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Economic analysis of organic cropping systems under different tillage intensities and crop rotations

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Abstract

Costs of production and organic price premiums are defining factors influencing the economic viability of organic crop production systems. Different agronomic practices, such as crop rotation and tillage intensity, are known to affect the economic performance of the production systems. The aim of this study was to compare the impact of two crop rotation sequences (simplified and diversified) and two levels of tillage intensity (high and low) on the cost of production, gross return and gross margin of crops when grown under organic management in the semi-arid Brown soil zone of the Canadian Prairies. The 2-year simplified rotation sequence consisted of forage pea (*Pisum sativum* L.) grown as a green manure followed by hard red spring wheat (HRSW) (*Triticum aestivum* L.), while the 4-year diversified rotation sequence was forage pea green manure followed by flax (*Linum usitatissimum* L.) or yellow mustard (*Sinapis alba* L.), field pea or lentil (*Lens culinaris* L.) and HRSW. Our hypothesis that a more diversified crop rotation would increase profitability over a traditional simplified crop rotation was supported by the findings. However, the findings did not support our hypothesis that reducing tillage intensity, and the combination of tillage reduction and diversified crop rotation through a synergetic response, would further enhance profitability. