PROJECT DETAILS

- **Title**: The environmental footprint of canola and canola-based products (part 1)
- **Funders:** Agriculture and Agri-Food Canada, Alberta Canola, Canola Council of Canada, Manitoba Canola Growers and SaskCanola
- **Research program:** Growing Forward
- **Principal investigator:** Vern Baron
- **Collaborators/additional investigators:** Reynald Lemke
- **Year completed:** 2012

Executive summary

Canola acreage is close to 8 million ha and 90% of the production is exported. This is a large footprint nationally and globally. Sustainability is one of four market issues that impact canola market accessibility, particularly the large European biofuel market. Improving agronomic efficiency through improved and changing management practices should go hand in hand with economic stability and environmental sustainability. In this new marketing reality, environmental impacts need to be documented along the product value chain down to the farm gate on a product intensity basis (i.e. greenhouse gas emitted / kg seed produced).

Life cycle assessment (LCA) and carbon footprints are metrics based on environmental impact as a ratio of product produced (functional unit). These are often conducted on an entire industry basis including impacts of processing and the processed product, including the disposal of the products. These may be valuable nationally, but interpretation locally and recommendations to producers may be at odds with the conclusion of those assessments conducted for a whole industry (cradle to grave). Thus there is a need for assessments that reflect on farm management and reveal the drivers of change so that improvement in production efficiency may lead to environmental benefits. Further there is uncertainty in how well actual measurements of greenhouse gas emission agree with IPCC methodologies often used in LCA studies and applied universally. There is uncertainty about how all of the assessments and methodologies apply on a field scale and farming operations, particularly for canola in high yielding and high input regions. Generally speaking high levels of inputs are not associated with sustainability.

Objectives

Part 1. A cradle to farm gate life cycle assessment entitled: Life cycle assessment of Western Canadian canola crop production: 1990 versus 2010 was conducted by the Saskatchewan research Council for the project. The objectives were:

1. Determine if the environmental footprint of canola changed over the last 20 years and how projected production efficiencies will further influence that footprint relative to that for other crops.

Find more information on this project and many other relevant canola studies on the Canola Research Hub.
The Canola Research Hub is funded through the substantial support of the Canadian Agricultural Partnership and the canola industry, including Alberta Canola, SaskCanola, Manitoba Canola Growers and the Canola Council of Canada.

2. Determine if implementation of beneficial management practices for canola production affect its environmental footprint.

Part 2. Studies on existing long term rotations were carried out on the brown soil zone where canola was part of the rotation sequence. The objectives were:

1. Determine how canola production systems affect emissions of nitrous oxide and the soil N balance compared with other crops.
2. Determine how canola production affect the land carbon balance compared with other crops.
3. Evaluate continuous measurement of N2O as a means of reducing uncertainty about in-field N_2O–N loss estimates.

Part 3. A field-scale study using three 50 ha fields was set up to evaluate the impact of growing high-yielding canola using high inputs and two planting dates compared to barley grown at the same planting dates and medium levels of fertilizer-inputs. The objective was:

1. Compare field-scale maximum-yield and common late-planting BMP for canola production with barley on a greenhouse gas balance and energy intensity basis.

Results

Part 1. The life cycle assessment was conducted on three soil zones in each of the three prairie provinces for an era bracketing 2010. Sufficient information on production practices could only be obtained for the 1990 era from the black soil zone in Alberta. So the comparison of eras (2010 vs. 1990) was carried out by comparing the Alberta Black Soil Zone. The functional unit for comparison was impact per kg canola grain (e.g. kg CO_2 eq. / Mg canola for the carbon footprint). Therefore improved canola hybrids were fundamental to the improved environmental impact as average yield increased by 1.6 times. The fact that the hybrids are herbicide resistant reduced the amount of herbicide used and its' environmental impact. A movement from conventional to minimum tillage enhanced carbon sequestration and reduced the fossil fuel requirement. The carbon footprint of canola grown on the Grey, Black and Brown soil zones improved from 787 to 488 kg CO_2 eq. / Mg canola, from 689 to 365 kg CO2 eq. / Mg canola and from 501 to 399 kg CO2 eq. / Mg canola, respectively between 1990 and 2010. Impacts of soil carbon sequestration as a result of changing tillage practices amounted to 15 to 91 kg CO2 eq. per Mg canola seed produced. Besides improved soil carbon sequestration, change in tillage practices between 1990 and 2010 resulted in a 53 to 65% overall reduction in environmental impacts because of reduced fossil fuel use per Mg of canola seed produced. Due to the reduction in herbicide use as a result of herbicide tolerant canola all of environmental impacts have been reduced to less than 40% of 1990 herbicide impacts.

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Part 2. Crop Rotation studies at Scott, SK indicated that crops such as wheat following canola emitted significantly more nitrous oxide (N_2O) than those following other crops. The reasons for this are unknown, but likely reflect relatively high N-inputs from the canola residue.

On the other hand crop rotations grown at Swift Current, SK. indicated that rotations including canola were more likely to reach the level of carbon inputs (minimum 2.4 Mg C/ha/yr) from roots and residue that would promote soil carbon–sequestration than crops such as wheat and over many years would result in increasing soil-C stores in the semi-arid environment.

Studies investigating the use of Fourier Transform Infrared (FTIR) continuous measurement of N_2O in the crop environment were conducted successfully over several weeks of 24-h N_2O detection at very low concentrations.

