Final Report
Application of Sustainable Agriculture Metrics to Canadian Field Crops
2015

Prepared For
Canadian Field Print Initiative

Prepared By
Serecon Inc.

March, 2016

March 3, 2016

Mr. Denis Tremorin
Director, Sustainability
Pulse Canada
1212-220 Portage Avenue
Winnipeg, Manitoba R3C 0A5

Dear Mr. Tremorin:

RE: APPLICATION OF SUSTAINABLE AGRICULTURE METRICS TO CANADIAN FIELD CROPS, 2015
OUR FILE #545411.1

We are pleased to provide you with the Final Report on the above-referenced project. We have enjoyed working with you and value the input that you and the Canadian Field Print Initiative have provided over the past year.

This report outlines the approach taken to expanding the macro-level indicators to include Ontario, and updating them to 2011. It also presents the resulting indicators based on our final runs of data for energy use and climate impact.

This Final Report incorporates the changes discussed with the CFPI Funders Committee on May 28. We look forward to your review of this Final Report, and will answer any questions that arise.

Please contact me by phone at 780-448-7494, or by email at bburden@serecon.ca.

Yours truly,
SERECON INC.

Robert E. Burden, MBA, AVA,P.Ag.
Edmonton Office

Enclosure

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Abstract

This report presents environmental sustainability metrics for Canadian field crop production, developed under the leadership of the Canadian Field Print Initiative (CFPI). The CFPI is working to develop metrics that will promote understanding of the sustainability of Canadian crop production over the long term. The macro-level indicators reported here complement the Canadian Field Print Calculator, which measures performance on the same indicators at the field level.

It is recognized that geography differs widely from region to region across Canada, and consequently, comparison of results between regions is of little relevance. Rather, the CFPI metrics follow the premise that sustainability is about improvement over time, on relevant environmental criteria. Emphasis is placed on demonstrating continuous improvement over time, within a given geographical context.

The CFPI metrics are based on science, and are market-driven and outcome-based. Thus the approach focuses on environmental impacts, rather than practices and processes. Other key principles underlying this work include objectivity, and representation of relevant environmental impacts.

The indicators in this report track progress over the thirty years from 1981 to 2011, as follows:

- Indicators – land use, soil loss, soil organic carbon change, energy use, and climate impact
- Scope – crops and geography:
  - In the prairie provinces – spring wheat, winter wheat, durum wheat, oats, peas, flax, canola, lentils, and soybeans (Manitoba)
  - In Ontario - winter wheat, soybeans, and corn

This report comprises indicators in two distinct formats:

- **Resource impact indicators** – resource impact per unit of area (all the indicators are reported on an area basis, enabling comparison of trends between all indicators)
- **Efficiency indicators** – resource use or impact per unit of production (where data permits, indicators are reported as resource use per unit of crop produced)

Efficiency indicators are reported where crop-specific data is available. This form of indicator focuses on how efficiently resources are being used to meet the increasing demand for food. Increasing yields over the thirty year study period are a key driver of improvements in sustainability, when measured as resource use per unit of crop produced (efficiency indicator). Land use, energy use and climate impact are all reported on this basis. These three efficiency indicators, for all the crops assessed, both in Ontario and on the prairies, showed improvement over the thirty year study period.

When sustainability is reported as resource use per unit of area, the increases in sustainability over time are less pronounced, and small decreases are seen in some crop-geographies for energy use and climate impact.

Due to data limitations, it was not possible to calculate the risk of soil loss and soil organic carbon change on a crop-specific basis. Instead, soil loss and soil organic carbon change were calculated on the basis of land area, i.e. as resource impact indicators. Both soil loss and soil organic carbon change improved considerably over the study period, both in Ontario and on the Prairies.

The results in this report demonstrate that Canadian farmers have achieved considerable reductions in their environmental footprint, between 1981 and 2011.

1.0 Introduction

1.1 Context

The challenge of producing enough food for a rapidly growing population in a sustainable fashion is increasingly on the minds of consumers. As a result, demand for information on the sustainability of agricultural production continues to gain strength. Canadian farmers are continually adopting practices that improve productivity and sustainability. For all these reasons, there is a growing need to monitor these sustainability improvements with outcomes-based indicators built from available data.

Grain companies and food companies are responding to the demands of their customers by asking for validation that producers are following sustainable production practices:

- General Mills has committed to "sustainably source 100% of its 10 priority ingredients by 2020", including wheat, oats, corn, dairy (General Mills News Release, September 2013)
- Unilever intends to source 100% of its agricultural raw materials sustainably by 2020 (Unilever, 2015)
- Walmart is sending out questionnaires to suppliers, asking for more information on sustainability performance and sourcing of commodities (Walmart, 2015)

The Canadian Field Print Initiative (CFPI), is working toward the objective of meeting this demand for information on sustainable production. The CFPI is actively engaged in the development of sustainable agriculture metrics, at the macro level as well as at the farm level.

The work of Field to Market: The Alliance for Sustainable Agriculture, in the United States, has served as a key reference for the early work of the Canadian Field Print Initiative. This applies both to the macro-level indicators outlined in this report, and to the Canadian Field Print Calculator. Field to Market has been a leader in the development of sustainable agriculture metrics in North America.

1.2 The Canadian Field Print Initiative

The CFPI has its roots in a group of Canadian grower associations, agricultural companies, food companies and environmental organizations. These groups initially joined together in 2009 to lead the development of sustainability metrics for Canadian grains, oilseeds and pulses. While the focus has been on Canadian production systems, the metrics developed have followed the design of those built by Field to Market (see Appendix) in the United States.

The CFPI is focused on the development of metrics that are market-driven, science-based and outcomes-based (i.e. emphasis is on impacts, not practices). The CFPI's key objectives include:

- Providing a widely accessible tool and results/benchmarks
- Enabling sourcing of sustainably-produced crops

- Strengthening the industry and informing public policy by documenting sustainability, using publicly available data
- Taking into consideration the sustainability of the entire crop rotation/production system
- Maintaining alignment and seeking collaboration with other initiatives

In 2014, the CFPI was formalized under the Canadian Roundtable for Sustainable Crops (CRSC), as the Canadian Field Print Initiative. Also in 2014, funding was secured from Agriculture and Agri-Food Canada, under Growing Forward 2 (GF2), for the sustainability metrics project entitled "Aligning Canadian Sustainable Agriculture Metrics to the Sustainability Needs of the Global Food Industry". This project comprises three Activities:

1. Development of macro-level sustainability indicators
2. Development of the farm-level Canadian Field Print Calculator
3. A fertilizer use survey

Participants in the Canadian Field Print Initiative include:

- Canadian Canola Growers Association
- Pulse Canada
- Grain Farmers of Ontario
- Prairie Oat Growers Association
- Manitoba Pulse and Soybean Growers
- CropLife Canada
- Fertilizer Canada
- Canadian Association of Agri-Retailers
- General Mills
- Enns Brothers
- Syngenta
- Farmers Edge
- AgriTrend
- Ducks Unlimited Canada

The structure of the CFPI includes an Executive Committee, comprising contributing members who are responsible to Agriculture and Agri-Food Canada (AAFC) for completion of the GF2 project. The larger group of participants comprises the CFPI Steering Group. The CFPI's structure also includes a Technical Resource Group, comprising individuals with relevant technical expertise.

The macro-level indicators, updated in this report, provide the big picture of sustainability trends in Canadian agriculture. While this level of analysis is important, it was recognized that it contains limited information for producers as to how they can improve sustainability within their own operations. The need was identified for a tool that the producer can use to estimate sustainability impacts within his specific operation, with reference to site-specific data on climate, soil and topography. The Canadian Field Print Calculator is such a tool, and has the key benefits of enabling the individual producer to see his performance on sustainability impact areas, in comparison to:

- regional averages (initially provincial averages, but ultimately more local benchmarks)
- his own farm, over time
- his own farm, under alternative management scenarios

The ability of the producer to see the sustainability impacts of alternative management practices, and the impacts of his own operation in comparison to those of his neighbours, has turned out to be a strong motivator of continual improvement in crop production sustainability. This is a key finding of pilot projects conducted in the United States, using Field to Market's Fieldprint Calculator.

1.3 CFPI Macro-Level Indicators

A complete summary of the original sustainability indicators developed for Western Canadian field crops can be found in the 2011 report, "Application of Sustainable Agriculture Metrics to Selected Western Canadian Field Crops" (Pulse Canada et al, 2011). The 2011 report is a predecessor to this one, and can be found on Pulse Canada's web site. The methods used to develop the original macro-level indicators for Western Canada are described in the 2011 report, and are not repeated in detail here.

All the indicators developed and reported in the 2011 report, for all crops, showed improvement from 1981 to 2006.

This report updates the indicators reported in 2011, as well as expanding both the geographic scope of the analysis and the number of crops assessed, and adding a Soil Organic Carbon Change Indicator. This process included:

- Addition of new data from the 2011 Census of Agriculture
- Adjustment of methodologies to reflect changes that have taken place in relevant Canadian research and data development
- Expansion of the indicator set to include production of wheat, corn and soybeans in Ontario, as well as soybeans in Manitoba
- Including Soil Organic Carbon Change in the Climate Impact Indicator, and creating an independent Soil Organic Carbon Change Indicator

2.0 Data and Methods

2.1 Overview of Data and Methods

CFPI Macro-Level Indicators - Principles

There are many possible approaches to measuring sustainability at the macro level. All have strengths and weaknesses. The Canadian Field Print Initiative works from the fundamental premise that what is important is to demonstrate improvement in key areas of environmental impact. Thus the key criterion to demonstrate sustainability is **continuous improvement over time**. Emphasis is on assessing the sustainability of production within the physical context of that production. Under this paradigm, comparison of different crops, or of the same crop in different physical environments, is not an objective.

The following principles govern the development of CFPI macro-level indicators. Indicators are

- **Outcomes-based** – they quantify environmental impacts or causative factors (which are related by coefficients to the environmental impacts)
- **Representative of relevant environmental impact areas** – they capture the most significant sources of impact
- **Objective**
- **Science-based** - based on well-developed methodology
- **Consistent with the intent of Field to Market indicators**
  - Provide crop-specific data on environmental impacts
  - Provide data on environmental impacts on a per unit area basis
- **Temporally representative** – consistent across time, and sensitive to changes over time
- **Regionally representative** – data that works well at smaller or larger scales may not translate to good regional data
- **Collaborative**
  - Facilitate communication between groups with potential to contribute to Canadian indicators over time
  - Tie in with other initiatives
- **Representative of entire production systems** (long-term goal)

Project Scope

This report documents the development of sustainable agriculture indicators for Canada, encompassing the following:

- Crops – spring wheat, winter wheat, durum wheat, oats, peas, flax, canola, lentils, soybeans and corn

- Indicators – Land Use, Energy Use, Climate Impact, Soil Loss and Soil Organic Carbon Change
- Geography – Prairie Provinces and Ontario
- Time frame – 1981-2011

CFPI Process to Update and Expand Macro-Level Indicators in 2015

The updating and expansion of the CFPI's macro-level indicators has followed a similar approach and methodology to the original indicator development undertaken in 2011. It is helpful to distinguish two streams of work necessary to complete this work:

- Updating of existing indicators – this consisted primarily of populating the models developed in 2011 with updated data from the same sources (differences are noted under Data and Methods for each indicator)
- Expansion of geography and crops – this required some systematic assessment of alternative data sets and models, with input from the scientists responsible for them, particularly with the expansion of indicator coverage from the relatively uniform Prairie Provinces into Ontario, which has a markedly different geography

While the methodologies used to develop the original CFPI indicators in 2011 were chosen partly for their ability to apply across Canada, the differences between the prairies and Ontario are significant. It was therefore essential to systematically consider the research and modelling that have taken place in Ontario, while still following the basic principles of indicator development outlined above.

To this end, Serecon organized and facilitated a series of workshops in Ontario in September 2014. While these workshops largely related to the development of the Canadian Field Print Calculator (CFPC) in Ontario, they also provided essential contacts, information and insight relevant to the development of the macro-level indicators. An example of this is the work done in Ontario relating to water quality, both at the provincial level and as applied nationally (NAHARP indicators of water quality). This work will definitely inform future CFPI work on water quality indicators.

A further element of the process to update and expand the CFPI macro-level indicators has been ongoing communication with the scientists and modellers who were involved in the development of the original CFPI indicators in 2011. As in 2011, the CFPI Soil Loss Indicator is built on the AAFC work that feeds into the NAHARP Soil Erosion Indicator. Likewise, the CFPI Energy Use and Climate Impact Indicators continue to be produced from the AAFC work feeding into NAHARP's Greenhouse Gas Indicator.

Indicator Formats

Results for each indicator are presented in two different formats in this report:

1. **Resource impact indicator**. Resource impact per unit of area normalizes the four metrics to a common basis, for comparison.
2. **Efficiency indicator**. Resource use or impact per unit of production. These efficiency indicators illustrate resource impact relative to our ability to meet productivity demands.

These two indicator formats are constructed from three basic sets of data for each crop:

1. Resource impact data
2. Crop yield
3. Resource impact per unit of crop output

Summary of Canadian Field Print Indicator Units (illustrating indicator dimensions)

	Land Use	Soil Loss	Energy Use	Climate Impact
Resource Impact	hectares	tonnes of soil/ hectare	GJoules/hectare	T CO_2e/hectare
Crop Yield	tonne/hectare	tonne/hectare	tonne/hectare	tonne/hectare
Efficiency Indicator	hectare/tonne of crop	tonnes of soil/ tonne of crop	GJoules/tonne of crop	T CO2e/tonne of crop

Where data permits, results are presented graphically in three forms:

1. **Line graph for each crop**, for each indicator, on a per unit of **area basis**. Resource values (e.g. energy use in GJoule/hectare) are plotted by year, for the study period (generally 1981-2011). Shows change over time, on a per hectare basis.
2. **Line graph for each crop**, for each indicator, on a per unit of **production basis** (efficiency indicators). Resource values (e.g. energy use in GJoule/tonne of crop) are plotted by year, for the study period (generally 1981-2011). Shows change over time, on a per tonne of product basis.
3. **Summary spidergram** for each crop, showing the change in all efficiency indicators over time. To facilitate comparison of relative changes over time across multiple indicators, with different units, the spidergram is built from the four efficiency indicators for the crop, each indexed to 1 for the census year 2001. Thus, for example, a 10% change in any indicator appears the same in the spidergram. Trends represented by movement toward the centre of the spidergram (toward a value of zero) are efficiency improvements, or reductions of resource use or impact per unit of food produced.

These graphical representations are consistent with the philosophy that there is no specific end point that defines sustainability. Also in line with Field to Market philosophy, sustainability is represented by diminishing resource impact outcomes over time.

Updated Methods for the 2015 CFPI Indicators – Overview

1. **Soil Organic Carbon Change (SOCC)**: AAFC has developed SOCC data for Census years since 1981. The CFPI reports this data twice, once in a standalone SOCC Indicator, and again as a component of the Climate Impact Indicator. The

CFPI SOCC Indicator shows change over time in soil carbon change, which is in itself an important indicator of sustainability. Soil organic carbon is also an important contributor to climate impact (or, in the case of Canada's Prairies, a credit against climate impact), and for this reason we also report it as part of the Climate Impact Indicator.

2. **Soil Erosion**: The modelling of soil erosion for this report follows a new methodology developed by AAFC. This results in a Soil Erosion Indicator which, unlike the one reported in 2011 for Western Canada, is not crop-specific. AAFC intends to apply the new methodology on a crop-specific basis in the future. Until this has been done, the CFPI will report non-crop-specific soil erosion. As a result, the Soil Erosion Indicator reported here is not crop-specific.

2.2 Land Use Indicator

Land is a primary input for all agricultural production. Agriculture is in competition for land with other land uses, including forestry and urban uses. Crop production involves a large area of land, leading to significant challenges and opportunities for sustainable land use.

The CFPI Land Use Indicator focuses on changes in use of cropland for production, over the study period, from 1981 to 2011.

The Land Use Indicator we report here is the same as that reported for Western Canada in 2011. It would be preferable to calculate land use on the basis of planted area, rather than harvested area, since planted area accounts for crop area abandoned due to to adverse weather or other conditions. This would give a more inclusive indication of the impacts of such losses on overall production efficiency. However, we have found that Canadian data for areas planted to crops does not go back to 1981, for most crops. As a result, we have reported land use on the basis of harvested area.

The Land Use Indicator is a simple inverse of yield. It provides a perspective that emphasizes use of the land resource in terms of crop production. The results presented for the Land Use Indicator include:

1. Yield, in tonnes of crop per harvested hectare
2. Land Use Indicator, in harvested hectares per tonne of crop

The Land Use Indicator is calculated from Census of Agriculture crop areas and production data (reported in Statistics Canada's Field Crop Reporting Series). This data set also provides the area basis for the Energy Use and Climate Impact Indicators. This approach enables reporting of the Land Use, Energy Use and Climate Impact Indicators on as consistent an area basis as possible.

Note that the Census of Agriculture crop areas used to calculate the Land Use Indicator are only reported for Census years, i.e. one year out of five. Analysis showed that the year-to-year variability inherent in crop yield data (due to weather and other factors) caused considerable distortion of thirty-year time trends, when only the seven Census year data points were used. To address this, and to reflect crop yields from all years in the time period reported, the yield data from the Census of Agriculture dataset was adjusted using annual yield data from CANSIM (these two datasets were found to be different, but relatively consistent internally). In this way, annual, moving-average yield data was generated for each crop. This annual, moving-average yield data, based on Census of Agriculture crop areas, was used to calculate the Land Use Indicator.

2.3 Soil Loss Indicator

Canada does not have a detailed history of agricultural land use, cropping and management practices. Field to Market's Soil Loss Indicator is based on much more detailed data from the National Resource Inventory (NRI) of the US National Resources Conservation Service (NRCS). In spite of this lack of available data in Canada, a soil loss indicator was created in 2011 that is similar to the US indicator.

The 2011 Western Canada macro-level Soil Loss Indicator was built using a methodology developed by the National Agri-Environmental Health Analysis and Reporting Program (NAHARP). This work was funded by AAFC, and resulted in development of the Soil Erosion Risk Indicator (SoilERI) across Canada. While not based on the high density of data available in the US, SoilERI leverages the data available in Canada to provide fairly accurate spatial and temporal trends, when interpreted at provincial and national scales.

SoilERI was reported as the total soil loss (tonnes/ha/year), encompassing water, wind and tillage erosion indicators:

- The Water Erosion Risk Indicator (WaterERI) was calculated based on Universal Soil Loss Equation (USLE) methodology, where regression equations were adjusted based on intensive runs of the Revised Universal Soil Loss Equation (RUSLE) and RUSLE 2
- The Wind Erosion Risk Indicator (WindERI) was calculated based on the Wind Erosion Equation (WEQ), however this method was not validated like the water and tillage erosion calculations
- The Tillage Erosion Risk Indicator (TillERI) was calculated as the product of tillage erosivity and landscape erodibility

SoilERI was calculated as the sum of WaterERI, WindERI, and TillERI for each segment in each landform. The total soil erosion risk value was then area-weighted for each landform, crop type and tillage system, and aggregated to the value for each segment at the ecodistrict, provincial and national (Western Canada) levels.

Due to the landscape, topography, and agricultural practices in western Canada, soil erosion in this region is mainly in the form of downward movement of soil on the eroding portions of hill slopes. In other words, almost all of the eroded soil stays within the field boundary (within-field erosion). For this reason, soil erosion in western Canada should be reported as the most erodible segment within the area in question.

Based on critical review of the Western Canada Soil Loss Indicator reported in 2011, several changes were made to the macro-level indicator in 2015:

- In 2015, the macro-level Soil Loss Indicator was updated with 2011 Census of Agriculture data. Integrated data from the 2011 erosion dataset provided by AAFC included WaterERI and TillERI for each SLC polygon in each Census year from 1981 to 2011. In this dataset, these erosion risk indicator values are calculated based on the most severely erodible slope segment of a two-dimensional hill slope. WaterERI is based on soil erosion from the middle-slope segment, whereas TillERI is based on soil erosion from the upper-slope segment, due to these segments being the most severely erodible slope segment under each type of soil erosion in Western Canada.

- Unlike the 2011 macro-level indicator, these data were not separated by crop type. The integration of the 2011 Census data removed the functionality of the SoilERI to separate soil erosion by crop type. Consequently, for this report, all crops within a given geographic unit have been assigned the same rate of soil erosion. This enables us to report the best available soil erosion data. The crop-type separation is to be included in the SoilERI when separated 2011 data is available.
- In 2015, the updated Census data was aggregated from the SLC polygon level to the ecodistrict level, using polygon area-weighted averages of WaterERI and TillERI within each province. Ecodistrict area-weighted averages were then used to aggregate WaterERI and TillERI values from ecodistrict to provincial levels. Soil ERI is reported as the sum of WaterERI (mid-slope segment) and TillERI (upper-slope segment).
- Wind erosion is not included in the macro-level Soil Loss Indicator in this report, for two reasons. First, a high level of uncertainty still surrounds the available modelled estimates of wind erosion for Canada. As well, while the prairie provinces are considered to have a relatively high risk of soil erosion for Canada, wind erosion in this region has been found to be minimal. One caveat that applies to this methodology is the application to eastern provinces (e.g. Ontario), where wind erosion may play a significant role in total soil erosion.
- The Soil Loss Indicator is presented in this report for Ontario cropland, and for Prairie Provinces cropland. Values reported represent estimated risk of soil loss, in tonnes of soil per hectare of cropland per year.

2.4 Energy Use Indicator

Crop production involves many uses of energy, ranging from the production of crop inputs and machinery to the burning of fuel to perform field work.

The CFPI Energy Use Indicator captures the major energy-intensive activities necessary for crop production. As with the other CFPI indicators, emphasis is on demonstrating how energy use to produce crops has changed over the study period, from 1981 to 2011.

The 2015 CFPI Energy Use Indicator includes estimates of the following categories of farm energy use:

- Fuel for farm field work – tillage, seeding, manure/fertilizer application, weed control, harvesting
- Gasoline/diesel for farm transport vehicles
- Electricity
- Heating fuel
- Production of fertilizer and pesticide
- Production of machinery

The Energy Use Indicator reported here uses essentially the same methodology, applying essentially the same algorithms, as used in 2011, to produce the original Western Canada Energy Use Indicator (see Pulse Canada et al, 2011).
The Energy Use Indicator is presented in this report in two forms:

1. Energy use per harvested hectare
2. Energy use per tonne of crop produced (calculated by dividing 1, above, by yield)

This Energy Use Indicator is based on a data run provided by AAFC early in 2015. This differed from the data provided for the 2011 Western Canada indicators in that it included data for the 2011 Census year, and data for wheat, soybeans and corn produced in Ontario. The data provided comprised energy intensities, on a harvested area basis.

2.5 Climate Impact Indicator

Canadian agriculture contributed 8% of Canada's greenhouse gas emissions in 2013 (Environment Canada, 2015). In turn, agriculture is susceptible to the impacts of climate change resulting from greenhouse gas emissions.

The CFPI Climate Impact Indicator demonstrates how the climate impact of crop production has changed over the study period, from 1981 to 2011. It includes the terms incorporated in the Energy Use Indicator, converted to CO_2 equivalents (T CO_2e). In addition, it includes the climate impact of nitrous oxide emissions, in T CO_2e and an estimate of Soil Organic Carbon Change (SOCC). Thus, the 2015 CFPI Climate Impact Indicator includes estimates for:

- The energy use categories listed above under the Energy Use Indicator
- Direct nitrous oxide emissions
  - From nitrogen fertilizer application (both chemical and organic)
  - From nitrogen that becomes available after crop residue decomposition
- Indirect nitrous oxide emissions
  - From leaching/runoff
  - From volatilization
- Soil organic carbon change (SOCC)
  - From tillage changes
  - From summerfallow frequency changes
  - From changes between annual crops and perennial hay or pasture

The nitrous oxide elements of the CFPI Climate Impact Indicator use the same methodology as the Western Canada Climate Impact Indicator reported in 2011 (see Pulse Canada et al, 2011). Nitrous oxide emissions were calculated using the Intergovernmental Panel on Climate Change (IPCC) Tier 2 methodology. Emissions were estimated as the product of nitrogen inputs and specific emission factors.

The Climate Impact Indicator is presented in two forms:

1. Climate impact per harvested hectare
2. Climate impact per tonne of crop produced (calculated by dividing 1, above, by yield)

Both forms of the Climate Impact Indicator show both

- the contribution of energy use and nitrous oxide emissions (but not soil carbon change), and
- the total climate impact, incuding soil carbon change

Thus the magnitude of the contribution of SOCC to climate impact is clearly illustrated.

The 2015 Climate Impact Indicator is based on a data run provided by AAFC in early 2015 for energy use and nitrous oxide, and a run of soil organic carbon change data provided by AAFC in December, 2015. These runs provide for

- updating of the 2011 indicator to incorporate 2011 Census data
- expansion of the geography and crops covered to include wheat, soybeans and corn in Ontario
- incorporating SOCC into the Climate Impact Indicator, to provide a more comprehensive estimate of climate impact
- incorporating updated emission factors and global warming potentials.

The data provided comprised energy intensities, nitrous oxide intensities, and soil carbon change, on a harvested area basis.

In Canada, estimation of direct nitrous oxide emissions from agricultural soils follows a country-specific (Tier II) methodology, at the regional scale, developed by Rochette et al (2008). In this methodology, the default constant IPCC N_2O emission factor for nitrogen inputs is replaced with a climate-dependent factor that increases with increasing moisture levels. This generally results in the application of higher emission factors in Ontario than on the prairies, owing to the relatively humid climate in Ontario.

In addition to this, the nitrous oxide emission factor applied for Ontario (but not the one for the Prairies) increased over the study period, to reflect increasingly humid conditions in eastern Canada (X. Verge, personal communication, April 2, 2015).

In turn, the Climate Impact Indicators in this report reflect the impact of varying moisture levels, throughout Canada and across time, on nitrous oxide emissions. This is seen in the results presented below.

The SOCC portion of the Climate Impact Indicator is based on AAFC modelling of SOCC, with data provided to the CFPI in December, 2015. This data comprises SOCC estimates in CO2 equivalents, for the agricultural land (land in crops, improved pasture and summerfallow, but not unimproved pasture) in each province. Thus the agricultural land (excluding unmanaged pasture) is the area over which the carbon change should be allocated, to be consistent with the carbon modelling approach (D. Worth, personal communication, Nov. 26, 2015). Using this approach, the carbon change for a given spatial area is independent of crop type. As a result, while the energy use and nitrous oxide elements of the CFPI Climate Impact Indicator are calculated and reported on a crop-specific basis, the SOCC element is not. This has the implication that the SOCC component is not strictly comparable to the others.

