ECONOMIC AND ENVIRONMENTAL ASSESSMENT OF PULSE ROTATIONS IN CANADIAN PRAIRIES

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Abstract

As consumers regard for corporate responsibility increases, governments, industries and organizations have begun to assess the sustainability of their activities. Sustainability has many criteria, and those related to environmental impacts and economic effects are of interest to policy makers. Pulse (dry peas) crop production is on the rise in Saskatchewan. Although exports of peas to other countries are important from a local development perspective, their use for local activities has some appeal. In this paper, a combined life cycle assessment (LCA) and economic impact analysis (EIA) of growing peas or lentils in a four-year rotation was undertaken and compared to a rotation without pulse crops (i.e. an oilseed-cereal rotation). Inclusion of peas in a rotation is desirable as it is known to break disease and pest cycles, as well as fix atmospheric nitrogen through symbiotic association with Rhizobia. This results in decreased requirements of fertilizer, pesticide and insecticide application. These changes resulted in major financial implications for the producers, as the economic returns increased by $131 to $158 per ha for the pulse rotation over the baseline rotation. The LCA results demonstrated lower environmental impacts in all categories with the pea or lentils rotations as compared to the oilseed-cereal rotation. The results of the study suggest that adding dry peas and /or lentils in oilseed-cereal rotations improve the sustainability of crop production systems.

Keywords: life cycle assessment, economic assessment, pulses, Canadian Prairies, rotations

1. Introduction

The Prairies play a very important role in Canadian agriculture, providing 32 million hectares of arable land and accounting for approximately 85% of farmland. Historically, cereal-fallow rotations have been the predominant cropping system in the semiarid Canadian Prairies and northern Great Plains of the USA (Spratt et al., 1975; Grant et al., 2002). With the demise of grain transportation subsidy in Canada on shipping grains to export locations, and facing cost-price squeeze, producers are seeking better avenues for diversification. Pulses offer this opportunity, particularly in production areas where other crop alternatives are limited. In addition, pulse crops are an attractive crop to include in the rotation because not only do they break disease cycles, but in a symbiotic association with bacteria (called *Rhizobium* spp.), they are capable of using nitrogen from the atmosphere in a process called fixation. Nitrogen fixation reduces the dependence on inorganic fertilizer application on the pulse crop itself and, due to residual soil nitrogen, reduces nitrogen fertilizer requirements for the following grain crop.

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2. Project objective

The major objective of this study was to assess the sustainability of the environmental effects of including pulse crops in a crop rotation and the associated economic effects.

The environmental and economic effects associated with the production of pulse crops were examined to determine the environmental effects and economic implications of including pulse grains in an oilseed-cereal rotation and various pulse grain end-uses.

3. Study methodology

Various tools are available to investigate the sustainability of a product. A popular and useful tool that measures the environmental sustainability of a product is life cycle assessment (LCA). The LCA is a cradle-to-grave approach in that it takes into consideration the major activities during the product's life span from its manufacture, distribution, use and final disposal. Recognizing the necessity for LCA analysis of pulse crops on a rotational level, Nemecek and Baumgartner (2006) modeled the environmental and economic effect of including pulse crops in cereal/oilseed-based rotations in Europe, as well as the effect of replacing the soybean meal in swine feed with pulse grains. Results of the crop rotation scenario indicated that crop rotations that included pulse grains had a lower life cycle environmental effect compared to the alternative scenarios.

Similar to environmental sustainability, multiple tools are available to assess the socio-economic sustainability of products. Typical approaches that can be used to evaluate economic desirability of a crop rotation include partial equilibrium approach, whole farm systems models and stochastic dominance models. Of these approaches, the partial equilibrium approach is the simplest and most appropriate for comparison of alternative rotation regimes. Such an approach can be used in simulation models, as suggested by Hewitt (1995). Furthermore, it also complements LCA, as it can be performed using the exact parameters used for the LCA.

The focus of this study was a comparison of the baseline rotation against the alternative rotations involving pulses. A four year rotation is commonly followed on the Canadian Prairies. These rotations were:

- baseline: canola – wheat – wheat – wheat,
- alternative rotation 1: canola – wheat – peas – wheat,
- alternative rotation 2: canola – wheat – lentils – wheat.