Part 3. Generally the field scale studies at Lacombe, AB reflect those of the rotation studies. Early planted canola appeared to sequester more ecosystem carbon than late planted canola and barley. This is likely because canola carries out uptake of CO_2 from the atmosphere through photosynthesis longer than the barley and early planting enables the crop to extend this period of uptake. However, because more fertilizer-N is used in canola production and more residue is returned from canola to the soil than from barley, canola production may result in larger amounts of N_2O emitted than barley. Chamber-based emissions appear to be approximately 75 to 80% of IPCC calculated emissions. Currently canola provides more net revenue/ha than barley seeded early or late. High yields of grain DM and oil are essential to minimize environmental and carbon footprints. This appears possible with early planted canola.

Impacts or implications (realized or anticipated)

Part 1. The life cycle assessment shows that agricultural research in Canada has been successful in developing crops that are not only economically successful, but sustainable. The impact is that on the whole-canola producers and the canola industry is following sustainable procedures. This should be of interest to the consumers of Canada and consumers in foreign markets.

Part 2. Previously the impact of canola in cropping systems was not investigated thoroughly for impacts on carbon sequestration and greenhouse gas emission. The information shown may provide insights as to the role canola can play in improving soil carbon stores. However, further investigation is required to verify the higher than desired N2O emissions. The information is of interest to scientists who work in the crop production and greenhouse gas areas of research.

Part 3. Further information is being revealed on how cropping systems involving canola can be designed to maximize carbon sequestration through early planting and use of full-season crops and how canola compares to barley. This shows how simple BMP can influence environmental impacts positively. It is of interest to the canola industry and those interested in the social conscience of agriculture.

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Next steps

Part 1. The report on the life cycle assessment of canola production entitled: Life cycle assessment of Western Canadian canola crop production: 1990 versus 2010 needs to go through a third party review to be in compliance with ISO standards. Then it should be published.

Part 2. Further research involving the role of canola and canola residue in N_2O emission is required and comparisons of methods for N_2O measurement is required to optimize sample timing across methods to improve accuracy and precision. The IPCC equations used for estimating N_2O emission will be refined.

Part 3. More years of research are required to determine annual variability of carbon footprint for treatments and to refine the resolution of measurements.

Final report

Part 1. Introduction
Canola acreage is close to 8 million ha and 90% of the production is exported. This is a large footprint nationally and globally. Sustainability is one of four market issues that impact canola market accessibility, particularly the large European biofuel market. Improving agronomic efficiency through improved and changing management practices should go hand in hand with economic stability and environmental sustainability. In this new marketing reality, environmental impacts need to be documented along the product value chain down to the farm gate on a product intensity basis (i.e. greenhouse gas emitted / kg seed produced). Yields of seed and oil per unit of input are important. This research will document impact of management change through life cycle analyses (LCA), emission coefficients may be reduced through work on canola rotations and impacts of high yield production on greenhouse gas intensity tested.

There is great societal concern about the environmental impact of producing agricultural products, particularly for non-food uses such as biofuel. There is an increasing movement to provide quantified estimates of sustainability and the environmental footprint (e.g. de Vries et al. 2010). The Keystone Alliance for Sustainable Agriculture, with a large membership including a wide spectrum of the American food industry, along with various governmental and non-governmental organizations, has identified climate impact, energy use, soil loss, water use, and land use as a useful suite of indicators to access the sustainability of food (The Keystone Center 2009). Detailed life-cycle analyses are invaluable tools to appropriately assess the environmental impact for canola and key canola products including oil, meal, and biodiesel. Life cycle analysis (LCA) is a tool used to estimate energy, greenhouse gas, water use efficiency etc. on a product intensity basis within a prescribed production chain. LCA may be focused on single or typical management practice that produces a single product such as biofuel, while comparing canola to soybeans or other suitable crop options (e.g. Halleux et al. 2008; Nemecek and Erzinger 2005). Often the basic data required for LCA does not come from the canola adaptation zone, Western Canada, or is simply unavailable.

The increasing adoption of Beneficial Management Practices have greatly improved production efficiencies and thereby decreased canola's footprint. For example, hybrid cultivars produce about 20% more yield per unit of N than conventional open-pollinated cultivars (Cutforth et al. 2009; Smith et al. 2010) and this correspondingly reduces energy input and greenhouse gas emissions per tonne of canola.

Part 1 Objectives

1) Determine if the environmental footprint of canola changed over the last 20 years and how projected production efficiencies will further influence that footprint relative to that for other crops.

2) Determine if implementation of beneficial management practices for canola production affect its environmental footprint.

Materials and Methods

An open competition for a life cycle assessment (LCA) resulted in AAFC awarding a contract to the Saskatchewan Research Council. A detailed description of the process may be obtained by reading the report entitled "Life cycle assessment of Western Canadian canola crop production: 1990 versus 2010" by MacWilliam et al. (2013). The assessment was conducted in accordance with International Standards Organization (ISO) recommendations. Simapro (version 7.3.2, Pre 2011) LCA modeling software was used along with a selected impact assessment method, IMPACT 2002+. The most recent global warming impact factors were used (IPCC 2007). Besides determining the carbon footprint an environmental impact assessment was conducted which included global warming, non-renewable energy, eutrophication, acidification, eco-toxicity and land use.