This creates an issue for the reporting of SOCC as part of the CFPI Climate Impact Indicator. There is considerable complexity and uncertainty in the measurement of SOCC, and in the science relating to the contributions of different crops. The issue of allocating SOCC across crops was discussed by the CFPI's Technical Review Committee in October 2015. It was decided at that time that SOCC should be allocated across crops on the basis of each crop's share of the rotation, i.e. on the basis of crop areas. Note that, since the CFPI is reporting climate impact on a per-hectare basis (and on a per-hectare basis adjusted for yield), this amounts to reporting the same rate of soil carbon gain or loss for all crops in a given geography.

Data Limitations

Fertilizer application rates represent a data gap for analysis of climate impact from crop production in Canada. In this analysis, provincial recommended nitrogen application rates were taken from Yang et al, 2007. This dataset contains significant inaccuracies, for example application of nitrogen to pulse crops such as peas and lentils is probably overestimated.

This data gap surrounding fertilizer management in Canada was identified during the development of the 2011 indicator report (Pulse Canada et al, 2011). As a result, the Growing Forward 2 project, "Aligning Canadian Sustainable Agriculture Metrics to the Sustainability Needs of the Global Food Industry", comprises a Fertilizer Use Survey, as well as the macro-level indicator work reported here, and the development of the Canadian Field Print Calculator.

The Fertilizer Use Survey will provide data on nutrient management practices in Canadian crop production, with data being collected from 2014 to 2017. The data collected will provide for improved quantification of current and historic fertilizer use for future versions of the macro-level indicators in this report.

Of particular importance for environmental sustainability, two key points must be noted about this new data that is becoming available from the Fertilizer Use Survey:

1. the Fertilizer Use Survey will provide extensive data on the adoption of 4R Nutrient Stewardship practices
2. the new data will reflect the importance of source, place and timing of fertilizer application, unlike the current data which only accounts for application rate

Data collection for the Fertilizer Use Survey began in the winter of 2014. An online survey was conducted, engaging

- 400 Western Canada producers (plus top-up surveys) – canola, peas, spring wheat
- 250 Ontario and Quebec producers – corn, soybeans

The tables below present fertilizer application rates from both data sources, for comparison, revealing substantial differences between the two. Based on this preliminary survey data, on the Prairies, the recommended application rates used for the present report are much lower than actual rates for canola, much higher for peas, and much lower for spring wheat. For Ontario, the recommended rate is somewhat higher than the actual rate for corn, and lower for soybeans.

Fertilizer Application Rates, Prairie Provinces

	Fertilizer Application Rates (kg N/ha)					
	Canola		Peas		Spring Wheat	
	Recomm.	FUS	Recomm.	FUS	Recomm.	FUS
Alberta	85	110	40	16	55	96
Saskatchewan	75	105	25	9	35	92
Manitoba	90	125	15	11	80	115

Recomm. = recommended nitrogen application rates (Yang et al, 2007) - used in modelling of CFPI macro-level indicators

FUS = Fertilizer Use Survey, 2015, Canadian Field Print Initiative - average rate of nitrogen applied in 2014 (in fields where nitrogen was applied)

Fertilizer Application Rates, Ontario

	Fertilizer Application Rates (kg N/ha)			
	Corn		Soybeans	
	Recomm.	FUS	Recomm.	FUS
Ontario	170	154	0	16

Recomm. = recommended nitrogen application rates (Yang et al, 2007) - used in modelling of CFPI macro-level indicators

FUS = Fertilizer Use Survey, 2015, Canadian Field Print Initiative - average rate of nitrogen applied in 2014 (in fields where nitrogen was applied)

This data demonstrates the importance of improved fertilizer application data, given both the disparity between the two datasets, and the importance of nitrogen fertilizer use as a driver of both energy use and nitrous oxide emissions. Also important for sustainability, nitrogen fertilizer enables increased crop yields, which directly increase sustainability when assessed on an output basis.

Modelling Limitations

Nitrous Oxide from Crop Residues of Grain Legumes. An additional weakness in the modelling of climate impact relates to residues left on the fields by grain legumes. Nitrous oxide emissions from nitrogen that becomes available after crop residue decomposition, in the case of grain legumes, are likely still overestimated in the climate impact indicators presented here. This issue was identified in the 2011 indicator report (Pulse Canada et al, 2011).

In this report, the nitrous oxide emissions from crop residues are estimated from

- Crop-specific estimates of the amount of above-ground and below-ground crop residue, and the nitrogen content of each (sourced from Janzen et al, 2003), and

- Site-specific emission factors (the same emission factors are used for all direct nitrous oxide emissions)(X. Verge, personal communication, June 28, 2015)

Of the crops covered in this report, peas have relatively high amounts of crop residue nitrogen, resulting in a relatively high estimate of nitrous oxide emissions for peas. However, research has been conducted by Zhong et al (2011) comparing nitrous oxide emissions from crop residues of grain legumes (lentils and peas) to those from a cereal crop (spring wheat). This work suggests that nitrous oxide emissions are not directly related to biological N_2 fixation by grain legumes such as peas and lentils. Rather, it was found that, in the short term, nitrogen-rich residues of N_2-fixing crops have a limited impact on nitrous oxide emissions.

To summarize, the modelling used to generate the Climate Impact Indicators reported here assumes that fixed nitrogen in the crop residues of grain legumes, such as peas and lentils, contributes to nitrous oxide emissions in the same way as nitrogen in other crop residues, e.g. wheat. It is likely that this leads to overestimation of nitrous oxide emissions from the residues of peas and lentils. The Climate Impact Indicators in this report should be interpreted in this context (R. Lemke, personal communication, July 14, 2015).

Nitrous Oxide from Crop Residues of All Crops. There is evidence that crop residues release nitrogen (as nitrous oxide) more gradually than does nitrogen fertilizer. This has raised the question of whether the same emission factors should be applied to both fertilizer nitrogen and crop residue nitrogen, as in the modelling behind the indicators reported here. The contributions of crop residues and other nitrogen sources to nitrous oxide emissions are presently being actively researched in Western Canada.

The release of nitrous oxide from fertilizer is highly moisture-dependent, and highly variable. However, it has not been demonstrated to be higher than that from crop residues, when averaged over time. Thus, for macro-level modelling over a thirty-year time period, the use of the same emission factors for nitrogen fertilizer and crop residue nitrogen still reflects current understanding of nitrous oxide sources (R. Lemke, personal communication, July 14, 2015).

2.6 Soil Organic Carbon Change Indicator

The CFPI reports soil organic carbon change (SOCC) both as an indicator of SOCC alone, and as part of the CFPI Climate Impact Indicator (see previous section). This dual reporting of SOCC has the following advantages:

1. SOCC is, in itself, an important indicator of sustainability. The CFPI SOCC Indicator demonstrates progress over time in this key sustainability area. Uniquely, soil carbon responds to what happened in the past, and can swamp the impacts of current management practices, so it is important to highlight what is happening with SOCC alone.
2. SOCC is also a major component of whole-system greenhouse gas accounting. Inclusion of SOCC in the CFPI Climate Impact Indicator provides an indicator that captures all the major contributors of greenhouse gas emissions from Canadian crop production, and aligns with international conventions and standards for carbon footprinting.

AAFC produces a Soil Organic Carbon Change Indicator which assesses how organic carbon levels change over time, in Canadian agricultural soils (McConkey et al, 2010). Change in soil organic carbon gives an indication of soil health. It also provides an estimate of the amount of CO_2 sequestered as soil organic carbon in agricultural soils. This dataset is well suited to the reporting format of the CFPI SOCC Indicator.
AAFC's SOCC Indicator is based on the methodology used for Canadian National Inventory reporting by Environment Canada. The AAFC SOCC Indicator uses the Century model to predict the rate of change in organic carbon in Canada's agricultural soils, due to changes in land use and land management, including:

- Tillage changes
- Summerfallow frequency changes
- Change between annual crops and perennial hay or pasture
- Breaking native grass for cropland
- Clearing forests for agricultural production

The CFPI SOCC Indicator reported here is derived from AAFC's SOCC data. The CFPI SOCC Indicator reflects the impact of the three management practices on soil organic carbon – tillage changes, summerfallow frequency changes and changes between perennial and annual crops. While management changes drive the majority of SOCC in the regions reported here, it should be noted that the CFPI SOCC indicator does not account for the conversion of forest and grasslands to agriculture.

Thus the CFPI SOCC Indicator demonstrates broad trends in SOCC in prairie and Ontario agricultural land, attributable to farm management practices. "Agricultural land", in the context of the indicator reported here, includes all land in crops, improved pasture and summerfallow, but does not include unimproved pasture.

Note that these SOCC trends relate to the entire crop production system rather than to any specific crop. These results are reported as SOCC, in T CO_2e/ha/year, on agricultural land, by year. Negative values indicate a loss of carbon from the soil to the atmosphere, and positive values indicate sequestration of carbon from the atmosphere.

3.0 Results

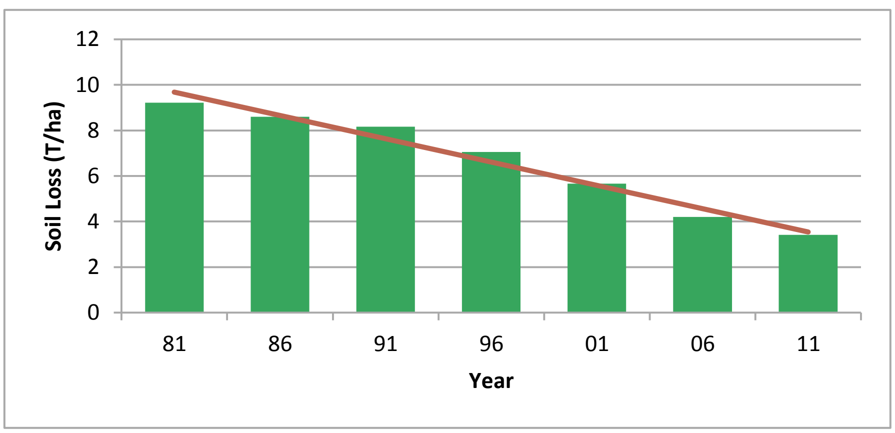
3.1 Soil Loss Indicator

Prairie Provinces

The reduction in risk of soil loss from Canadian cropland between 1981 and 2011 has been dramatic. Most of this change occurred between 1991 and 2006. Figure 1 shows the risk of soil loss on prairie cropland decreasing from over 9 T/ha/year in 1981 to less than 4 T/ha/year in 2011.

The decrease in all forms of soil erosion across Canada is largely attributable to the widespread adoption of conservation tillage, particularly no-till (Lobb et al, 2010). On the Prairies, specifically, the risk of soil erosion has dropped as a result of widespread adoption of conservation tillage, particularly no-till, in combination with reduced use of summerfallow. On the prairies, the share of cropland in the very low soil erosion risk class increased from 49% in 1981 to 86% in 2006. (Lobb et al, 2010). As well, some of the more erodible land on the Prairies has been converted from annual crops to perennial forages and tame pasture (McConkey et al, 2012).

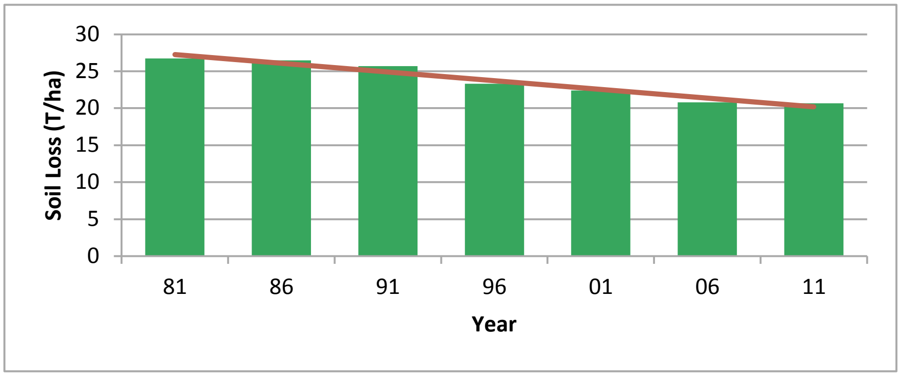
Figure 1: Soil Loss per Hectare, Prairies



Ontario

In Figure 2, the risk of soil loss on Ontario cropland is seen to have fallen from about 27 T/ha/year in 1981 to just over 20 T/ha/year in 2011. This is a substantial improvement, with the share of Ontario cropland in the very low soil erosion risk class increasing from 18% to 29% between 1981 and 2006. During the same time period, the share of Ontario cropland in the very high risk class decreased from 33% to 17% (Lobb et al, 2010). This improvement is largely the result of reduced tillage (see below).

Figure 2: Soil Loss per Hectare, Ontario



Context Relevant to Risk of Soil Erosion – Ontario and the Prairies

As noted above, substantial improvements have been made in the risk of soil loss both in Ontario and on the Prairies. The risk of soil loss on the Prairies, on the basis of cropland area, decreased by 57% over the study period, as compared to 25% in Ontario. Adoption of reduced tillage practices (62% decrease in conventional till from 1991 to 2006 on the Prairies, 39% reduction in Ontario) has been a strong positive driver in both regions.

Differences between the contexts of production in Ontario and on the Prairies underlie both the higher overall risk of soil loss in Ontario, and the greater reduction in the risk of soil loss on the Prairies. Ontario includes the Mixedwood Plains Ecozone (southwestern Ontario), which has the highest erosion risk in Canada, for reasons including:

- Water erosion is a constant threat in Ontario, where large, intense rainstorms occur regularly
- The western part of Ontario's agricultural area has large areas of cropland on hummocky landforms with maximum slopes of 10% or greater, creating a high risk of both water and tillage erosion
- Row crops of corn and soybean produced with conventional tillage have relatively high risks of soil erosion. The acreage of corn has been constant throughout the study period, but the acreage of soybeans has almost quadrupled

In short, Ontario's combination of moist climate, steep terrain (soil landscapes with high erosion risks) and cropping systems with high erosion risks, leads to serious overall levels of risk of erosion (Lobb et al, 2010).

3.2 Soil Organic Carbon Change

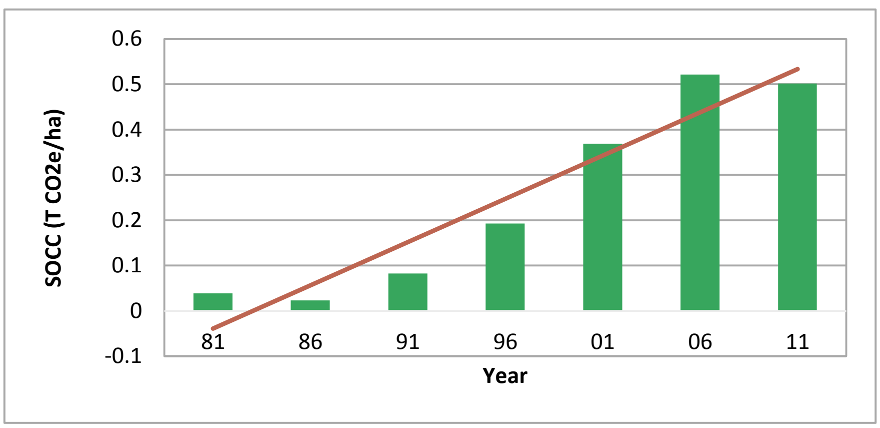
Prairie Provinces

Figure 3 shows a strong increase in the rate of carbon sequestration by prairie agricultural soils, between 1981 and 2011. SOCC was barely positive in the 1980's, indicating a low level of sequestration in prairie soils. By 2006, the rate of carbon sequestration had increased to 0.5 T CO_2e/ha/year. This is a substantial offset to the greenhouse gas emissions from crop production on the Prairies, which ranged from 0.45 T CO_2e/ha to 1.3 T CO_2e/ha in 2011.

The increase in soil carbon on the Prairies from 1981 to 2006 resulted primarily from reduced tillage and summerfallow (McConkey et al, 2010). Note that soil carbon increases driven by these management changes cannot be sustained indefinitely. Rather, they will drop off with the rate of implementation of the management changes.

The decrease in carbon sequestration in the prairie provinces between 2006 and 2011 reflects both a decrease in the rate of adoption of reduced till and no-till, and a shift in crop production systems from perennial to annual crops (D. Cerkowniak, personal communication, February 11, 2015).

Figure 3: SOCC per Hectare of Agricultural Land, Prairies

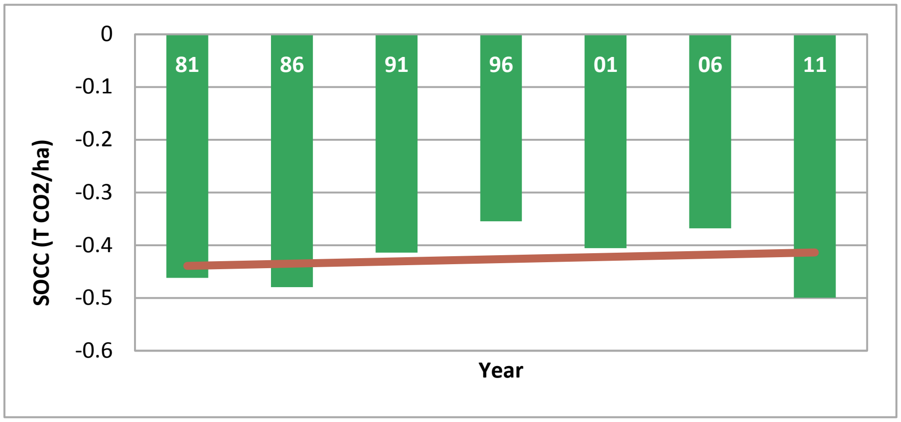


Ontario

Figure 4 shows a steady rate of soil carbon loss from Ontario agricultural land between 1981 and 2011. On average, during the study period from 1981 to 2011, Ontario agricultural land has lost soil carbon at a rate exceeding 0.4 T CO_2e/ha.

Soil carbon loss from Ontario agricultural land has been driven by reduced areas of hay and pasture in favour of annual crops, as the cattle industry shifted from Ontario to Western Canada. Meanwhile, the negative impact of this land use change on Ontario's soil carbon levels has been partially offset by adoption of conservation tillage in Ontario (McConkey et al, 2010).

Figure 4: SOCC per Hectare of Agricultural Land, Ontario



Differences Between the Prairie and Ontario Contexts Relevant to Soil Organic Carbon Change

Losses of soil organic carbon can be slowed (or gains of soil organic carbon can be increased) by the following practices (McConkey et al, 2010):

- Decreasing soil erosion
- Reducing tillage intensity
- Reducing summerfallow
- Using cover crops
- Periodically producing forages and crops that leave large quantities of residue

Historical practices, as well as recent practice changes, have a large impact on current soil organic carbon levels in Canada. Prior to 1981, decades of tillage and summerfallow practices on the Prairies had reduced soil carbon to very low levels. Consequently, the adoption of improved management practices such as reduced tillage and summerfallow had the effect of rebuilding this lost soil carbon since 1981. This situation contrasts with Ontario, where soil organic carbon levels benefited from the use of land for production of forages (pasture and hayland), prior to 1981. Shifting this land base into annual crops has had the effect of lowering soil organic carbon levels in Ontario since 1981. Both historical and more recent practices are important, and both must be taken into account to provide the full context of the state of soil organic carbon in any given region.

Land Use Changes on the Prairies and in Ontario, between 1981 and 2006, have had opposite impacts on SOCC as estimated by NAHARP, and as presented in this report. These SOCC estimates are based on the area of agricultural land: agricultural land, in this context, includes all land in crops, improved pasture and summerfallow (but not unimproved pasture) (personal communication, D. Cerkowniak, 9 February, 2015). Significant land use changes include:

- On Canada's Prairies, between 1981 and 2006, summerfallow area declined by 64%, primarily resulting in an increased area of land in crops (T. Huffman and W. Eilers, 2010). Area in crops increased by 19% during this time. Given the area basis defined above for SOCC estimation, this means that the area of SOCC estimation on the Prairies has shifted to land uses increasingly conducive to carbon sequestration (from summerfallow to land in crops).

- Between 1981 and 2006, cattle numbers in Ontario declined by 32%, allowing the area of pasture to be reduced by 48% (T. Huffman and W. Eilers, 2010). Increases in the proportion of land in more intensive annual crops came from this decrease in pasture, and from decreases in idle land. Given the land base defined above for estimation of SOCC, this means that agricultural land in Ontario shifted toward uses increasingly conducive to loss of soil carbon (from pasture to land in crops).

Land Management Changes. The use of conservation and no-till on cropped land more than doubled in Canada between 1991 and 2006 (T. Huffman and W. Eilers, 2010). This trend has had a positive impact on SOCC both on the Prairies and in Ontario.

- On the Prairies, the area under conventional till decreased by 62% between 1991 and 2006
- In Ontario, the area under conventional till decreased by 39% between 1991 and 2006

Approaches to reducing tillage need to be specific to different regions of Canada (Soil Conservation Council of Canada, 2004). The benefits of seeding directly into wheat and barley stubble in Western Canada have been widely demonstrated. However, in Eastern Canada, where different crops are produced, under higher-moisture weather conditions, different approaches need to be evaluated.

In summary, the 1981-2011 study period has seen benefits to soil organic carbon levels resulting from adoption of reduced tillage, by producers on the Prairies and in Ontario. At the same time, land use changes relating to shifts in production have affected the Prairies and Ontario asymmetrically. In Ontario, pasture has given way to annual crops, due to economic factors external to the individual producer that have caused the cattle industry to shift westward, and Ontario production to shift from perennial to annual crops that are generally more profitable. This land use change has been detrimental to soil carbon levels. Meanwhile, on the Prairies, reduced use of summerfallow has been beneficial to soil carbon levels.

Soil Management Practices. A variety of practices are being used by Ontario producers to maintain and build soil carbon levels. As identified above, the modelling of soil carbon change reported here accounts for changes in tillage, summerfallow, and annual vs. perennial crop production. Ideally, soil management practices that maintain and increase soil carbon levels would also be modelled, but, to date, this analysis is not available. Consequently, important soil management practices that are becoming prevalent in Ontario are not reflected in the indicators in this report.

The following practices are part of a strong movement in Ontario to maintain and build soil carbon levels (C. Brown, personal communication, July 10, 2015):

- Use of cover crops that add organic matter to the soil (e.g. grasses that have extensive, fibrous root systems)
- Crop rotations including forages (e.g. red clover) and cereals
- Addition of organic amendments, including manure, compost, biosolids
- Improved crop residue management

The following observations provide an estimate of the extent of implementation of some of these practices in Ontario (C. Brown, personal communication, July 17, 2015):

- About a million acres of winter wheat is planned each fall (this goal is not always reached, depending on soybean harvest/planting conditions and weather)
- The majority of cash crop farms have some winter wheat in rotation, and most have some red clover as a cover crop. Other cover crops are also coming into use, e.g. oats, cereal rye, oilseed radish and crimson clover and cover crop mixes.
- Dairy farms contribute substantially to sustainability by using rotations with coverage from alfalfa/grass forage stands for 3 or 4 years. A typical dairy rotation is: grain corn – silage corn (or soybeans) – cereals (oats/barley) underseeded to alfalfa/grass mix – forage – forage. As well, manure is applied to forage crops immediately after harvest, and ahead of corn crops in fall and/or spring.
- Biosolids and compost are applied mainly to cash crop fields ahead of corn, adding significant organic matter to fields that otherwise would receive none
- Residue management is increasing, and varies by location within Ontario. Much residue management consists of no-till soybeans and no-till wheat, but there is also some more aggressive tillage ahead of corn (in a corn – soy – wheat rotation) to deal with the wheat straw and/or cover crop.

3.3 Energy Use Indicator

Canada-wide, energy use has remained fairly constant over the past 30 years. Included in this is energy used for synthesis of nitrogen fertilizers, and for field operations. Synthesis of nitrogen fertilizers has increased substantially over the study period, as consumption of nitrogen fertilizers has increased. Energy use for field operations has fallen significantly over the study period, primarily due to adoption of reduced and no-till by Canadian farmers, and also due to development of more efficient machinery. Over time, energy costs from increased use of nitrogen fertilizer and energy savings from reduced tillage have largely offset each other (Verge and Dyer, 2014).

The carbon footprints of the legumes were significantly lower than those of the non-legume crops, as a result of not needing to apply as much synthetic nitrogen fertilizer. The highest CO_2 emission intensities were for corn, winter wheat and canola, again owing to their high requirememts for nitrogen fertilizer (Verge and Dyer, 2014).

3.4 Climate Impact Indicator

The CFPI Climate Impact Indicator reported here combines energy use, nitrous oxide emissions and soil organic carbon change.

Differences Between the Prairie and Ontario Contexts Relevant to Climate Impact

Regional Differences in Climate Impact. Geographical differences between Ontario and the Prairies affect the climate impact indicators. Nitrous oxide emission intensities in Ontario are from two to four times higher than on the Prairies, as a direct result of the more humid climate in Ontario. An additional factor contributing to the higher nitrous oxide emissions in Ontario is the high application rate of nitrogen fertilizer required by high-yielding crops, such as corn (Verge and Dyer, 2014).

Change Over Time in Climate Impact. Climate impact, on an area basis, increased moderately over the study period (1981-2011) for the three Ontario crops studied: corn, soybeans and winter wheat. This trend is likely due in large part to the combination of increasing yields over the 30-year study period, and a wetter climate than that seen on the Prairies. Yield is a major factor driving nitrous oxide emissions. Increasing yield leads to increased amounts of nitrogen remaining in the fields in the non-harvested portion of the crop, i.e. crop residues. This leads to increasing nitrous oxide emissions associated directly with the crop residues, and to increased indirect nitrous oxide emissions from leaching and runoff, due to the increased nitrogen contained in crop residues. In addition to this, the nitrous oxide emission factor applied for Ontario (but not the one for the Prairies) increased over the study period, to reflect increasingly humid conditions in eastern Canada (X. Verge, personal communication, April 2, 2015).

Note that climate impact, on the basis of production, decreased over the 30-year study period for production of corn, soybeans and winter wheat in Ontario.

Context: Impact of Uncertainty Surrounding Nitrous Oxide Emissions from Crop Residues on the Climate Impact Indicator

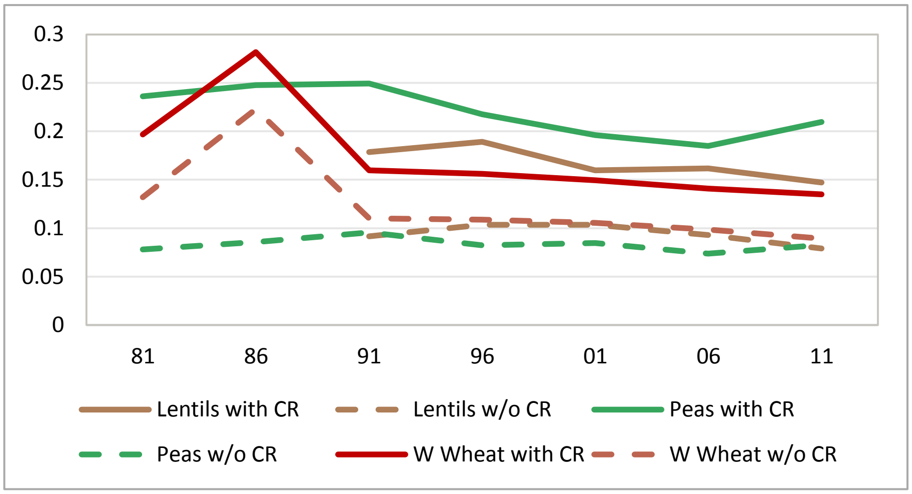
As stated in section 2.5 above, nitrous oxide (N_2O) emissions from crop residues are a subject under active research in Canada. A high level of uncertainty surrounds the quantification of these emissions. This is particularly true for legume crops, where the residues have a high nitrogen content.

Ongoing research suggests that N_2O emissions from legume crop residues may be much lower than previously assumed. Research with the potential to confirm this will be completed and reported within the next two years.

Meanwhile, the modelling of N_2O emissions reported here is based on previously established assumptions. This includes the assumption that N_2O is emitted from different sources – fertilizer nitrogen and crop residue nitrogen – at the same rate. As a result, there is a possibility that N_2O emissions from crop residues, and particularly those from legume crops, are substantially overestimated in this report.

This is illustrated in Figures 82 and 83. Figure 82 shows the contribution of N_2O emissions from crop residues to total N_2O emissions, for lentils, peas and winter wheat grown on the prairies. This in turn provides an illustration of the impact on overall N_2O emissions in the event that it is confirmed that N_2O from crop residues has been seriously overestimated.

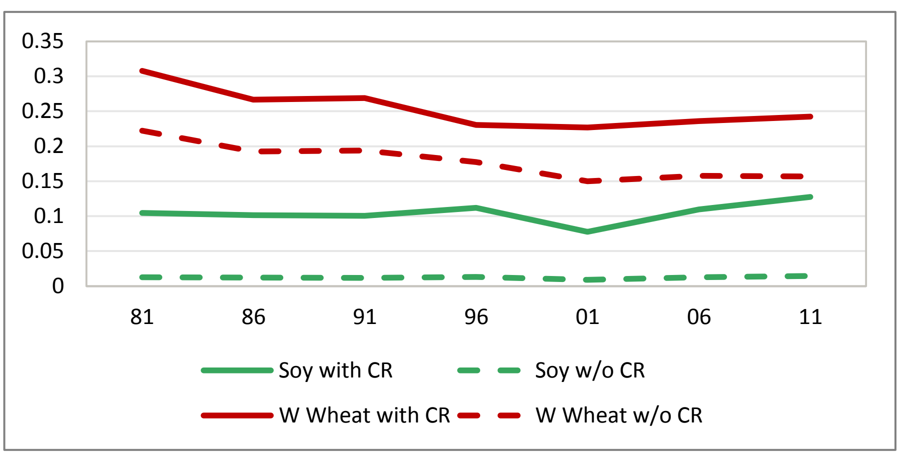
Figure 82: Nitrous Oxide per Tonne (T CO_2e/Tonne) – Lentils, Peas and Winter Wheat, Prairies



As seen in Figure 82, a high proportion of N_2O emissions from production of legume crops is attributed to crop residues in our analysis – almost a half for lentils, and over half for peas. A considerably lower share of N_2O emissions from winter wheat production is attributed to crop residues – well under half. Thus, of these three crops, a future reduction of the estimated N_2O emissions from crop residues will reduce climate estimates most for peas, and least for winter wheat.

In Figure 83, Ontario production of soybeans and winter wheat are compared in the same way. About a third of winter wheat's N_2O emissions, and almost all of the N_2O emissions of soybeans, are attributed to crop residues. If N_2O emissions from crop residues are indeed overestimated, then N_2O emissions from winter wheat production may be significantly less than estimated here, but N_2O emissions from soybean production could, in reality, be only a fraction of the estimates in this report.

Figure 83: Nitrous Oxide per Tonne (T CO_2e/Tonne) – Soybeans and Winter Wheat, Ontario



Of all the crops studied here, the uncertainty around N_2O emissions from crop residues has much the strongest impact on soybeans. As a crop where fertilizer nitrogen is assumed to be absent (Yang et al, 2007)(due to biological fixation of nitrogen in soybeans), N_2O emissions from soybean production are strongly dominated by crop residues. If crop residue N_2O emissions are overestimated, then soybeans will be the most extreme case of the resulting overestimation of climate impact.

It should also be noted that soybean production has among the lowest overall estimated N_2O emissions of the crops studied here. As well, over time, soybeans have been integrated into cropping systems at the expense of wheat and corn acres in Ontario, and of wheat and canola acres in Manitoba. To this extent, soybean production has been good for agriculture's climate impact, as a result of replacing crops whose production involves higher N_2O emissions.

3.5 Spring Wheat, Prairie Provinces

Land Use Indicator

The trend in the efficiency of land use in the production of spring wheat is clearly seen in Figures 5 and 6, which allow us to observe the changes over a period of 30 years. Agronomic developments have led to substantial yield improvements, resulting in a much more effective and efficient use of the production land base. These yield improvements are seen in Figure 5, which shows steady increases in the yield of spring wheat from 1981 to 2011. Expressed per unit of spring wheat produced, land use efficiency has improved by 35% (Figure 6) over the same period.

Figure 5: Spring Wheat, Prairies - Tonnes per Harvested Hectare

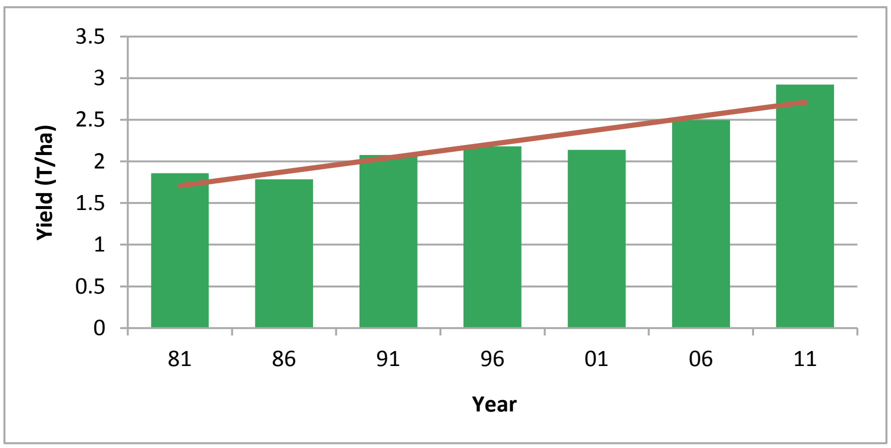
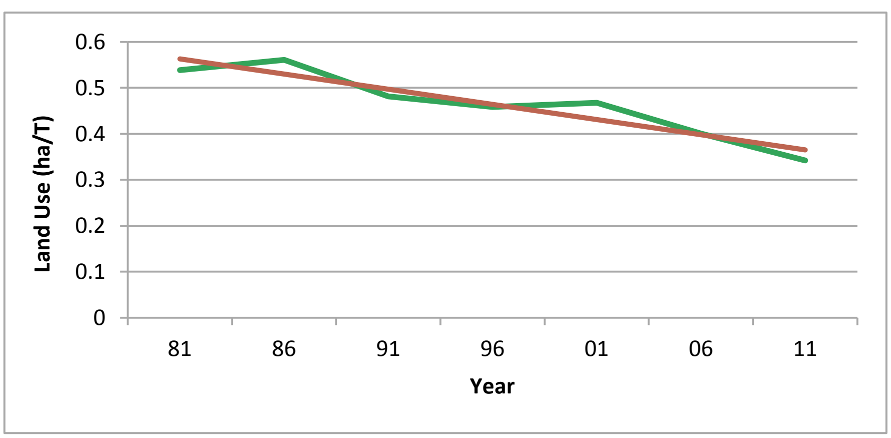


Figure 6: Spring Wheat, Prairies - Harvested Hectares per Tonne



Energy Use Indicator

Improvements in energy use have also been dramatic. Energy use in production of spring wheat decreased by 6% between 1981 and 2011, on a per hectare basis (Figure 7). On a per unit of output basis (Figure 8), energy use was reduced by 39% during the same time period. The yield of spring wheat increased by 59% during this period. These trends suggest that further improvements can be expected.

Figure 7: Spring Wheat, Prairies - Energy Use per Harvested Hectare

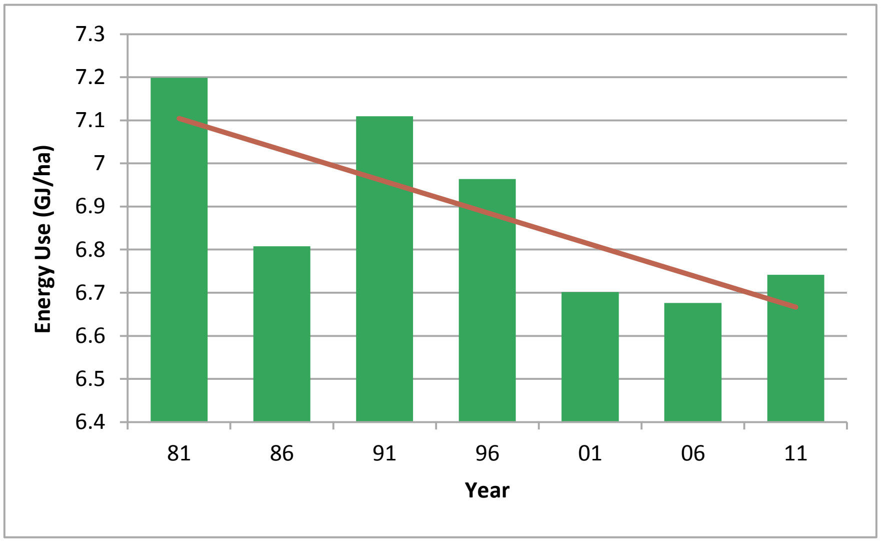
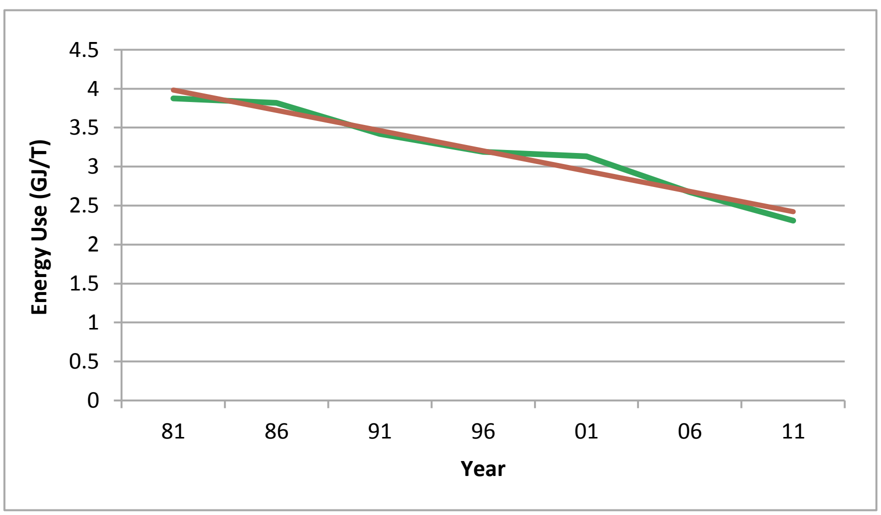


Figure 8: Spring Wheat, Prairies - Energy Use per Tonne



Climate Impact Indicator

Not surprisingly, the climate impact indicators for spring wheat follow similar trends to the energy use indicators, combined with the soil carbon indicator. The model suggests an improvement of 67% on a per hectare basis (Figure 9), between 1981 and 2011. On a per unit of output basis, the improvement was 80%, over the same period of time (Figure 10). Again, yields improved by 59%.

Figure 9: Spring Wheat, Prairies - Climate Impact per Harvested Hectare

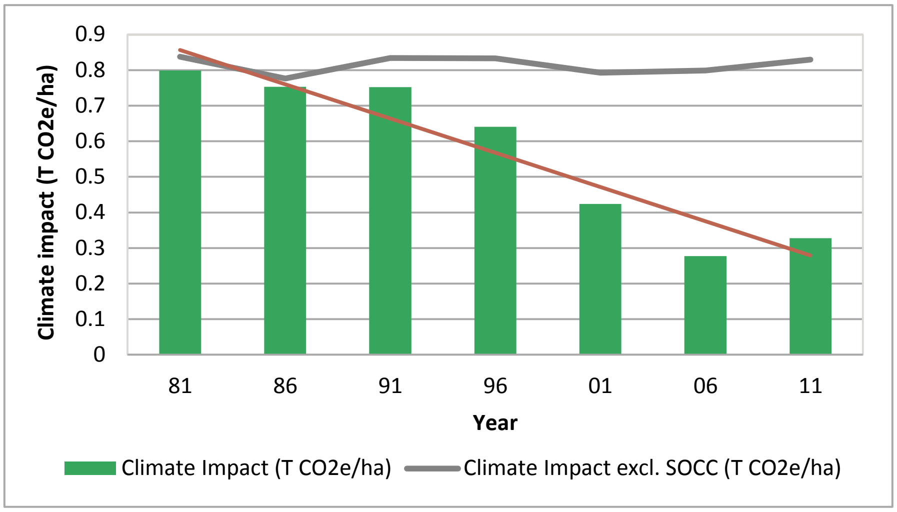
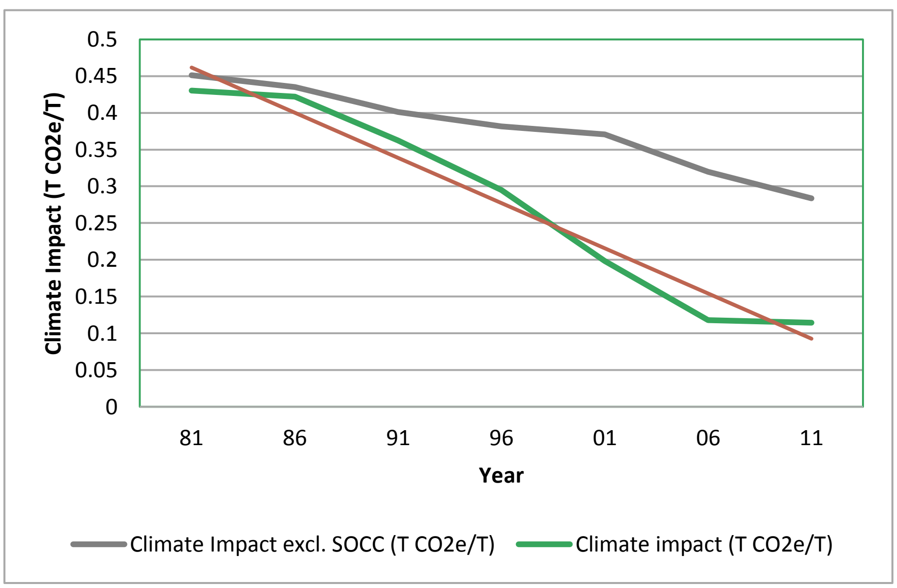


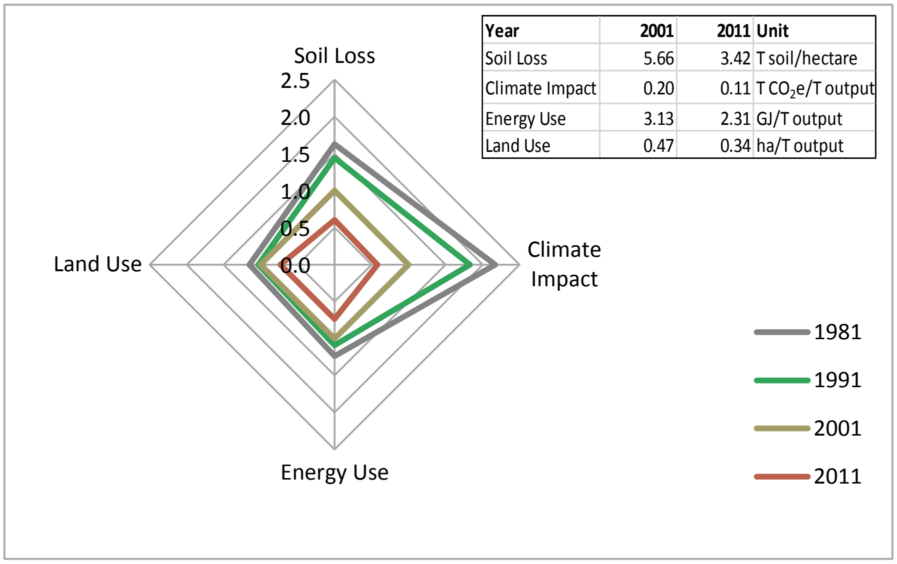
Figure 10: Spring Wheat, Prairies - Climate Impact per Tonne



Indicator Summary – Spring Wheat, Prairies

In summary, the story for spring wheat is a very good one. As can be observed in Figure 11, all of the efficiency indicators improved consistently between 1981 and 2011. Figure 11 shows improvement in soil loss on prairie cropland by 57% (not specific to production of spring wheat), between 1981 and 2011, on the basis of cropland area. Over the same time period, per tonne of spring wheat produced, energy use improved by 39%, climate impact by 80%, and land use by 35%.

Figure 11: Spring Wheat, Prairies – All Indicators



3.6 Winter Wheat, Prairie Provinces

Land Use Indicator

Average yields of winter wheat have shown similar increases to those seen for spring wheat. The yield of winter wheat has increased between 1981 and 2011, and particularly from 1996 onward (Figure 12). This has allowed for considerably improved land use efficiency (Figure 13). From 1981 to 2011, land use per unit of output decreased by 40% (Figure 13). This improvement is driven by consistent yield increases over the past 15 years, following decreases in the early 1980's (Figure 12).

Figure 12: Winter Wheat, Prairies - Tonnes per Harvested Hectare

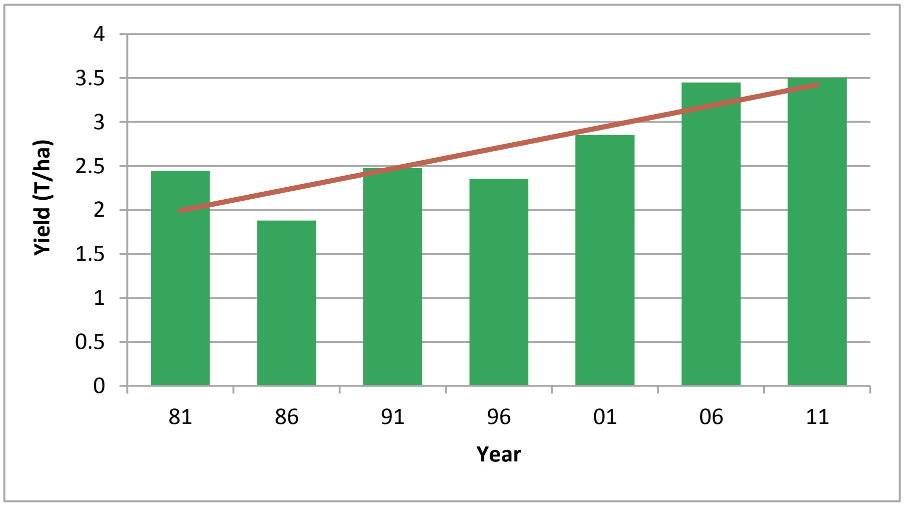
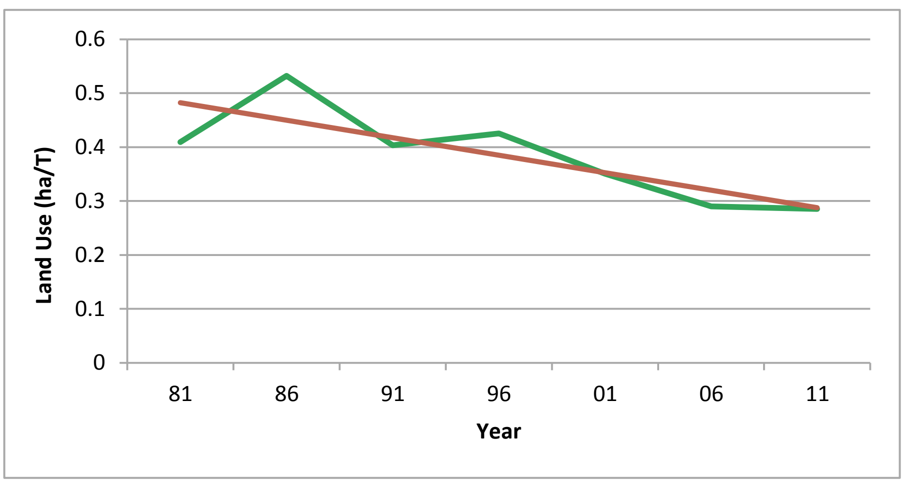


Figure 13: Winter Wheat, Prairies - Harvested Hectares per Tonne



Energy Use Indicator

The use of energy in winter wheat production on the Prairies has decreased by 11% from 1981 to 2011, on a per hectare basis (Figure 14). Over the same period, energy use per unit of output has improved by 48% (Figure 15). Energy use per unit of output actually increased between 1981 and 1986, but has improved dramatically since 1986.

Figure 14: Winter Wheat, Prairies - Energy Use per Harvested Hectare

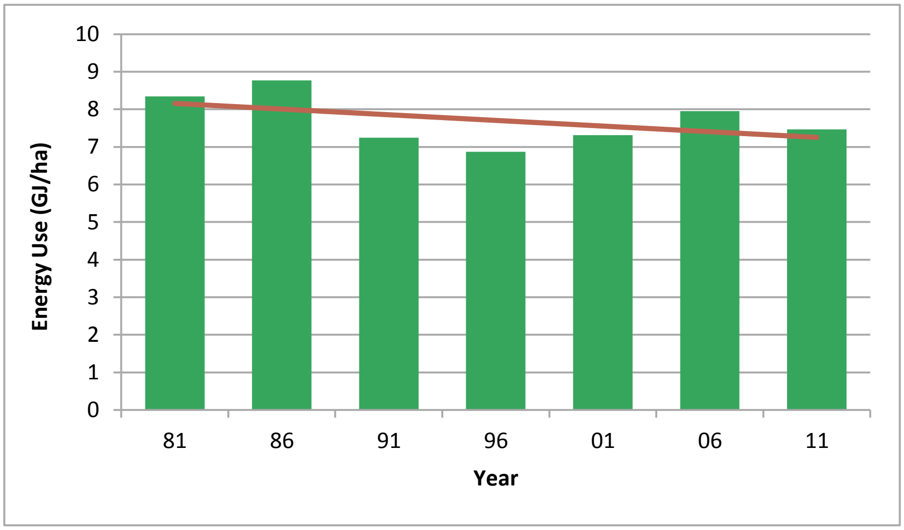
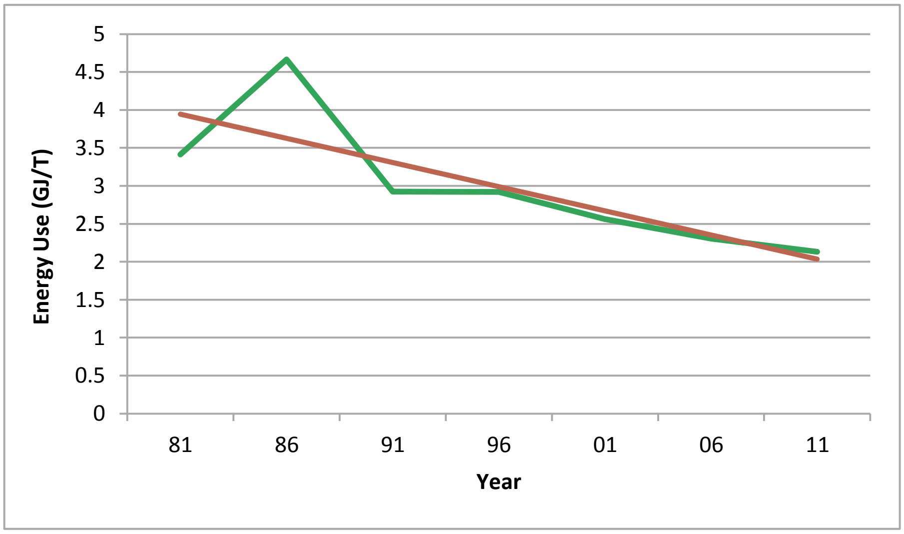


Figure 15: Winter Wheat, Prairies - Energy Use per Tonne



Climate Impact Indicator

The indicators of climate impact for winter wheat production follow similar patterns to those for energy use, but with more pronounced decreases due to increasing sequestration of soil carbon. Climate impact per hectare decreased by 63% between 1981 and 2011 (Figure 16), and climate impact decreased by 80% on a per unit of output basis (Figure 17). The Climate Impact Indicator has improved steadily since 1986, when based on winter wheat output.

