Life Cycle and Economic Assessment of Western Canadian Pulse Systems: Dry Pea Versus Soybean Meal as A Source of Protein in Swine diets

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Abstract
In recent years, the interest in dry peas as a source of protein in Western Canadian swine operations has grown due to its nutritional similarity to soybean meal, a common source of protein in swine diets, imported nature of soybean meal. Life cycle and economic assessments were used to examine the environmental effects and economic implications of replacing imported soybean meal from the United States with locally grown dry pea as the main source of protein in a swine diet. In most impact categories, the potential environmental effects were comparable for both swine production systems; however, benefits to energy use (11% decrease), acidification (17% decrease) and respiratory organics (30% decrease) and negative effects to Eutrophication (63% increase) were observed when swine consumed dry pea instead of soybean meal. On the economic side, feed ingredients accounted for almost 62% of the total cost of swine production. Dry pea substitution for soybean meal improved the net income per sold swine by 72%. Although dependent on swine diet composition, dry peas a substitute for soybean meal in Western Canadian swine diets may enhance the sustainability of swine production.

Keywords: Life cycle assessment; Environmental impact; Economic assessment; Swine production; Dry pea; Soybean meal

Introduction

Pulse refers to the dry, edible seeds of pod-bearing plants in the legume family, such as dry pea, lentil, dry bean and chick pea. Pulses are significant crops in several capacities including providing an important source of food and feed protein worldwide, demonstrating consistent economic returns and contributing to the growth of the Canadian agricultural sector. Pulse crops are often included in rotations because not only do they break disease cycles, but they also have the ability to fix atmospheric nitrogen. Nitrogen fixation reduces the fertilizer requirements of the pulse crop and the following cereal crop, as well as improves the yield and grain protein content of the following cereal crop [1,2 and 3]. In essence, the inclusion of pulse crops in a cropping rotation improves the overall grain yield and decreases the total fertilizer requirements of the entire rotation.

Traditionally, diets of swine raised in Western Canada have been composed of various combinations of wheat, corn, barley, soybean meal (SBM) and canola meal [4-10]. SBM has been the primary source of protein in swine diets for many years as it is an excellent source of protein, digestible energy, as well as several important amino acids such as lysine [4,5] Lysine is often the first limiting amino acid in swine diets and, as such, SBM complements other low lysine-content feeds such as cereal grains. Conversely, SBM is low in sulphur amino acids [4,11]. As cereal grains are a source of sulphur amino acids, SBM in combination with cereal grains are commonly fed to swine for a complete source of amino acids.

In recent years, interest in the value of dry peas as a protein source for swine has grown due to its similar dietary composition to SBM. Dry pea is also rich in lysine, low in sulphur amino acids and provides an excellent source of protein and digestible energy [4,5,11 and 9]. Several studies have shown that dry pea can be successfully used as a replacement protein supplement for imported SBM with no effect on the palatability of the diet for the swine or the pork meat for human consumption [4-10,12].

Substituting locally grown, unprocessed dry pea for imported, processed SBM may result in changes in the environmental effects of swine feed production and processing due to differences in required chemical application and field operations between soybean and dry pea production, and the higher material and energy costs of SBM processing when compared to unprocessed dry pea. The goal of this study was to investigate the environmental effects and economic implications of replacing imported SBM from the United States (US) with locally grown dry pea as a source of protein in the diet of swine raised in Western Canada.

Life Cycle Assessment methodology

Life Cycle Assessment Overview

Life cycle assessment (LCA) is a method of examining the environmental effects of a product, processor system across its entire life span. An International Standards Organization (ISO)-conforming [13,14] LCA was conducted to assess the environmental effects of dry pea and SMB as sources of protein in swine diets. Sima Pro (version 7.1.8) [15] LCA computer modelling software, combined with the IMPACT 2002 + midpoint method [16] was used. Impact assessment categories included impacts to human health (carcinogens, non-carcinogens, respiratory inorganic, ionizing radiation, ozone layer depletion and respiratory organics), ecosystems quality (aquatic ecotoxicity, terrestrial ecotoxicity, terrestrial acidification/nitrification, land occupation, aquatic acidification and aquatic eutrophication), global warming potential (GWP) and resource use (non-renewable energy and mineral extraction). IMPACT 2002 + was modified to calculate GWP on a 100-year time horizon instead of a 500-year time horizon based on the most recent IPCC GWP factors [17].

The results of this study are intended to provide objective and transparent information to the public on the effects of growing and using pulse crops and to guide future research. The LCA has undergone review by an external, third-party review panel comprised of three members as per 2006 ISO 14040 [13] and 14044 recommendations [14].

LCA System Details

A Western Canadian grower-finishers wine operation which included the starter, grower and finisher phases of swine production was examined. Weaned piglets were assumed to be purchased from breeding facilities and sent to the grower-finisher operation. The environmental effects and economic implications of the breeding facilities were outside the system boundary. The grower-finisher operations consisted of swine barns with slatted floors where manure was periodically emptied into liquid storage systems outside of the swine barns and stored for eventual application to cropland. Swine feed was housed in a storage facility outside the swine barns and delivered by an auger system. Three diets based on the varying nutritional requirements of growing swine were analyzed: a starter, grower and finisher diet (Table 1).