Initially, the objective was a comparison of the 1990 and 2010 eras of canola production impacts using a functional unit of 1 tonne (1 Mg) of canola seed on a soil zone basis in each of Manitoba, Saskatchewan and Alberta. The system boundary included all inputs for seed or grain production. It begins with the production of energy and materials and ends at the farm gate after the canola is harvested and ready to sale. This was possible for the 2010 era, but the comparison of eras could only be completed for Alberta because production practices for the 1990 era were documented sufficiently for Alberta, only, and not for the other provinces. The specific product systems (seeding, tillage, herbicides, harvests methods etc.) for 2010 were based primarily on the survey and report compiled by Smith and Barbieri (2012). The 1990 canola production systems information was based on a report of producer survey information from Alberta (AB AFRD 1993).

Choice of yield data was important to the study. Multi-year yield data were used to avoid weather related issues that might be confined to a single year and region. In the 1990 era-yields Alberta provincial averages (Hartman 2013) from 1991 to 1995 were utilized and for 2010 average yields from 2008-2012 for Manitoba, 2008-2011 for Saskatchewan and 2009-2012 from Alberta. More detail on methods can be obtained from the report (MacWilliam et al. 2013) when it is released.

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Results and Discussion

Because of the functional unit (kg CO_2eq / Mg seed) change in yield was very important. During the 1990 era there was only a small area of production on brown soils. After direct seeding, reduced and zero tillage methods (including herbicide resistant varieties) were introduced, canola production spread to the brown soil zone. Average yields indicate that yield increased substantially in Alberta between eras. However, the Alberta survey from the 1990 era indicated that a group of high yielding producers had yield levels that were higher than the average of the 2010 era (Table 1) and 170-182% of respective regional averages of the time. This indicates that given the technology and genetic capacity of the time producer excellence is long-standing. Overall, average yields of the 1990 era were 62% of the 2010 era.

Table 1. Provincial average canola yield[z] from Grey, Black and Brown soil zones from three province for the 2010 era[Y] and from Alberta for the 1990 era[X].

	Manitoba	**Saskatchewan**	**Alberta**
Era		**kg/ha**	
		Grey Soil Zone	
2010	**1838**	**1836**	**1802**
1990	**-----**	**------**	**1021**
		Black Soil Zone	
2010	**1967**	**1761**	**2032**
1990	**------**	**------**	**1240**
		Brown Soil Zone	
2010	**------**	**1652**	**1726**
1990	**------**	**------**	**1198**

[z] yield in kg/ha. 1 Mg = 1 tonne = 1000 kg.

[Y] Yields for the 2010 era were averages of MB: 2008-2012 from MASC (2013); SK: 2008-20011 Government of SK (2012); AB: 2009-2012 from AFSC (2013).

[X] Yields for the 1990 era were averages from 1991-1995 (Hartman 2013).

The environmental effects of crop production are a function of crop inputs to yield. Therefore the environmental effects of canola production are inversely proportional to yield and any improvement in yield or reduction inputs per unit yield is directly proportional to yield. This is especially important as both canola yield per unit area, area of production and total production have increased. The higher yield and improved environmental footprint were a result of increased yields and plant biomass from enhanced genetics and adoption of herbicide tolerant and hybrid canola as well as improved crop production management practices.

Carbon Footprint

When soil carbon sequestration was included, the carbon footprint of the production of one Mg of canola for the 2010 era in Western Canada averaged 459 kg CO_2 eq. Across provinces the Grey soil zone averaged 578 kg CO_2 eq. (range 550-628 kg CO_2 eq.), Black soil zone averaged 515 kg CO_2 eq. (range 489-564 kg CO_2 eq.) and Brown soil zone averaged 478 kg CO_2 eq. (range 469-494 kg CO_2 eq.) per Mg canola produced. The reasons for the decrease in GHG emissions from Grey to Black to Brown soil zones were reduced tillage, reduced fertilizer application and reduced field emissions per Mg seed produced. The carbon footprint values were in agreement for the 2010 era with other studies despite differences in methodologies. Dyer et al (2010) did not include changes to soil organic carbon (621 kg CO_2 eq.), while (S&T)[2] (2010) did include changes to soil organic carbon, arriving at 401 kg CO_2 eq., but used different software.

Change in management and genetic composition were captured in the footprint when 1990 values are compared to those of 2010 with the change in soil organic carbon included (Table 2). This indicates an aggregated improvement of 38%, 47% and 20% between 1990 and 2010 for Grey, Black and Brown soil zones, respectively. Impacts of soil carbon sequestration amounted to 15 to 91 kg CO_2 eq. per Mg canola seed produced. By not including C-sequestration impacts of genetics, fossil fuel reduction and changes to other inputs are captured in exclusion of impacts of reduced tillage on C-sequestration.

Table 2. Change in carbon footprint of canola for three soil zones in Alberta between 1990 and 2010 considering impacts of tillage on soil carbon (SOC) sequestration

	1990	2010	2010
Soil Zone	**Δ in SOC sequestration not included**		**SOC Δ included**
	kg CO_2eq / Mg canola		
Grey	**787**	**594**	**488**
Black	**689**	**499**	**365**
Brown	**501**	**494**	**399**

Environmental Impact

A range of environmental impacts including aquatic eco-toxicity, terrestrial eco-toxicity, terrestrial acidity, land occupation, aquatic acidification, aquatic auto-toxicity, eutrophication, global warming and non-renewable energy were investigated. Global warming summarized impacts relating to the carbon footprint. The environmental footprint included the broader range of impacts. Relative to practices and inputs the major contributors to environmental impacts were production and use of fertilizers and use of field equipment for on-farm practices and tillage. Nitrous oxide emission, released as a consequence of applying fertilizer-N, represented 34-63% of all contributions to global warming. Combustion of fossil fuels for on-farm processes and tillage represented 8 to 22% and production of synthetic fertilizers represented 11 to 34% of all contributions.