Although three wheat crops may not always be grown in succession in Western Canada, the selected rotation ensured that the LCA was modeled using the best available field data. To ensure that all changes in impacts between the cereal-oilseed scenario and the scenarios including pulse crops were due to the inclusion of pulse crops, the pulse crop was the only variable to change in the rotation. Each of these rotations was subjected to a combined economic analysis and life cycle assessment.

3.1. Economic Analysis

A simulation model for the three Prairie Provinces was developed for three soil zones: Brown, Dark Brown and Black soil zones. In addition, it contained three types of tillage systems, summerfallow, continuous cropping system and direct seeding. The model consists of a series of integrated worksheets linking yield and input levels for various crops in each of the three Prairie

Provinces[1] under different tillage systems. Results of relative economics of the rotation were estimated in nominal values and present values using a 5% rate of discount.

The economic analysis was based on several assumptions. The following are noteworthy:

1. Crop yield and fertilizer and pesticide application rates assumed were the same as that used in the LCA modeling.
2. All crops were grown using direct seeding technology.
3. Cost of production and, therefore, the economics of a rotation were determined by the location of the farm, where type of soil is a major factor.
4. Cost of production of various crops reflects 2010 economic and market conditions. This was the most recent data available for western Canada. These prices were obtained from Saskatchewan Ministry of Agriculture (2009a).
5. Producers were assumed to be price takers. In other words, a change in the rotation and level of production is assumed to not change the level of the price received at the farm gate.
6. In the Brown soil zone, canola is not a major crop produced. It was assumed that mustard is an equivalent crop for canola in this soil zone. Being oilseed crops, they were considered to be agronomically equivalent for this study.

The economics of a given crop rotation was an aggregation of the crops grown over four years in a given rotation. The economics were also presented in present value (PV) form by using a discount rate of 5%. This level of discount rate is commonly used, and is close to the rate of discount used for public benefit-cost analysis. The PV was calculated using the following equation:

$$PV\ Rotation = \sum (NR_i) / r^{(1+t)};\ i = 1, \ldots, 4.$$

Where:

NR – the net returns from the crop during year I,

r – rate of discount (assumed to be 5%) and

t – time counter.

Gain in the net return under the alternative rotation provided the basis for economic desirability of the said rotation.

3.2. Sensitivity analysis for economic assessment

One of the major sources of variability in economics of a rotation is the pricing of products – inputs and outputs. In this study the three rotations were simulated under varying market conditions.

Table 1. Details of simulations for sensitivity analysis of economic returns

Simulation No.	Price of cereal and oilseed	Price of pulses	Price of fertilizer
1 (HHH)	high	high	high
2 (HHL)	high	high	low
3 (HLH)	high	low	high
4 (HLL)	high	low	low
5 (LHH)	low	high	high
6 (LHL)	low	high	low
7 (LLH)	low	low	high
8 (LLL)	low	low	low

[1] Since very little area is devoted to pulse crops in the province of British Columbia, the data for three Prairie Provinces is taken as representative of Western Canada.

Different level of prices for grain, oilseed, and pulse crops were selected for various simulations by examining past ten year (1991-2010) farm level prices received. Using two standard deviations around the mean, price levels were determined. The 'high' prices were taken at two standard deviations to the right of the mean, and the 'low' prices were determined as two standard deviations away to the left of the mean. Eight such simulations were conducted, as shown in Table 1.

4. Life cycle analysis

A popular and useful tool that measures the environmental sustainability of a product is life cycle assessment (LCA). It is a cradle-to-grave approach in that it takes into consideration the major activities during the product's life span from its manufacture, distribution, use and final disposal. Furthermore, LCA is an inclusive method, which allows changes in a system to be tracked throughout the analysis and identified in the outcome.

The system boundary differentiates the system under analysis from its environment (Audsley et al., 2003). The system boundary for agriculture ideally stops when identical products pass out of the farm gate. The crop rotation analysis includes all inputs required for grain production. The analysis endpoint is the grain elevator – the point at which all grain has been cleaned, packaged and is ready for use.

