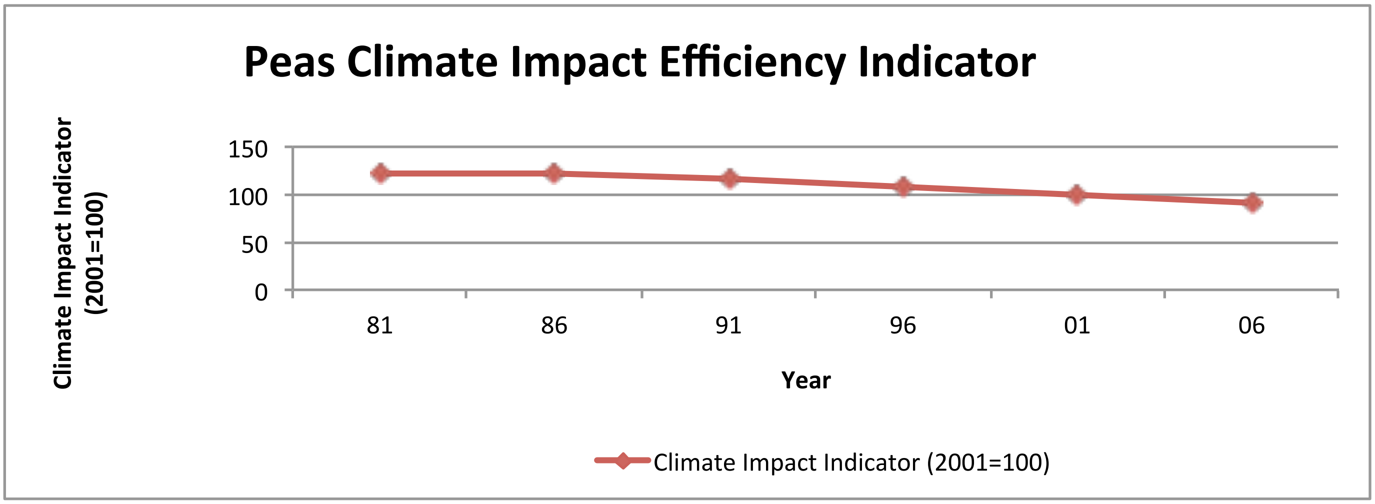


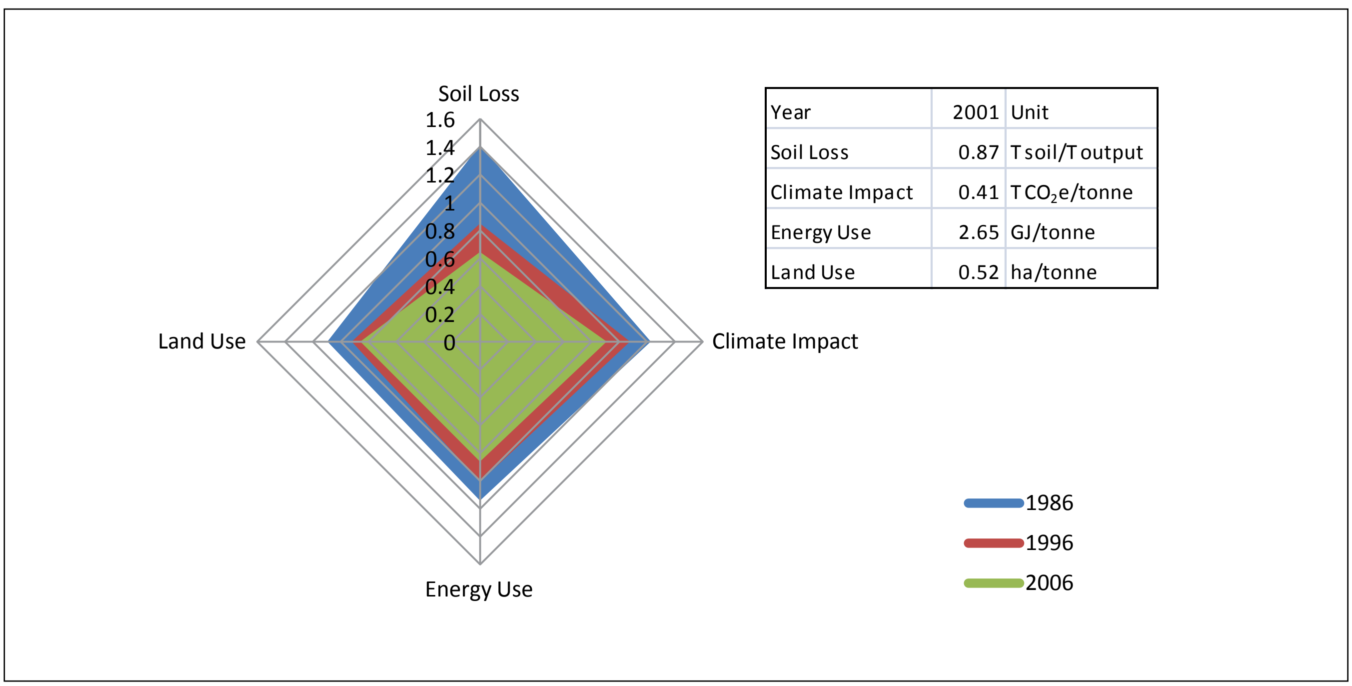
Figure 51: Peas Climate Impact Efficiency Indicator



Indicator Summary - Peas

In summary, the story for peas in Western Canada is also very positive. All four indicators improved significantly between 1986 and 2006, with the changes in the soil loss indicator efficiency leading the way (Figure 52). Between 1986 and 2006, soil loss efficiency improved by 54%, climate impact efficiency by 26%, energy use efficiency by 25%, and land use efficiency by 22%.

Figure 52: Peas Efficiency Indicators Over Time



Year	2001	Unit
Soil Loss	0.87	T soil/T output
Climate Impact	0.41	T CO_2e/tonne
Energy Use	2.65	GJ/tonne
Land Use	0.52	ha/tonne

Flax

Land Use Indicator

The flax land use indicators clearly show a tendency toward more efficient use of land, over the period analyzed, i.e. from 1965 to 2010. Harvested area declined by 10% between 1965 and 2010, and yield increased by 75% during the same tine (Figure 53). Driven by this yield increase, land use efficiency improved by 47% between 1965 and 2010 (Figure 54). Significant improvement took place between 1973 and 1985 (Figure 54).

Figure 53: Flax Land Use and Yield

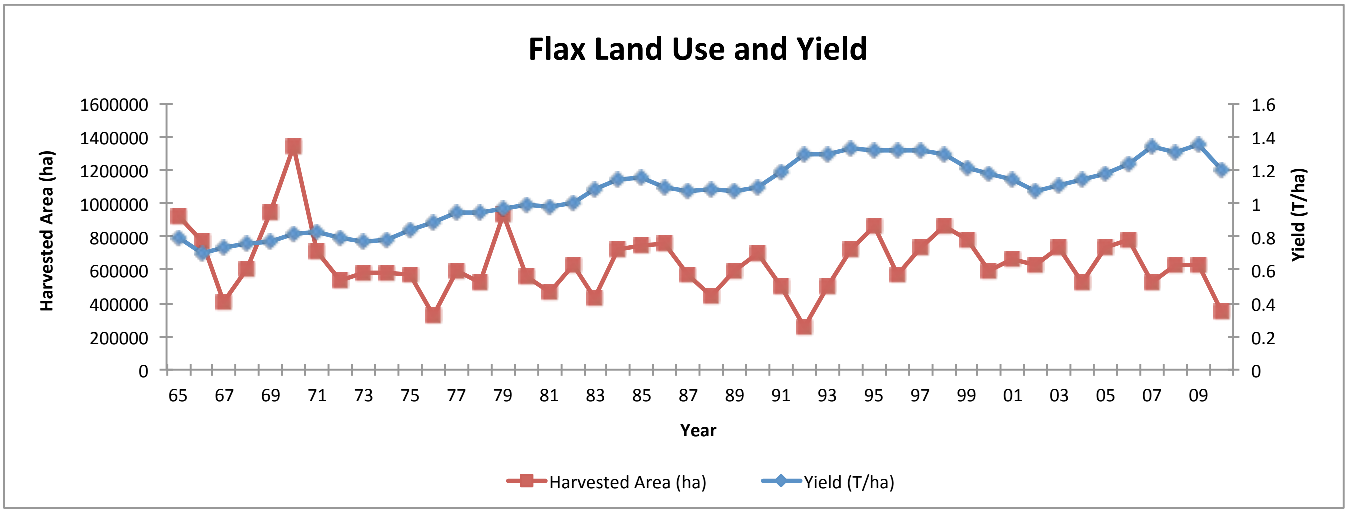
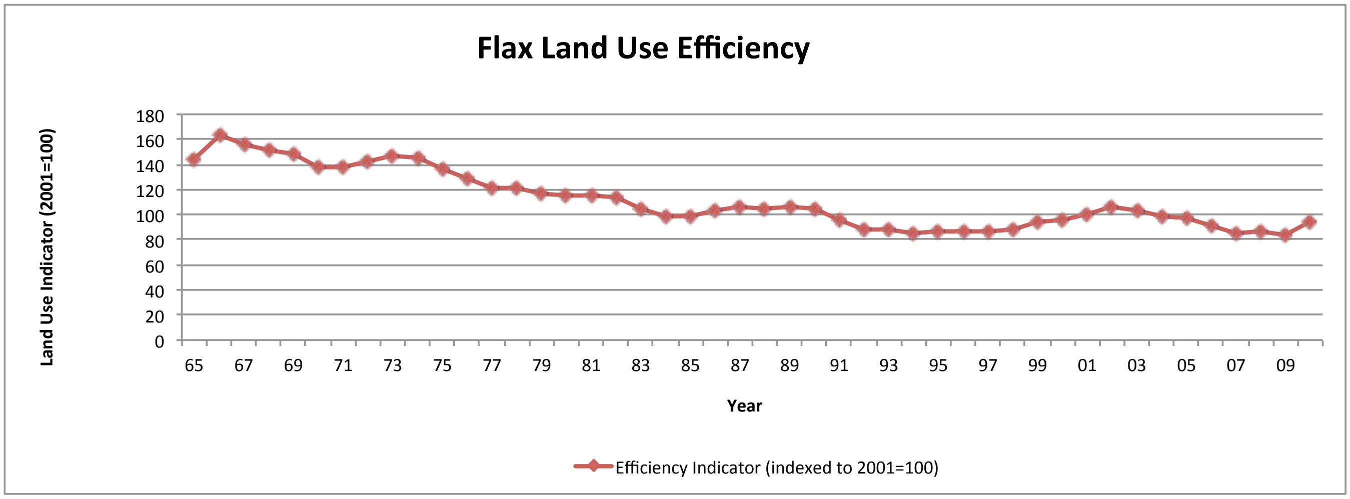


Figure 54: Flax Land Use Efficiency



Soil Loss Indicator

Improvements in soil management, as suggested by the soil loss indicators, were moderate for flax, in comparison to the other crops. Soil loss for flax, on a per hectare basis, decreased by 54% between 1981 and 2006 (Figure 55), while yield increased by 22% (Figure 55). Soil loss, on a per unit of output basis, improved by 55% (Figure 56). The relative change in soil loss efficiency has been quite consistent over time (Figure 56), and suggests that farmers have been making serious efforts to maintain soil capability.