Besides improved soil carbon sequestration, change in tillage practices between 1990 and 2010 resulted in a 53 to 65% overall reduction in environmental impacts because of reduced fossil fuel use per Mg of canola seed produced.

Fertilizer nitrogen and phosphorus application rates have increased up to 30% from 1990 to 2010, but by 2010 canola yields had increased to 1.6 times the 1990 level. Therefore the environmental impact has been reduced as fertilizer used per Mg canola produced has decreased. That being said, nitrogen fertilizer is a major contributor to nitrous oxide emission and phosphorous fertilizer to eutrophication, especially on Grey wooded soils where it is required, and fertilizer manufacturing contributes to non-renewable energy consumption.

Due to the reduction in herbicide use as a result of herbicide tolerant canola all of the previously mentioned environmental impacts have been reduced to less than 40% of 1990 herbicide impacts. Amounts of herbicide currently used are in general agreement with other studies.

Figure 1 summarizes the suite of environmental impacts assessed with solid bars representing 2010 and hatched bars the 1990 era.

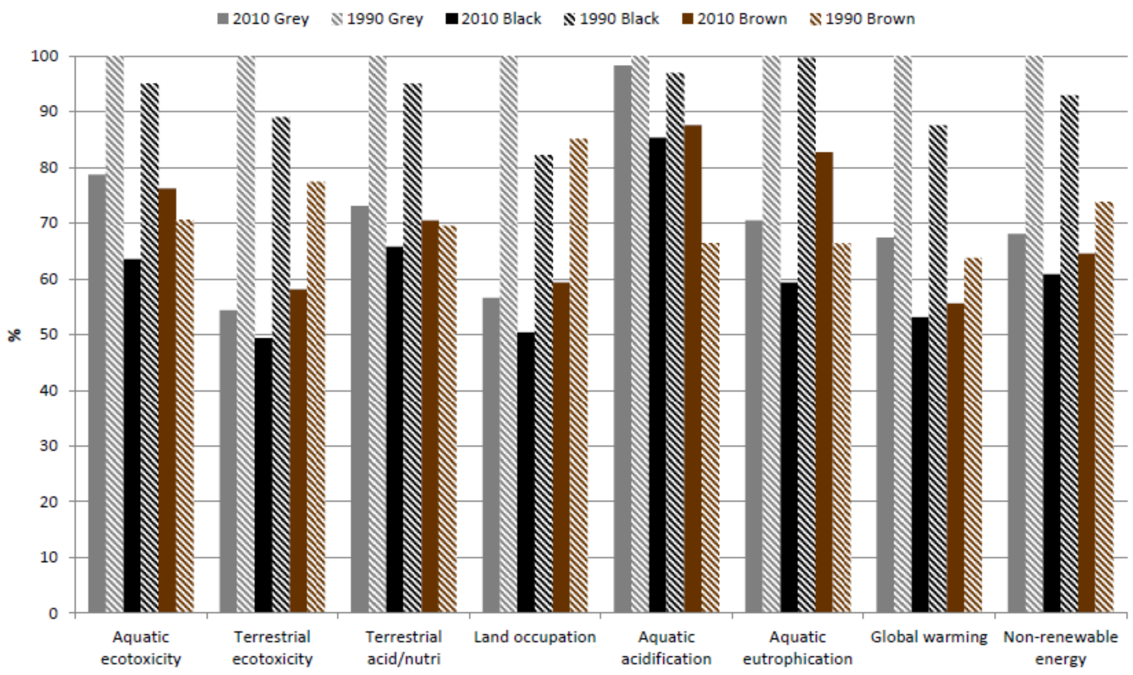

Figure 1. Comparison of current (2010) and past (1990) canola for a range in environmental impacts

Next Steps

The life cycle assessment report will have to be reviewed by a third party and then it should be published.

Part 2.

Title: Improve accuracy and reduce uncertainty of N_2O emissions and determine effects of Canola rotations on N_2O emission and soil carbon balance

Introduction

The emission of N_2O associated with canola production is a major part of the canola and canola product GHG LCA but is not well known. Therefore new field work is included to improve estimates and reduce uncertainty of the N_2O associated with canola production. Also, while the effect of pulse crops in rotation with cereals on N_2O emission in the dark brown and brown soil zones has been reported effects of canola on N_2O emission and carbon balance is less well known. Comparisons among management systems on the basis of N_2O-N loss estimates in the field are usually done with a chamber method over deliberate time frames throughout the season, while taking soil moisture and precipitation events into consideration. Then interpolation occurs over the season. These estimates are sometimes subject to large variation and therefore measurement uncertainty is a factor.