Figure 16: Winter Wheat, Prairies - Climate Impact per Harvested Hectare

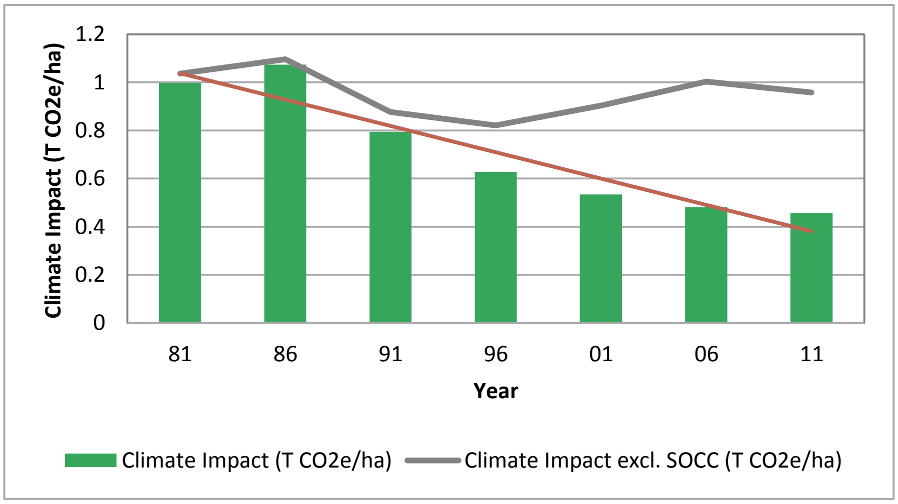
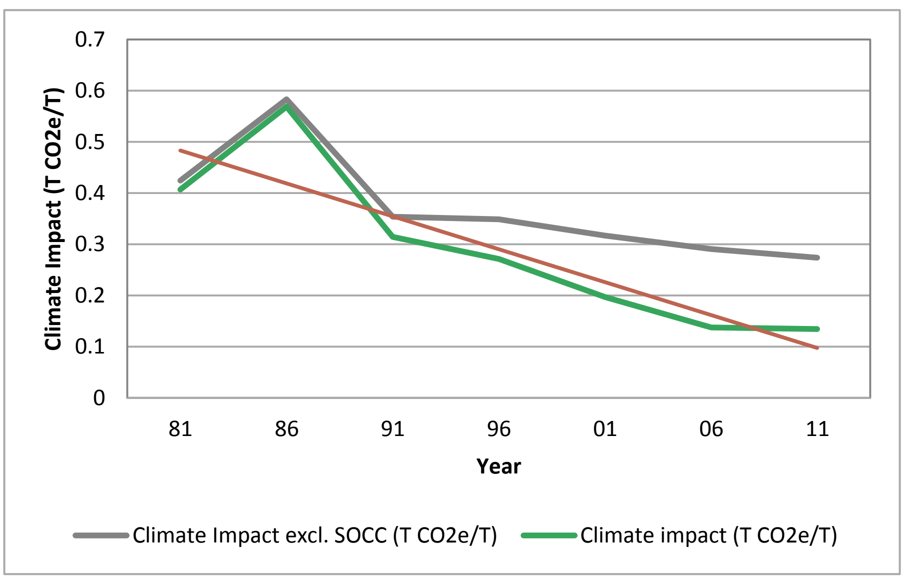


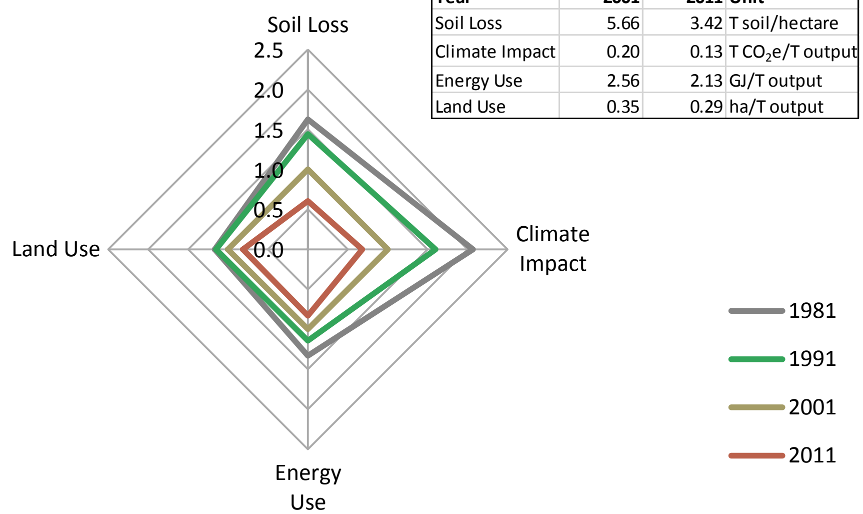
Figure 17: Winter Wheat, Prairies - Climate Impact per Tonne



Indicator Summary – Winter Wheat, Prairies

For winter wheat, every indicator has improved significantly from 1981 through 2011 (Figure 18). This is in spite of the impacts of low yields in 1986, and 1996, on the indicators based on winter wheat output. As with spring wheat, the most dramatic improvement for winter wheat was in climate impact (80%). While soil loss efficiency improved by 57% between 1981 and 2011, land use efficiency improved by 40%, energy use efficiency improved by 48%, and climate impact efficiency improved by 80%.

Figure 18: Winter Wheat, Prairies – All Indicators



Year	2001	2011	Unit
Soil Loss	5.66	3.42	T soil/hectare
Climate Impact	0.20	0.13	T CO_2e/T output
Energy Use	2.56	2.13	GJ/T output
Land Use	0.35	0.29	ha/T output

3.7 Winter Wheat, Ontario

Land Use Indicator

In Ontario, yields of winter wheat increased consistently between 1981 and 2011 (Figure 19), as did those on the Prairies. This provided for an increase in land use efficiency of 35% for winter wheat production in Ontario (Figure 20).

Figure 19: Winter Wheat, Ontario - Tonnes per Harvested Hectare

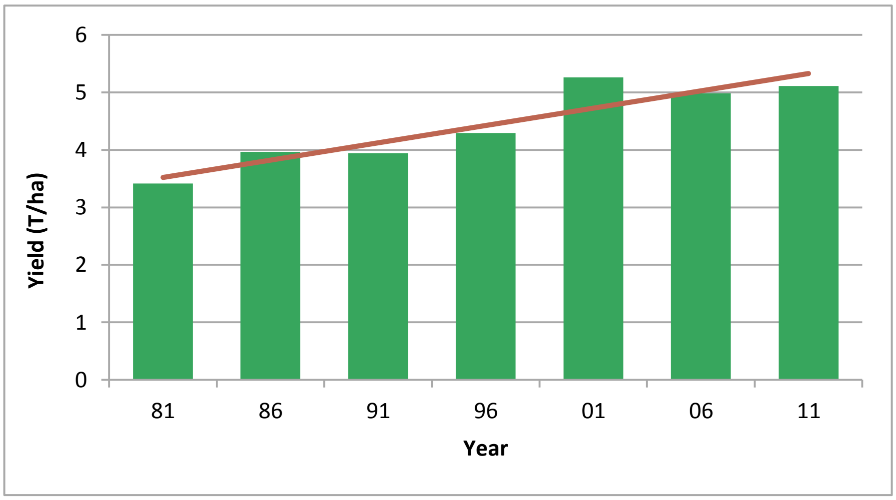
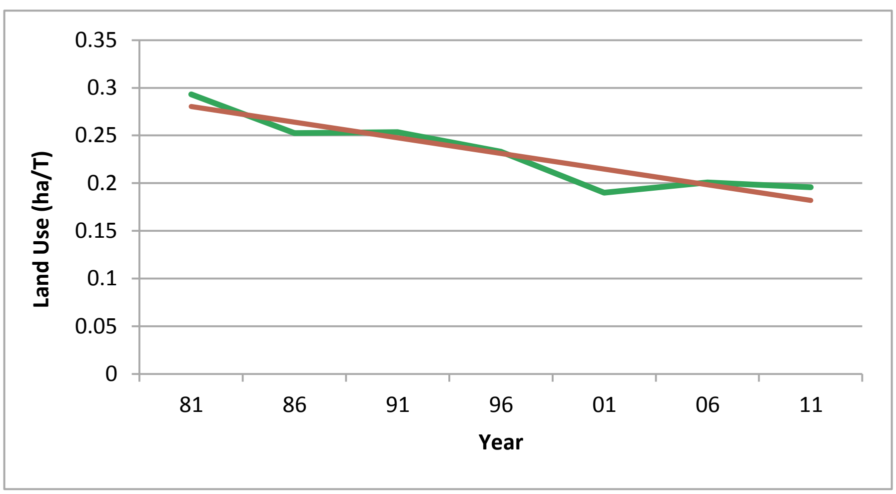


Figure 20: Winter Wheat, Ontario - Harvested Hectares per Tonne



Energy Use Indicator

For winter wheat production in Ontario, energy use on the basis of harvested area was almost level between 1981 and 2011. An increase of 1% was seen over the study period (Figure 21). On the basis of winter wheat production, given the steady improvements in yield, energy use improved by 34% (Figure 22).

Figure 21: Winter Wheat, Ontario – Energy Use per Harvested Hectare

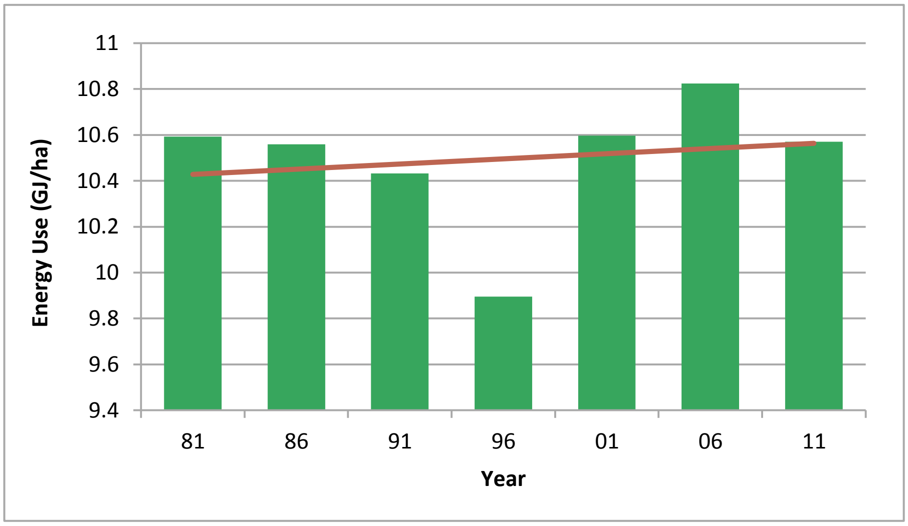
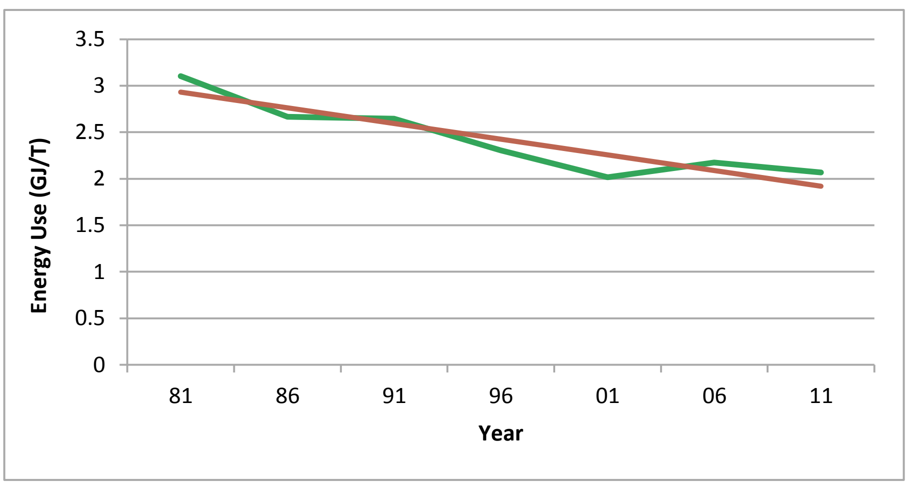


Figure 22: Winter Wheat, Ontario – Energy Use per Tonne



Climate Impact Indicator

Climate Impact for winter wheat production in Ontario shows similar trends over time to energy use. As seen in Figure 23, climate impact for winter wheat in Ontario increased moderately – by 9% – on the basis of harvested area, between 1981 and 2011. On the basis of winter wheat produced (Figure 24), climate impact decreased by 30% between 1981 and 2011.

Figure 23: Winter Wheat, Ontario – Climate Impact per Harvested Hectare

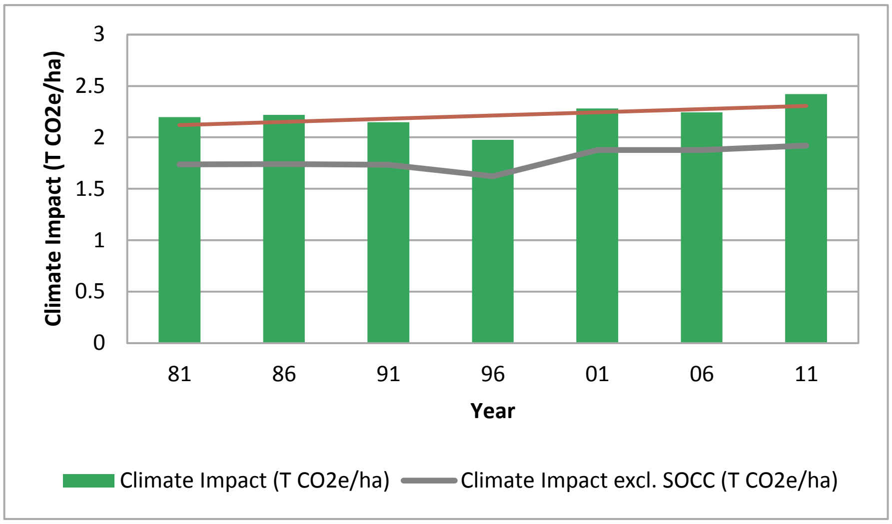
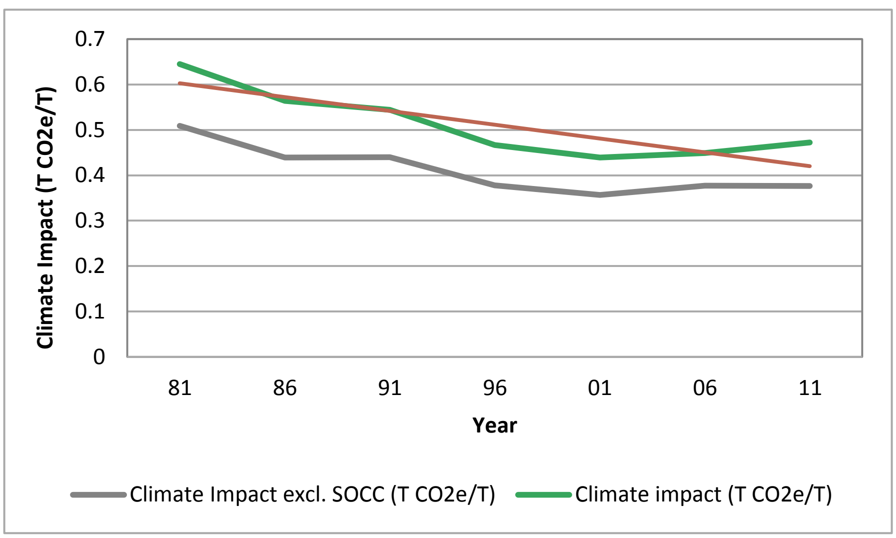


Figure 24: Winter Wheat, Ontario – Climate Impact per Tonne

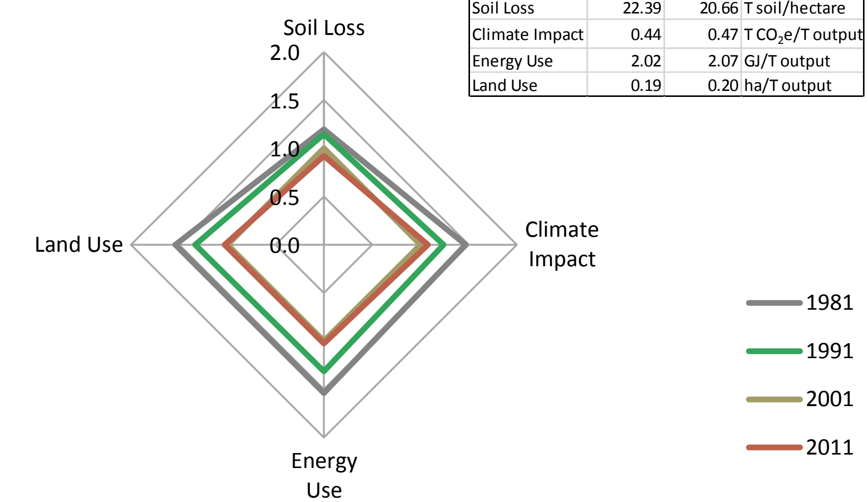


Indicator Summary – Winter Wheat, Ontario

Figure 25 shows the improvement in all the output-based indicators for winter wheat production in Ontario, from 1981 to 2011. Soil loss for winter wheat production in Ontario decreased by 25%, on the basis of cropland area. Meanwhile, on the basis of crop output, land use improved by 35%, energy use improved by 34%, and climate impact improved by 30%.

Figure 25: Winter Wheat, Ontario – All Indicators

Year	2001	2011	Unit
Soil Loss	22.39	20.66	T soil/hectare
Climate Impact	0.44	0.47	T CO_2e/T output
Energy Use	2.02	2.07	GJ/T output
Land Use	0.19	0.20	ha/T output



3.8 Durum Wheat, Prairie Provinces

Land Use Indicator

Yield of durum wheat on the Prairies has increased substantially between 1981 and 2011 (Figure 26). This has driven a 35% improvement in land use on a per unit of output basis (Figure 27).

Figure 26: Durum Wheat, Prairies - Tonnes per Harvested Hectare

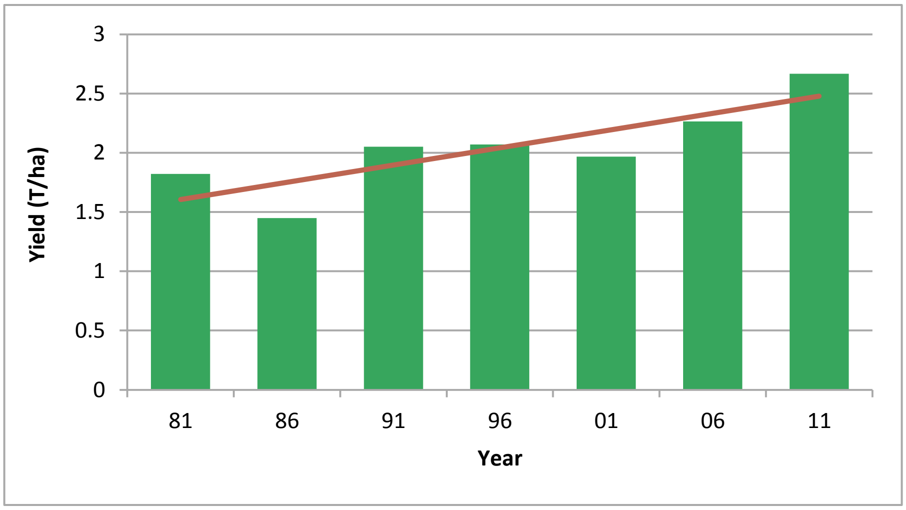
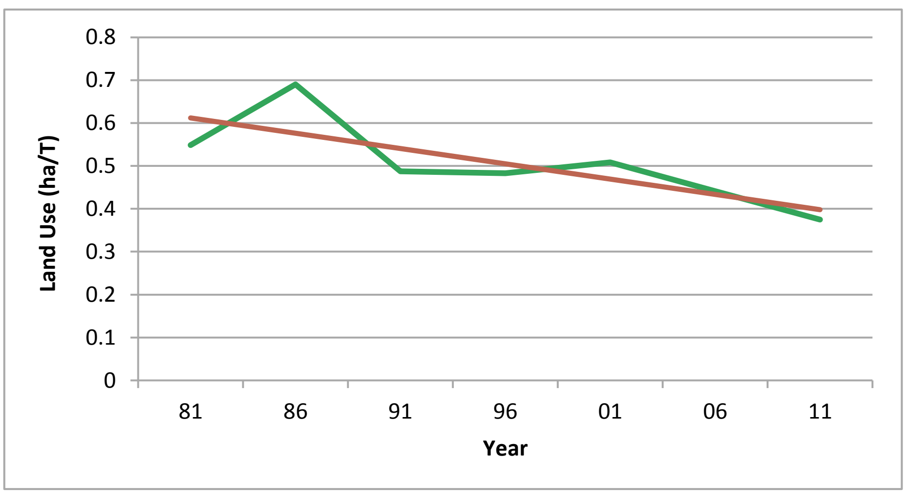


Figure 27: Durum Wheat, Prairies - Harvested Hectares per Tonne



Energy Use Indicator

From 1981 to 2011, energy use for production of durum wheat showed a decrease of 16% on a per hectare basis (Figure 28). Durum wheat yields increased by 54% over this period (Figure 26). Driven by this yield increase, energy use on the basis of production of durum improved by 46% from 1981 to 2011 (Figure 29).

Figure 28: Durum Wheat, Prairies - Energy Use per Harvested Hectare

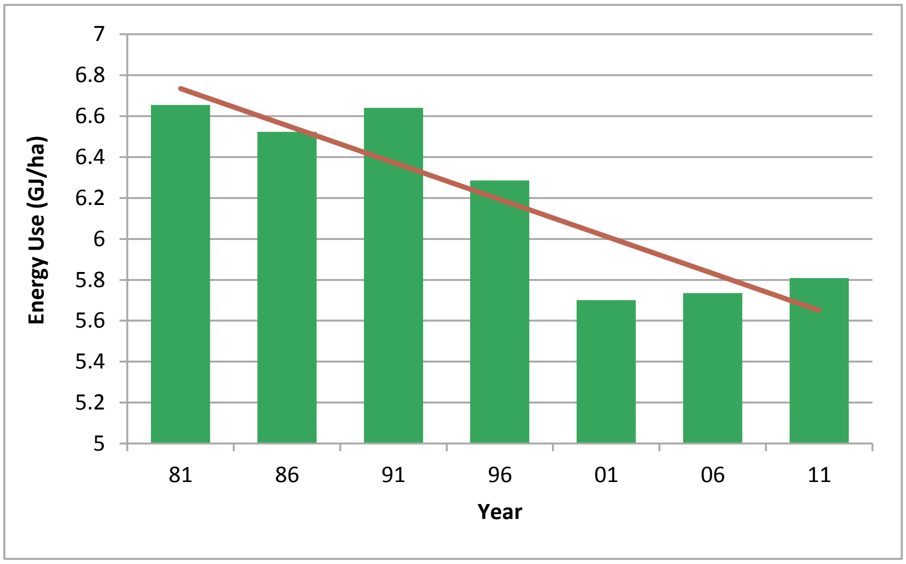
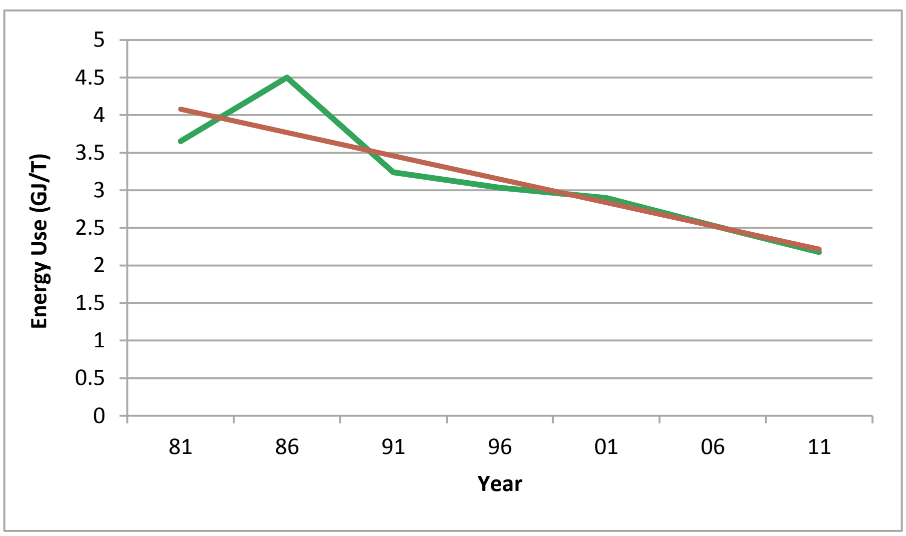


Figure 29: Durum Wheat, Prairies - Energy Use per Tonne



Climate Impact Indicator

Climate impact from production of durum wheat decreased by 86% on the basis of harvested area, between 1981 and 2011 (Figure 30). During this period, yields of durum wheat increased by 54% (Figure 26). Driven by this increase in yield, and by strong increases in soil carbon sequestration, climate impact on a per unit of output basis improved by 95% (Figure 31).

Figure 30: Durum Wheat, Prairies - Climate Impact per Harvested Hectare

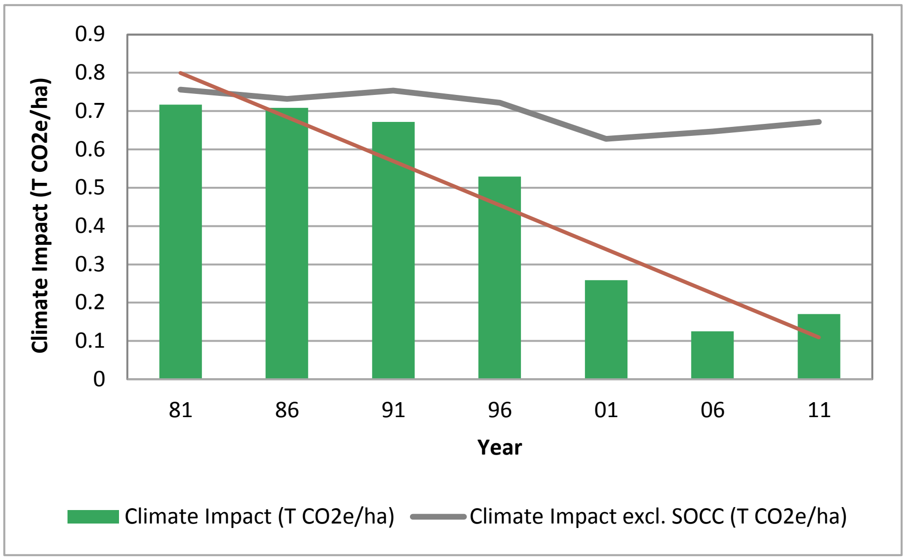
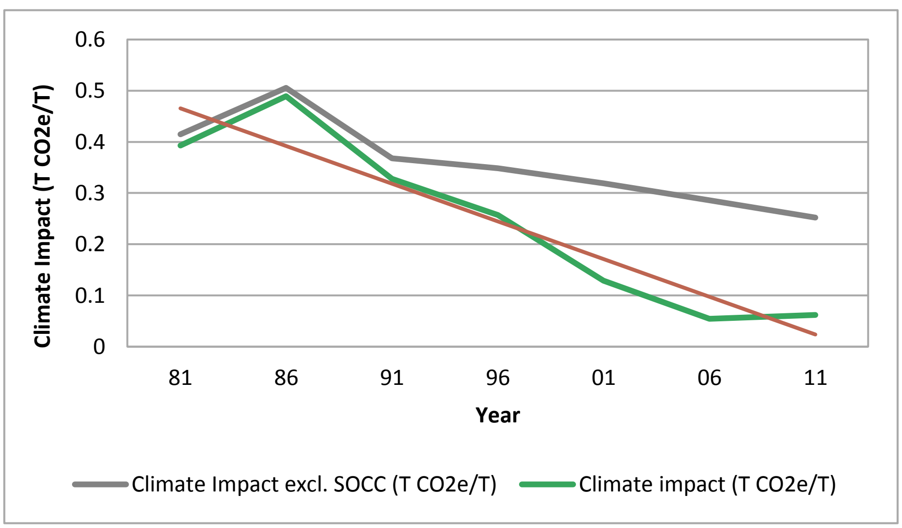


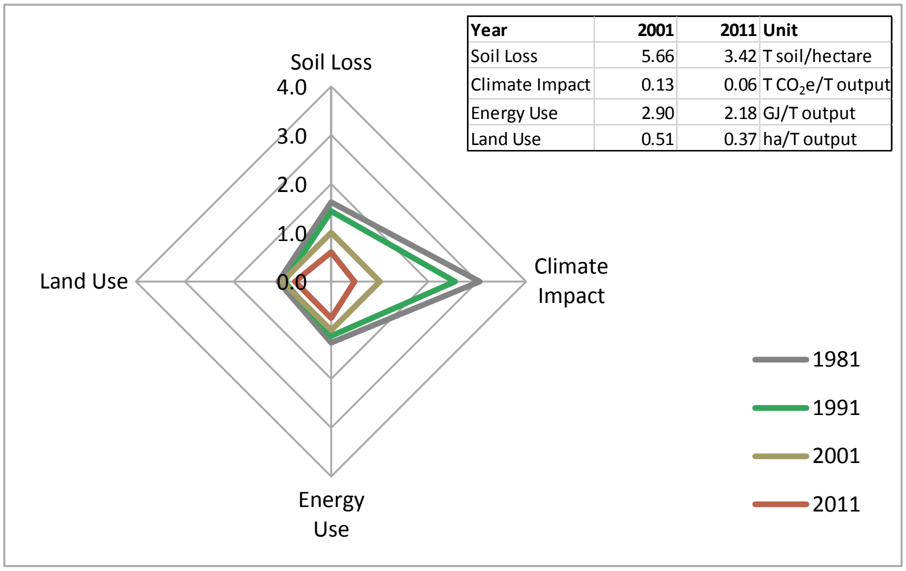
Figure 31: Durum Wheat, Prairies - Climate Impact per Tonne



Indicator Summary – Durum Wheat, Prairies

As with production of spring and winter wheat, all four efficiency indicators for durum wheat showed improvement between 1981 and 2011 (Figure 32). The efficiency indicator showing the most improvement is that for climate impact (95%). Soil loss (on the basis of all cropland area) improved by 57%. Meanwhile, on the basis of durum wheat production, land use improved by 35%, and energy use efficiency by 46%.