Figure 55: Flax Soil Loss and Yield

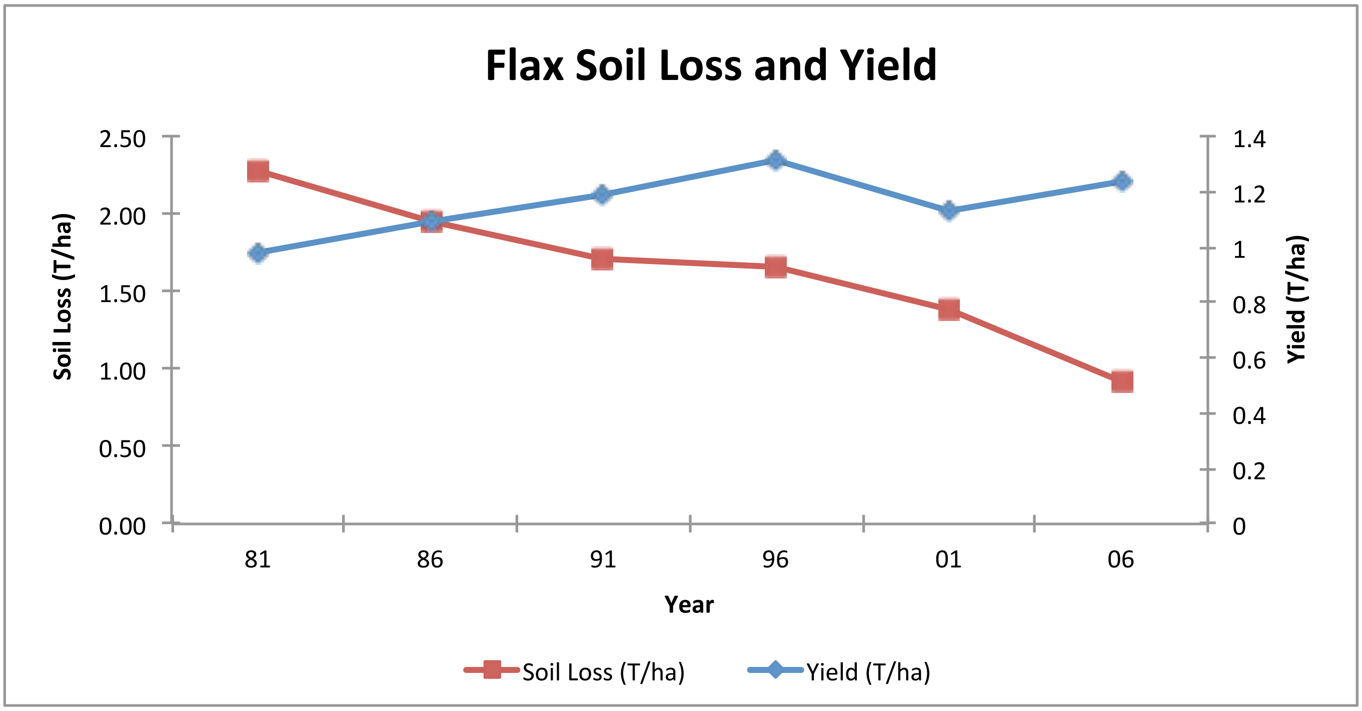
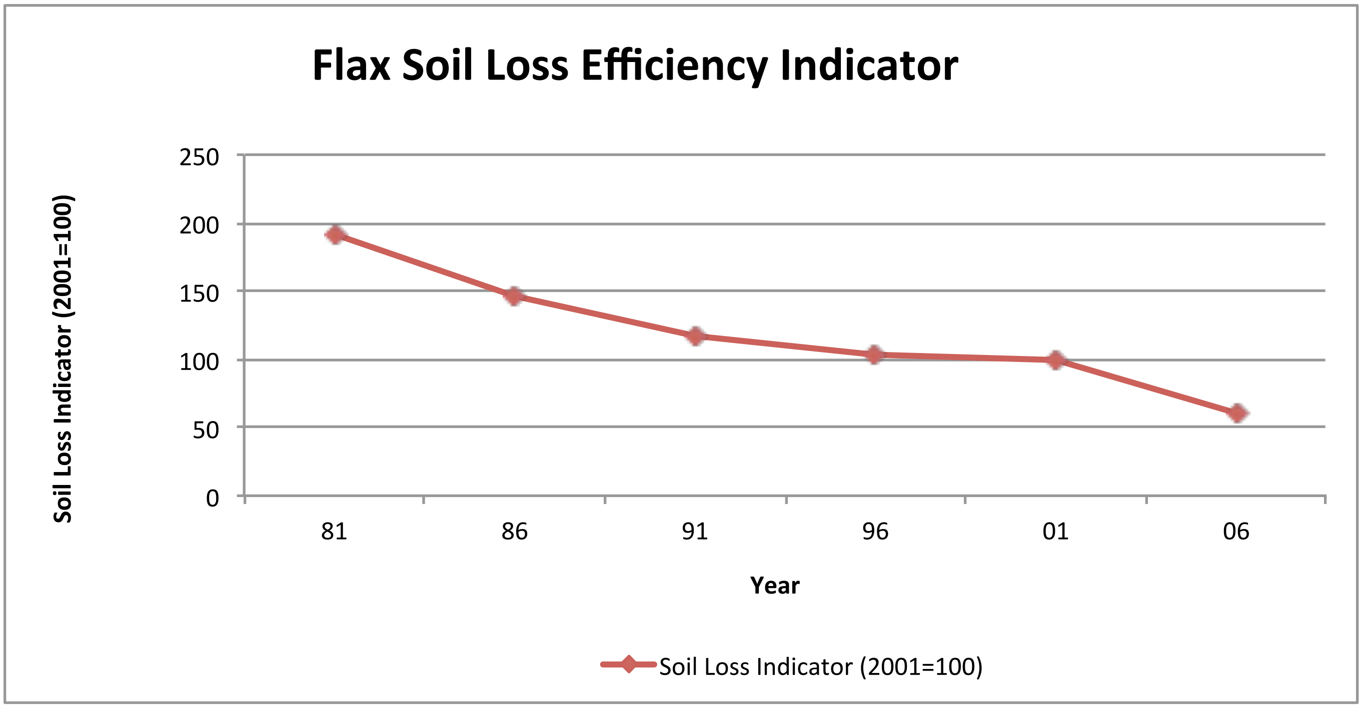


Figure 56: Flax Soil Loss Efficiency Indicator



Energy Use Indicator

Energy use, on a per hectare basis, has improved by 15% between 1981 and 2006 (Figure 57). During the same time, yields of flax have increased by 22%, and energy use per unit of output, as seen in the efficiency indicator, has improved by 29% (Figure 58). The greatest improvement in energy use efficiency occurred between 1981 and 1996. Poor yields around 2001 created a bit of a blip, but the improvement has resumed since that time.

Figure 57: Flax Energy Use and Yield

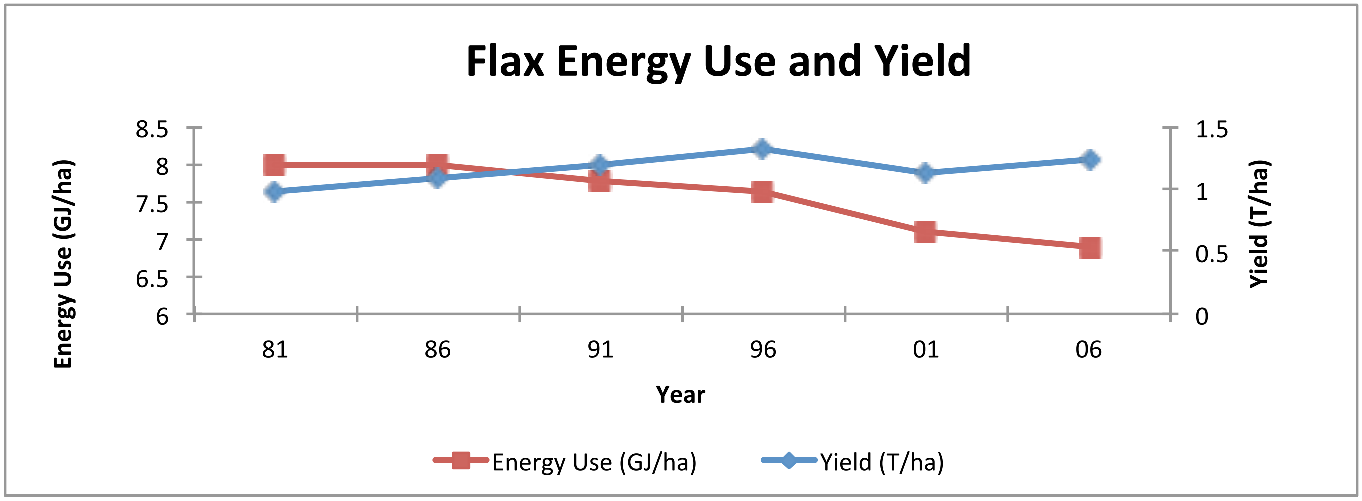
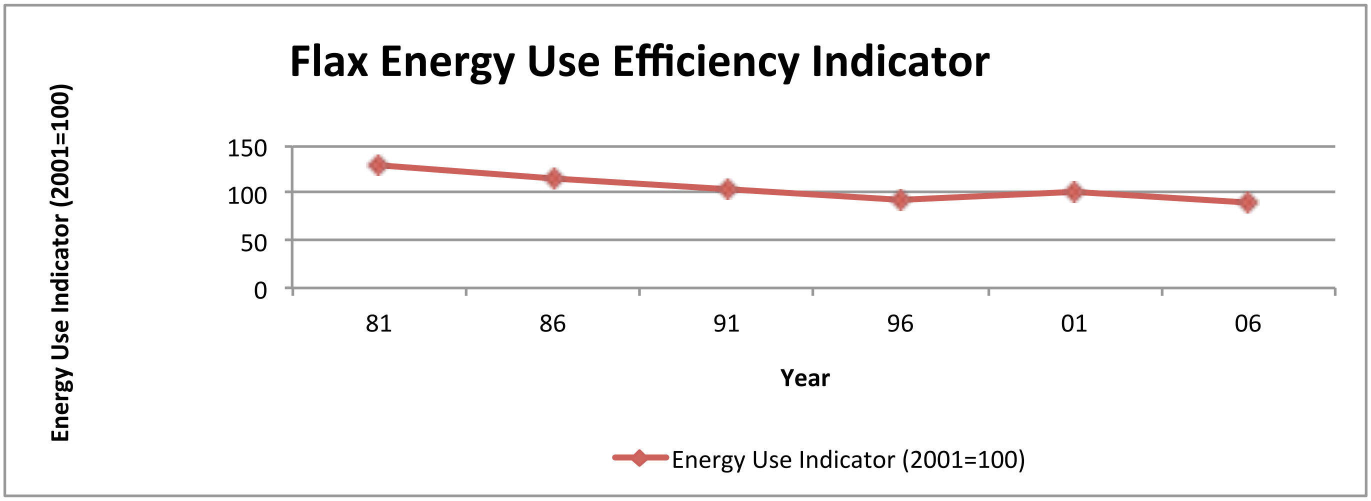


Figure 58: Flax Energy Use Efficiency Indicator



Climate Impact Indicator

The climate impact indicators for flax have followed the trends set by energy use, but show somewhat more improvement than the energy use indicators. Climate impact, on a per hectare basis, has improved by 20% between 1981 and 2006 (Figure 59). At the same time, while yields have improved by 22%, climate impact efficiency has improved by 34% (Figure 60). A similar issue occurred around 2001, but once again the trend resumed by 2006.

Figure 59: Flax Climate Impact and Yield

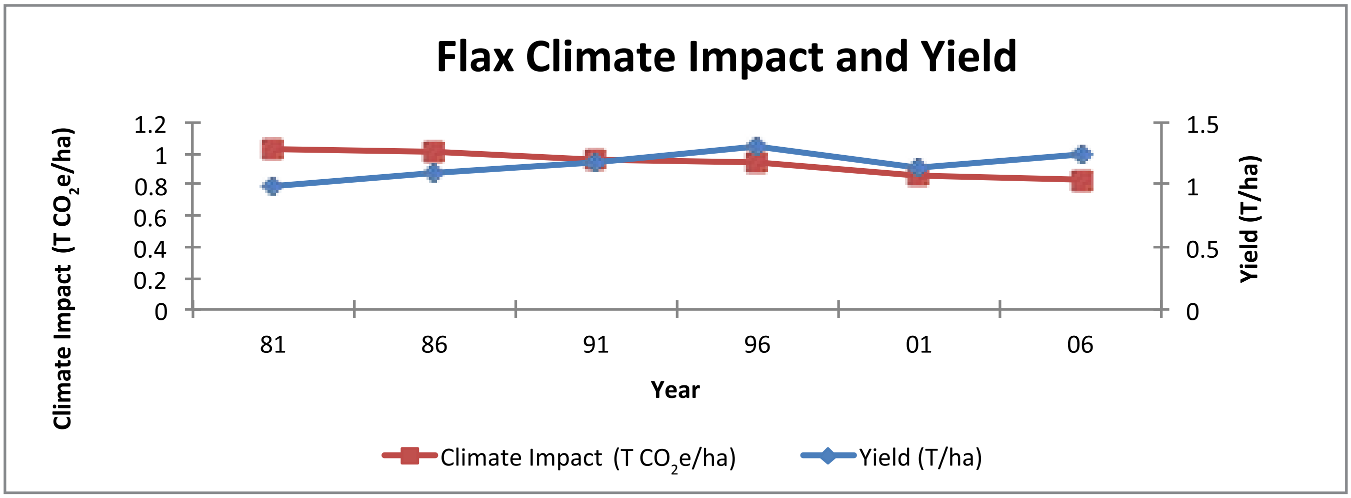
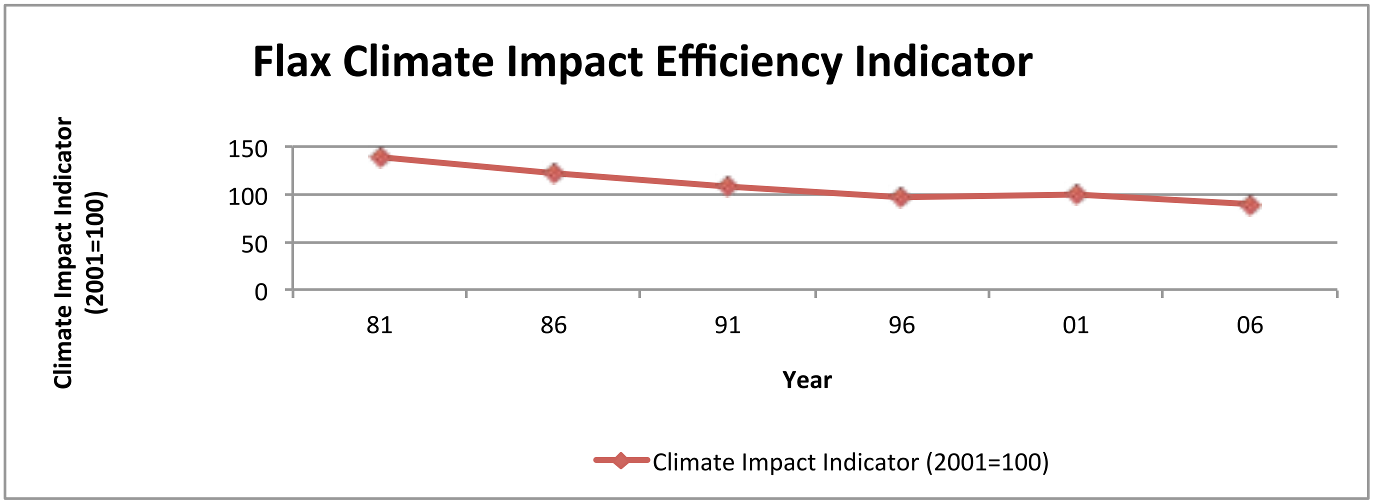


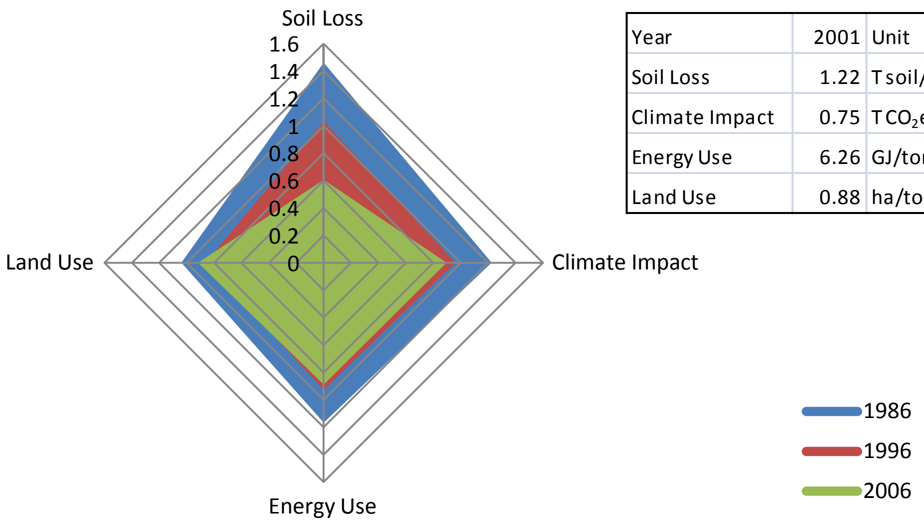
Figure 60: Flax Climate Impact Efficiency Indicator



Indicator Summary - Flax

The spider diagram (Figure 61) clearly indicates that the production of flax has demonstrated improvements in all four indicator areas from 1986 through 2006. While the changes in soil loss indicators are most significant, the changes in energy use and climate impacts are also significant. For flax, between 1986 and 2006, soil loss efficiency improved by 59%, climate impact efficiency by 27%, energy use efficiency by 24%, and land use efficiency by 12%.

Figure 61: Flax Efficiency Indicators Over Time



Year	2001	Unit
Soil Loss	1.22	T soil/T output
Climate Impact	0.75	T CO_2e/tonne
Energy Use	6.26	GJ/tonne
Land Use	0.88	ha/tonne

Canola

Land Use Indicator

The results for the canola land use indicator suggest that significant improvements have been made between 1965 and 2010. Harvested area has increased from about half a million hectares to over 6 million hectares, and yields have increased by 93% during this period (Figure 62). Land use efficiency has improved by 45% between 1965 and 2010 (Figure 63). As was the case with all other crops, improved yields accounted for this improvement (Figure 46).

Figure 62: Canola Land Use and Yield

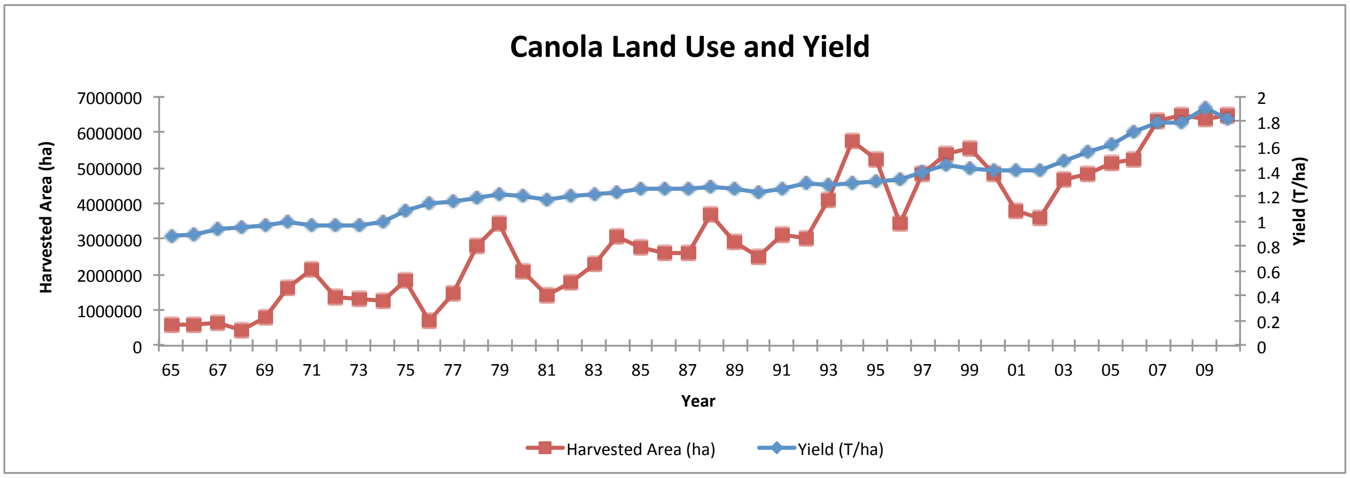
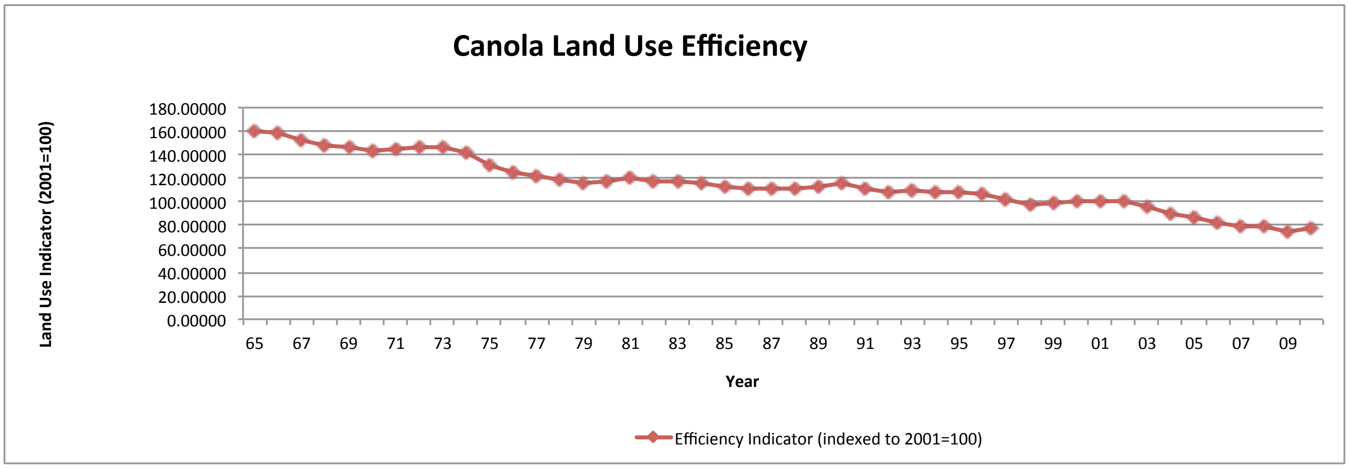


Figure 63: Canola Land Use Efficiency



Soil Loss Indicator

Of all the indicator areas, the most significant changes for canola relate to soil loss. In fact canola achieved the most significant improvement in the soil loss efficiency indicator of any crop in the analysis, except winter wheat.