Objectives

1. Determine how canola production systems affect emissions of nitrous oxide and the soil N balance compared with other crops.
2. Determine how canola production affect the land carbon balance compared with other crops.
3. Evaluate continuous measurement of N_2O as a means of reducing uncertainty about in-field N_2O–N loss estimates

Materials and Methods

Rotation studies

Long-term rotation experiments exist at Scott and Swift Current, SK. The experiments have existed in some cases from the 1980’s. While canola has not always been part of the rotations it has been incorporated into the rotations in the last decade. A field experiment at Scott, Saskatchewan was established in 1998 to investigate the influence of increasing frequencies of pea and canola in rotation with wheat on disease incidence and severity and general agronomic performance. This study also provided an opportunity to address the questions:

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1. Does the presence of the particular crop itself change net annual emissions? In other words, will emissions during the canola phase of a rotation be different than during the cereal phase?
2. Will the type of residue affect N_2O emissions differently during the following growing season?

Specific rotations considered in the current work included field pea grown every year (Cont.P), a field pea-wheat sequence (Pea-W), a canola-wheat sequence, a field pea-canola-wheat sequence (Pea-C-W), and a field pea-wheat-canola-wheat sequence (P-W-C-W). Selecting these crop sequences allowed us to make comparisons of direct N2O emissions from soils under canola, spring wheat and field pea, and also allowed us to test for fertilizer N x crop residue interactions.

The rotation experiment at Swift Current was set up to evaluate tillage interactions with crop rotations on many factors, soil-C balance being one of them. The experimental designs are variations of a randomized complete block with variation to accommodate farm or plot equipment required.

Optimizing N_2O measurement in the field

A Fourier Transform Infrared (FTIR) multigas analyzer was acquired in the fall of 2010. Performance of this analyzer under controlled conditions was evaluated during the winter period of 2011. The system was interfaced with long-term automated soil flux chambers via a 16 port multiplexer. The complete system was to be field tested during the 2011 growing season, however record spring rainfall resulted in serious flooding and the study site had to be abandoned. The system was deployed again in 2012.

Field plots were laid out in a randomized complete-block design with four blocks (replicates). Three treatments were established including spring wheat and canola with N fertilizer applied (40 kg N ha^{-1}), and a minus N canola (check) treatment. One automated chamber was installed per plot, thus a total of 12 chambers were deployed. Each chamber could be sampled about 5 times per 24 hour period. This sampling frequency is temporally dense enough to allow diurnal trends to be characterized, and to investigate the duration and magnitude of the episodic bursts of activity inherent to N_2O emissions. Soil moisture and temperature sensors were installed near each chamber.

Results and Discussion

Rotation Studies

Estimated cumulative annual (growing season plus following spring thaw) N_2O loss ranged from 330 to 810 g N_2O-N ha^{-1} for 2008, from 160 to 460 g N_2O-N ha-1 for 2009 and from 380 to 1110 g N_2O-N ha^{-1} in 2010 (Table 3). These cumulative losses are quite low, but within the range of values reported in other studies in western Canada (e.g. Burton et al., 2008; Lemke et al., 1999, Malhi and Lemke 2007). In particular, emissions during the spring thaw period (from snow melt until seeding) were very low (data not shown). Dry conditions disfavour N_2O loss and conditions at the study site were dry, with particularly low amounts of snow cover received during the winters of 2009 and 2010.

Two trends can be discerned in the cumulative N_2O data. Nitrous oxide emitted from the wheat phase of the C-W rotation presented the highest emissions in two of three years. Conversely, N_2O emissions from the pea phases tended to be amongst the lowest emissions, and were generally as low or lower, although not statistically different from, the unfertilized reference treatment [Cont.W (-N]. Emissions generally reflected fertilizer-N inputs and showed no evidence of an interaction with pulse residues, but there does appear to be an interaction with canola residue. In other words, cumulative N_2O losses were comparable for wheat or canola grown on wheat or pea residues, but emissions were significantly higher for wheat grown on canola residue. We can, at the moment, offer no explanation for this interaction.

Table 3. Estimated cumulative nitrous oxide loss measured over three years from various crop rotations at Scott, SK

Treatment	2008	2009	2010	3-yr cumulative
	g N_2O-N ha^{-1}			
Cont.W (-N)	570 b	160 c	380 c	1110 c
Cont.W (+N)	510 b	310abc	570 bc	1390 b
Cont.P	400 b	160 c	480 bc	1040 c
(P)-W	340 b	170 c	740 ab	1250 bc
(W)-P	330 b	430 a	540 bc	1300 b
(C)-W	400 b	460 a	620 b	1480 b
(W)-C	810 a	380 ab	1100 a	2290 a
P-(C)-W	360 b	250 bc	580 bc	1190 bc

Values within the same column followed by different letters are statistically significant ($p<0.05$).

Effects of Rotation on soil–C balance

Fallow-wheat-wheat, fallow-canola-wheat, fallow-wheat-pulse; fallow-pulse-wheat; wheat-oilseed-pulse rotations were followed from 1995 to 2005 at Swift Current, SK in no-tillage and minimum tillage systems. The purpose was to relate carbon inputs from root and residue material to gain or loss in soil organic carbon. Soil organic carbon increased about 0.33 Mg per Mg of C-input above 2.4 Mg C/ha/yr. However, when C-inputs are less than 2.4 Mg C/ha/yr SOC decreased at the same rate. Canola grown on fallow produced more C-input than wheat. Canola had a subsequent rotational effect because C-inputs were greater for wheat grown on wheat. Pulse and canola provided about 10% greater C inputs advantage in comparison to wheat. Thus maintaining canola in the rotation frequently should enhance probability of increasing soil organic carbon (Shrestha et al. 2013).