The diets examined were based on the results of two research trials, one starter [18] and one grower-finisher [4], where SBM was replaced with dry pea as the main source of protein in swine diets. The diets were selected based on the following criteria:

a. The research trials were conducted in Western Canada.

b. Diets were from research trials where the purpose of the study was to examine the effects of replacing SBM with dry pea in swine diets.

c. The SBM and dry pea diets for each stage of swine growth were from side-by-side trials in the same literature source and

d. Diets met or exceeded the National Research Council’s [19] nutrient specifications for swine.

These criteria were established to enable comparison between the swine systems and to ensure the results of the analysis were representative of Western Canadian swine operations.

Consensus on the optimal rate of inclusion for dry pea in swine diets has not been reached. Studies which have examined the inclusion rates of dry pea in starter swine diets have shown variable performance results [17,21-25]. While it is clear that further research is required, 15% dry pea is considered to be the maximum recommended inclusion rate [26,18 and 27]. Based on this recommendation, the starter diets examined in this study had a 15% rate of dry pea inclusion.

Grower and finisher swine are able to digest their feed more effectively than starter swine [4]; therefore, they can consume a larger amount of dry pea without adverse effects on performance. The diets examined in this study assumed 42.5% and 30% inclusion rates of dry pea for grower and finisher swine, respectively, based on Robertson., et al. [8].

LCA Functional Unit

The function of the system was to produce swine which would eventually be used for production of pork meat. The functional unit for the analysis was one market-ready swine, defined as a swine weighing 110 kg [8,28 and 29]. Swine slaughter and meat production, packaging and distribution were not included in this study as differences in performance or meat processing were not expected from swine consuming well balanced diets.

Table 1: Composition of starter, grower and finisher\(^4\) swine diets.

For the purposes of this LCA, swine were classified as starter from 6 to 25 kg [20], grower from 25 to 80 kg and finisher from 80 to 110 kg [8].

Source: Friesen., et al. [18].

Source: Robertson., et al. [4].

\(^4\)Soybean meal.

<table>
<thead>
<tr>
<th>Component</th>
<th>Starter (swine 6-25 kg)(^2)</th>
<th>Grower (swine 25-80 kg)(^3)</th>
<th>Finisher (swine 80-110 kg)(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SBM</td>
<td>Drypea</td>
<td>SBM</td>
</tr>
<tr>
<td>Wheat (%)</td>
<td>30</td>
<td>30</td>
<td>71.1</td>
</tr>
<tr>
<td>Barley (%)</td>
<td>-</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Dry pea (%)</td>
<td>-</td>
<td>15</td>
<td>-</td>
</tr>
<tr>
<td>Soybean meal (%)</td>
<td>24</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Corn (%)</td>
<td>25.8</td>
<td>14.9</td>
<td>-</td>
</tr>
<tr>
<td>Fish meal (%)</td>
<td>5</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>Vegetable oil (%)</td>
<td>2</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Whey (%)</td>
<td>8</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>Calcium carbonate (%)</td>
<td>0</td>
<td>0</td>
<td>1.2</td>
</tr>
<tr>
<td>Calcium phosphate (%)</td>
<td>0.6</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>Sodium chloride (%)</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Synthetic amino acids (%)</td>
<td>0.16</td>
<td>0.08</td>
<td>0.2</td>
</tr>
<tr>
<td>Daily feed amount (g)</td>
<td>566</td>
<td>516</td>
<td>2100</td>
</tr>
<tr>
<td>Daily weight gain (g)</td>
<td>385</td>
<td>353</td>
<td>851</td>
</tr>
<tr>
<td>Feed/gain ratio</td>
<td>1.47</td>
<td>1.46</td>
<td>2.48</td>
</tr>
<tr>
<td>Dietary energy (Kcal/kg)</td>
<td>3,502</td>
<td>3,485</td>
<td>3360</td>
</tr>
<tr>
<td>Crude protein (%)</td>
<td>21.9</td>
<td>21.9</td>
<td>16.6</td>
</tr>
</tbody>
</table>

\(^1\)For the purposes of this LCA, swine were classified as starter from 6 to 25 kg [20], grower from 25 to 80 kg and finisher from 80 to 110 kg [8].

\(^2\)Source: Friesen., et al. [18].

\(^3\)Source: Robertson., et al. [4].

\(^4\)Soybean meal.
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It was assumed that both the SBM-containing diets (herein referred to as SBM diet) and the alternative dry pea-containing diets (herein referred to as dry pea diet) produced good quality swine; therefore, no differences in meat quality were taken into account [4,6,8,9,11 and 30].

System Boundaries
The system boundaries for the swine production systems (herein referred to as the SBM system and the dry pea system) begin with the production of inputs required for producing the feed grains (i.e. wheat, barley, dry pea, corn and soybean). The end point of the analysis is the swine farm gate, where one swine is raised to a market weight of 110 kg. Figure 1 provides a flowchart of the general scope of activities included in the swine systems. Both feed systems are shown in Figure 1; however they are separate systems and were examined as such.