In this study, LCA was conducted using SimaPro (version 7.1.8, PRé, 2008). The software includes thousands of processes and substances across several inventories, as well as methods for impact assessment. The environmental effects of completed life cycles are categorized and quantified based on the type of damage they cause. A list of these impacts included in the study is shown in Figure 1. The following is a brief description of each impact category, as well as the units used:

- *Human toxicity*: Carcinogenic and non-carcinogenic emissions from metals and inorganic

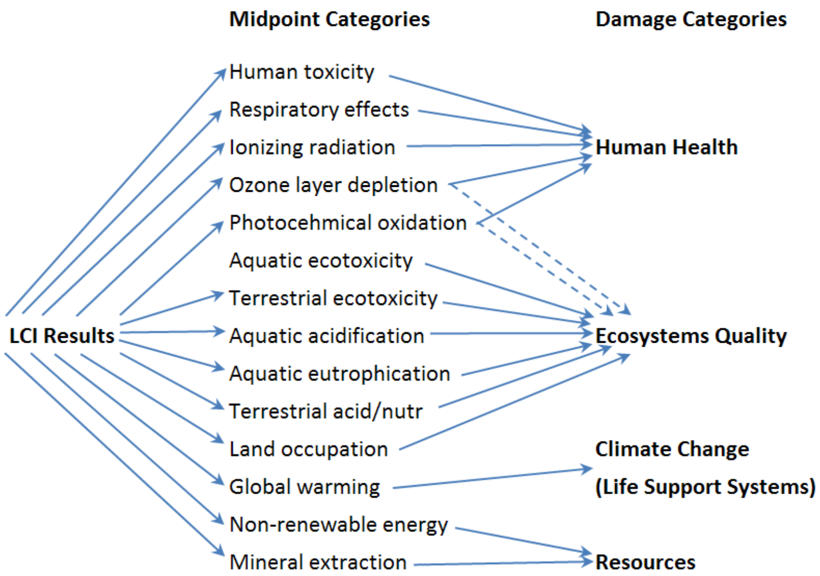

Figure 1. Midpoint and endpoint categories of life cycle impact assessment method
Source: Jolliet et al., 2003

compounds from soil, water and air (kg chloroethylene into air equivalents/kg emission);

- *Respiratory effects*: Air pollutants such as sulfur oxides and volatile organic compounds [kg particulate matter (PM) below 2.5 micron size/kg emission];
- *Ionizing radiation*: Natural and artificial radiation sources (becquerel of C-14 equivalents/kg emission);Ozone layer depletion: Several ozone depleting gases, such as chlorofluorocarbons (CFCs) and halogenated compounds (kg CFC-11 equivalents/kg emission);
- *Photochemical oxidation*: Includes smog-forming particles, such as olefins and hydrocarbons (kg ethylene into air/kg emission);
- *Aquatic ecotoxicity*: Emissions to water sources, such as surface water, lakes and rivers (kg triethylene glycol (TEG) equivalents into water/kg of emission);
- *Terrestrial ecotoxicity*: Emissions to soil, such as metals, hydrocarbons and pesticides (kg TEG equivalents into water/kg of emission);
- *Aquatic acidification*: Potential proton release of substances such as nitrogen oxides and ammonia [kg sulfur dioxide (SO2) equivalents into air/kg emission];
- *Aquatic eutrophication*: Chemical nutrient contribution to bodies of water from such sources such as nitrogen oxides and phosphates [kg phosphate (PO43-) into water/kg of emission];
- *Terrestrial acidification and nitrification*: Proton release and/or chemical nutrient release to soil (kg SO2 equivalents into air/kg emission);
- *Land occupation*: Effects of occupying and transforming land on the species-area relationship (m2 organic arable land*year equivalents);
- *Global warming*: All gases thought to contribute to global warming, such as carbon dioxide, methane and nitrous oxide [kg carbon dioxide (CO2) equivalents/kg emission]; The global warming impact category is based on the 2001 IPCC global warming potential (GWP) factors across a 500 year time horizon (IPCC, 2001).
- *Non-renewable energy*: Finite sources of energy, such as fossil fuels [mega joules (MJ) of total primary non-renewable or kg crude oil (860 kg/m3) equivalents/kg emissions]; and
- *Mineral extraction*: Based on the theory that additional energy will be required for every subsequent mineral extraction after primary extraction due to the depletion of resources and quality of the remaining minerals [MJ of additional energy or kg of iron (in ore) equivalents/kg of emission].