Optimizing N_2O measurement in the field.

Performance of the FTIR-MGA analyzer was found to be more than adequate for field based nitrous oxide detection. Documented response times were determined to be < 10s, detection limits were well below ambient concentrations, resolution was excellent (< 6 ppbv), and response was linear over the required working range (0.3 – 3.0 µL L^{-1}) with negligible interference from moisture and carbon dioxide.

Under field conditions, the FTIR-MGA was found to be affected by rapid temperature changes. The system was therefore installed in a small, well-insulated trailer with a simple thermostatically controlled ventilation system. This arrangement buffered against large temperature changes allowing the system to perform effectively. A few other initial “growing pains” were encountered during the first part of the 2012 growing season. These were resolved and excellent data was collected from the end of June until the soils froze in October

Figure 2. Measuring N2O with FTIR instrumentation in field, Saskatoon, SK.

Close examination of a flux “event” occurring on one of the chambers between day 256 and day 260 reveals a clear diurnal pattern (Figure 3). During this time, maximum emission rates were observed near mid-afternoon (between 2:00 - 3:00 pm) while minimum emission rates were measured in the early morning (around 6:00 am). Within a 24 hour cycle, emission rates could change by as much as a factor of 5. Clearly, if N_2O flux had been estimated during this period based on a single sampling time, as is normally the case for manual sampling approaches, then flux estimates would be strongly influenced by the particular time of day selected. For example, cumulative N_2O loss for the entire sampling period (July-Oct) was calculated based on the entire data set (4 or 5 sampling points per day), and then cumulative N_2O loss for the sampling period was also estimated based on a single measurement taken at about 2:00 pm (as is commonly done). The point-in-time estimates were about 20% greater than estimates based on the entire data set. Emissions were generally low during this

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sampling period, thus it is entirely possible that differences between cumulative losses could be even greater if more substantial emissions events had been encountered.

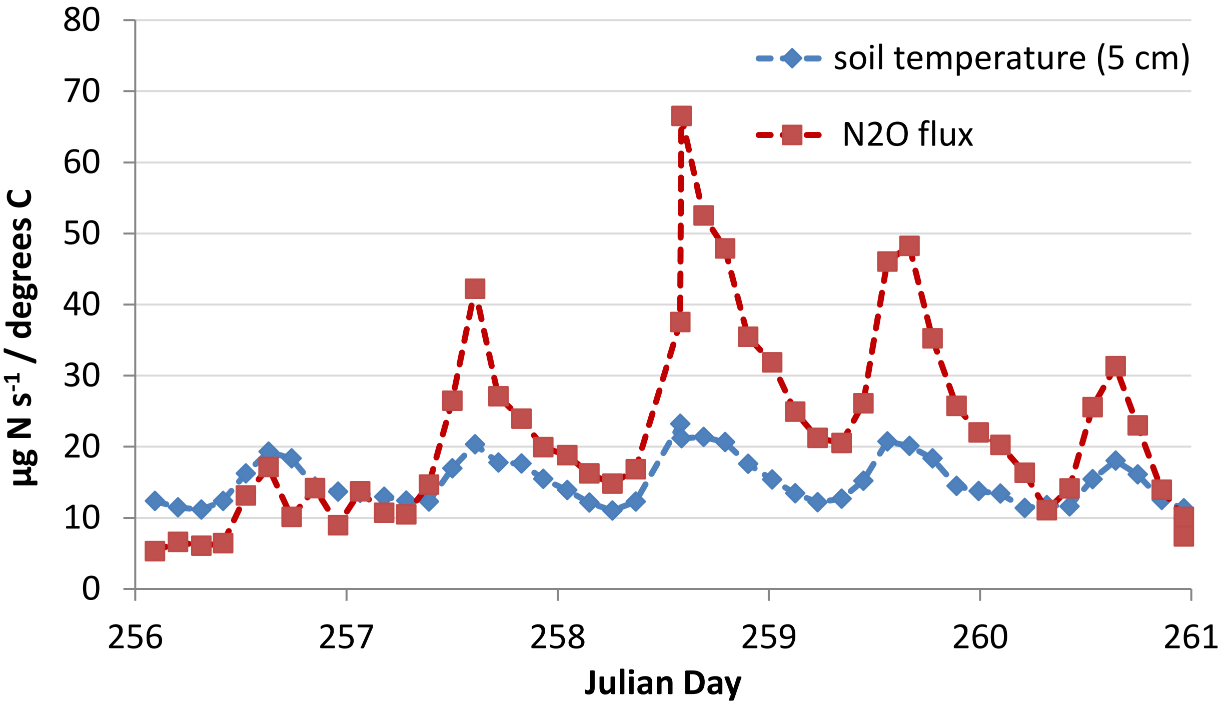

Figure 3. Nitrous oxide emissions and soil temperature measured about every three hours during a 5-day period using a FTIR-multigas analyzer connected to a long-term flux chamber.

During this 5-day period N_2O flux rate strongly correlated (r = 0.82) to soil temperature measured at 5 cm depth. If a similarly strong relationship can be demonstrated for other periods in the year, then this relationship may provide a simple tool to more accurately predict N_2O loss based on single point-in-time measurements.