The results of LCAs have been shown to be largely affected by a few limiting processes in the system. As such, cut-off criteria are often set to eliminate processes that contribute less than a defined mass, energy or environmental relevance. The cut-off criteria applied to this LCA was 3% of the life cycle system mass, energy or environmental significance (i.e. emissions). As this is a comparative LCA, processes that were identical in compared systems were also excluded from the analysis [31]. Based on the cut-off criteria, the magnesium, manganese, iron, zinc, copper, iodine, vitamin A, vitamin D3, vitamin E, vitamin K, cholinechloride, niacin, calcium pantothenate, riboflavin, thiamine, pyridoxine, vitaminB12, biotin, folic acid and selenium in the swine diet supplements were not included in the analysis (contributed 0.01-0.7% of the mass of diet). In addition, evidence indicating that the production and use of antibiotics and hormones, activities related to breeding and artificial insemination, mortality rates and swine barnd is infecting materials and practices would differ as a result of swine consuming dry pea instead of SBM was not found. These activities were, therefore, deemed to be similar between the systems and were excluded from the analysis.

LCA Data Quality and Data Sources
The majority of the data used to model crop production were specific to the region of growth (i.e., Western Canada for wheat, barley and dry pea, and the US for corn and soybean). In cases where location-specific data were not available, data were obtained, in order of preference, from the United States Life Cycle Inventory (USLCI) database [32] and from the European Eco inventv 2.0 databases [33].

The cropping data used were no older than 20 years from the onset of the analysis (2008) and covered no less than one full cropping season (i.e. four months). The farm operations modelled were assumed to be current, best-management practices.

The SBM processing and animal husbandry processes modelled represent typical and current technology as defined by the literature (e.g. [34]) and personal communications with swine production experts. Data used to model SBM processing and animal husbandry were no older than three years prior to the onset of the study. At the onset of the analysis, the 1998 National Research Council (NRC) guidelines [19] for swine nutrition were the primary authority on formulating swine diets. Therefore, diets adhering to these guidelines were deemed to be representative of current practices.

Swine Diet Data
The starter diets examined in this study were from a search trial conducted by the University of Manitoba in Winnipeg, Manitoba [18]. The grower and finisher diets examined were from Roberts en., et al. [8]. Both the starter and the grower-finisher diets adhered to the data quality guidelines outlined in this study.

Crop Production Data

The wheat, barley and dry pea crop production data were specific to Western Canada where possible to ensure practices were representative of local conditions. Similarly, corn and soybean crop production data were specific to the Mid West Corn Belt region of the US, where possible. Data were obtained from a variety of sources including the literature, personal communications with crop production experts, as well as field trials conducted at Swift Current, Scott and Indian Head, Saskatchewan (Lemke R., Personal Communications, 2009).

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As this study is part of a larger scope of work, crop production data were from the precursor to this study which examined the environmental effects and economic implications of including pulse crops in oil seed-cereal crop rotations [35]. Based on the scope of the precursor study, swine feed crop production data are from:

a. regions in the crop producing areas of Western Canada (wheat, barley and dry pea production) or the Mid west Corn Belt Region of the US (corn and soybean production).
b. livestock-free, grain-only, rain-fed (i.e. no irrigation) farms where straw is not baled.
c. sites practicing zero-tillage.

Further descriptions of the methodology and data sources used to model crop production are available in Mac William., et al [35].

SBM Processing Data

The SBM production process was modelled to be representative of typical processing conditions in the US. SBM production begins with the cleaning, drying, de hulling and breaking down of soybean into smaller pieces by a process called cracking [34,36-38]. The outer exterior of the soybean, or hull, absorb soil and must be removed; however, they are often added back into the defatted SBM later in the production process. The de hulled beans are heated to increase plasticity and passed through a roller to generate flakes. Hexane is then passed over the flakes several times to extract the oil. At this point, the oil fraction is separated from the meal fraction and both components are further refined. The hexane-oil component is run through an evaporator to remove the solvent, after which the crude oil is degummed and refined. The SBM flakes are toasted with steam to remove the solvent. Once dry and cool, the flakes are mixed with the previously extracted hulls and both are ground into a 44% protein SBM.

The average transportation distance of soybean to the SBM crushing facility was 80.5 km, based on Pradhan., et al [34]. The majority of the soybean oil and SBM processing material and energy data were from a United States Department of Agriculture (USDA) LCA on the energy cost of soybean bio diesel [34], except for the water consumption data, which were from Sheehan., et al [37].

Animal Husbandry Data

For diet preparation, wheat, barley and dry pea were ground in a roller mill at the swine farm. The electricity requirement for the use of the roller mill was estimated from a variety of roller mill product specifications. The majority (65%) of the Western Canadian feed grains were assumed to be purchased from gain suppliers, while 35% were assumed to be grown on the swine farm [39]. The transportation distance from the grain supplier to the swine farm was 100 km [39]. Grain produced at the swine farm was assumed to be transported 5 km. The rail transportation of SBM was estimated at 2,500 km based on Canadian National Railway routes [40].