On a per hectare basis, soil loss for canola decreased by 56% between 1981 and 2006 (Figure 64). Meanwhile, yields increased by 39% (Figure 64), and soil loss efficiency improved by 68% (Figure 65).

Figure 64: Canola Soil Loss and Yield

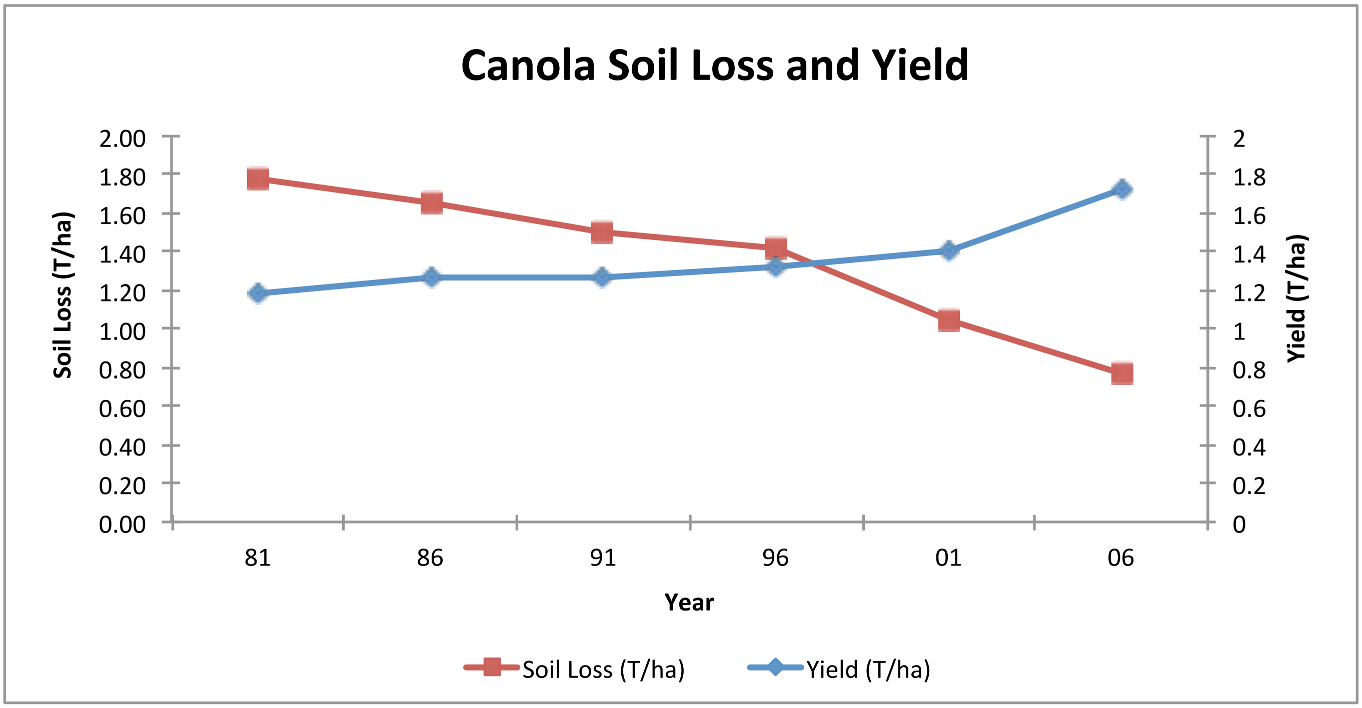
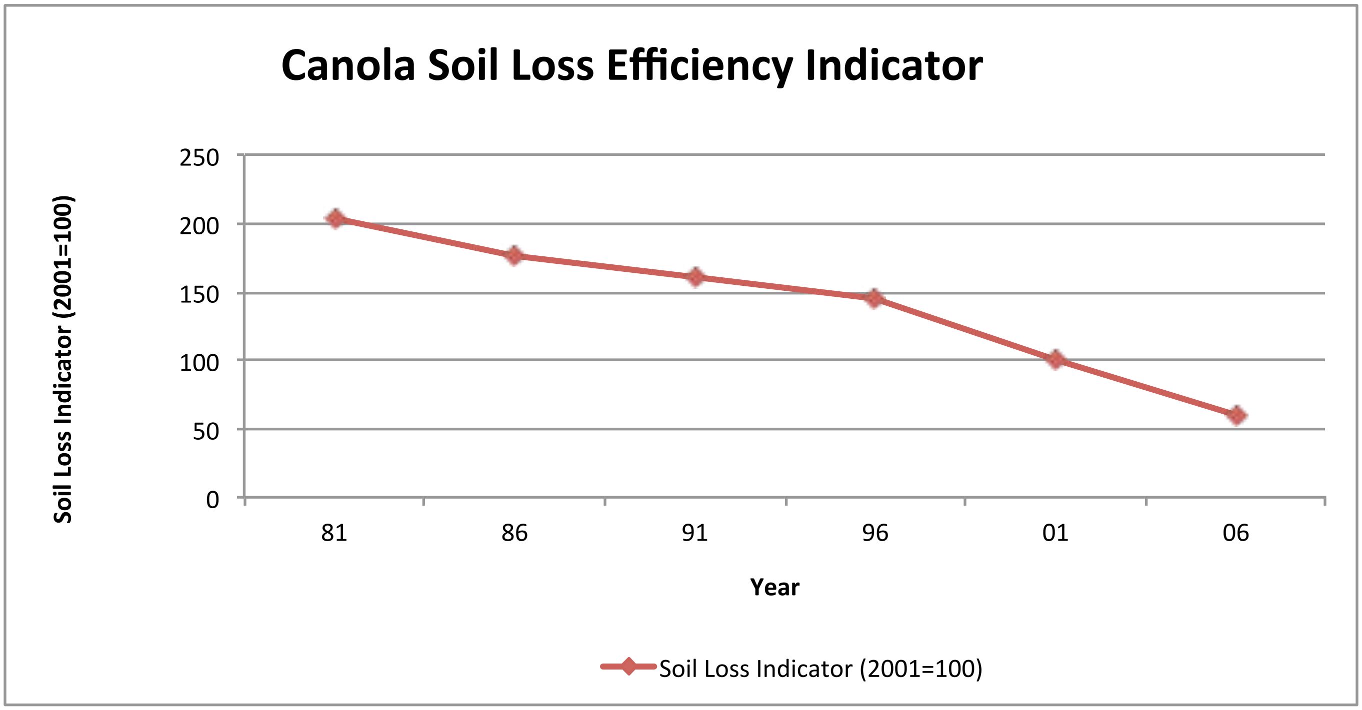


Figure 65: Canola Soil Loss Efficiency Indicator



Energy Use Indicator

Canola also improved in the area of energy use, with an improvement of 6% on a per hectare basis, between 1981 and 2006 (Figure 66). Energy use for canola, on a per unit of output basis, improved by 32% between 1981 and 2006 (Figure 67), with yields increasing by 39% (Figure 66). Perhaps most importantly, significant improvement occurred between 1996 and 2006.

Figure 66: Canola Energy Use and Yield

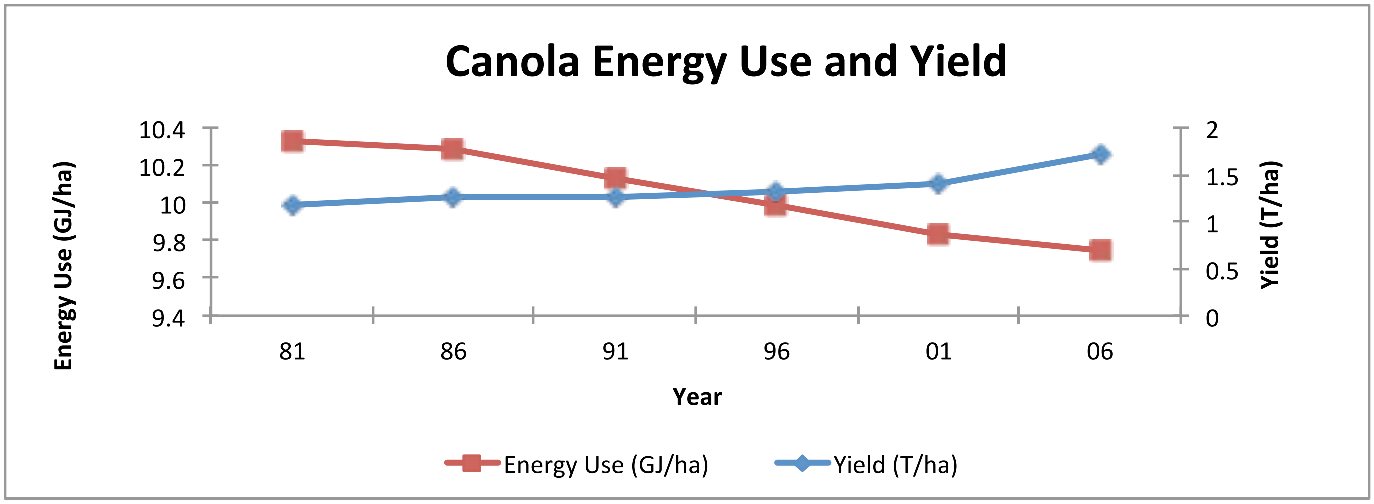
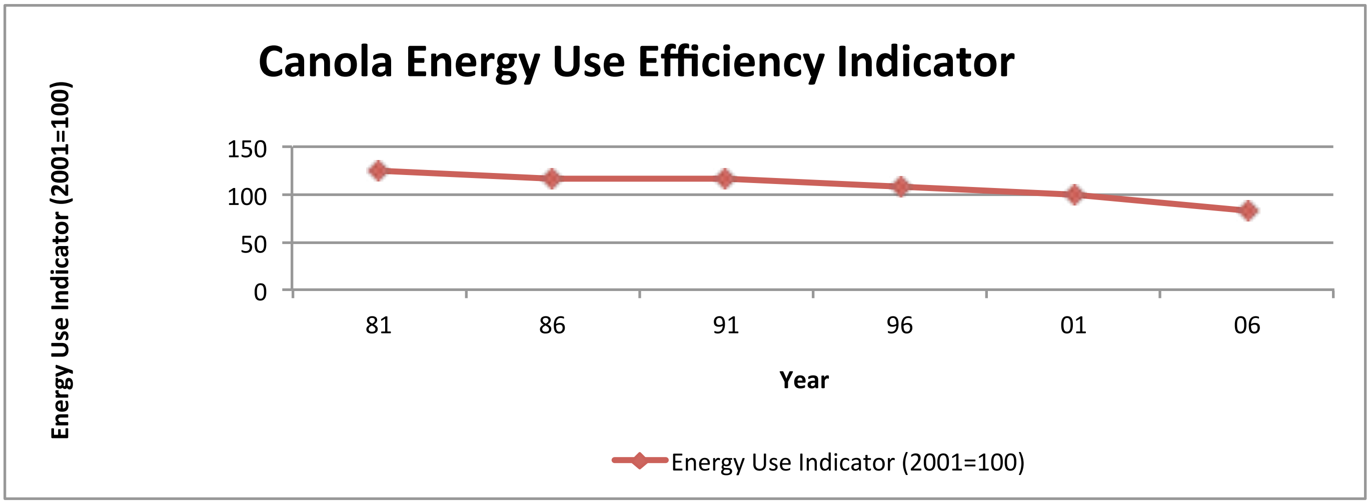


Figure 67: Canola Energy Use Efficiency Indicator



Climate Impact Indicator

Canola's indicators for climate impact suggest that the trends of energy use are mirrored, both in terms of magnitude and timing. The absolute emissions intensity (climate impact per hectare) only decreased by 6% between 1981 and 2006 (Figure 68). However, with yields of canola increasing by 39% over this period, climate impact per unit of output (climate impact efficiency) improved by 32% (Figure 69).