Part 3. Quantification of combined greenhouse gas fluxes for canola BMP at field and whole-farm scale:

Introduction

Life cycle analyses (LCA) are carried out based on literature and summarized on a country and regional scale. They are sometimes not completely relevant at the farm level. They may not reflect year to year differences and differences in yield and quality of canola, depending on the management practice. They may make recommendations which are at conflict with regional capability to produce crops in a certain manner and at a high or low level. Therefore LCA results must be compared, contrasted and discussed with whole-farm scale footprints and production factors.

Objective

Compare field-scale maximum-yield and common late-planting BMP for canola production with barley on a greenhouse gas balance and energy intensity basis.

Materials and methods

This field scale experiment has been conducted at Lacombe, Alberta and has completed a full year study.

Location: The study will be conducted in three fields, each surrounding an Eddy Co-variance tower, at the Neumenko farm area of Lacombe Research Centre

Field 1. (Tower 1.) At the south end of S.W. ¼ SEC. 15-40-27-4
Field 2. (Tower 2.) At the North end of N.W. ¼ SEC. 10-40-27-4
Field 3. (Tower 3.) Approx. 400 m south of Tower 2 on NW ¼ SEC 10-40-27

Experimental design: Landscape design with pseudo-replication (sub-samples; n=6) within the sampling block around each tower.

Rotational trial (for 3 years and may be continued longer)

Table 4. Summary of rotation and fertilizer used in the field trial.

Rotations	2009 (history)	2010 (year 1)	2011 (year 2)	2012 (year 3)
Field/tower 1	Meadow Brome	Barley silage	Barley Early Planted (High input)	BAYER L-130 Canola Early Planted (High input)
Field/tower 2	Canola (LL)	Barley silage	Pioneer 43E01- Canola (Late planted) Medium input	Barley Medium Input (late planted)
Field/tower 3	Canola (LL)	Barley silage	BAYER L-130 Canola Early Planted (High input)	Barley Early Planted (High input)

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Fertilizer Rate:

Rotations	2010 (year 1)	2011 (year 2)	2012 (year 3)
Field/tower 1	Barley silage 100-30-30 kg ha^{-1}	Barley early A.C. Metcalfe 80-20-20 kg ha^{-1}	BAYER L-130 early 125-30-30-15 kg ha^{-1}
Field/tower 2	Barley silage 80-30-30 kg ha^{-1}	Pioneer 43E01canola Late 80-20-20-10	A.C. Metcalfe Barley late 80-20-20 kg ha^{-1}
Field/tower 3	Barley silage 80-30-30 kg ha^{-1}	BAYER L-130 early 125-30-30-15 kg ha^{-1}	A.C. Metcalfe Barley early 80-20-20 kg ha^{-1}

Varieties:
Year 1 = Champion Barley
Year 2 = A.C. Metcalfe Barley and BAYER L-130 and Pioneer 43E01canola
Year 3 = A.C. Metcalfe Barley and BAYER L-130 canola

General Field Design and sampling area:

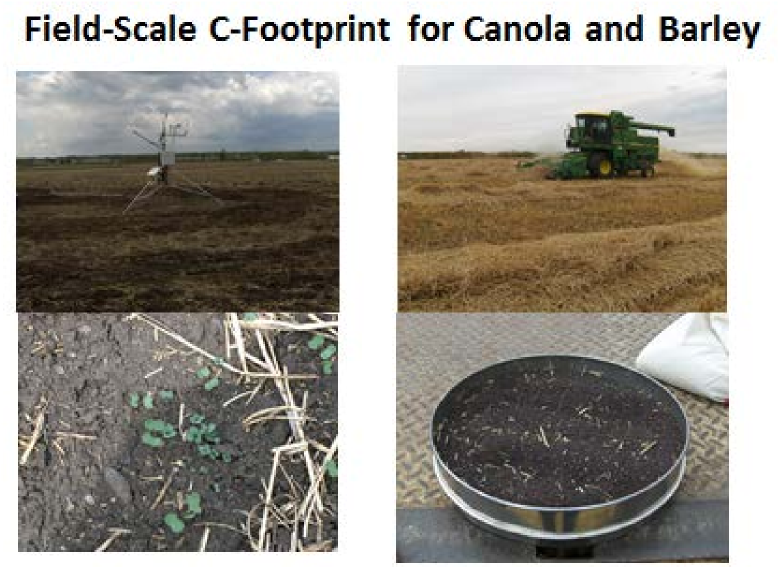


Figure 4. Clock-wise from top left: 1. Eddy co-variance system in early-planted canola; 2. Combining Metcalfe barley; 3. Emerging canola; 4. Freshly harvested canola prior to "green-seed" test.

Greenhouse gas emission

Towers are situated on the mid slope of the west facing ridge with approximately 200 m between the tower and borders. A 1-ha sampling area, close to the footprint of the tower running 50 m (actually 100 m x 100 m) square on each side of the tower. Eddy covariance equipment and the sampling blocks will be identified in all three fields by August-September of 2010. Field 1 will have both Eddy and BREB in operation by early spring of 2010.