Data for modelling the calcium carbonate (CaCO₃) and calcium phosphate (CaPO₄) components of the swine diets were from Schenck., et al [41], while calcium carbonated at a were from the USLCI data base [32]. Phosphoryl chloride production data from the Ecoinvent 2.0 library was deemed to be a reasonable proxy for the production of the amino acids in the diets [44].

The LCI data for the materials and construction of a fully-slatted swine housing system were from Eco invent [43]. Electricity, natural gas and water consumption rates of the housing system over the course of the swine production were from the SNC-Lavalin Agro [39] LCA. Methane emissions from enteric fermentation were calculated based on the National Inventory Report (1990-2006)–Green house Gas Sources and Sinksin Canada [44], which provides an emission factor of 1.51 kg CH₄ per head of swine per year; Methane emissions from manure management were also calculated based on the National Inventory Report [44] methodology. Direct and indirect nitrous oxide emissions from manure management were calculated using Inter governmental Panel on Climate Change (IPCC) Tier 1 recommendations [45]; however, the default nitrogen excretion rates were not used. For the purposes of this study, nitrogen excretion rates were calculated based on the amount of crude protein consumed through the SMB and dry pea diets to account for the potential digestive differences between the two feeding options. Nitrogen excretion rates (4.1 kg of nitrogen for swine consuming SMB diet, 3.6 kg for swine consuming dry pea diet), as well as in-barn ammonium nitrogen losses (0.63 kg for swine consuming SMB diet, 0.51 kg for swine consuming dry pea diet) from excreted matter, were estimated using methodology described in Eriksson., et al[46].

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Co-Product methodology

Soybean Meal Production

LCA systems are often multi-output systems where more than one product is generated. For example, in the production of SBM, soybean oil is also produced. It is therefore necessary to divide the material and energy inputs that go into making soybean products, as well as the environmental impacts consequent of the processes, among the various products. System expansion was used to manage the co-production of soybean during the production of SBM, as per ISO 14040 recommendations. When the method of system expansion is applied, all location of inputs and outputs is avoided by broadening the system boundary to account for the displacement of functionally equivalent products in the market. The US Census Bureau [47] reported that canola oil is the second most commonly used oil inedible products in the US after soybean oil. Therefore, it was assumed that increased production of soybean oil would displace an equivalent weight of canola oil in the US food market. Although canola oil and soybean oil differ in composition, it is reasonable to assume that they may be substitute data one to one ratio in many food products [48].

The system expansion methodology for soybean oil and SBM production described in Dalgaard., et al. [49] was applied to this LCA. Canola crop production data were obtained from Western Canadian literature and canola oil and canola meal processing data were from the Eco invent library [36]. Based on the looping methodology described in Dalgaard., et al. [49], it was calculated that a demand of 777 g of SBM per 1 kg soybean [34] would require or result in the production (positive value) or avoided production (negative value) of: 1,033 g SBM; 253 g soybean oil; -253 g canola oil; -388 g canola meal; and 111 g barley.

Animal Husbandry

System expansion was also used to approach the co-production of swine manure during animal husbandry. Manure is commonly applied to the soil as a source of nutrients for crops and may, in part, replace synthetic fertilizers. The swine production system examined in this study ended at the on-farm storage of manure; therefore, the application of manure to agricultural land was outside of the system boundary. It was therefore assumed that manure displaced the production (not the application) of synthetic nitrogen (i.e. urea fertilizer), phosphorous (i.e. mono ammonium phosphate) and potassium fertilizers (i.e. potassium chloride) (Rosen and Bierman, 2005) at a one-to-one ratio of available nitrogen, phosphorous or potassium. Based on the values reported in Rosen and Bierman [50], it was determined that swine consuming the SBM diet generated 2.6 kg of available nitrogen, 2.3 kg phosphorous oxide and 2.3 kg potassium oxide. Swine consuming the dry pea diet generated 2.3 kg of available nitrogen, 2.1 kg of phosphorous oxide and 2.1 kg of potassium oxide.

Economic Analysis

Measures of Economic Performance

The economic methodology was based on the principles of comparative statics in which a comparison of a given situation at a given point in time is made against a base situation for the same point in time. All baseline conditions were maintained for all simulations, except those that pertained to the scenario itself. These included no change in the size of the swine enterprise, inclusion of new enterprises, farm input and output prices and regulations. Economic performance was measured using net income of the barn (total as well as a per swine basis) and return on investment. These were estimated using standard farm management account as suggested by Herbst and Erickson [51]:

a. **Breakeven price per market swine**: Estimated by dividing the total cost (operating, loan payment and labor costs) by the number of swine sold. This measure indicates the level of swine price at which total revenue is breaking even against all operating and labor costs plus loan payments.

b. **Cash over cost**: Amount of cash left after certain categories of costs have been paid. Three alternative measures included here were:

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For this study, the conditions included a 50-sow swine barn producing 10,556 swine annually. This operation reflects the trend in the industry towards larger production units in Western Canada. All swine were sold at current market prices. The barn was financed through owned capital as well as borrowed capital from commercial institutions. All operations related to swine production were assumed to be the same for evaluation of the various scenarios.

Economic System Details

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Economic Data for Swine Production

Most of the parameters applied to the LCA were also applied to the economic assessment. The main difference between the LCA and economic analysis assumptions is that the swine farm assumed for the economic analysis was a specialized operation without any feed grain production of its own. The profitability of feed grains production was therefore excluded. The 500 sow farrow-to-finish operation was integrated, with activities involving weaning to finishing of swine. The operation sold 10,566 markets wine on an annual basis (Table 2). The swine barn was assumed to be located on a 20-acre parcel of land. Total cost of the swine barn was estimated at $3.45 million. Approximately 60% of this cost was assumed to be financed through borrowed capital, with the remaining 40% being equity capital.

### Table 2: Indicators of productivity for the modelled swine farm business used for simulation of economics of feed diets.

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of swine</td>
<td>500</td>
</tr>
<tr>
<td>Liters/swine/year</td>
<td>2.3</td>
</tr>
<tr>
<td>Total number of swine marketed</td>
<td>10,556</td>
</tr>
<tr>
<td>Total capital investment</td>
<td>$3,451,483</td>
</tr>
<tr>
<td>Portion financed throughloans</td>
<td>60%</td>
</tr>
<tr>
<td>Interest rate</td>
<td>6%</td>
</tr>
</tbody>
</table>

Source: [52,53].

Market conditions facing swine producers in Western Canada have been highly variable over the last decade. During the period 2001-2011, price shave moved from a low of $116 (100 kg)$^{-1}$ in 2009 to a high of $162 (100 kg)$^{-1}$ in 2001. Although prices were relatively low during late 1998, a recent drop in prices was also observed during late summer to fall of 2009. Based on current market conditions, a market price of $138 per 100 kg (equivalent to $152 (110 kg)$^{-1}$ of finished swine was used in this study (Table 3). Prices for other feed ingredients are also shown in Table3.

The SBM diet and the dry pea diet compositions, in terms of various feeding redients, were converted into relative distribution by weight per tonne of total feed used. Price of SBM was estimated by taking into account transportation cost. Similar to the LCA, shipping by rail for a distance of 2,500 km and by truck a distance of 100 km was assumed. Based on information obtained from local trucking companies, trucking costs were estimated at ten cents tonne-kilometers$^{-1}$ (t-km). Using grain freight rate data, rail costs were estimated at fourcents (t-km)$^{-1}$. The economics of the two feed diets for swine production were simulated under varying feed and swine prices; prices were varied by ± 10%.

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market price of pork ($100 kg$^{-1})</td>
<td>$138</td>
</tr>
<tr>
<td>Wheat ($t^{-1}$)</td>
<td>$159</td>
</tr>
<tr>
<td>Barley ($t^{-1}$)</td>
<td>$135</td>
</tr>
<tr>
<td>Dry pea ($t^{-1}$)</td>
<td>$200</td>
</tr>
<tr>
<td>Soybean meal ($t^{-1}$)</td>
<td>$498</td>
</tr>
<tr>
<td>Corn ($t^{-1}$)</td>
<td>$279</td>
</tr>
<tr>
<td>Whey ($t^{-1}$)</td>
<td>$2,257</td>
</tr>
<tr>
<td>Fish meal ($t^{-1}$)</td>
<td>$1,380</td>
</tr>
<tr>
<td>Corn oil ($t^{-1}$)</td>
<td>$975</td>
</tr>
</tbody>
</table>

Source: [52,53].

Table 3: Assumptions for the simulation of economics of feed diets for swine production.

Results

LCA Results

Figure 2 presents the relative life cycle environmental performance of both swine production systems. The figure shows that the dry pea system had lower potential impacts in the categories of carcinogens (-5%), respiratory in organics (-7%), ionizing radiation (-7%), ozone layer depletion (-9%), respiratory organics (-30%), terrestrial acidification/nitrification (-17%), aquatic acidification (-13%), global warming (-2%), non-renewable energy use (-11%) and mineral extraction (-3%) when compared to the SBM diet swine production system. The dry pea system also resulted in higher potential impacts to the non-carcinogens (5%), terrestrial ecotoxicity (8%), land use (6%) and Eutrophication (63%) impact categories. Differences in aquatic ecotoxicity were not observed. Due to the uncertainty of the data, the impact assessment method characterization factors and the assumptions applied throughout the analysis, the majority of the differences between the dry pea and the SBM systems were deemed to be comparable. However, marked differences (i.e. > 10% as defined by the authors) occurred in the categories of respiratory organics (-30%), terrestrial acidification/nitrification (-17%), aquatic acidification (-13%), non-renewable energy use (-11%) and Eutrophication (63%).

A contribution analysis showed that the production of feed ingredients accounted for the majority (50% to 99%) of the environmental effects associated with swine production in almost all impact categories (Figure 3). The exception was global warming, where animal husbandry (i.e. enteric fermentation and manure management) was the major contributor (53 to 55%). Animal husbandry dry was also a large contributor (34 to 47%) to respiratory organics in both swine production systems.