Figure 32: Durum Wheat, Prairies – All Indicators



3.9 Oats, Prairie Provinces

Land Use Indicator

Overall improvements in yield have resulted in significant improvements in the land use indicator for oats on the Prairies. During the study period from 1981 to 2011, land use efficiency (Figure 34) has improved by 29%, driven by consistent yield increases as seen in Figure 33.

Figure 33: Oats, Prairies - Tonnes per Harvested Hectare

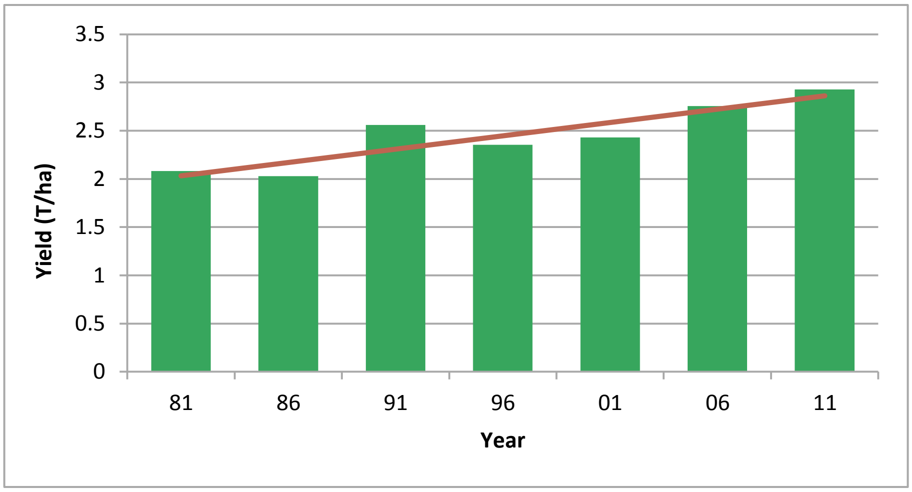
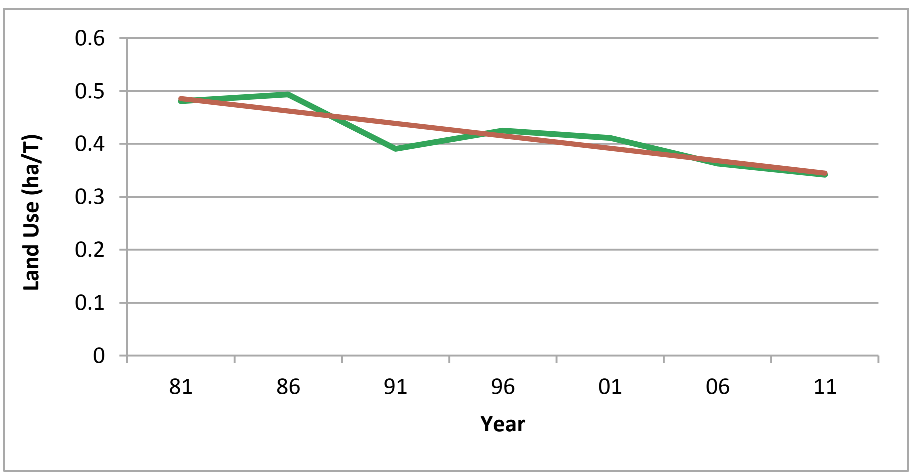


Figure 34: Oats, Prairies - Harvested Hectares per Tonne



Energy Use Indicator

Energy use for oats improved by 14% between 1981 and 2011 on a per hectare basis (Figure 35). When expressed on a per unit of output basis, this improvement was approximately 39% (Figure 36).

Yield increases of 41% account for the difference between the two indicators, clearly illustrating the impact of technological improvements in crop production on sustainability. In addition, it is important to note that the percent improvement has been fairly consistent from one period to the next. While it may 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 35: Oats, Prairies - Energy Use per Harvested Hectare

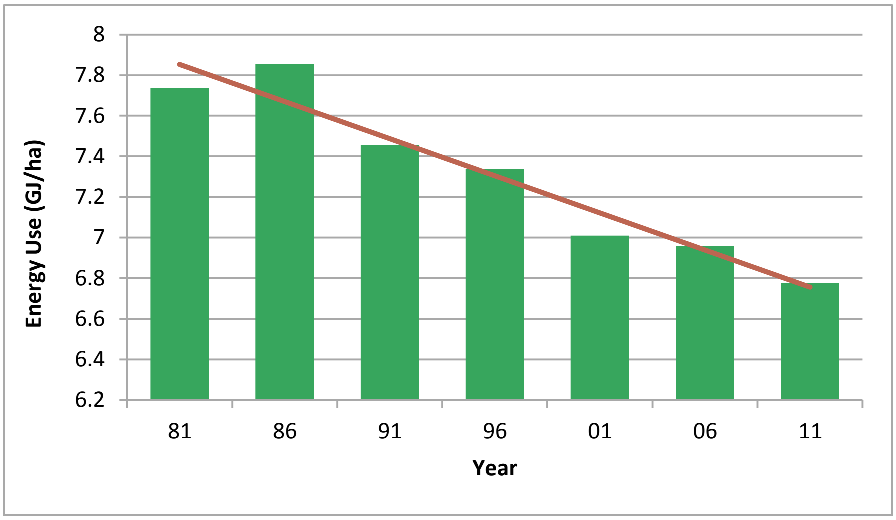
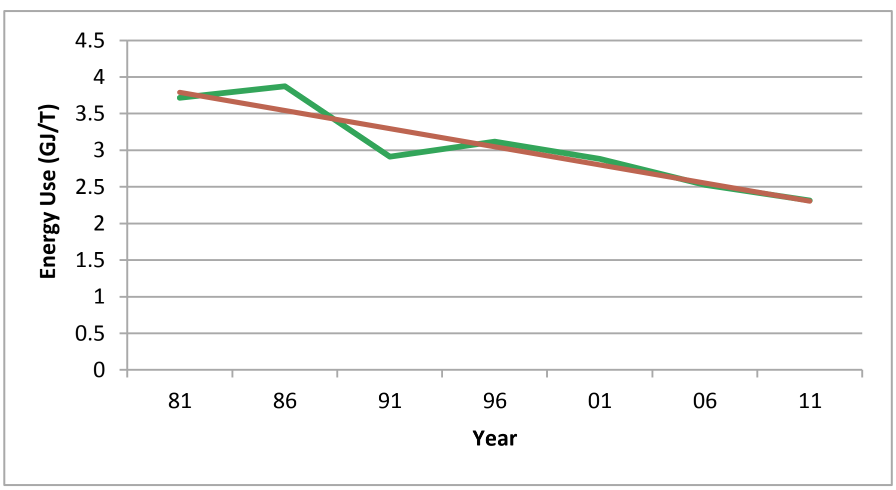


Figure 36: Oats, Prairies - Energy Use per Tonne



Climate Impact Indicator

The changes in the climate impact indicators for oats mirror those in the indicators for energy use and soil carbon change. On a per hectare basis, climate impact from production of oats dropped by 69% between 1981 and 2011 (Figure 37). On a per unit of output basis, climate impact improved by 80% over the same time (Figure 38). This improvement in climate impact efficiency is driven by the yield increase of 41% (Figure 33) and strong increases in soil carbon sequestration.

Figure 37: Oats, Prairies - Climate Impact per Harvested Hectare

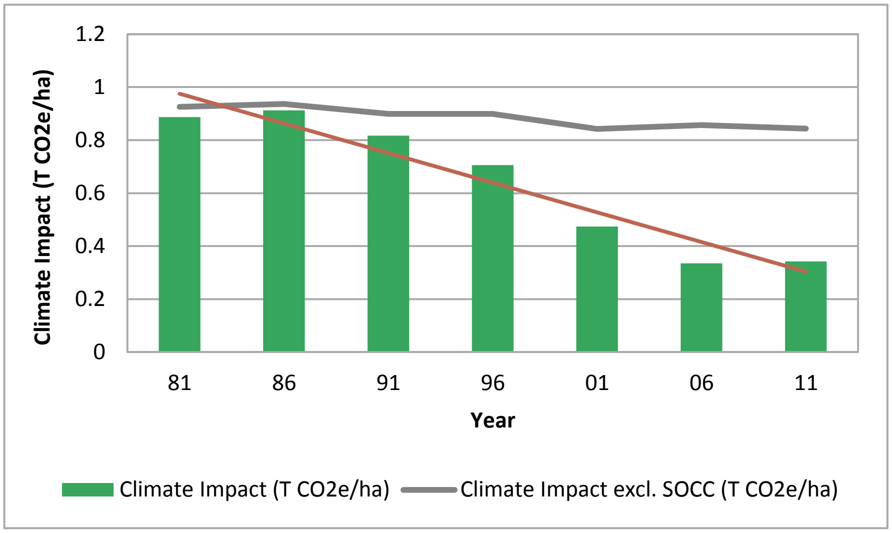
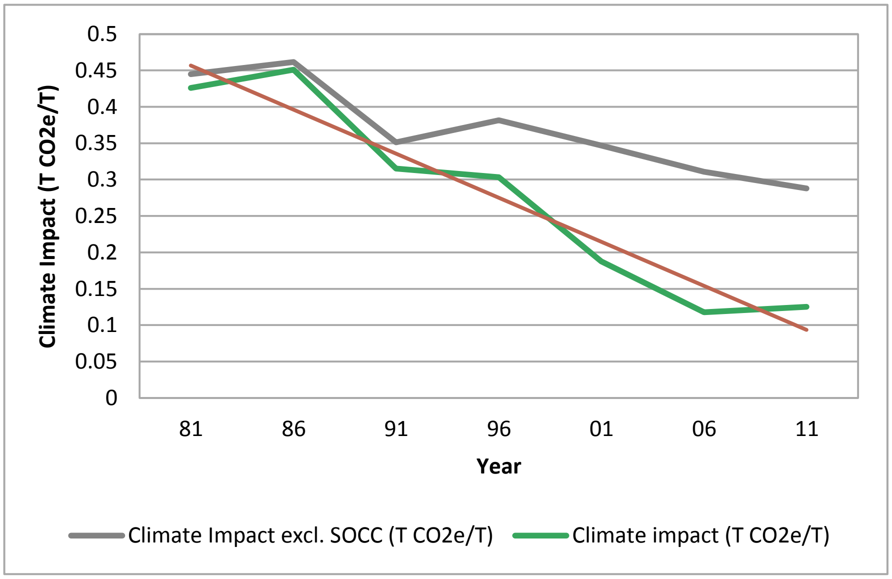


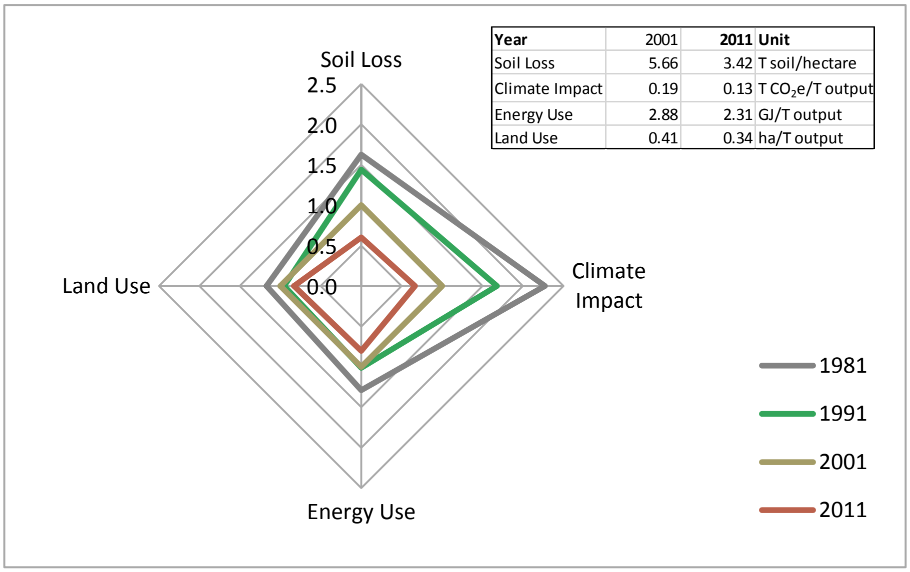
Figure 38: Oats, Prairies - Climate Impact per Tonne



Indicator Summary – Oats, Prairies

The overall efficiency of oat production improved for each of the four indicators measured, over the period from 1981 to 2011, as can be observed in Figure 39. The most significant change occurred in the area of climate impact, but the other three also improved significantly. This is largely a reflection of reduced tillage, the impact of which is also seen in improved energy use and soil erosion. For oats, between 1981 and 2011, soil loss efficiency improved by 57% (on the basis of cropland area), energy use efficiency by 39%, climate impact efficiency by 80%, and land use efficiency by 29%.

Figure 39: Oats, Prairies – All Indicators



Year	2001	2011	Unit
Soil Loss	5.66	3.42	T soil/hectare
Climate Impact	0.19	0.13	T CO_2e/T output
Energy Use	2.88	2.31	GJ/T output
Land Use	0.41	0.34	ha/T output

3.10 Peas, Prairie Provinces

Land Use Indicator

Land use efficiency for peas has improved by 18% in the period between 1981 and 2011 (Figure 41). This reflects overall improvement in yields for peas during the same time frame (Figure 40). Note that the yield improvement for peas between 1981 and 2011 was significantly lower than that for most of the other crops. This relatively small increase in yield results in relatively weak improvement in land use efficiency for peas.

One factor that may have affected this indicator is the large increase in area planted in peas. This area has increased from about 60,000 hectares in 1981 to over a million hectares in the 2000's, which suggests that production may be moving into areas where yield potential is not as high. If this is the case, it would affect the increase in yield as observed, and thus the land use efficiency indicator.

Figure 40: Peas, Prairies - Tonnes per Harvested Hectare

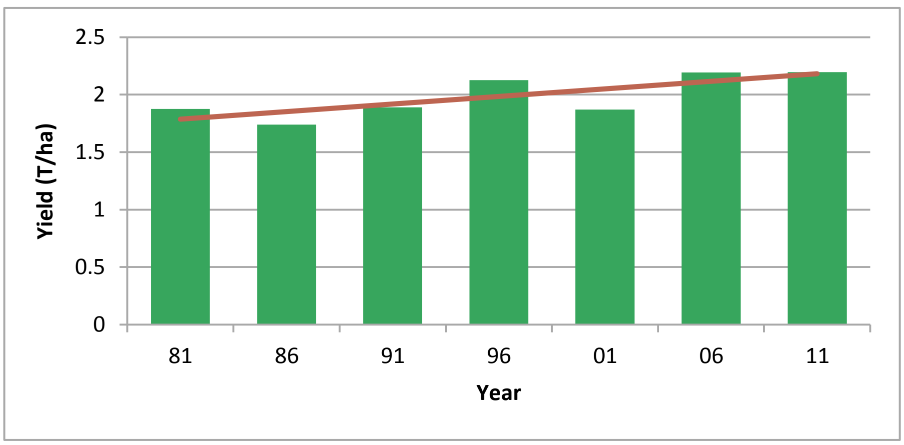
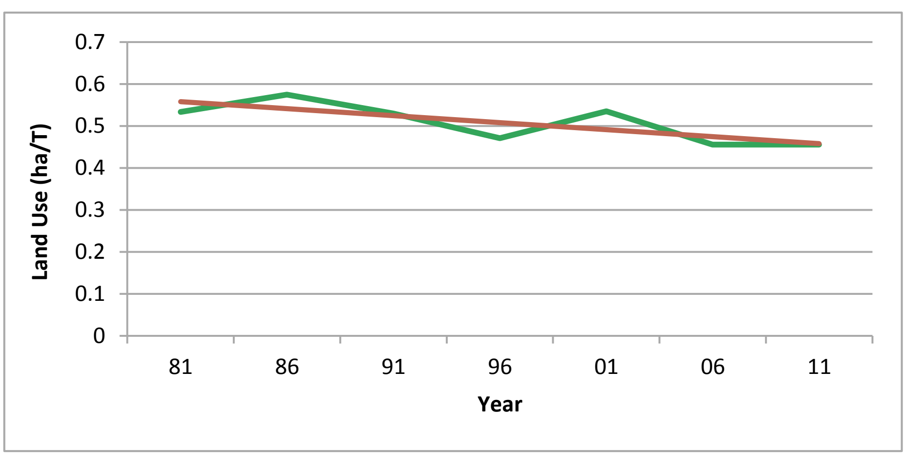


Figure 41: Peas, Prairies - Harvested Hectares per Tonne



Energy Use Indicator

On a per hectare basis, energy use for pea production increased modestly between 1986 and 1991, before falling dramatically from 1991 through 2006 (Figure 42). Based on a linear trendline for this period, energy use per hectare improved by 11% overall (Figure 42). When indexed with yield, the indicator declined by 27% from 1981 to 2011 (Figure 43).

Figure 42: Peas, Prairies - Energy Use per Harvested Hectare

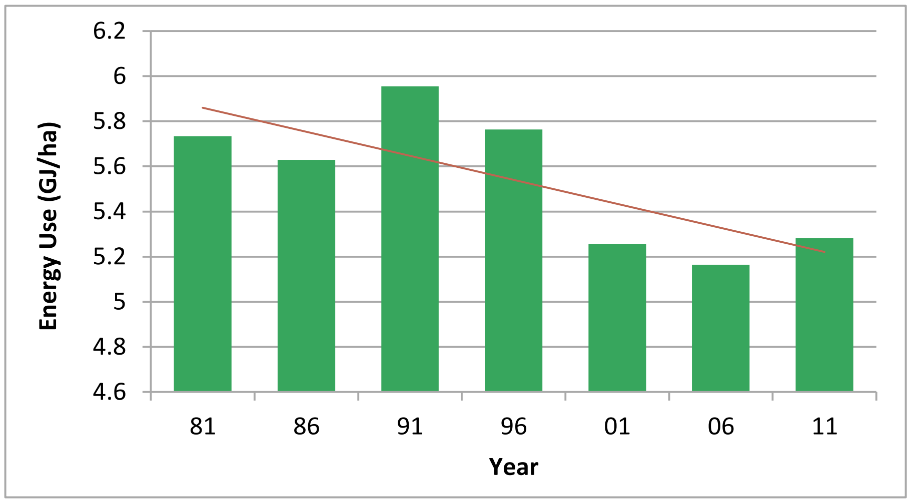
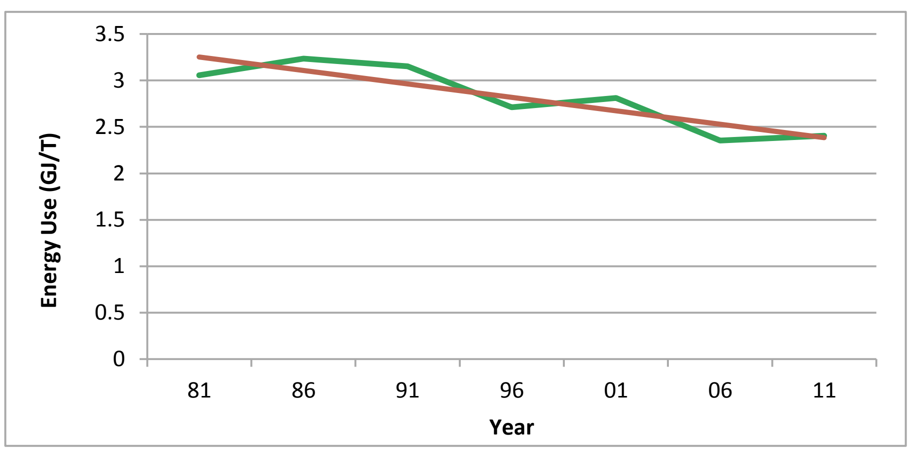


Figure 43: Peas, Prairies - Energy Use per Tonne



Climate Impact Indicator

While following similar patterns to the energy use indicators, the climate impact indicators for peas benfited from strong increases in carbon sequestration, and improved much more than energy use between 1981 and 2011. On a per hectare basis, climate impact for peas improved by 73% over this period (Figure 44). On the basis of peas produced, the climate impact indicator improved by 76% (Figure 45), with yield increasing by 22% (Figure 40).

Figure 44: Peas, Prairies - Climate Impact per Harvested Hectare

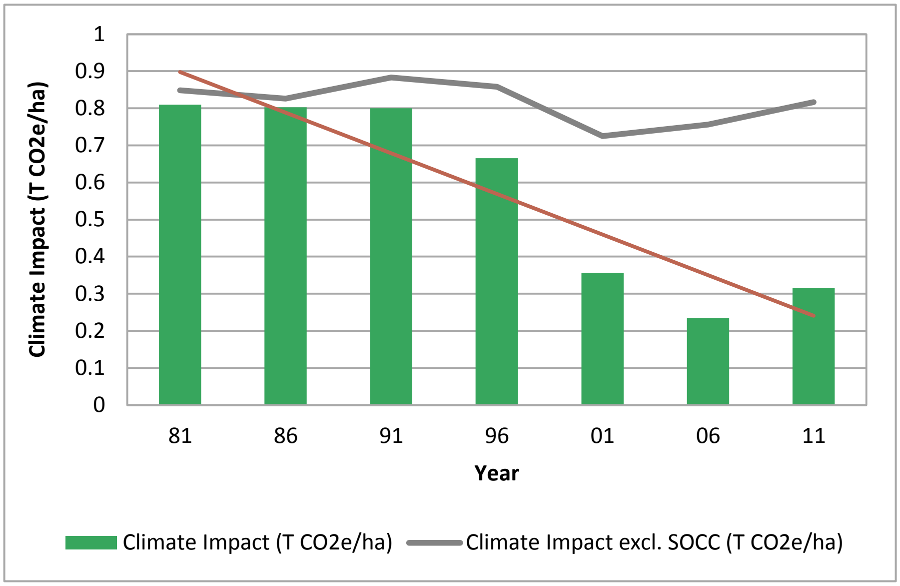
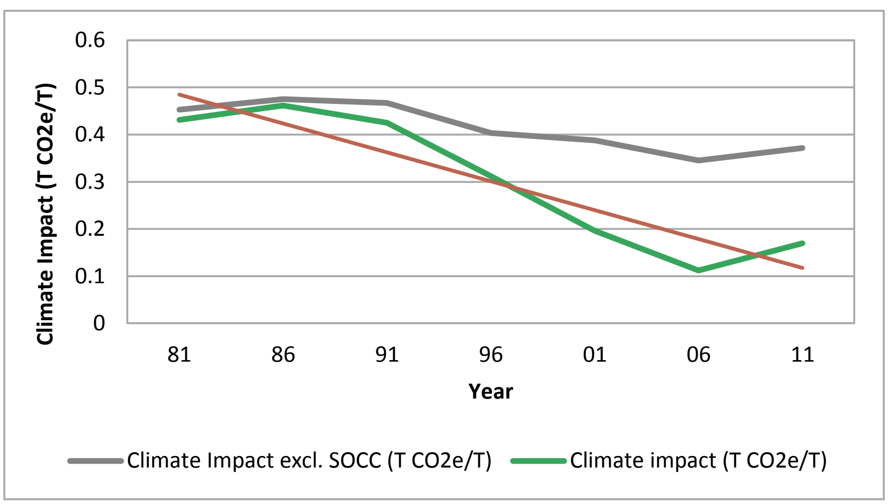


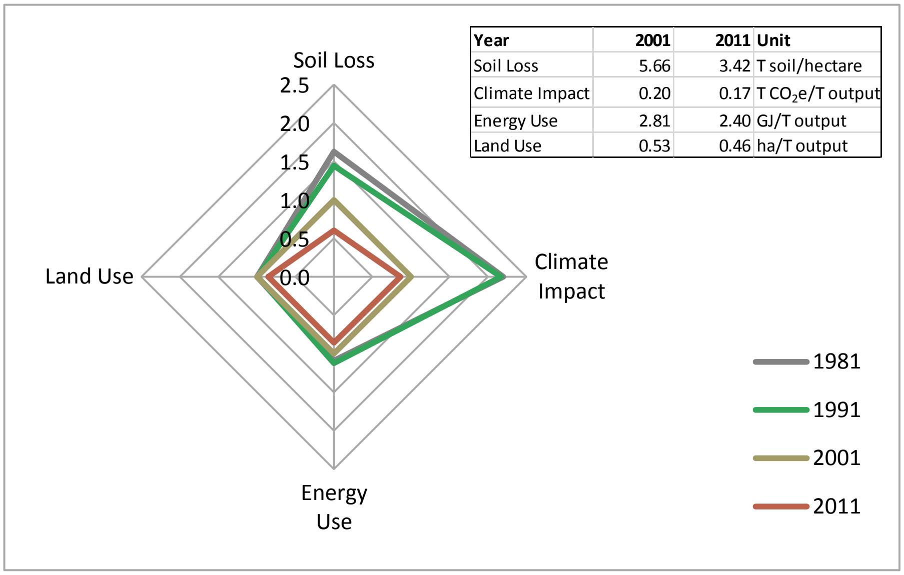
Figure 45: Peas, Prairies - Climate Impact per Tonne



Indicator Summary – Peas, Prairies

In summary, the story for peas in Western Canada is also very positive. All four indicators improved significantly between 1981 and 2011, with the changes in the climate impact efficiency again particularly strong (Figure 46). Between 1981 and 2011, soil loss efficiency improved by 57% (based on cropland area), climate impact by 76%, and energy use by 27%, and land use by 18%.

Figure 46: Peas, Prairies – All Indicators



3.11 Flax, Prairie Provinces

Land Use Indicator

The land use indicator for flax demonstrates an increasingly efficient use of land between 1981 and 2011. Yield increased significantly over this time period (Figure 47), accounting for a 20% increase in land use efficiency between 1981 and 2011 (Figure 48). Significant improvement took place between 2001 and 2011 (Figure 47).