Figure 68: Canola Climate Impact and Yield

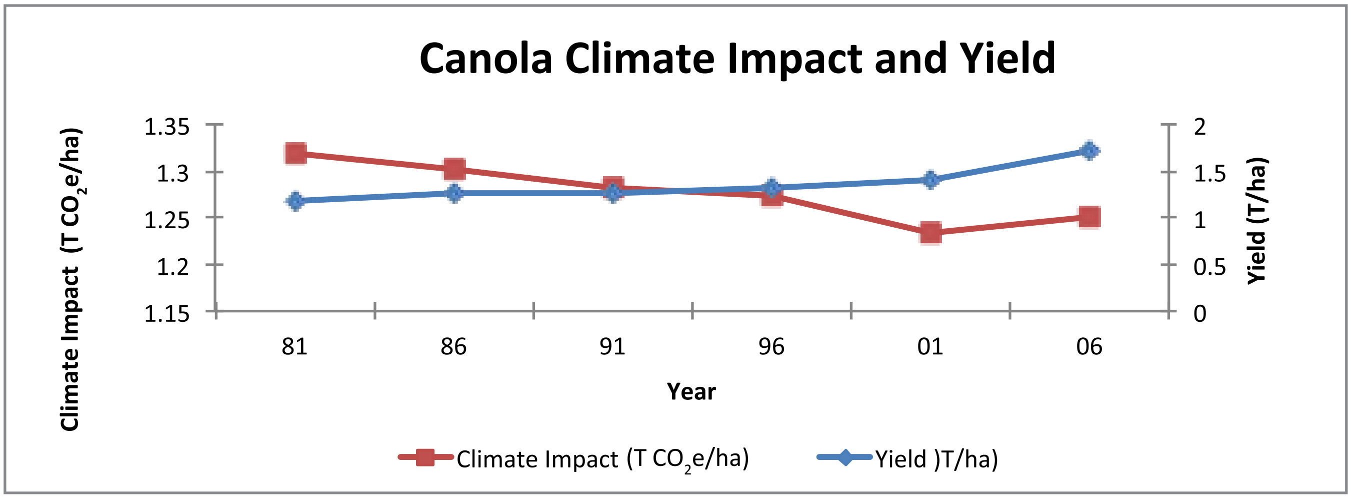
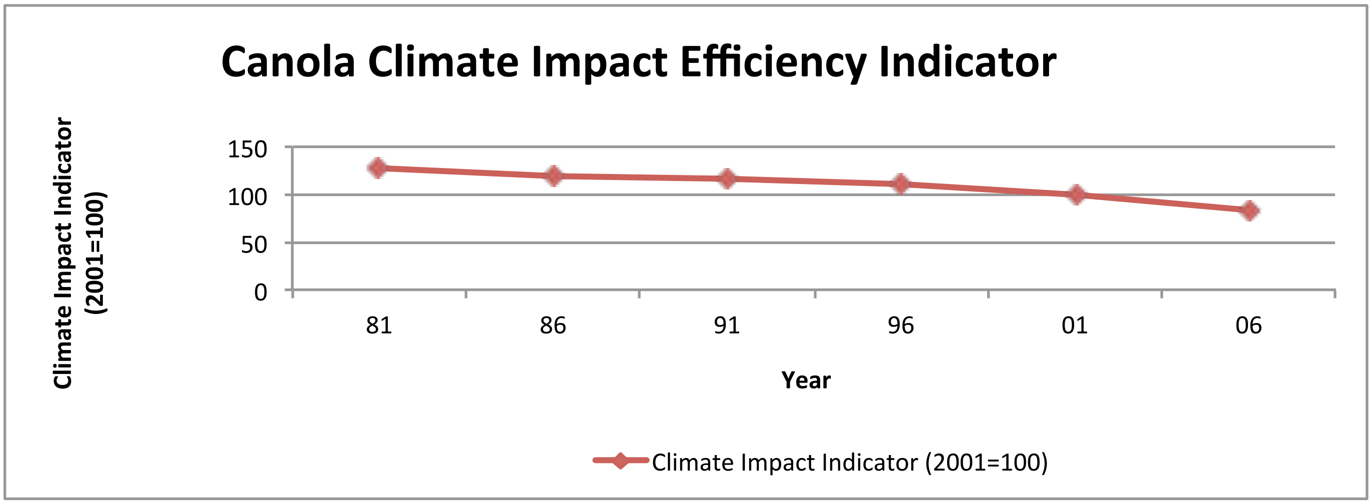


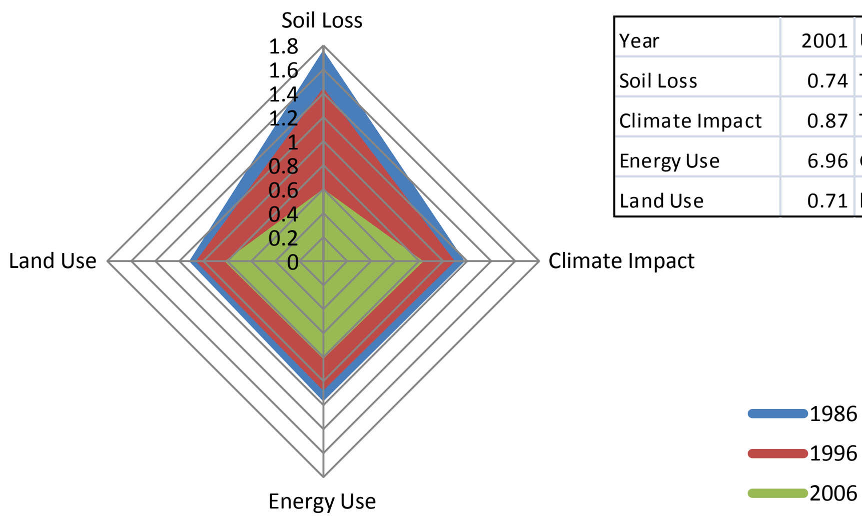
Figure 69: Canola Climate Impact Efficiency Indicator



Indicator Summary - Canola

In summary, canola production efficiencies have improved significantly from a sustainability perspective, as measured by the four indicators. While the most significant improvement was in the area of soil loss, improvements in all of the other areas were at least 25% between 1986 and 2006. Between 1986 and 2006, soil loss efficiency improved by 66%, energy use efficiency by 30%, climate impact efficiency by 29%, and land use efficiency by 26%.

Figure 70: Canola Efficiency Indicators Over Time



Year	2001	Unit
Soil Loss	0.74	T soil/T output
Climate Impact	0.87	T CO_2e/tonne
Energy Use	6.96	GJ/tonne
Land Use	0.71	ha/tonne

Lentils

Land Use Indicator

The harvested area of lentils has increased dramatically, from around 50,000 hectares in 1981 to well over a million hectares by 2010 (Figure 71). During the same period, yields of lentils have increased by 30% (Figure 71), and land use efficiency has improved by 25%.

Figure 71: Lentils Land Use and Yield

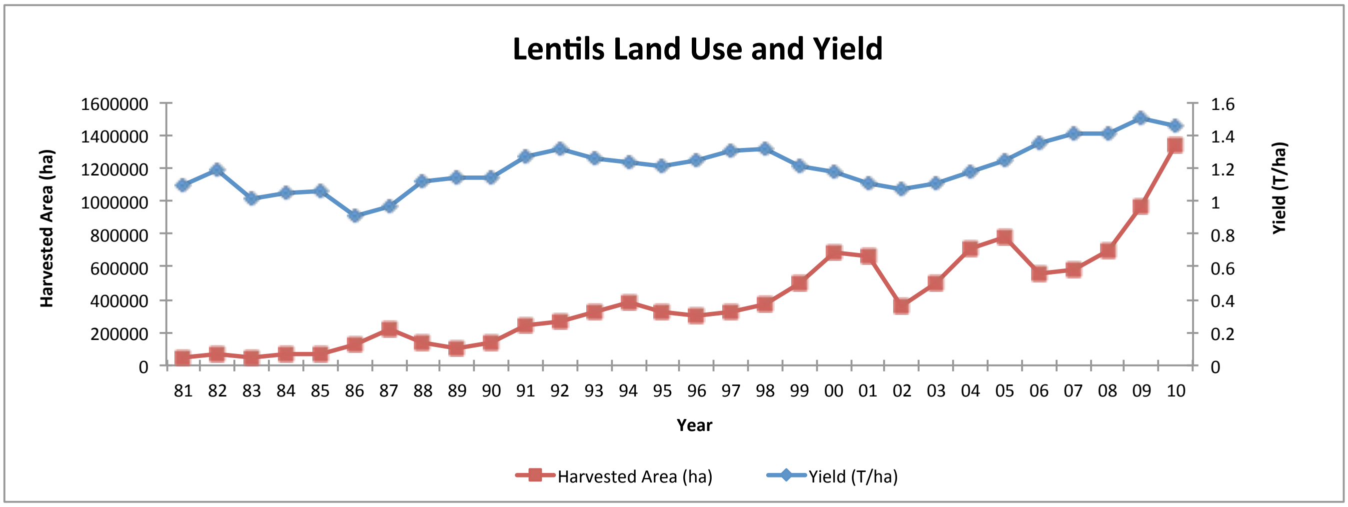
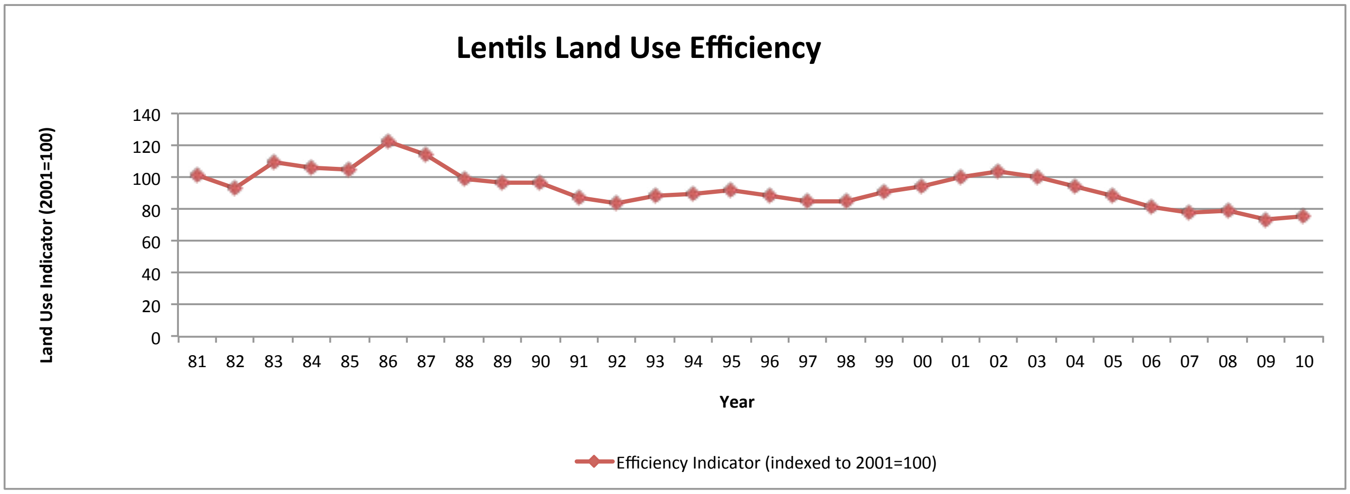


Figure 72: Lentils Land Use Efficiency



Soil Loss Indicator

The indicators for soil loss for lentils show substantial improvement between 1981 and 2006. Soil loss per hectare improved by 49% during this time, and yields increased by 25% (Figure 73). Soil loss efficiency (i.e. on a per unit of output basis) improved by 54% between 1981 and 2006 (Figure 74). The most significant improvements in soil loss efficiency came in the 10 year period between 1986 and 1996, but there was also a significant decline between 1996 and 2001.