Global Warming Potential

In both swine production systems, potential impacts to global warming were similar. The major contributor (55%) to global warming in both swine systems was animal husbandry (or, more specifically, enteric fermentation and manure management) (Figure 3). Enteric fermentation is the fermentation process that takes place during the digestion by animals of food. Methane gas is released as a by-product of fermentation, thus contributing to the life cycle GHG emissions. Similarly, methane, as well as other GHGs such as carbon dioxide, is released during the process of manure management. Swine manure is primarily made up of organic materials and, as such, when decomposition occurs, carbon-based GHGs are released.

**Figure 2:** Comparison of the environmental effects of the soybean meal (SBM) system and the dry pea system.

**Figure 3:** Contribution (%) of feed production, animal husbandry and transportation impacts to the life cycle effects to the soybean meal (SBM) and dry pea system.

Life Cycle and Economic Assessment of Western Canadian Pulse Systems: Dry Pea Versus Soybean Meal as A Source of Protein in Swine diets

In terms of the avoided global warming impacts resulting from the avoided production of synthetic fertilizer from the use of manure as a fertilizer (negative emissions, Figure 4a), manure from swine consuming the SBM diet would result in greater avoided fertilizer production due to the higher protein content of the diet. The SBM diet was higher in protein content than the dry pea diets which lead to higher levels of nutrients in the manure excreted by swine consuming the SBM diet. The higher level of nutrients in the SBM manure would ultimately result in more nutrients being available to plants when the manure is applied to crops, thereby avoiding a greater amount of synthetic nitrogen fertilizer production.

Although the combined production of dry pea and wheat in the dry pea diet had slightly lower global warming potential than wheat production in the SBM diet, it was offset by the global warming credit when canola oil was the avoided product in the SBM diet system (Figure 4a). Canola oil production had relatively high associated global warming potential from crop production activities and carbon dioxide released during processing; therefore, the production of SBM was found to have negative GHG emissions when the production of canola oil was avoided. The end result was that the two production systems had similar GHG emissions.

Figure 4a: Greenhouse gas emissions (Kg CO₂ eq) from the soybean meal (SBM) system and the dry pea system. Note: “Other” refers to low contribution materials and energy inputs (e.g. grinding of feed at the swine farm.)

Non-renewable Energy Use

The dry pea system resulted in reduced non-renewable energy by 11% compared to the SBM system. This reduction in non-renewable energy was attributed to the lower amount of wheat in the dry pea diet when compared to the SBM diet (Figure 4b), as the production of wheat requires a relatively high amount of energy. SBM and dry pea are excellent sources of digestible energy for swine; however, the relatively low protein content of dry pea (23% protein) requires that a greater amount be consumed to provide the equivalent protein content of SBM (44% protein). Consequently, diets composed largely of dry pea require fewer additional sources of dietary energy, such as cereals. Wheat production requires more non-renewable energy than dry pea production due to the lower yields and higher fertilizer requirements. As such, replacing the SBM in swine diets with dry pea reduced the overall life cycle energy.
requirements by reducing the amount of wheat in the diet. As feed production was the largest contributor (71-74%, Figure 3) to swine production non-renewable energy, reductions to non-renewable energy in the feed production stage affected the life cycle energy of swine production.

Acidification

The dry pea system was found to have decreased potential aquatic and terrestrial acidification due to the reduced fertilizer requirements of producing dry pea compared to soybean. Aquatic and terrestrial acidification is a result of nutrient management activities in feed production (Figures 4c and 4d).

**Figure 4b:** Non-renewable energy use (MJ) in the soybean meal (SBM) system and the dry pea system. 
Note: “Other” refers to low contribution materials and energy inputs (e.g. grinding of feed at the swine farm).

**Figure 4c:** Aquatic acidification (Kg So₂, eq) from the soybean meal (SBM) system and the dry pea system. 
Note: “Other” refers to low contribution materials and energy inputs (e.g. grinding of feed at the swine farm).

The interaction between crops and applied ammonium-based fertilizers, such as urea and mono ammonium phosphate, causes their lease of acidifying protons to the soil, which contribute to acidifying the soil. Water then passes through the soil, carrying the acidifying protons in to nearby bodies of water and resulting in aquatic acidification. The total amount of nitrogen and phosphorus applied during the production of wheat and SBM in the SBM diets (5.56 kg N as urea, 1.93 kg P as mono ammonium phosphate) was greater than the total amount applied to wheat and dry pea in the dry pea diets (3.72 kg N as urea, 1.81 kg P as mono ammonium phosphate). It is important to note that the volatilization of ammonia during the spreading of manure on crop land was outside the system boundary (i.e. manure was in storage when swine reached a market weight of 100 kg) and was, therefore, not included in the analysis. As the use of manure as a fertilizer for crop production results in acidification, the life cycle acidification is affected by the system boundary.

**Eutrophication**

Potential Eutrophication in both swine production systems was almost exclusively from mono ammonium phosphate fertilizer applications to wheat, barley and dry pea crops in the dry pea diet, and to wheat and barley in the SBM diet (Figure 4e). The swine production systems had comparable life cycle Eutrophication prior to accounting for manure as a co-product of swine production.

Manure is a co-product of swine production as it can be used as a source of fertilizer. Once manure was accounted for as a co-product by system expansion and was assumed to displace the production of synthetic fertilizers, the SBM system was found to have 63% lower potential Eutrophication than the dry pea system as a result of avoided fertilizer production. Swine consuming the SBM diet excreted more manure nitrogen (4.1 kg N) over the production period than swine consuming the dry pea diet (3.6 kg N) due to the higher protein content of the SBM diet. Thus, there was more avoided synthetic fertilizer production from swine consuming the SBM diet than from swine consuming the dry pea diet. However, it is important to keep in mind that manure was assumed to be in storage when swine reached market weight and, as such, Eutrophication resulting from the application of manure to crop land was outside the system boundary (i.e. not included in the analysis). The life cycle Eutrophication in both swine production systems was from manure production and storage as well as avoided fertilizer production and storage, but not from the application and use of the manure as a fertilizer. As is the case with all LCA studies, the results of this analysis should be kept within the context of the study.

The authors identified the expansion of the system boundary to include manure application to agriculture land and the resultant potential for acidification and Eutrophication as a recommendation for future research. The short-term environmental effects of manure application to crop land, as well as the long-term land use effects associated with repeat application, are complex issues and should be examined in detail.

**Respiratory organics**

The potential impacts of the swine production systems to human health were wide ranging (5% to -30%). Although impacts to most human health impact categories were comparable (i.e. carcinogens, non-carcinogens, respiratory in organics, ionizing radiation and ozone layer depletion) (Figure 2), replacing the SBM with dry pea in swine diets resulted in a marked decrease (i.e. -30%) in life cycle respiratory organics (Figure 4f). Manure management was a major contributor to respiratory organics in both the SBM and dry pea diets wine production systems due to the volatilization of ammonia in the barns. Ammonia gas causes irritation to the respiratory tract and exposure has been reported to be fatal to humans at high concentrations [54]. However, the high level of respiratory organics in the SBM system compared to the dry pea system was due to the use of hexane to extract soybean oil in the SBM production process (Figure 4f). Hexane readily evaporates in to the air and is toxic to humans when in haled [54].

**Sensitivity Analysis**

Sensitivity analyses were performed to determine the extent to which the parameters and assumptions of the study affected the results; namely, the yield of the wheat crop, the amount of synthetic fertilizer applied to the wheat crop, the rate of inclusion of dry pea in the diets, the method of managing co-products and the impact assessment method. The results of the sensitivity analyses showed that the results of the LCA were dependent on the yield of the wheat crop and the amount of synthetic fertilizer applied to the wheat crop. When wheat yields are high and fertilizer application amounts are low, there is no longer a benefit to displacing the wheat with dry pea in the swine diets. Alternatively, if wheat production is assumed to generate average yields relative to dry pea (as assumed in this study), increasing the rate of dry pea inclusion in the swine diets results in greater environmental benefits because more wheat is displaced in the swine diet.

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Two analyses were performed to determine the effects of the system expansion methodology applied to the co-production of soybean oil during SBM processing. In the first sensitivity analysis, the production of palm oil was assumed to be placed instead of canola oil, while these cond analysis examined the effects of employing mass allocation. Both sensitivity analyses relating to managing the co-production of soybean oil improved the environmental benefits of including dry pea in swine diets then compared to SBM.

A sensitivity analysis on the method of managing the co-production of manure was conducted where mass allocation was used. The results showed that the swine systems were comparable when mass allocation was applied.

The results of the sensitivity analyses of the parameters and assumptions applied in the LCA showed that the environmental effects of dry pea-based swine diets compared to SBM-based diets were dependent on a) the composition of the swine diets; b) the crop management strategies of feed production; and c) the methodology for managing co-products in the system. As such, when considering only the environmental pillar of sustainability, it is necessary to examine the full life cycle effects of specific swine production systems to determine whether replacing the SBM in swine diets with dry pea is beneficial.

**Economic Analysis**

Similar to the LCA, the swine barn was assumed to have switched from the SBM diet to the dry pea diet to produce the same number of market swine. The outcome of this change was an improvement in the economic performance of the swine farm. Results of relative performance of the barn are shown in Table 4. The break-even price for the swine improved by approximately $5 (swine sold)\(^{-1}\) – from $144,477 to $139.

Similar improvements were recorded for the dry pea system when compared to the SBM system for other measures as well. The swine farm, even after paying all costs (i.e. operations, labour and loan payments), had an surplus of $53,511 yr\(^{-1}\), an improvement of $55,544 yr\(^{-1}\). These improvements were made possible through a reduction in the feed costs. The net income per swine sold improved
by $12, estimated now at $7 (sold swine)\(^1\). The rate of return on assets was 4.44%, an improvement of 3.55% over the 0.89% estimated when the swine farm was using the SBM diet. Although this rate was still lower than the cost of borrowing money, it was a substantial improvement over the SBM diet.