Figure 47: Flax, Prairies - Tonnes per Harvested Hectare

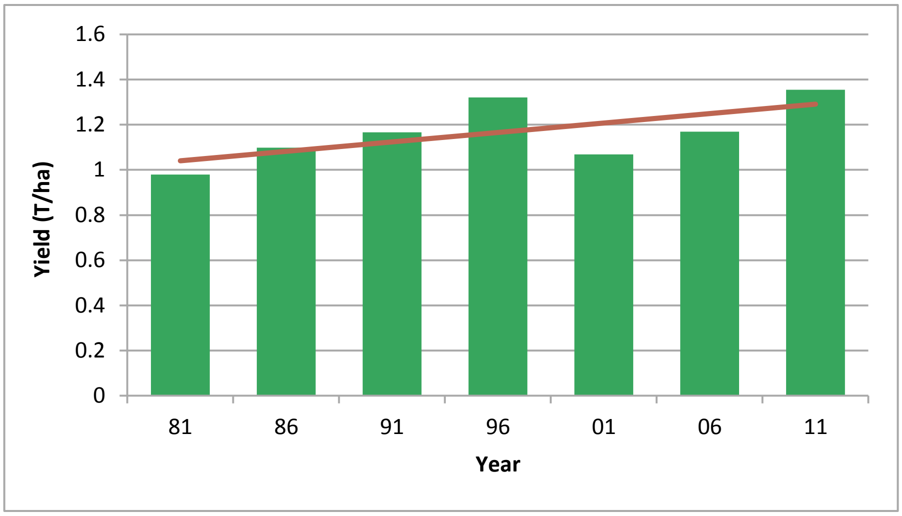
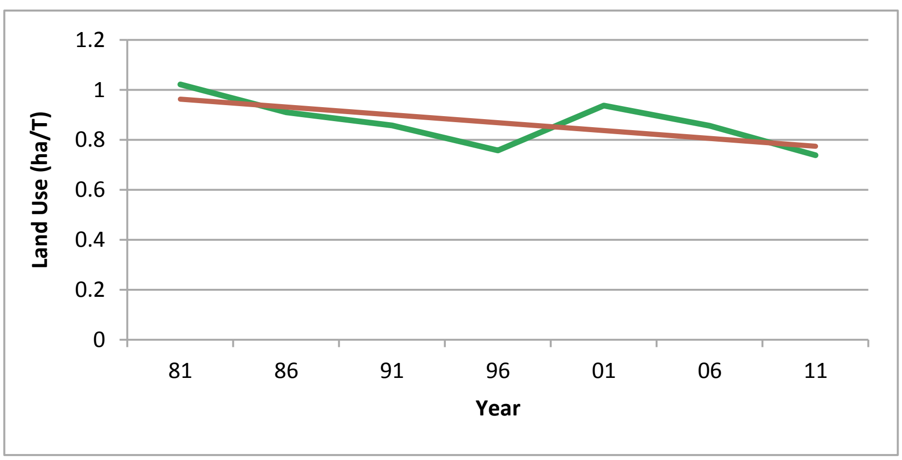


Figure 48: Flax, Prairies - Harvested Hectares per Tonne



Energy Use Indicator

Energy use, on a per hectare basis, has improved by 18% between 1981 and 2011 (Figure 49). During the same time, yields of flax have increased by 24%, and energy use per unit of output, as seen in Figure 50, has improved by 34%. Strong improvement in output-based energy use occurred between 1981 and 1996. Poor yields around 2001 created a bit of a blip in the output-based indicator, but the improvement has resumed since that time.

Figure 49: Flax, Prairies - Energy Use per Harvested Hectare

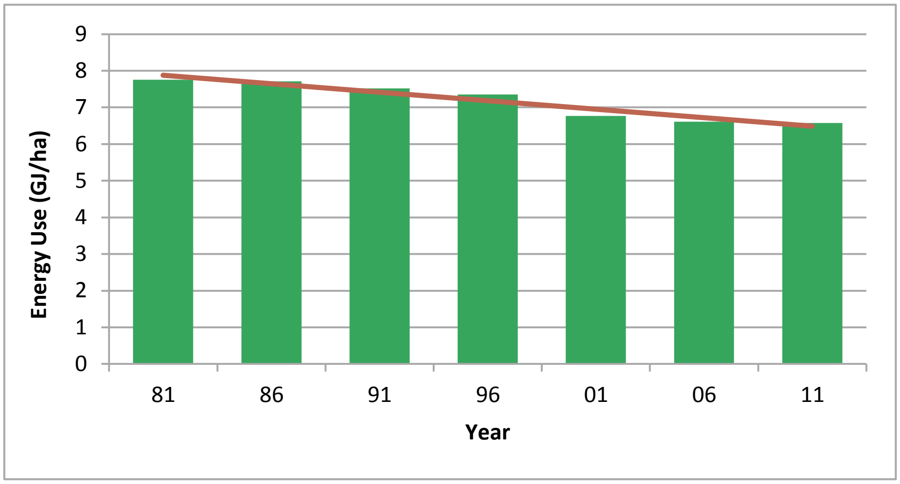
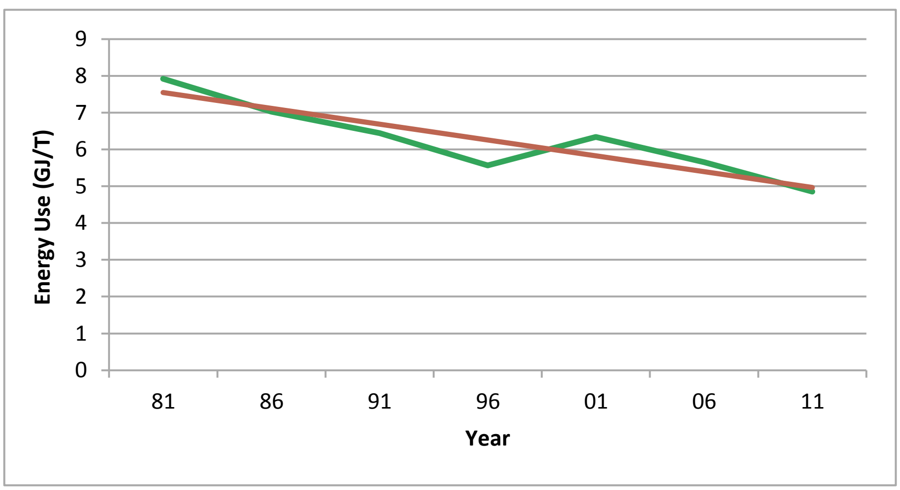


Figure 50: Flax, Prairies - Energy Use per Tonne



Climate Impact Indicator

The climate impact indicators for flax have followed the trends set by energy use, but show much more improvement than the energy use indicators, on the strength of increasing soil carbon sequestration. Climate impact, on a per hectare basis, has improved by 78% between 1981 and 2011 (Figure 51). At the same time, while yields have improved by 24%, climate impact per unit of output has improved by 82% (Figure 52).

Figure 51: Flax, Prairies - Climate Impact per Harvested Hectare

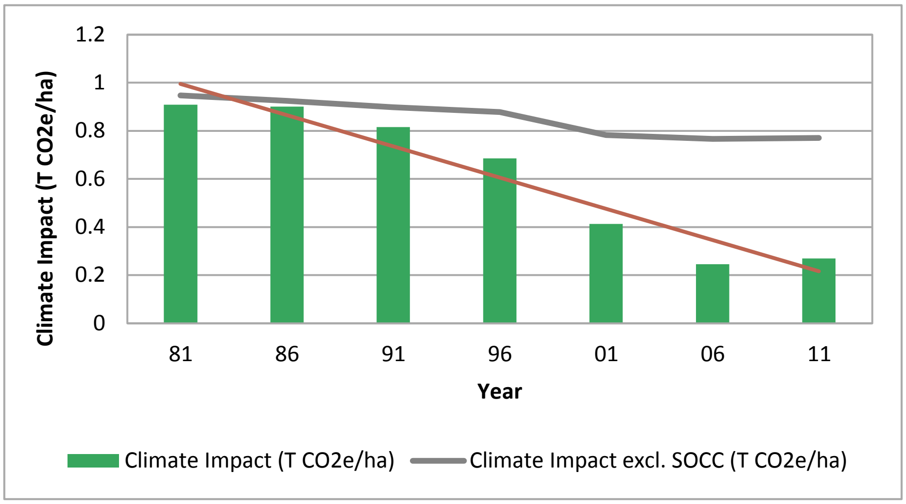
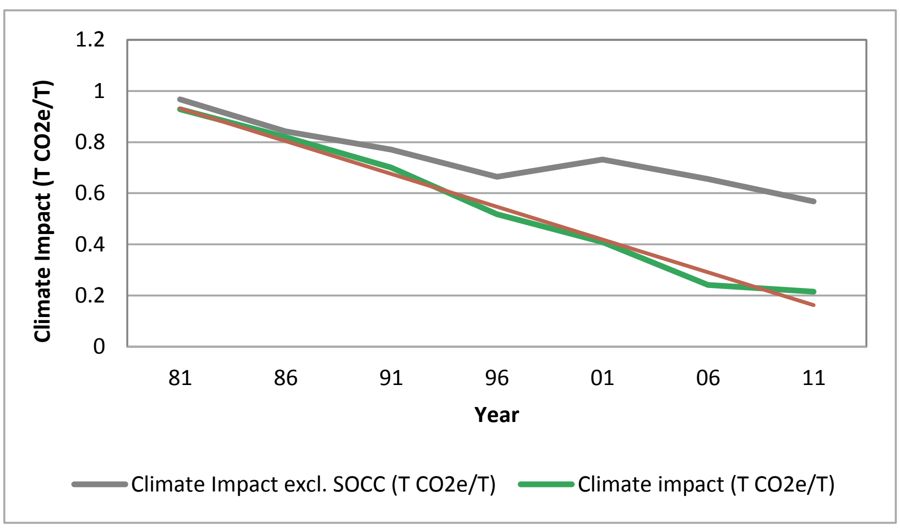


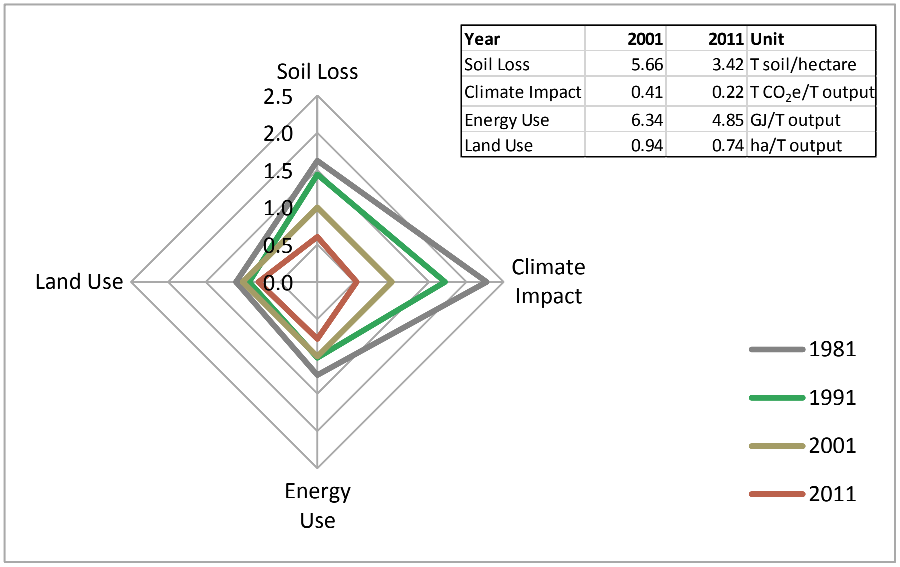
Figure 52: Flax, Prairies - Climate Impact per Tonne



Indicator Summary – Flax, Prairies

The spider diagram (Figure 53) clearly indicates that the production of flax has demonstrated improvements in all four indicator areas from 1981 through 2011. While the improvements in soil loss (on a cropland area basis) are very strong, the changes in climate impact are even stronger, largely on the strength of increasing carbon sequestration. For flax, between 1981 and 2011, climate impact improved by 82%, energy use by 34%, and land use efficiency by 20%.

Figure 53: Flax, Prairies – All Indicators



Year	2001	2011	Unit
Soil Loss	5.66	3.42	T soil/hectare
Climate Impact	0.41	0.22	T CO_2e/T output
Energy Use	6.34	4.85	GJ/T output
Land Use	0.94	0.74	ha/T output

3.12 Canola, Prairie Provinces

Land Use Indicator

The results for the canola land use indicator show that major improvements have been made between 1981 and 2011. Yields have increased substantially during this period (Figure 54). Land use efficiency has improved by 37% between 1981 and 2011 (Figure 55). As was the case with all other crops, improved yields accounted for this improvement (Figure 54).

Figure 54: Canola, Prairies - Tonnes per Harvested Hectare

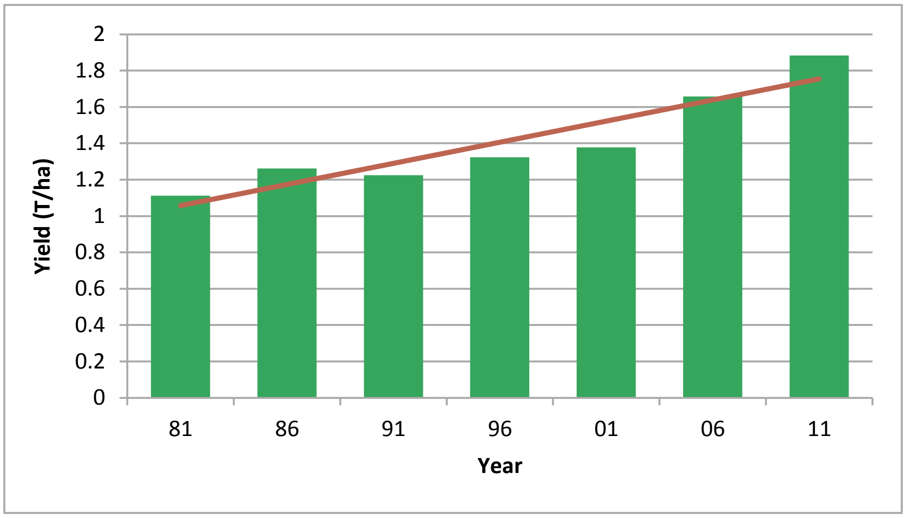
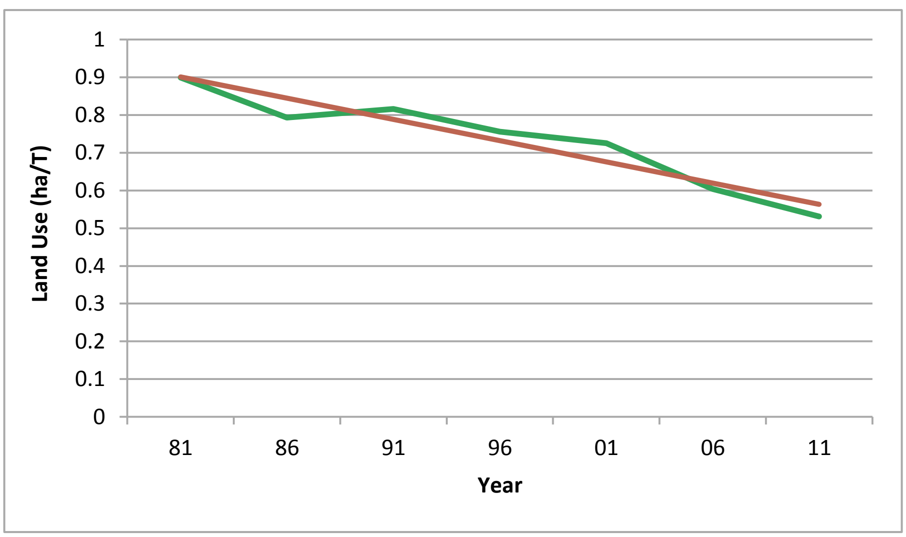


Figure 55: Canola, Prairies - Harvested Hectares per Tonne



Energy Use Indicator

Canola also improved in the area of energy use, with an improvement of 8% on a per hectare basis, between 1981 and 2011 (Figure 56). Energy use for canola, on a per unit of output basis, improved by 43% between 1981 and 2011 (Figure 57), with yields increasing by 66% (Figure 54).

Figure 56: Canola, Prairies - Energy Use per Harvested Hectare

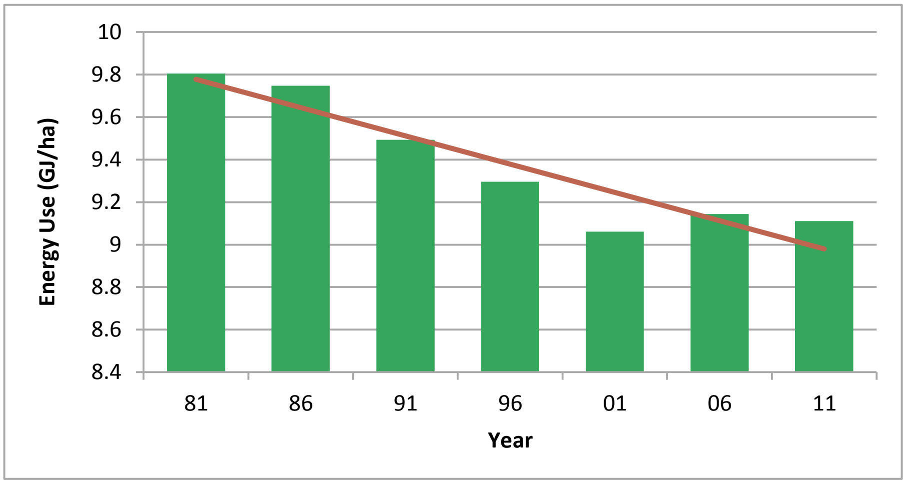
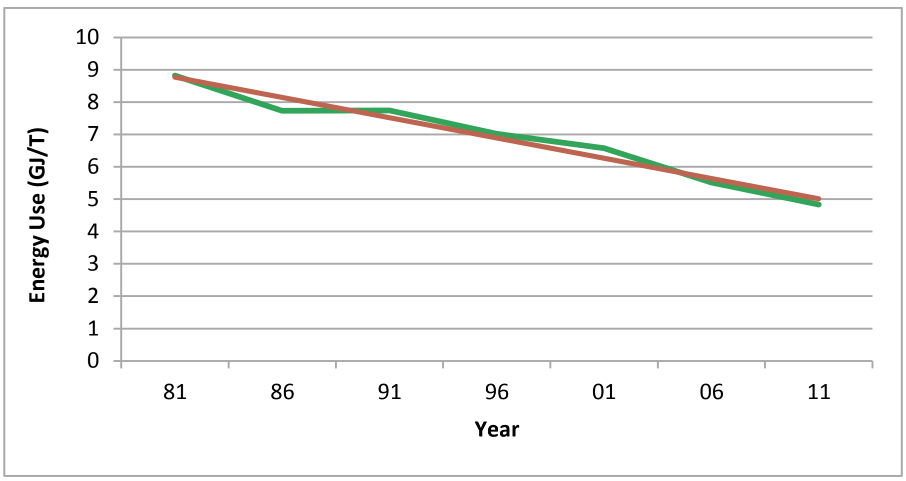


Figure 57: Canola, Prairies - Energy Use per Tonne



Climate Impact Indicator

Canola's indicators for climate impact mirror the trends in energy use, both in terms of magnitude and timing. Climate impact for canola also reflects strong increases in soil carbon sequestration on the Prairies. The emissions intensity on a harvested area basis (climate impact per hectare) decreased by 53% between 1981 and 2011 (Figure 58). However, with yields of canola increasing strongly over this period, climate impact per unit of output improved by 71% (Figure 59).

Figure 58: Canola, Prairies - Climate Impact per Harvested Hectare

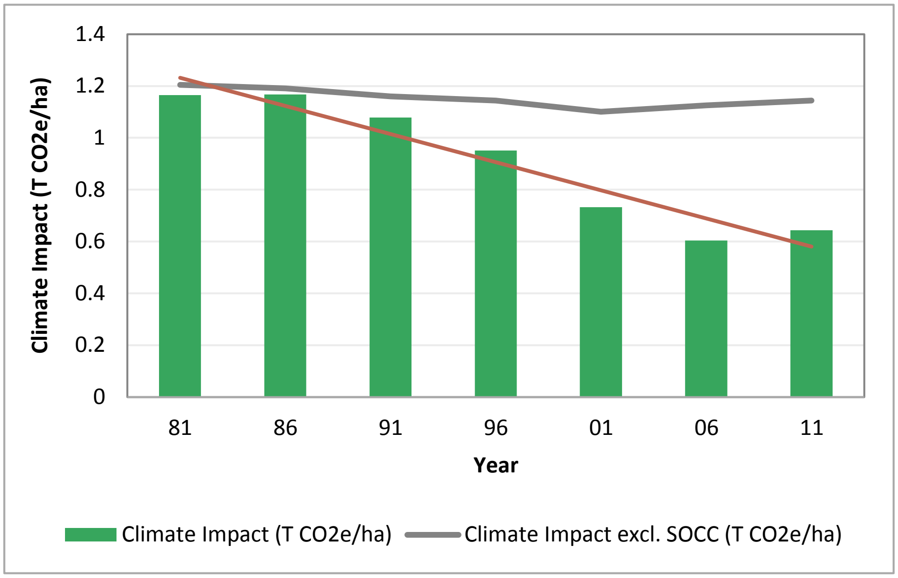
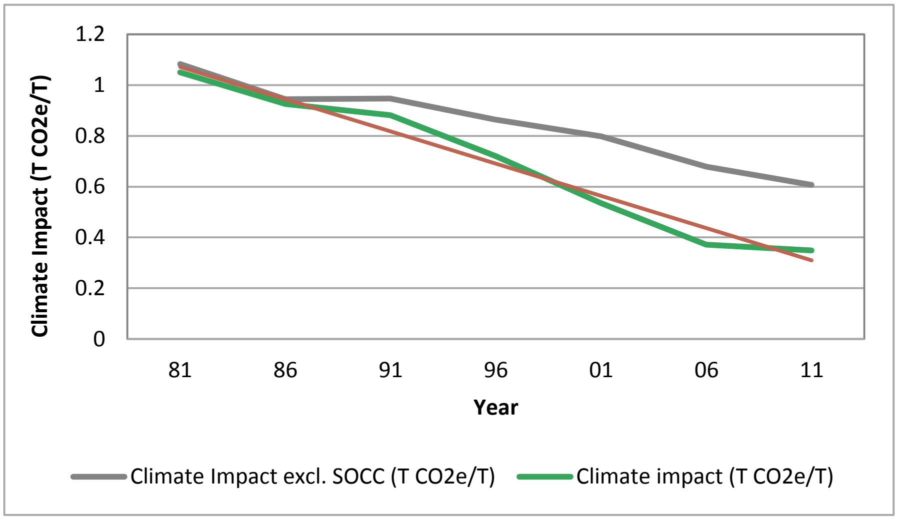


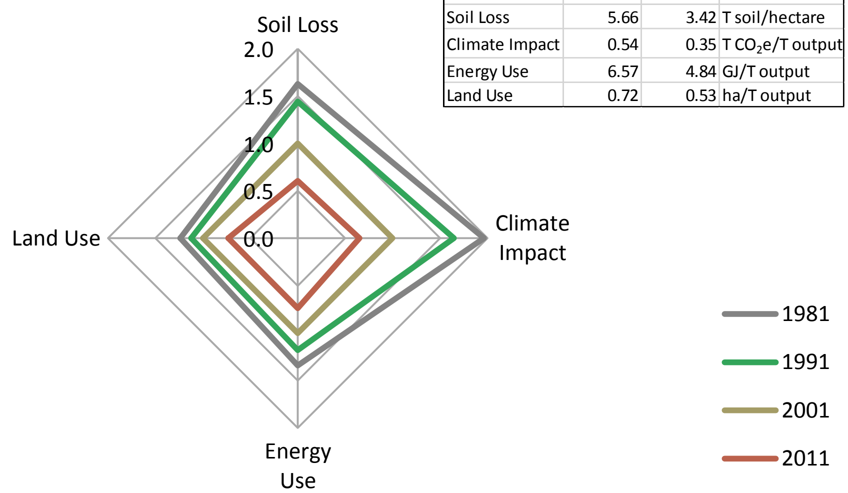
Figure 59: Canola, Prairies - Climate Impact per Tonne



Indicator Summary – Canola, Prairies

In summary, the sustainability of canola production has improved significantly between 1981 and 2011. While, as for other crops produced on the Prairies, the most significant improvement was in the area of climate impact, improvements in all of the other areas were at least 37% between 1981 and 2011. Between 1981 and 2011, soil loss efficiency improved by 57%, on the basis of area of cropland. On the basis of production, energy use improved by 43%, climate impact by 71%, and land use efficiency by 37%. These improvements are clearly evident in the 1981 to 2011 time frame represented in Figure 60.

Figure 60: Canola, Prairies – All Indicators



Year	2001	2011	Unit
Soil Loss	5.66	3.42	T soil/hectare
Climate Impact	0.54	0.35	T CO_2e/T output
Energy Use	6.57	4.84	GJ/T output
Land Use	0.72	0.53	ha/T output

3.13 Lentils, Prairie Provinces

Lentil production has a shorter history than production of most of the crops in this report. As a result, all indicators for lentils reflect the time period from 1991 to 2011.

Land Use Indicator

The harvested area of lentils on the Prairies has increased dramatically, from around 50,000 hectares in 1981 to over a million hectares by 2010. During the 20-year study period, from 1991 to 2011, yields of lentils have increased strongly (Figure 61). During this same time frame, land use efficiency has improved by 13% (Figure 62).