The functional unit is a clearly defined measure of performance which the system delivers and is the basic unit of comparability for the study (Audsley et al., 2003). To determine the functional unit, the basic function of a system must be identified, which in the case of farm level rotations is to produce grain for the purposes of human consumption. As both pulse and cereal grains are considered to be sources of protein (Whitney and Rolfes, 2005), protein was chosen as the unit of comparison in terms of nutritive value. A protein content of 14% was chosen for the crop rotation LCA as it is the average protein content in wheat when all methods of farming and crop rotations are included (Canadian Grain Commission, 2009). In summary, the functional unit selected for the crop rotation study was one tonne of fourteen percent protein-corrected grain (1 t 14% protein-corrected grain).

5. Results

Results of net returns of various crops in the three rotations were estimated using a fixed price (given as of 2010 crop year prices). For this reason, a test of robustness of the three rotations was examined further under different price and cost conditions. To undertake sensitivity of results to changing conditions, additional simulations were made. Three types of prices were subjected to

Table 2. Weighted average economics of alternative crop rotations, present value of net returns ($/ha), western Canada, 2010

Particulars	Baseline (oilseed-cereal)	Alternative rotation 1 (Dry pea)	Alternative rotation 2 (Lentil)
Weighted average for western Canada: Net returns Over variable costs ($/ha)	-$19.40	$115.97	$145.72
Weighted average for western Canada: Net returns over total costs ($/ha)	-$522.22	-$403.84	-$378.49
Difference from BAU rotation for net returns over variable costs ($/ha)	--	$137.42	$175.14
Difference from BAU rotation for returns over total costs ($/ha)	--	$130.85	$158.86

Table 3. Results* of sensitivity analysis – discounted value of rotational period net returns over variable costs (ha) under study scenarios

Study scenario**	Base rotation	Dry pea rotation	Lentil rotation
1 (H-H-H)	$1,136.86	$1,440.38	$1,289.19
2 (H-H-L)	$1,205.85	$1,501.19	$1,385.72
3 (H-L-H)	$1,068.78	$1,103.89	$939.80
4 (H-L-L)	$1,205.85	$1,211.52	$1,039.45
5 (L-H-H)	-$224.61	$270.92	$320.95
6 (L-H-L)	-$72.22	$378.55	$420.60
7 (L-L-H)	-$196.23	-$22.91	-$9.67
8 (L-L-L)	-$72.22	$96.94	$74.33

* Results are based on weights for various soil zones in western Canada using proportion of dry pea area,
** Scenario symbols are: first letter for grain prices (high or low), second symbol for pulse prices (high or low) and the third symbol is for fertilizer prices (high or low)

change: price of non-pulse crops (spring wheat, canola and mustard); price of pulses (dry pea and lentil); and price of fertilizer. In total, eight simulations were made (Table 2).

The study model was used to estimate economic desirability of the two study rotations – dry pea rotation (canola – wheat – dry pea – wheat) and lentil rotation (canola – wheat – lentil – wheat), over the Table 3 in terms of net returns over variable costs for these rotations plus the base rotation (canola – wheat – wheat – wheat). Results suggest that under high grain and oilseed prices, all rotations generate a positive return over variable costs. However, when low grain and oilseed prices are assumed, results for the base rotation (canola – wheat – wheat – wheat) show a negative return over variable costs, but this is not the case for the pulse rotations (either the dry pea or lentil rotation) except when pulse prices are low and fertilizer prices are high.

Economic desirability of pulse crop rotations (those having a dry pea or lentil) was further examined using returns over and above total cost relative to the base rotation. Results are shown in Figure 2.