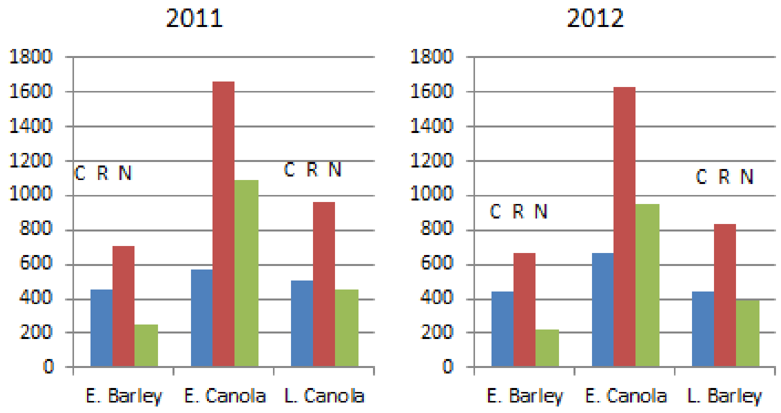
Daily and annual CO_2 flux measurements will be conducted in adjacent fields using the Eddy covariance method (Fluxnet-Canada Measurement Protocols 2003). Towers separated by 400 m. Field 1 will have both Eddy and Bowen Ratio Energy (BREB) equipment in operation by early spring of 2010. Year 1 will be used to calibrate, synchronize and evaluate corrections required among the three towers, which should be in operation by mid-summer. Soil respiration rates bi-weekly n = 6 within measurement blocks; soil N_2O flux (n = 6) (Livingston and Hutcheson 1995) snow-melt to freeze-up with annual flux determined with seasonal estimates made by linear interpolation (Lemke et al 1999).

Vegetation**:** bi-weekly above ground biomass dry matter with N and C composition and yield, LAI and stage; root dry yield, litter yield with N and C composition after harvest all at predetermined sites (n=6). Combine-Grain and standing biomass yield at maturity. Grain yield, grade, dockage and estimated oil, biodiesel, meal and protein yields.

Soil Analyses each fall with detailed analyses with texture and SOC down to 60 cm.

Results and Discussion

Figure 5. Production costs (C), gross revenue (R) and net revenue (N) ($/ha) for early and late canola and early barley in 2011 and early canola, late and early barley in 2012



Production

Yield on a dry matter basis was 3924 kg / ha for early barley, 3309 kg / ha for early canola and 1919 kg / ha for late canola in 2011. In 2012 yield was 3198 kg / ha for early canola, 3411 kg / ha for early barley and 4406 kg / ha for late barley. Early planted barley suffered considerable leaf disease compared to late barley in 2012. Costs included fixed and operating (fuel, lubrication and parts) for equipment, crop inputs (herbicides, fertilizer) and labour, but not land rental; barley and canola sold at $180 / t and $500 / (Figure 5). Due to higher crop value early canola was more profitable in both years. In 2011 net revenue for early barley, early canola and late canola was $252, $1087, and $449/ ha, respectively and in 2012 $219, $953 and $394 / ha for early barley, early canola and late barley.

Greenhouse Gas Emissions

Total emissions were higher for early canola in 2012 than 2011 (Table 5) because both N_2O emissions and Net Ecosystem Exchange (How much carbon is entering and leaving the ecosystem.) (NEE) emission were higher. The proportion of emissions among the sources was almost identical for the two years with 13 to 14 % from energy, 30 to 32% from N_2O and 54 to 59% from NEE emission, which is related to soil carbon loss. In both years the early planted canola had the lowest values for NEE compared to the other treatments. This is because the early planted canola has the longest period of ground cover during the growing season. These results are in concert with results discussed elsewhere in this report (Shrestha et al. 2013) where Canola has some advantage over other crops in carbon sequestration due to greater contributions of carbon from residue.

Nitrous oxide emission. As in 2011 canola had greater N_2O emission than barley. This is because higher fertilizer-N rates are commonly used for canola than barley and because of greater residue-N being returned to the field from canola (147 kg N /ha) than barley (58 kg N /ha). The N_2O values that are shown are estimates from IPCC Tier 2 methodology. The measured N_2O values are smaller (75 to 80%) than those shown (Table 5) and if this continues the information may be used to reduce the emission factors used in the IPCC process. The measured values From Lacombe are approximately three times larger than those found in the Brown soil zone at Scott, SK and shown earlier.

Find more information on this project and many other relevant canola studies on the Canola Research Hub.
The Canola Research Hub is funded through the substantial support of the Canadian Agricultural Partnership and the canola industry, including Alberta Canola, SaskCanola, Manitoba Canola Growers and the Canola Council of Canada.

Table 5. Summary of Greenhouse gas emissions and carbon footprint for field measurements in 2011 and 2012

	Yield (DM)	N_2O	Fossil Fuel	NEE^Z	Total Emission	Emission/product
Crop	kg/ha	kg $CO_{2\ eq.}$ / ha				kg $CO_{2\ eq.}$ / kg product
	2011					
Early Barley	3924	732	406	1410	2548	0.658
Early Canola	3309	1052	472	1150	2664	0.822
Late Canola	1919	1085	341	2340	3765	2.103
	2012					
Early Barley	3411	707	389	2470	3566	1.045
Early Canola	3198	1658	627	1620	3905	1.221
Late Barley	4406	670	390	2220	3583	0.744

[Z] NEE is net ecosystem exchange is the amount of carbon (CO_2 eq. / ha) entering and leaving the ecosystem. In this case the ecosystem acts as a source.

Carbon Footprint. Because total emissions were greater and yield was slightly lower in 2012 compared to 2011 the field-scale carbon footprint of early-planted canola was greater than in 2012 than 2011 (Table 5).

Next Steps

At least 3 more years of measurement are required to ensure that all crop treatments are repeated twice on each of the three fields, so that field effects can be removed.

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