Figure 61: Lentils, Prairies - Tonnes per Harvested Hectare

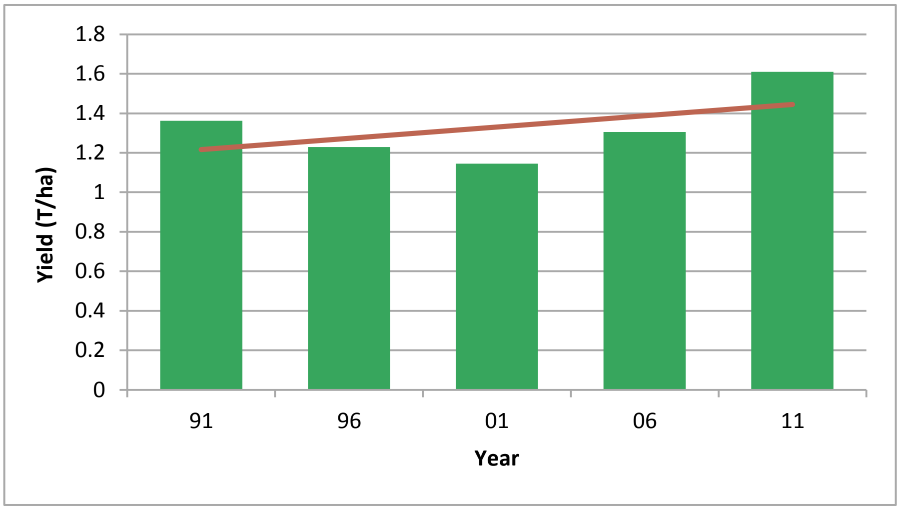
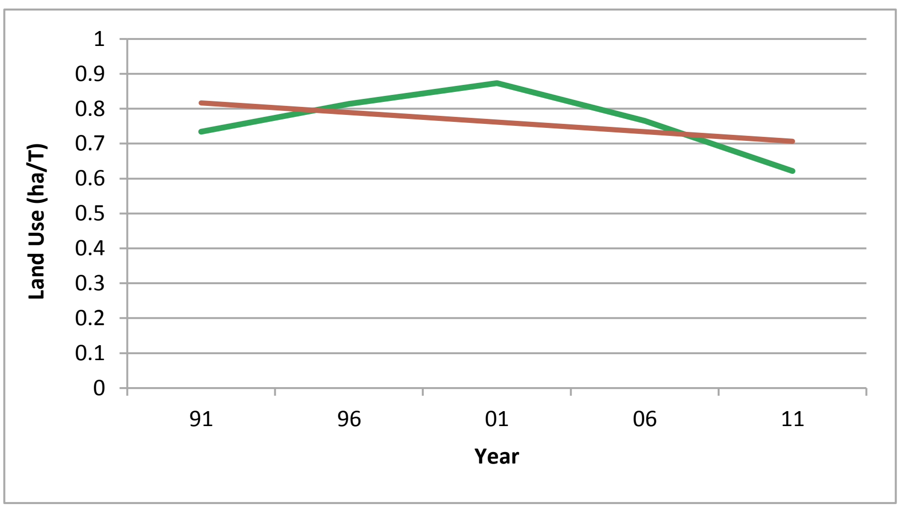


Figure 62: Lentils, Prairies - Harvested Hectares per Tonne



Energy Use Indicator

For lentils, energy use per hectare decreased by 14% between 1991 and 2011 (Figure 63). Over the same time, yields increased by 19% (Figure 61) and energy use per unit of output improved by 25% (Figure 64).

As with a number of the other crops, the output-based energy use indicator for lentils suggests a significant improvement between 1996 and 2011, following an initial increase between 1991 and 1996 (Figure 64). This increase in output-based energy use between 1991 and 1996 appears to have been driven in part by low yields around the years 1996 and 2001. Again, over the entire study period from 1991 to 2011, energy use per unit of output improved by 25% (Figure 64).

Figure 63: Lentils, Prairies - Energy Use per Harvested Hectare

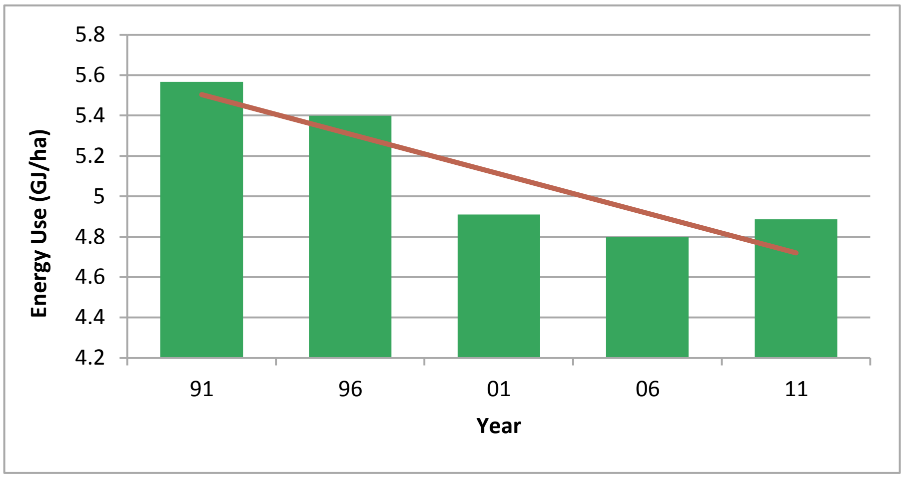
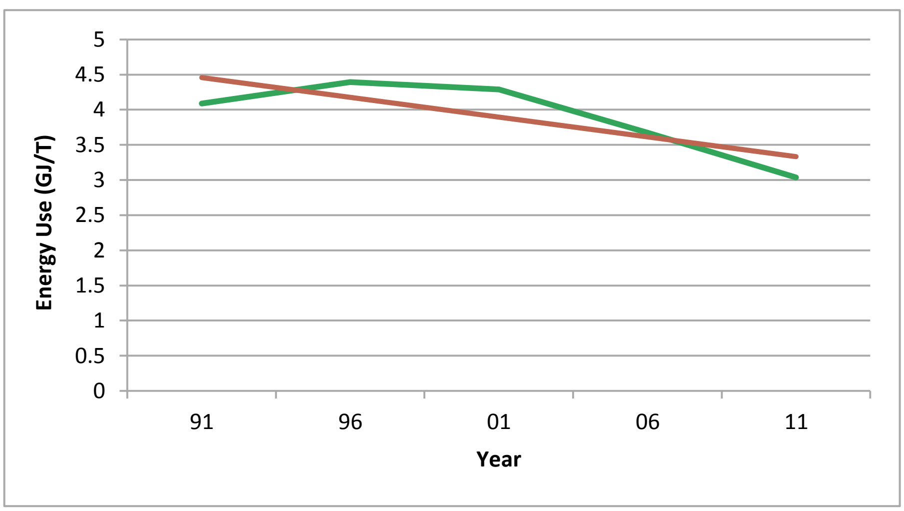


Figure 64: Lentils, Prairies - Energy Use per Tonne



Climate Impact Indicator

The indicators for the climate impact of lentil production show a similar pattern over time to the energy use indicators. The overall rate of decline in climate impact between 1991 and 1986 is also strongly influenced by increasing soil carbon sequestration. Strong improvement is seen in output-based climate impact for lentils, particularly between 1996 and 2006 (Figure 66).

Climate impact to produce lentils, on a per hectare basis, decreased by 106% between 1991 and 2011, based on a linear trend line (Figure 65). Thus, on the basis of a linear trend, soil carbon sequestration was able to outweigh greenhouse gas emissions from farm energy and nitrous oxide emissions, by 2011. With yields increasing by 19% over the same period, output-based climate impact improved by 104%, based on a linear trend line (Figure 66).

Figure 65: Lentils, Prairies - Climate Impact per Harvested Hectare

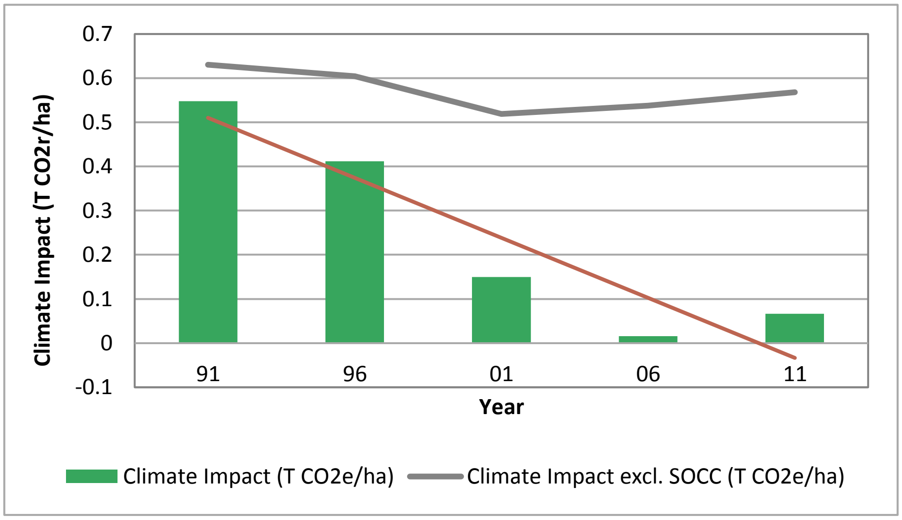
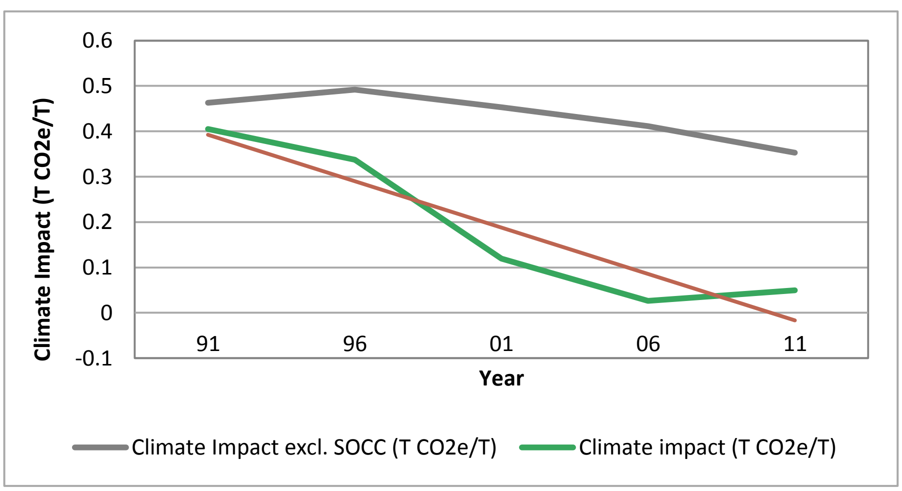


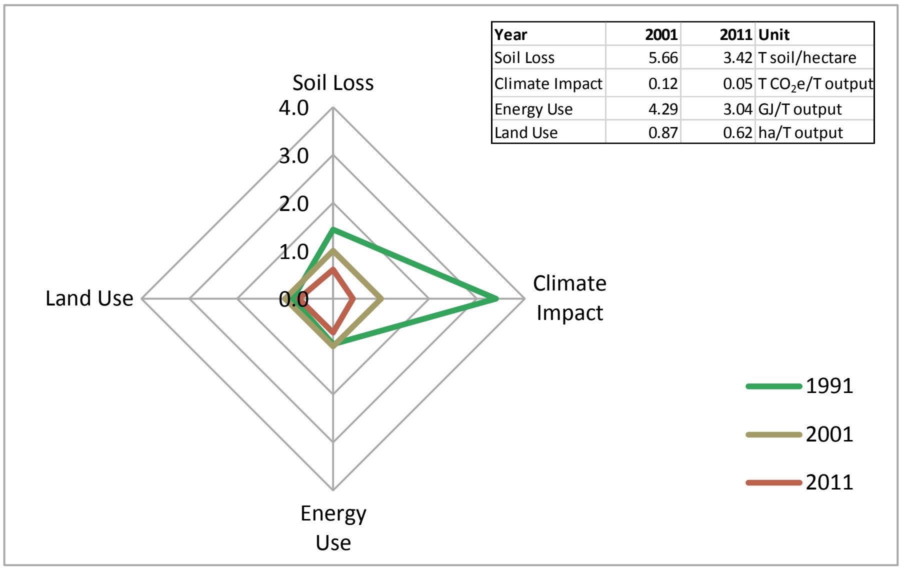
Figure 66: Lentils, Prairies - Climate Impact per Tonne



Indicator Summary – Lentils, Prairies

The story for lentils is very positive, based on the indicator analysis. After a bit of difficulty between 1991 and 2001, when yields declined, there have been consistent improvements in all four indicators between 2001 and 2011 (Figure 67). Lentils have demonstrated improvement across all four indicators, between 1991 and 2011. Between 1991 and 2011, soil loss efficiency improved by 38% (on the basis of cropland area). Output-based climate impact improved by 104%, energy use by 25%, and land use efficiency by 13%.

Figure 67: Lentils, Prairies – All Indicators



3.14 Soybeans, Manitoba

Production of soybeans in Manitoba has a short history, and is only recorded in CANSIM since 2001. As a result, all indicators for soybeans in Manitoba reflect a shorter time series than for other crops, extending from 2001 to 2011.

Land Use Indicator

Yields of soybeans in Manitoba have shown an overall increase during the period studied, from 2001 to 2011 (Figure 68). As a result, land use efficiency improved by 15% over this ten-year period (Figure 69).

Figure 68: Soybeans, Manitoba - Tonnes per Harvested Hectare

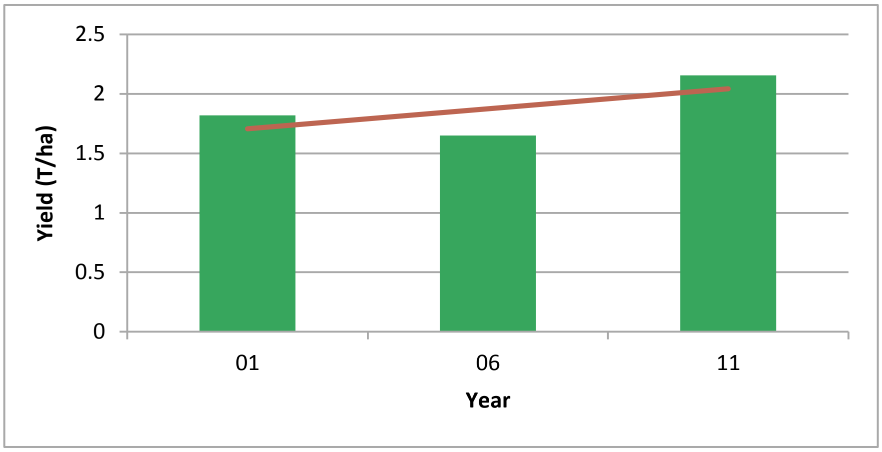
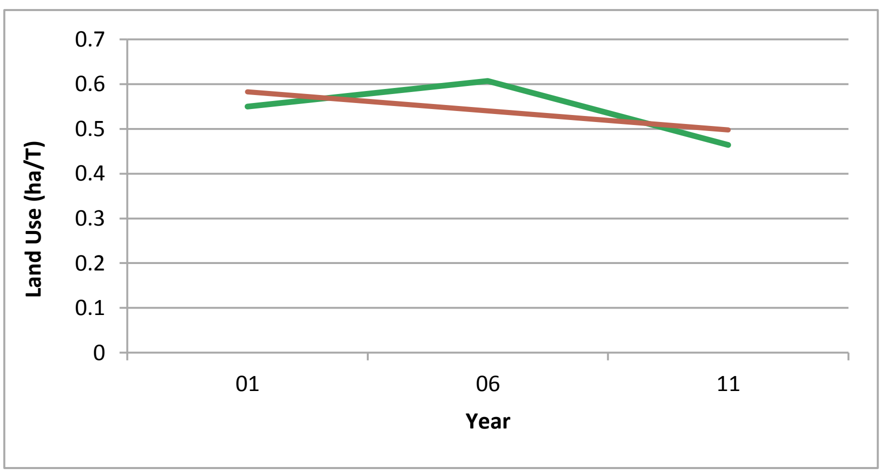


Figure 69: Soybeans, Manitoba - Harvested Hectares per Tonne



Energy Use Indicator

Energy use to produce soybeans in Manitoba showed a significant decrease between 2001 and 2011. An overall decrease of 7% in energy use based on harvested area, over the ten years, is seen in Figure 70. Output-based energy use decreased by 20% over the ten-year period, as seen in Figure 71.

Figure 70: Soybeans, Manitoba - Energy Use per Harvested Hectare

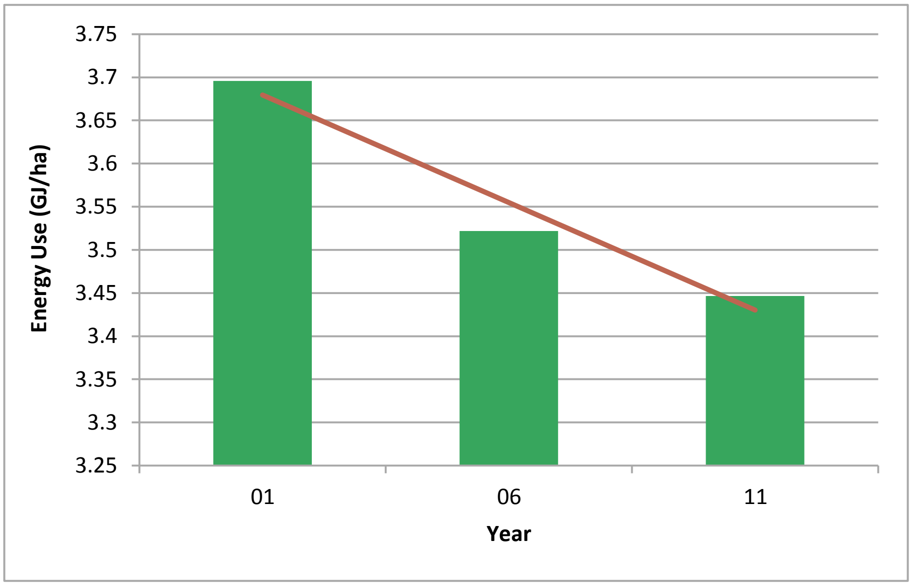
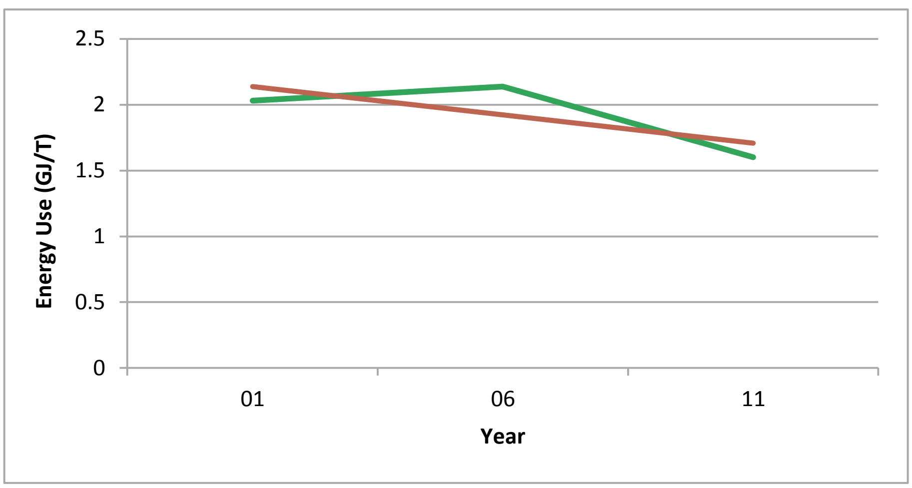


Figure 71: Soybeans, Manitoba - Energy Use per Tonne



Climate Impact Indicator

Output-based climate impact for soybean production in Manitoba follows a similar pattern to output-based energy use, from 2001 to 2011. As seen in Figure 73, output-based climate impact due to farm energy use and nitrous oxide emissions increased slightly between 2001 and 2006, but improved between 2006 and 2011. With increasing soil carbon sequestration, overall output-based climate impact has decreased almost to zero by 2011. The overall improvement was 95% over the ten-year period, based on a linear trendline. Meanwhile, on the basis of harvested area, climate impact for Manitoba soybean production improved by 100% over the ten years, based on a linear trendline.

Figure 72: Soybeans, Manitoba - Climate Impact per Harvested Hectare

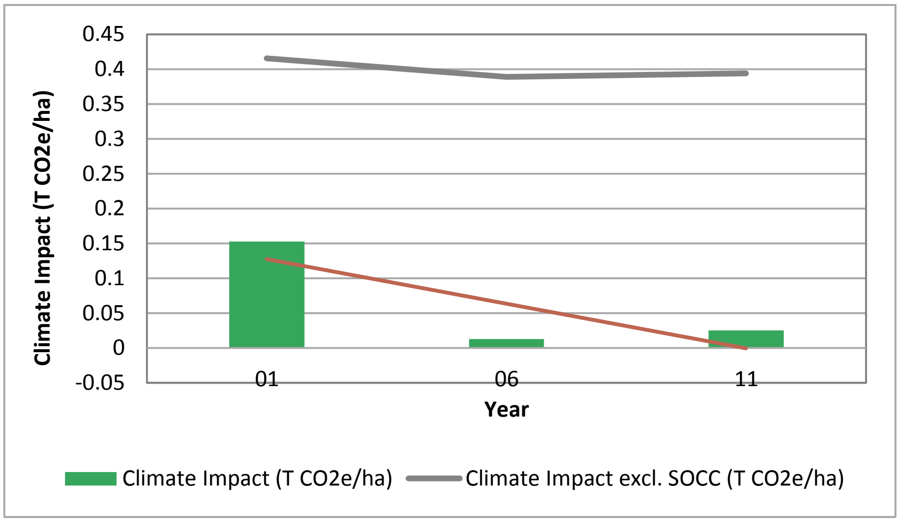
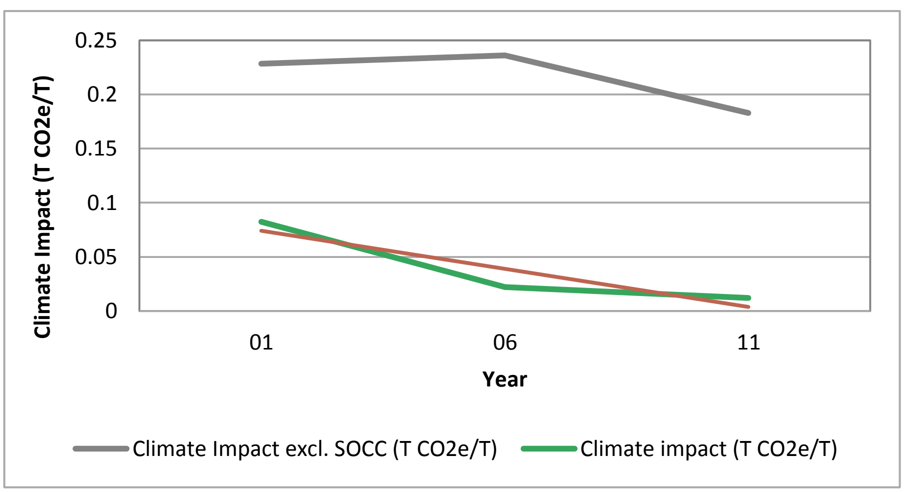


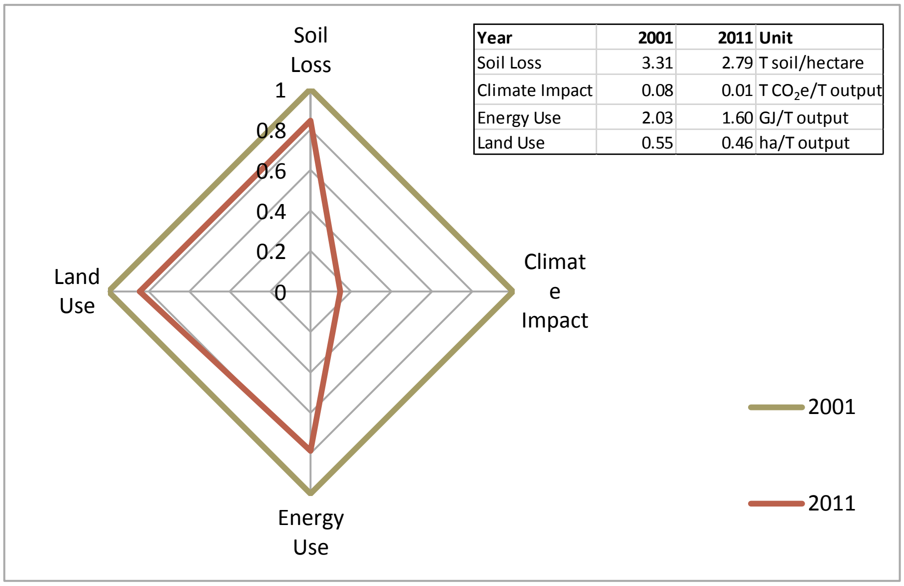
Figure 73: Soybeans, Manitoba - Climate Impact per Tonne



Indicator Summary – Soybeans, Manitoba

Figure 74 shows consistent improvement for Manitoba soybean production, on all four sustainability indicators over the ten years from 2001 to 2011. Output-based land use efficiency improved by 15%, energy use by 20%, and climate impact by 95%.

Figure 74: Soybeans, Manitoba – All Indicators



Context: Soybean Production in Manitoba and Ontario

Context is very important when results for Manitoba and Ontario soybeans are considered:

- Manitoba and Ontario represent markedly different physical environments in terms of climate, topography and soil type
- Production of soybeans has a shorter history in Manitoba
  - Manitoba soybean production is represented by three data points (10 years) in this analysis
  - Ontario soybean production is represented by seven data points (30 years)

  As a result of this shorter time series, the trends documented here for Manitoba soybean production are probably less reliable than those for Ontario soybean production.

Direct comparisons of soybean production in Ontario and Manitoba cannot be made.

3.15 Soybeans, Ontario

Land Use Indicator

In Ontario, soybean yields showed moderate increases between 1981 and 2011 (Figure 75). As a result of these modest yield increases, land use efficiency for Ontario soybeans improved by 17% over the 30-year study period from 1981 to 2011 (Figure 76).

The soybean aphid (*Aphis glycines*) first affected Ontario soybean production economically in 2001. This is seen in Figure 75, where soybean yield is substantially reduced in 2001.