When dry pea and lentil were included in an oilseed-cereal crop rotation, the environmental effects associated with the rotations were reduced in all categories (Table 4). Higher reductions (i.e. over 20% in both alternative rotations when compared to the base rotation) were noted for

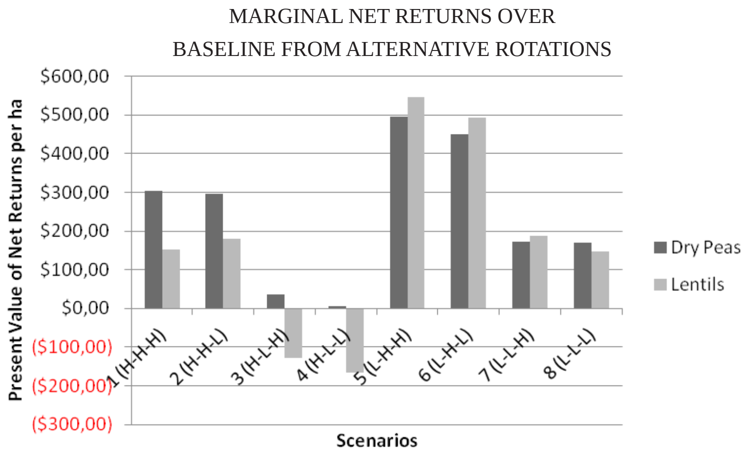

Figure 2. Results of sensitivity analysis for study rotations

Table 4. Selected results of life cycle assessment of rotations

Impact category	Percent reduction from baseline rotation	
	alternative rotation: dry peas (%)	alternative rotation: lentils (%)
Carcinogens	23	19
Non-carcinogens	15	3
Respiratory inorganics	21	13
Ionizing radiation	17	13
Ozone layer depletion	28	23
Respiratory organics	21	15
Aquatic ecotoxicity	19	11
Terrestrial ecotoxicity	15	1
Terrestrial acidification/ nutrification	24	21
Land occupation	17	1
Aquatic acidification	22	17
Aquatic eutrophication	20	8
Global warming	25	22
Non-renewable energy	21	17

Ozone layer depletion (23-28%), Terrestrial acidification/nutrification (21-24%), Global Warming (22-25%) and Non-renewable energy (21-25%). Since these rotations had greater nitrogen availability due to the inclusion of pulse crops, fertilizer application requirements were reduced (i.e. no application to the pulse crop and reduced application to the succeeding cereal crop) and the yield and grain protein content of the following wheat crop were increased.

These results suggest that dry pea and lentil rotations can generate lower environmental impacts than the oilseed-cereal crop rotation in all impact categories. Major reasons for these results could be explained as follows: the nitrogen fixation abilities of pulse crops; the reduction in nitrogen requirements of a cereal crop succeeding a pulse crop; and the increase in quantity (grain yield) and nutritive quality (protein content) of a cereal crop following a pulse crop. In Western Canada, crop nitrogen requirements are achieved via the application of synthetic nitrogen fertilizers, such as urea. By reducing the requirement for synthetic nitrogen fertilizers, pulse crops inherently reduce the emissions and energy use associated with the production, use and disposal of fertilizers. Furthermore, because pulse crops fix their own fertilizer, they do not require application of a synthetic nitrogen fertilizer to grow, except for the small amount in applied phosphorus fertilizer.

6. Study conclusions for economic analysis

This study suggests that pulse crop rotations, in general, are more sustainable than oilseed-cereal rotations. This conclusion is based on two major pillars of sustainability – economic desirability and environmental benefits. Only under lower pulse (either dry peas or lentils) prices are the alternative rotations (including pules) not more economically desirable over the baseline rotation. This conclusion is supported by the present economic analysis. Relative to the oilseed-cereal rotation (i.e. canola – wheat – wheat – wheat), pulse crop rotations (either canola – wheat – dry pea – wheat, or canola – wheat – lentil – wheat) generate higher net returns over variable as well as total (variable and fixed) costs. This conclusion remains unchanged under several assumptions of prices of grain, oilseed, and pulses, except when grain and oilseed prices are high and pulse crop prices are low.

The environmental effects of crop production are related to the amounts of material and energy required to produce a defined amount of grain. The inclusion of pulse crops into oilseed-cereal rotations is environmentally beneficial as pulses reduce the nitrogen fertilizer requirements and increase the overall grain yield and quality (i.e. protein content) of the rotation.

Higher producer profits and minimized effects on the environment can be realized with optimized crop management that can include combining dry pea and/or lentil with other high yielding crops in the rotation, as well reduced amounts of material and energy inputs.

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