Figure 73: Lentils Soil Loss and Yield

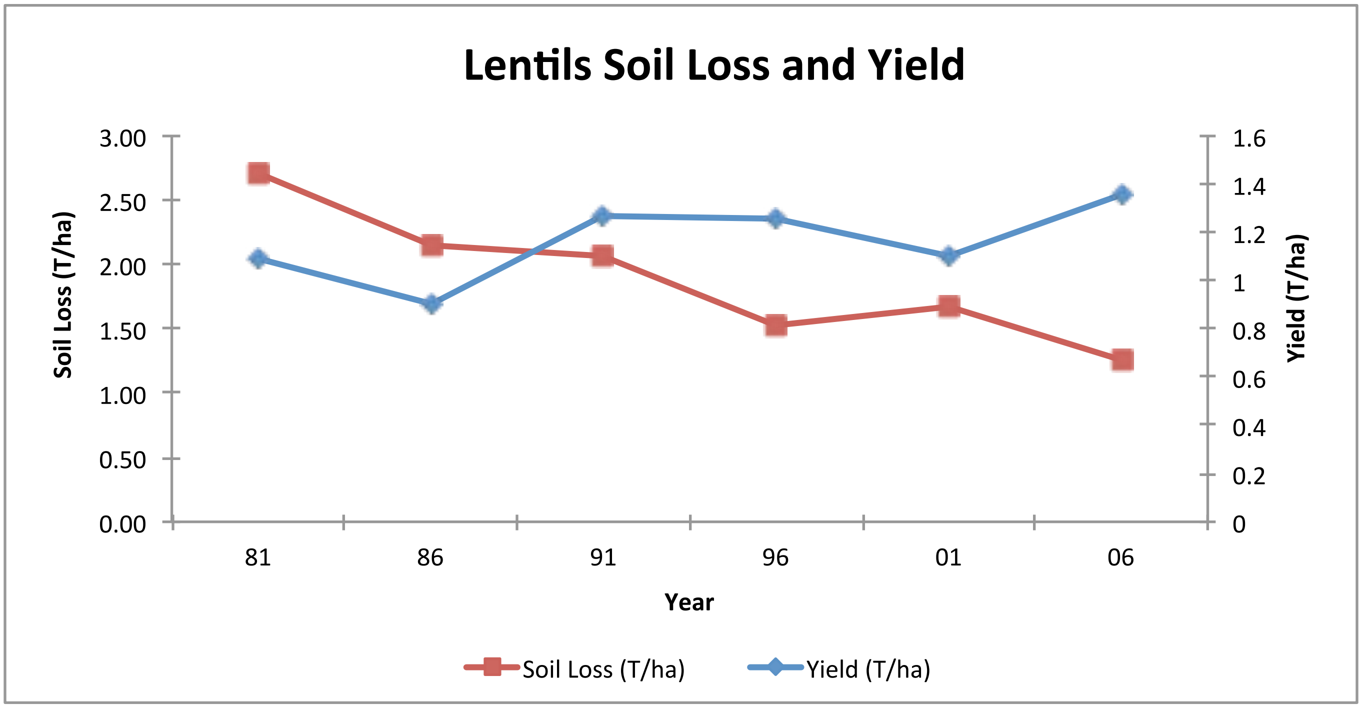
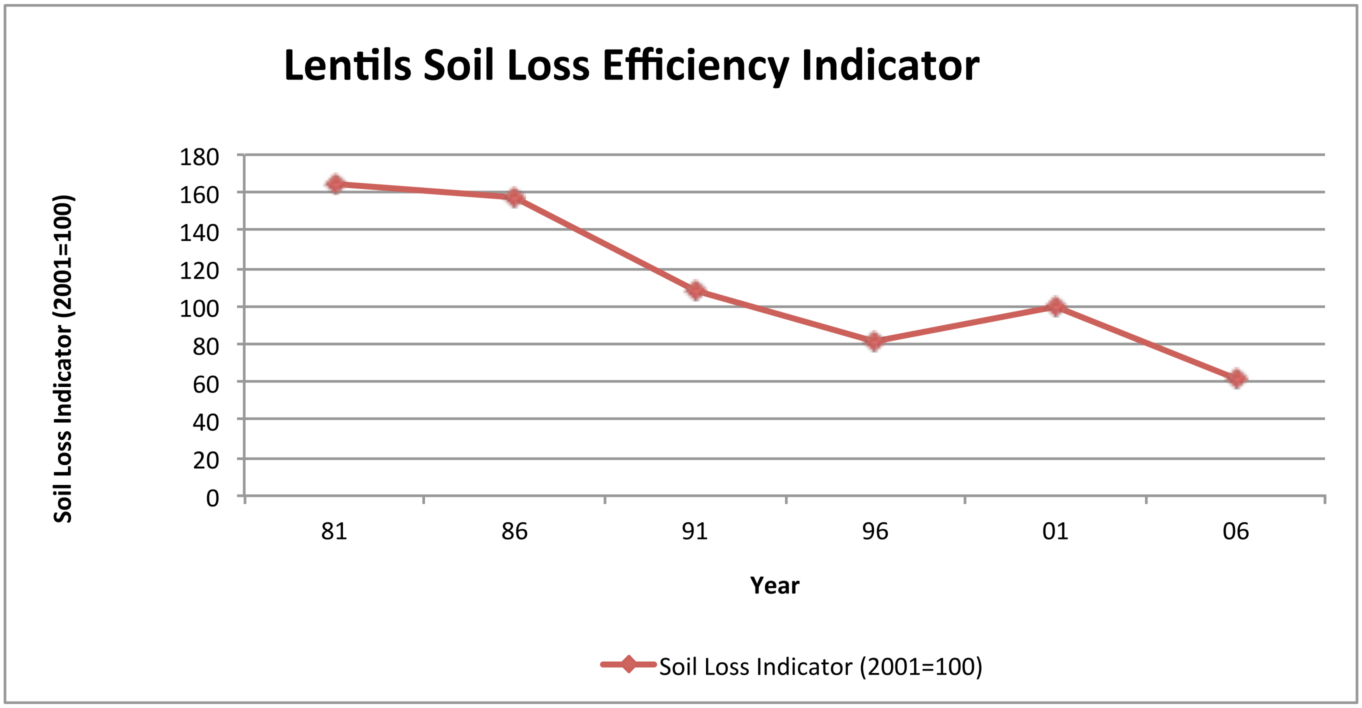


Figure 74: Lentils Soil Loss Efficiency Indicator



Energy Use Indicator

For lentils, energy use per hectare decreased by 17% between 1981 and 2006 (Figure 75). Over the same time, yields increased by 25% (Figure 75) and energy use efficiency improved by 38% (Figure 76).

As with a number of the other crops, the energy use efficiency indicator for lentils suggests a significant improvement between 1986 and 2006, following an initial decline between 1981 and 1986 (Figure 77). This decline in energy use efficiency between 1981 and 1986 appears to have been driven largely by declining yields. Again, over the entire period from 1981 to 2006, soil loss efficiency improved by 38% (Figure 76).

Figure 75: Lentils Energy Use and Yield

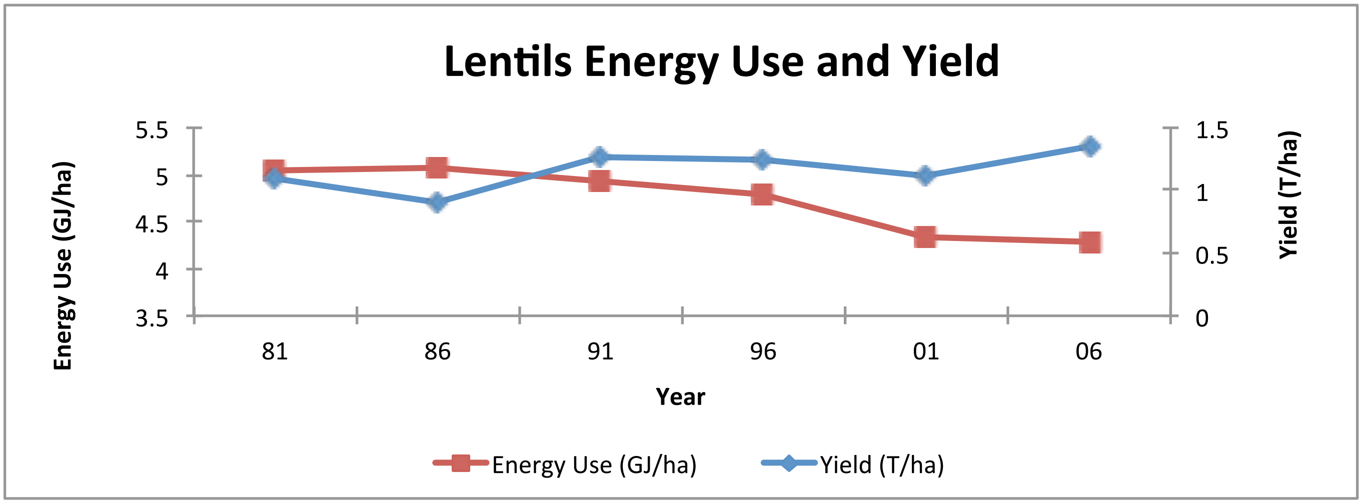
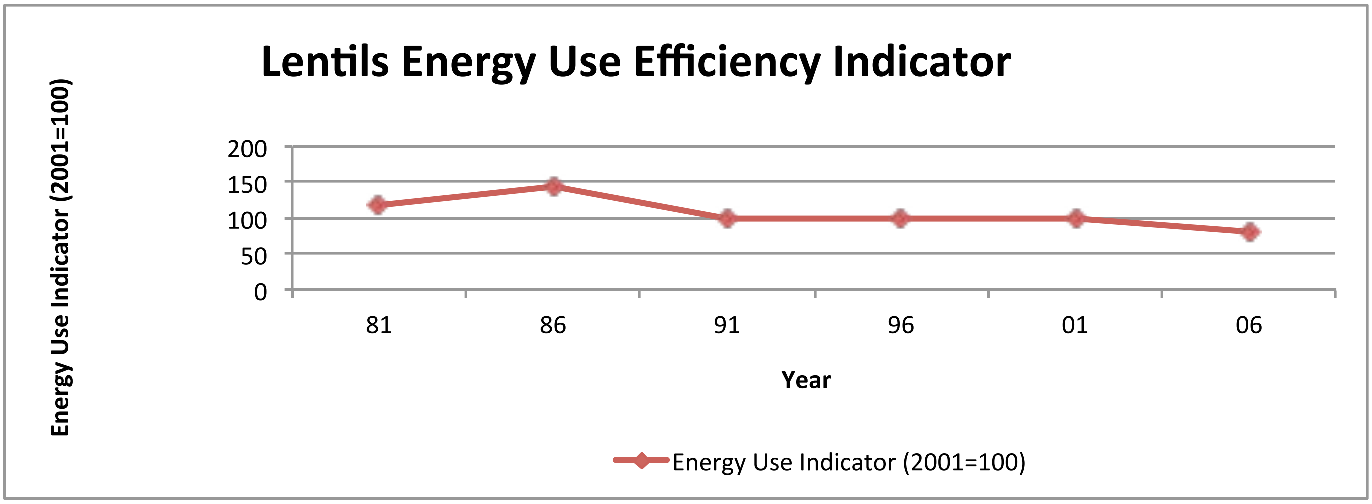


Figure 76: Lentils Energy Use Efficiency Indicator



Climate Impact Indicator

The indicators for the climate impact of lentil production follow a similar trend to the energy use indicators. However, the decline in climate impact efficiency between 1981 and 1986 was slightly greater, and the overall improvement between 1981 and 2006 was also slightly larger. Strong improvement is seen over the last twenty years.

Energy use to produce lentils, on a per hectare basis, decreased by 22% between 1981 and 2006 (Figure 77). With yields increasing by 25% over the same period, climate impact efficiency improved by 42% (Figure 78).

Figure 77: Lentils Climate Impact and Yield

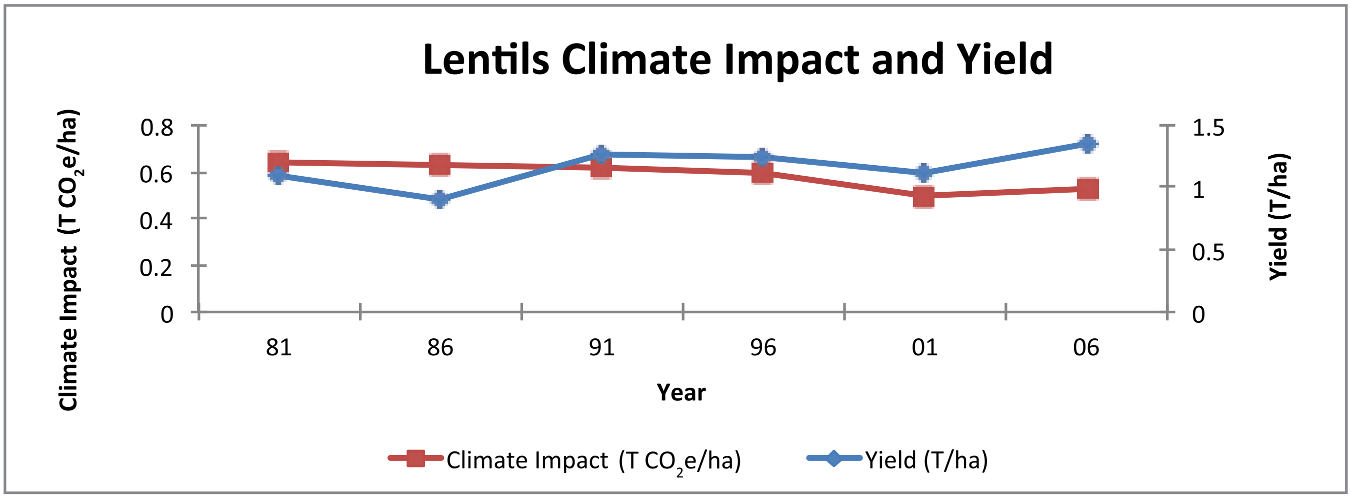
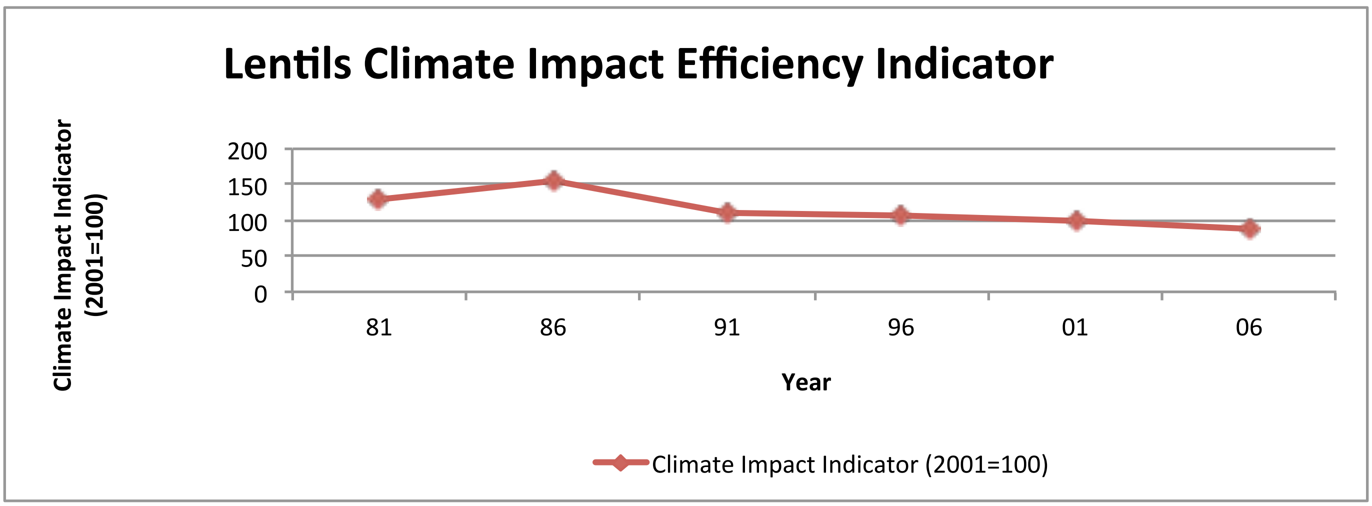


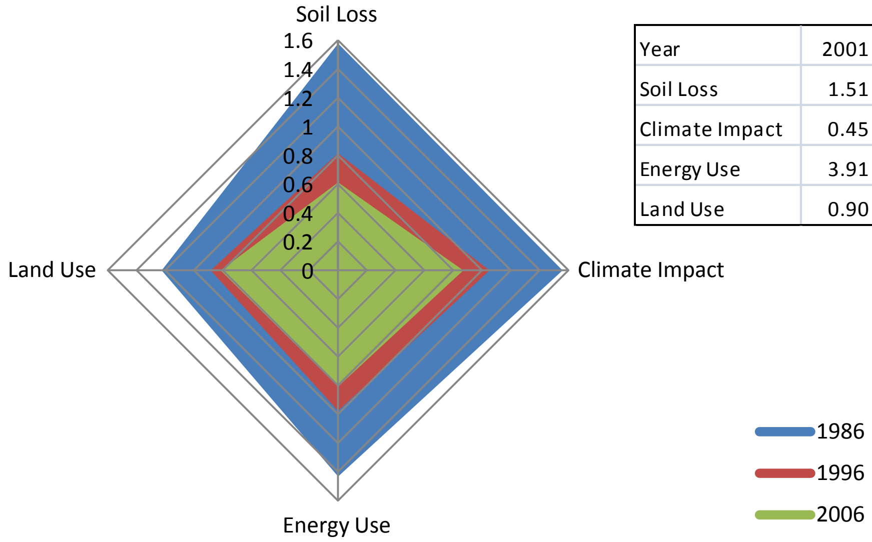
Figure 78: Lentils Climate Impact Efficiency Indicator



Indicator Summary - Lentils

The story for lentils is very positive based on the indicator analysis. There have been consistent improvements in all four indicators between 1986 and 2006 (Figure 79). Between 1981 and 2006, soil loss efficiency improved by 61%, climate impact efficiency by 44%, energy use efficiency by 44%, and land use efficiency by 33%.

Figure 79: Lentils Efficiency Indicators Over Time



Year	2001	Unit
Soil Loss	1.51	T soil/T output
Climate Impact	0.45	T CO_2e/tonne
Energy Use	3.91	GJ/tonne
Land Use	0.90	ha/tonne

Conclusions

This project has involved the consolidation of a significant amount of information from varied data sources that were in several different formats. It has also involved the assessment of how best to create a substantively equivalent set of information to that produced by the Field to Market group in the US.

In order to develop the indicators, several different modelling processes had to be considered, populated with the best available information and then run. Results were tested, tabulated and then reported in a more aggregated format.

As previously outlined, disparities in data availability and model development between Western Canada and the US make it very difficult, and potentially misleading, to compare the Western Canada indicators with the US ones. A significant amount of work would have to be completed in conjunction with the Field to Market group in order to have exactly replicated indicators. Even given directly comparable data, any comparison would have to be made within the context of the different geographic conditions of the two jurisdictions.

On the other hand, important results have been achieved. The process has served to bring together individuals from different areas of expertise, with the goal of developing a basic set of indicators that can be used to engage producers and work with them to continuously improve their practices. It has also identified a number of data gaps that need to be addressed if there is a serious intention to understand the sustainability of different agronomic practices at the farm level.

There were three specific objectives for the study:

1. Demonstrate the progress made in western Canadian cropping systems over the past two decades, with regards to environmental performance

    The results clearly indicate that Canadian producers have been successful in improving sustainability over the past 2 decades. The analysis shows that there has been an improvement in efficiency, in every crop, for all indicators.

2. Establish a baseline against which to monitor future improvements

    The modelling and data collection process that was developed in this study involved the use of a set of Indicator Selection Criteria that are replicable, objective and scalable to different levels of aggregation. As a result, the indicators themselves can be replicated as required. They can also be adjusted as better and more complete data becomes available. As these adjustments are made, the current algorithms can be re-established so that the baseline can be updated, allowing analysis on a go forward basis.

    The modelling and data collection process also demonstrates that some of the metrics used in the Field to Market approach are sub-optimal from a Canadian perspective. The analysis in this report clearly outlines which ones are more transferable to the Canadian context, and how corrective actions could be used in order to address any weaknesses. Field to Market has been very cooperative in this work and would welcome any joint discussions on how the models could be improved and/or made more compatible in the future.

3. Create enabling conditions for stakeholders in Canadian agriculture to contribute to discussion and development of commercial sustainability indicators in the food industry

    The analysis provides the evidence required in order to validate claims that actions are taking place that lead to a more sustainable set of agricultural practices. While the indicators are neither perfect nor complete, they are now available and can be used as the starting point for indicator advancement, improvement, and adoption.

Canadian farmers have historically been seen to be good stewards of the land. As the population continues to become more urban, the average consumer's understanding of the agricultural system becomes more remote. This results in increased difficulty in communicating the work being done to protect the environment in which food is produced. The indicators developed in this report could be used as one way of providing information to the average Canadian about food production and its impact on the environment. While not perfect at this point in time, they provide a starting point for what is likely to be an increasingly popular topic of discussion in the future.

This study was undertaken within a historical context of considerable changes in crop production systems over the past few decades. Crop production has increased in intensity, and efforts to reduce environmental impacts of production have been made in many areas, as identified in the introduction to this report. This work was undertaken with the overall objective of identifying how the impacts of crop production on the environment have changed in recent decades. Substantial improvements have been identified in all the impact areas studied.

A cropping system comprises many farm management practices. In the introduction to this report, we identified reduced tillage, reduced summerfallow, improved nutrient management and increased diversity of crop rotations as key areas where management practices have changed. Crop development, as well as these agronomic changes, has contributed to substantial increases in crop yields. Consequently, some of the improvement demonstrated by the efficiency indicators developed in this study is attributable to crop development.

Attributing causation of reduced environmental impacts to specific management practices always requires a great deal of caution. At one end of the spectrum, reduced tillage is a well defined practice, with substantial research evidence to say that it leads to reduced soil erosion, reduced energy use and reduced climate impact. Details of these relationships are discussed in this report. At the other end of the spectrum, it is very difficult to rigorously quantify the environmental impacts of increasingly diverse crop rotations. It is known that pulses, in particular, benefit other crops in rotations, and that more diverse crop rotations have improved the economics of production. Improvements in the indicators implemented here are partly attributable to increasingly diverse crop rotations. However, it is worth noting that the causative relationship between reduced tillage and improvements in the indicators is better established than that between more diverse crop rotations and improvements in the indicators.

Areas For Further Work

An important output of this project is the identification and prioritisation of areas where further work is needed. While the Project Team has been able to make use of well developed data in some areas (e.g. energy use and climate impact), better data and analysis are clearly needed in other areas. For example, future indicator development relating to land use will depend on analysis and data development that are not yet in place. Given the reality of limited resources for such work, priorities must be established in these areas.

Table 16 presents a prioritised list of the most important weaknesses of the approach adopted for this project, and of the areas where additional effort should be applied to both data collection and analysis.

Table 17: Prioritized List of Weaknesses in the Approach Taken, and Actions Needed

What are the main weaknesses in our approach?	
The failure of the land use indicator to address the key land use issues	This is a well recognized limitation with this analysis as well as the Field to Market analysis. At a minimum, there is a need to determine what the land capability is and to what extent it is being utilized. Strictly using the production per acre/hectare does not give a solid picture of the actual land use and really needs to be put in context.
What are the main weaknesses in our approach?	

The failure to address nutrient management impacts	The issue of nutrient management is becoming more important as land use becomes more intensive. There is a need to establish a protocol for the determination of how best to approach this issue. There are a number of provincial initiatives in this area, and it would be good to select a national level approach that could be included as part of the indicator series.
Lack of local context, failure to address impacts of local areas of intensive production ... macro analysis can hide micro problems	Data limitations on specific regional analysis are significant. However, now that the metrics have been defined it is important to work with regions to initiate the process of data collection at a level that would facilitate regional analysis.
The failure to come up with indicators that are directly comparable to the US ones	There are a number of reasons why the indicators are not directly comparable. Much of this relates to the different cropping systems. On the other hand, it is our opinion that in most cases the indicators developed for Canada are actually more accurate and reflective of the environmental impact of production systems. Regardless, the ability to observe relative change in the indicators is also of significant importance.
Where should we spend the next hour/$ on additional data?	
Geospecifc data on crops grown and management practices • At least beef up surveys – Census of Agriculture, FEMS	As discussed above, this is a critical issue and needs to be addressed. This report has provided the template for the data required and could be used as the basis on which to identify priorities in data collection.
Gaps in Soil erosion data	There is a need to get better soil cover data by crop, an improved representation of landforms and improved field validation of wind erosion. In addition there is the need to obtain an evaluation process for WEPS and RWEQ.
Data on Crop protection products	There is still a shortage of information on the energy required to produce crop protection products. While not as critical as some of the other issues, this information would significantly improve the indicators.
Where should we spend the next hour/$ on additional analysis?	
Analysis of land use data	1.Crop prevalence by census district, from CEEMA 2.Crop prevalence from NAHARP land use? 3.Biodiversity data, from ESTR wildlife habitat indicator (also presented by NAHARP) 4.Impact of annual crop production on the ecological productivity of non-agricultural acres (e.g. drainage reducing the biodiversity of wetlands)
Analysis of other NAHARP data	This could potentially be mined for information on nutrient management issues.
Soil erosion	1. Database development/maintenance and computer programming to support estimation of soil erosion by land managers for specific fields 2. Slope-gradient protocol for Manitoba (guidance for field analysis)
Energy/climate indicators	As identified in the report, there is a need to update the coefficients in these models. Given the focus on this by the general public, the need to validate climate change should be of interest.

Generally, there are five main areas where the analysis has provided evidence that additional data and/or research would be strongly beneficial. These have been summarized, identifying both suggested changes as well as an indication of how additional data could be used.

1. The Land Use Indicator is an area where further work could provide substantial benefits. A key outstanding issue is that of whether the intensity of use of agricultural land is consistent with the productive capacity of the land. Data sources are already in place for Western Canada which could be developed to provide insight into this issue. These are identified in this report.
2. Field to Market has identified several areas for development of indicators in the future, including pesticide and fertilizer use and water quality. This reflects the importance of nutrient management, an area with important scope for improvement on western Canadian farms.
3. Another important area for future work relates to the functional unit of the Field to Market efficiency indicators. Ultimately, it is important to go beyond expressing the relative impact on the environment, per unit of GDP. Aggregate environmental impacts must also be expressed, and compared to absolute environmental conditions. There is a danger that efficiency gains will lead to increased aggregate consumption of a resource when demand is strong, leading to increased pressure on the resource.
4. The time-series indicators presented in this report are the inputs required by integrated models, which can eventually enable us to see system linkages and synergies. By the nature of time-series data, significant time is needed to accumulate it. As a result, it is critical that priority be placed on identification of the process to be used to improve collection, validation and management of this data. This speaks to the urgency of data collection for time series indicators in two key areas:
   - Strengthening and further validating existing data, e.g. the soil erosion data used in this report
   - Collecting additional data, e.g. for land use indicators as proposed in this report.
5. An objective for further work is to demonstrate the aggregate effects of farm practices at the higher-level ecosystem scale. Ultimately, it is critical that correlation and causation be separated and completely understood, if there is to be a focus on motivating appropriate and/or desired behaviour. Farmers need to understand how their actions impact the indicators, and what can be done to improve these impacts. One necessary step in this is to create a farm-level tool that individuals can use to assess how their decisions impact the indicators. Field to Market has developed a tool like this, and the extension of this model into Canada needs to be considered.

The ability to measure the sustainability of agricultural production is likely to become even more relevant in the future. Not only is sustainable production the right thing to do, but it is also becoming a significant point of comparative advantage. As a result it is in the best interests of all stakeholders to work together to refine and improve sustainability measurement. Ultimately, accurate, timely and defendable indicators will become the basis of validating the promise behind a brand related to environmentally friendly agricultural production in Canada. Given the time it takes to collect the time-series data necessary to populate these indicators, it is essential to prioritize this effort and initiate a full time commitment to indicator development and support as soon as possible. The work completed under this project offers an excellent starting point. It is consistent with the work being completed by Field to Market in the US, and uses the best information available for Western Canada at this time. It also serves to identify where the key weaknesses in both data and scientific knowledge are, thus providing a basis for prioritization of actions.

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3. Mr. Paul Barlott, Serecon
4. Dr. Brian McConkey, Agriculture and Agri-Food Canada
5. Dr. Laszlo Pinter, International Institute for Sustainable Development
6. Ms. Aimee Rusillo, International Institute for Sustainable Development

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3. Mr. Sheng Li, University of Manitoba
4. Dr. Laszlo Pinter, International Institute for Sustainable Development (teleconference)
5. Ms. Aimee Rusillo, International Institute for Sustainable Development
6. Mr. Denis Tremorin, Pulse Canada
7. Mr. Mike Grenier, Canadian Wheat Board
8. Ms. Marla Riekman, Manitoba Agriculture/Soil Conservation Council of Canada
9. Mr. Bob Burden, Serecon
10. Ms. Angela Pearson, Serecon

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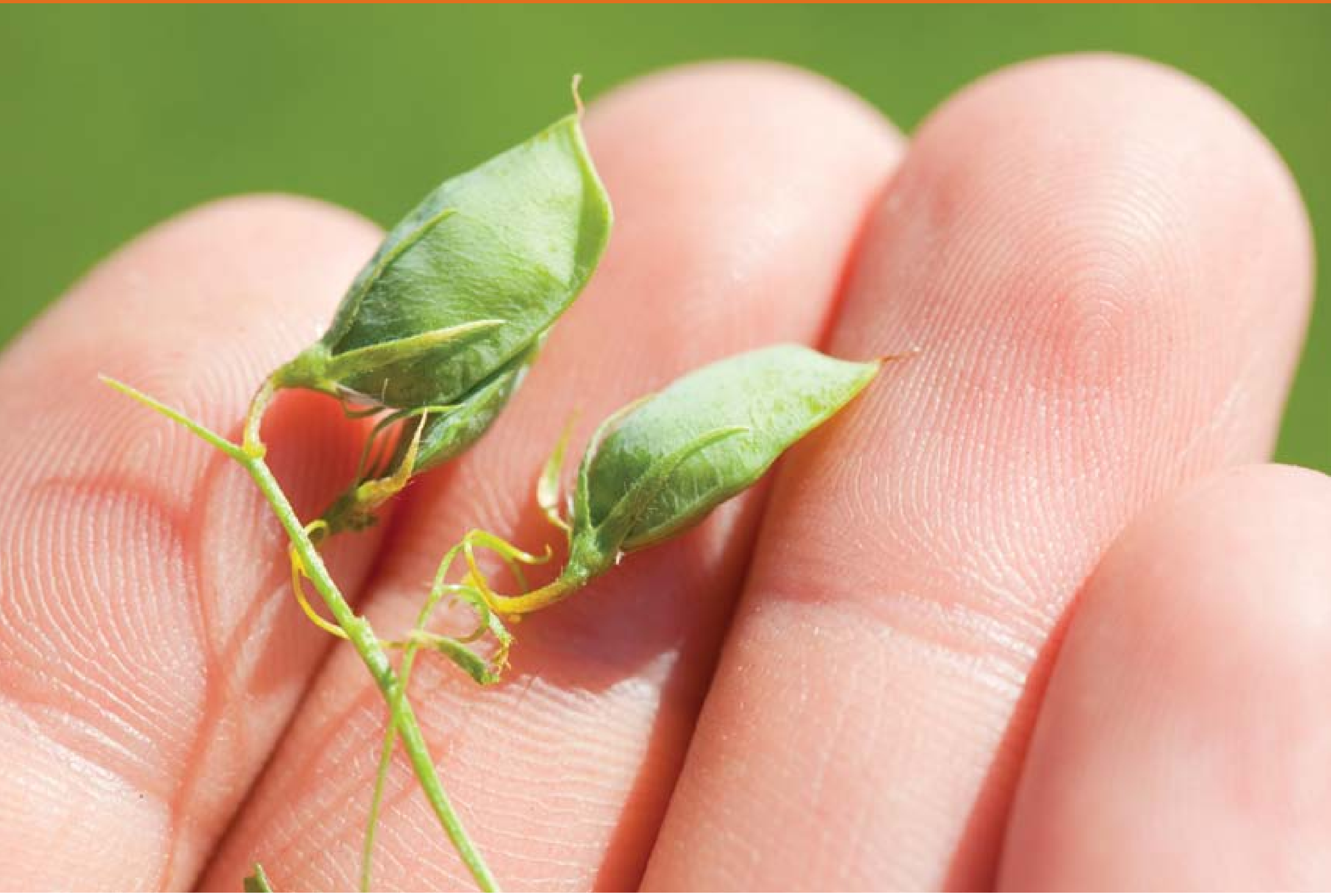

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