Figure 75: Soybeans, Ontario - Tonnes per Harvested Hectare

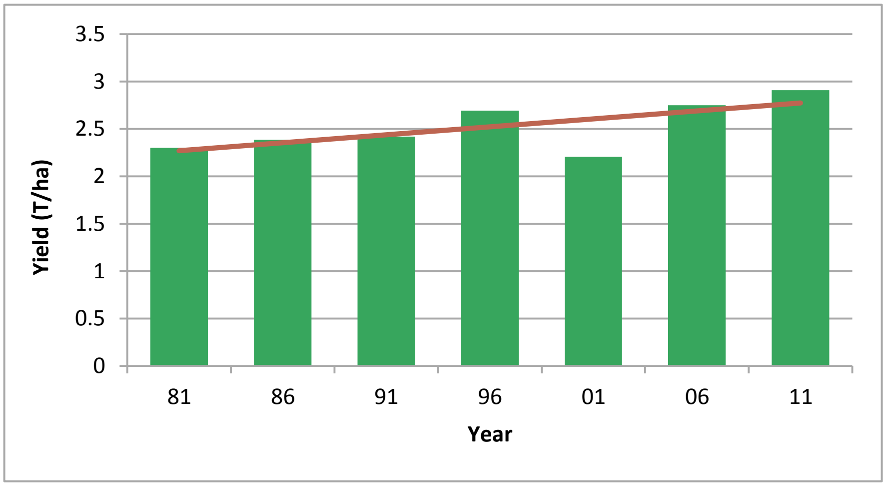
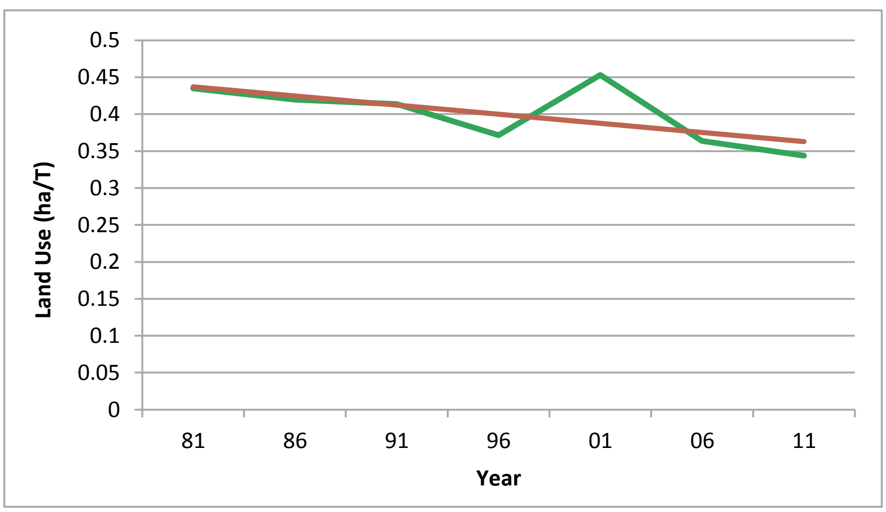


Figure 76: Soybeans, Ontario - Harvested Hectares per Tonne

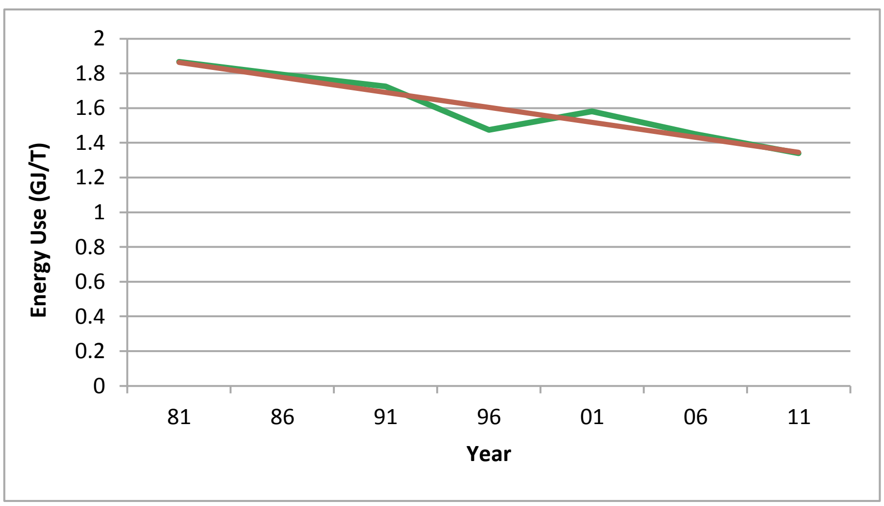


Energy Use Indicator

Energy use for soybean production in Ontario also improved, at a moderate rate. Energy use on the basis of harvested area decreased by 12% between 1981 and 2011 (Figure 77). Output-based energy use decreased by 28% over the same 30-year study period (Figure 78).

Figure 77: Soybeans, Ontario - Energy Use per Harvested Hectare

Figure 78: Soybeans, Ontario - Energy Use per Tonne



Climate Impact Indicator

From 1981 to 2011, climate impact for production of soybeans in Ontario increased slightly on the basis of harvested area, but improved moderately if based on output. Based on harvested area, climate impact increased by 3% over the 30-year study period (Figure 79). Based on output, climate impact improved by 17% over the same study period (Figure 80).

The slight increase in area-based climate impact for Ontario soybean production is largely the result of increasing yields resulting in increasing amounts of crop residue, in combination with relatively high moisture in Ontario, leading to relatively high nitrous oxide emissions (see box in section 3.6, Winter Wheat, Ontario).

As identified in section 2.5, above, research indicates that nitrous oxide emissions from crop residues of legumes, such as soybeans, may be overestimated in this study. Nitrogen-rich residues of N_2-fixing crops have been found to have a limited impact on N_2O emissions in the short term.

Figure 79: Soybeans, Ontario - Climate Impact per Harvested Hectare

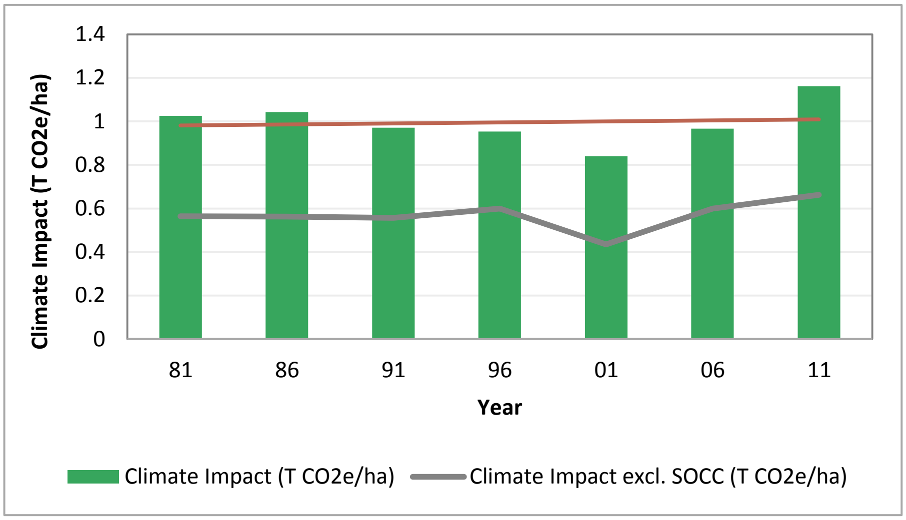
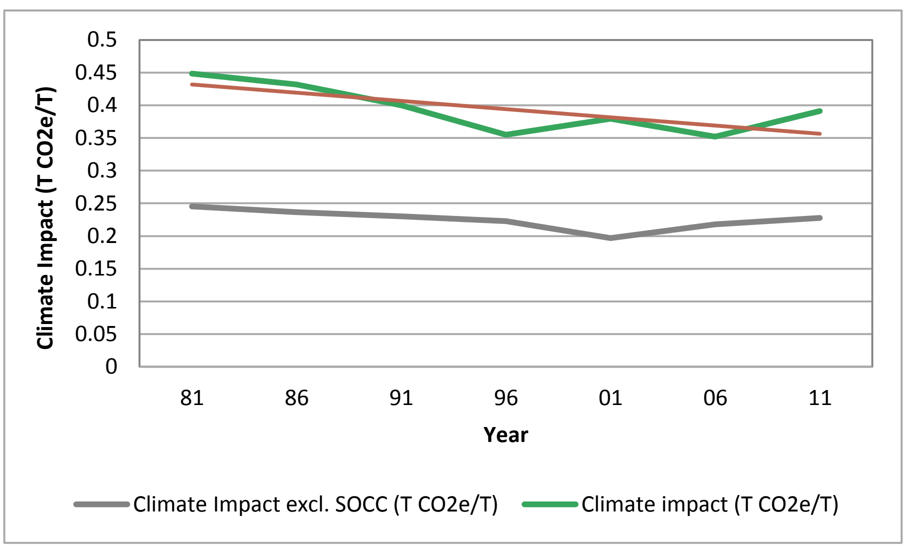


Figure 80: Soybeans, Ontario - Climate Impact per Tonne



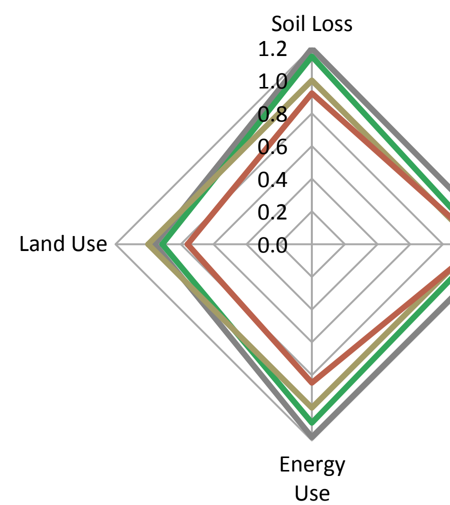
Indicator Summary – Soybeans, Ontario

Overall improvement on all three output-based sustainability indicators for Ontario soybeans is seen in Figure 81. This is in spite of a relatively low rate of yield increase over the period from 1981 to 2011, and of the evidence of low yields around 2001 in the land use indicator.

Based on cropland area, soil loss improved by 25% over the 1981-2011 study period (Figure 81). Over the same time frame, output-based land use efficiency improved by 17%, energy use by 28%, and climate impact by 17%.

Figure 81 shows the impacts of the soybean aphid on soybean yields in 2001. The low yield is seen in the high land use indicator in 2001, relative to 1991 and 2011. The low yield in 2001, and the resulting lower crop residue levels, are also seen in the climate impact indicator for 2001, which is low relative to 1991 and 2011. It is important to note that, even with the noticeably low climate impact indicator for 2001, and the increase in climate impact from 2001 to 2011, output-based climate impact from soybean production has decreased form 1981 to 2011, as seen in Figure 80.

Figure 81: Soybeans, Ontario – All Indicators



Year	2001	2011	Unit
Soil Loss	22.39	20.66	T soil/hectare
Climate Impact	0.38	0.39	T CO_2e/T output
Energy Use	1.58	1.34	GJ/T output
Land Use	0.45	0.34	ha/T output

3.16 Corn, Ontario

Land Use Indicator

Corn yields in Ontario showed strong improvement over the 1981-2011 period (Figure 82). This drove consistently strong improvements in land use efficiency, which improved by 39% overall between 1981 and 2011 (Figure 83).

Figure 84: Corn, Ontario - Tonnes per Harvested Hectare

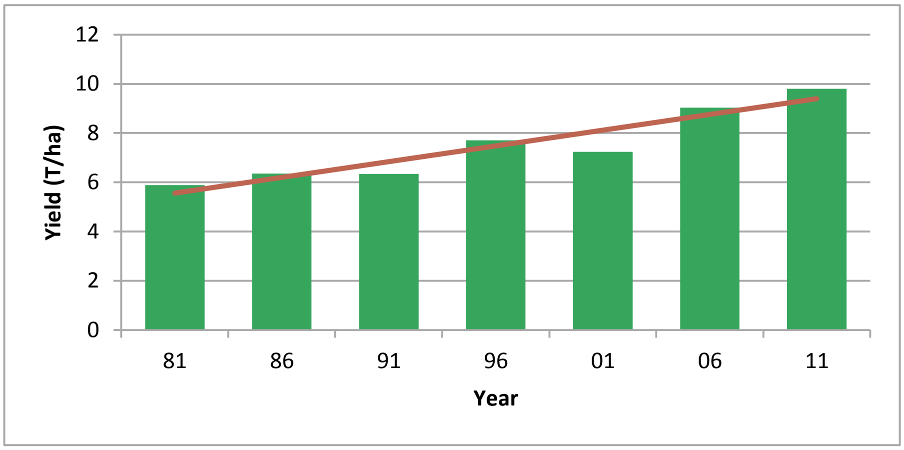
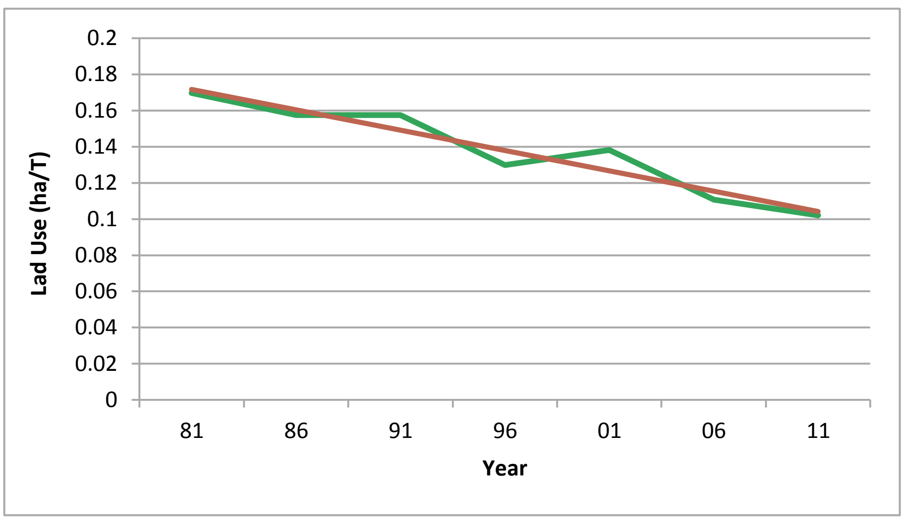


Figure 85: Corn, Ontario - Harvested Hectares per Tonne



Energy Use Indicator

Of the crops studied, corn has the highest area-based energy use, by a substantial margin, owing to the large amount of fertilizer required by this crop (Verge and Dyer, 2014).

Energy use for Ontario corn production shows relatively low per-unit-area intensities for 1996 and 2001. However, a slight overall increase of 0.2% is seen over the 30-year period from 1981 to 2011 (Figure 84). Over the same period, output-based energy use improved by 39%, driven by strong yield increases (69%) between 1981 and 2011 (Figure 85).

Figure 86: Corn, Ontario - Energy Use per Harvested Hectare

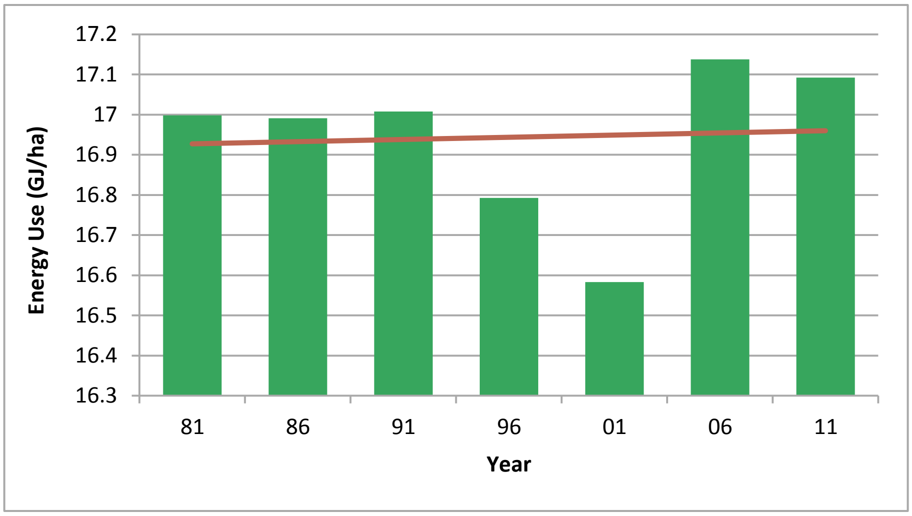
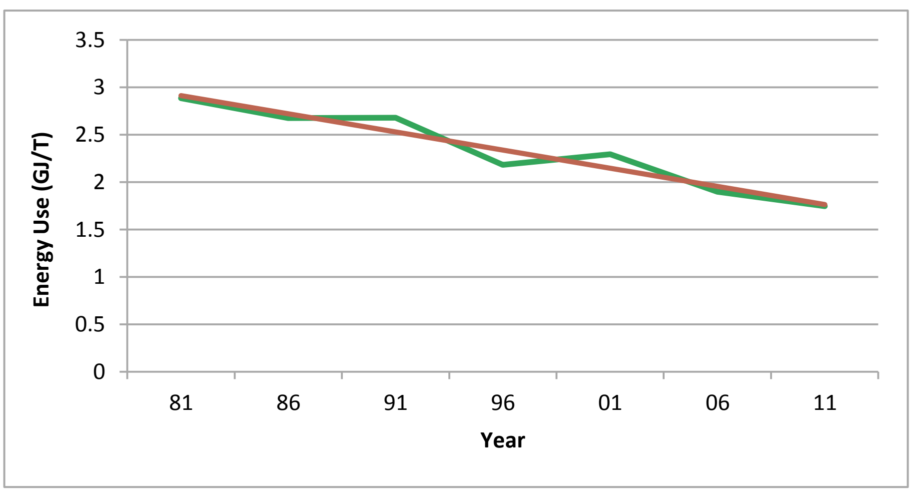


Figure 87: Corn, Ontario - Energy Use per Tonne



Climate Impact Indicator

Area-based climate impact shows the same low level as energy use for 2001. Over the 1981-2011 study period, area-based climate impact for Ontario corn production increased slightly, by 4% (Figure 86). Output-based climate impact decreased by 37%, on the strength of strong yield increases (Figure 87).

The increase in area-based climate impact for Ontario corn production is largely the result of increasing yields, resulting in increasing amounts of crop residue, in combination with relatively high moisture in Ontario, leading to relatively high nitrous oxide emissions (see box in section 3.6, Winter Wheat, Ontario).

Figure 88: Corn, Ontario - Climate Impact per Harvested Hectare

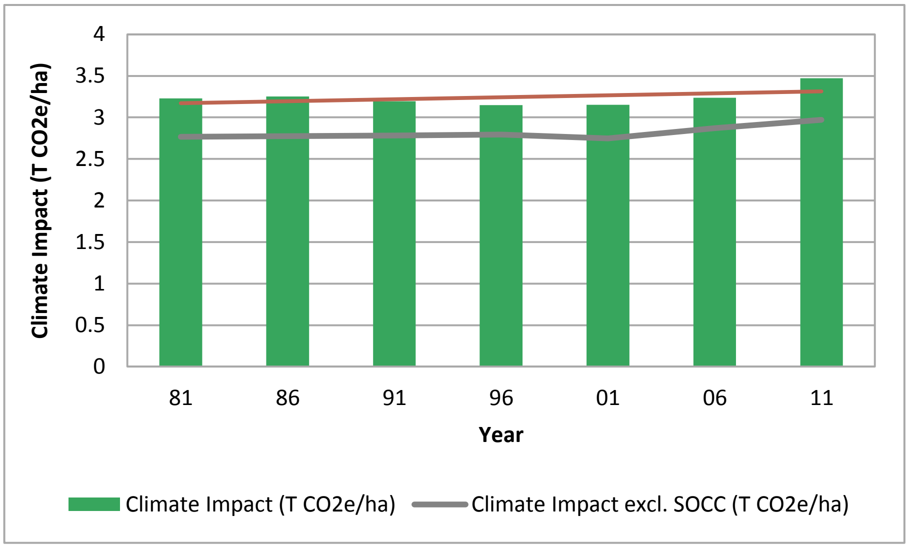
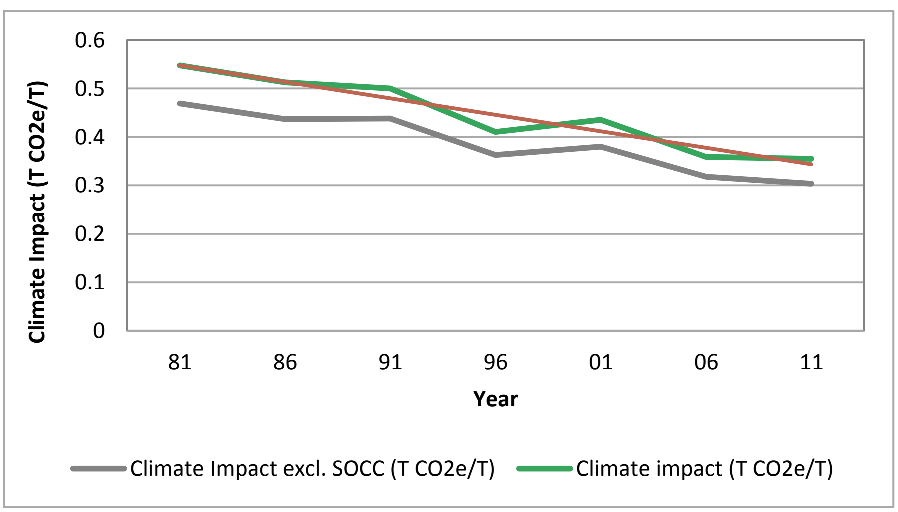


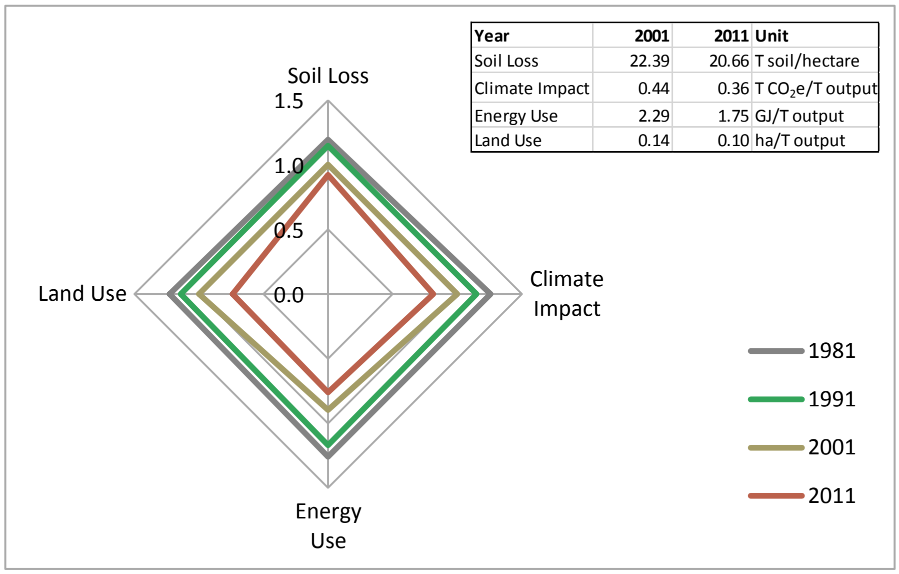
Figure 89: Corn, Ontario - Climate Impact per Tonne



Indicator Summary – Corn, Ontario

Figure 88 shows consistent improvement on all three output-based sustainability indicators for Ontario corn production, from 1981 to 2011. Land use efficiency improved by 39%, energy use by 39%, and climate impact by 37%. Meanwhile, soil loss (calculated on an area basis, and therefore without the benefit of corn's yield increases) improved by 25%.

Figure 90: Corn, Ontario – All Indicators



Year	2001	2011	Unit
Soil Loss	22.39	20.66	T soil/hectare
Climate Impact	0.44	0.36	T CO_2e/T output
Energy Use	2.29	1.75	GJ/T output
Land Use	0.14	0.10	ha/T output

4.0 Summary

This report documents trends on sustainability parameters for crop production in two distinct agricultural regions of Canada. Land use, soil loss, soil organic carbon change, energy use and climate impact are reported for the time period from 1981 to 2011, for Ontario and the Prairies. This represents expansion of the sustainability indicators reported in 2011 to include Ontario, and updating to include 2011 Census of Agriculture data.

The sustainability indicators show a very positive picture for crop production both in Ontario and on the Prairies. The positive trends reported in 2011 for the Prairie Provinces have continued over a further five years, and are also demonstrated for the 30-year study period in Ontario.

The premise underlying these indicators is that the key criterion for sustainability is improvement over time, in key areas of environmental impact. Emphasis is therefore on demonstrating continuous improvement over time, within a given geographical context. It is recognized that different regions and different crops provide very different opportunities to improve the sustainability of production. For this reason, comparisons of different crops, or of the same crop in different geographical regions, should not be made. The results in this report should be interpreted in this light.

Where data permitted, the sustainability indicators were calculated as resource use per unit of output, e.g. energy use was calculated as GJ/tonne of crop produced. This approach focuses on how efficiently farmers are using resources to meet increasing demand for food. Land use, energy use and climate impact were all calculated on this basis. These three efficiency indicators, for all the crops assessed, in both Ontario and on the Prairies, showed improvement.

Due to data limitations, it was not possible to calculate soil loss and soil organic carbon change on a crop-specific basis. Thus the output-based efficiency indicators calculated for land use, energy use and climate impact could not be created for soil loss and soil organic carbon change. Instead, soil loss and soil organic carbon change were calculated on the basis of cropland area, e.g. soil loss in tonnes/ha/year. Both soil loss and soil organic carbon change improved over the study period, both on the Prairies and in Ontario.

Land use, energy use and climate impact were also calculated on the basis of area. Thus, for example, energy use was calculated as GJ/ha, as well as GJ/tonne of crop. Resource use per unit of area normalizes the metrics to a common unit for comparison, as does resource use per unit of output. However, it must be understood that an equal amount of resources (land, energy or GHG production) may be used per hectare, with varying levels of production. Calculated on the basis of area, the following sustainability impacts increased somewhat over the study period:

- climate impact for production of winter wheat, corn and soybeans, in Ontario
- energy use for production of winter wheat and corn, in Ontario

For all other crop-geographies, area-based land use, energy use and climate impact showed improvement.

The sustainability indicators reported here on an output basis all showed improvement, largely on the strength of consistent yield increases. Of the indicators based on area rather than output, the strong improvements in the risk of soil loss are noteworthy.

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Appendix

Field to Market: The Alliance for Sustainable Agriculture

The work of Field to Market: The Alliance for Sustainable Agriculture, in the United States, serves as a key reference for the Canadian Field Print Initiative. This applies both to the macro-level indicators outlined in this report, and to the Canadian Field Print Calculator.

Field to Market continues to be a leader in the development of sustainable agriculture metrics in North America. This is true both in terms of the importance of the stakeholders engaged with Field to Market, and the extent of representation from the US food production sector. Field to Market's Fieldprint Calculator is listed by SAI Platform's Sustainability Performance Assessment (SPA) project among the most promising on-farm sustainability tools, demonstrating Field to Market's importance at the global level (Kuneman and Fellus, 2014). The SPA project aims to develop more uniform criteria for measuring and reporting on-farm sustainability. In addition to this work on on-farm sustainability measurement, Field to Market remains a leader in development of macro-level sustainability indicators for agriculture.

Field to Market is a collaborative stakeholder group working to define and measure agricultural sustainability (Field to Market, 2012). It includes producers, agribusinesses, food, fibre and retail companies, conservation organisations, universities and agency partners. These member organisations provide oversight and technical guidance in the development of metrics and tools.

Field to Market (2012) defines the following criteria for the macro-level indicators they develop:

- National scale – analysis of sustainability performance at the national level, ultimately providing context for smaller-scale projects
- Trends over time – metrics that provide for analysis of changes over time
- Science-based – application of the best available science and transparent methodologies
- Outcomes-based – focus on the sustainability impacts of a range of agricultural products and practices
- Public dataset availability – based on publicly available, national-level data
- On-farm – focus on outcomes resulting from on-farm production
- Grower direct control – focus on outcomes that respond directly to the producer's management decisions

Field to Market updated its macro-level indicators in 2012 (Field to Market, 2012 V2). Field to Market reports essentially the same environmental indicator set in 2012 as it did in its original indicator report in 2009 (Field to Market, 2009). Thus, the following environmental indicators are reported:

- Land Use
- Soil Erosion
- Irrigation Water Applied
- Energy Use
- Climate Impact

This indicator set reflects Field to Market's effort to define a relatively small set of key outcome indicators to reflect agricultural sustainability.