A comparison of the SBM diet against the dry pea diet under the four additional simulations is shown in Figure 5 for return on assets, and for net income per swine sold in Figure 6. Results suggested that there was an economic advantage in using the dry pea diet for swine production. Compared to the SBM diet, all the measures suggested that the dry pea diet was superior, except when swine prices were lower and feed costs increased.

<table>
<thead>
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<th>Particulars</th>
<th>Value</th>
<th>Change from SBM(^1)diet</th>
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</thead>
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<tr>
<td>Breakeven price per swinesold</td>
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<td>-$5</td>
</tr>
<tr>
<td>Cash over operating costs</td>
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<td>+$55,544*</td>
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<tr>
<td>Cash over operating and loanpayment</td>
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<td>+$55,544*</td>
</tr>
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<td>+$55,544*</td>
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<tr>
<td>Net income per swinesold</td>
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<td>$12</td>
</tr>
<tr>
<td>Return on assets</td>
<td>4.4%</td>
<td>+3.6%</td>
</tr>
</tbody>
</table>

\(^1\)Soybean meal.

Note: Values marked with an* remained the same for the three cash measures, since various cost items did not change from one measure to the other.

**Table 4:** Economic performance measures for the swine farm under the dry pea diet.

A comparison of the SBM diet against the dry pea diet under the four additional simulations is shown in Figure 5 for return on assets, and for net income per swine sold in Figure 6. Results suggested that there was an economic advantage in using the dry pea diet for swine production. Compared to the SBM diet, all the measures suggested that the dry pea diet was superior, except when swine prices were lower and feed costs increased.

**Figure 5:** Rate of return on assets of the swine farm under dry pea swine diet and change in feed and swine prices.

The potential environmental effects of the dry pea system compared to the SBM system were wide ranging (Global Warming and Resource Use: -2% to -11%; Ecosystem Quality: 63% to -17%; and Human Health: 5% to -30%). Although most impacts were comparable, some benefits were observed when swine consumed the dry pea diet. Marked differences were modelled in the categories of respiratory organics (-30%), terrestrial acidification/nitrification (-17%), aquatic acidification (-13%), non-renewable energy (-11%) and Eutrophication (63%). These marked differences occurred for several reasons, including: the avoided use of hexane for SBM production; the higher nutrient composition and subsequent avoidance of the production of synthetic fertilizer in the SBM diet swine production system; and the decrease in wheat in the swine diets when dry pea was fed as a source of protein instead of SBM.

Dry pea substitution for SBM improved the net income to $7 (sold swine)\textsuperscript{-1} from a negative return of -$5 (sold swine)\textsuperscript{-1} under the SBM swine diet system. Results suggested that the replacement would lead to favorable economic performance of the swine farm under all conditions simulated, except when feed costs increased by 10% or swine prices decreased by 10% over the current level. As feed costs constituted almost 62% of the total cost of production, any increase in the cost of feed would affect the economics of swine production unfavorably. Price of output determines the revenues received by the swine farm; therefore, any decrease in output may make the enterprise unprofitable. Thus, a change in swine prices would affect the overall economics of swine production in Western Canada.

Feed production and feed costs were the main contributors (45%-100% of the environmental impact categories and 62% of the economic) to the sustainability of swine production. As such, improvements to the sustainability of swine production should be focused on the selection of feed stuffs in the swine diets and associated feed production practices and crop management strategies. Transportation was not found to be a major contributor to the environmental effects (average of 3% contribution to impact categories in the SBM system and 1% contribution to the dry pea system); however, the economic returns to the swine barn improved as a result of using locally grown pea.

Some environmental benefits were observed when dry pea replaced SBM in the diet since dry pea served to partially offset the wheat requirements of the diet. SBM is relatively high in protein (44% protein) compared to dry pea (23% protein); therefore, a greater

amount of dry pea is required to fulfill the protein requirements of a swine diet. Dissimilar to SBM, dry pea is a source of energy and therefore partially fulfills the energy requirements of the diet, thereby offsetting the need for energy feeds such as wheat. The production of wheat typically requires greater amounts of fertilizers than dry pea and results in comparatively low yields [35]. As a result, dry pea production is environmentally preferable to wheat production and the life cycle environmental profile of the swine diet improves with the substitution of dry pea for SBM. In addition, the economics of the dry pea system, when considering the life cycle, are preferable to the SBM system.

Areas for Future Research

One method for further improving the environmental effects and economic implications of the dry pea system compared to the SBM system is to include wheat, as well as other feed grains, that were produced as part of a well-managed, dry pea-containing rotation. The fertilizer requirements of wheat production have been shown to be reduced when it is grown after a dry pea crop. Furthermore, the protein content and yield of the wheat crop is improved. The result is that the sustainability of wheat production is improved when grown after a dry pea crop. As the sustainability of swine production is dependent on feed choices, the environmental and economic profile of swine production is likely to improve with the inclusion of dry pea as an ingredient, as well as other ingredients grown in rotation with dry pea.

Acknowledgments

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Author Contributions

Susan Mac William and Monique Wismar undertook life cycle assessment, where as economic Analysis was handled by Suren Kulshreshtha.

Conflicts of Interest

The authors declare no conflict of interest.

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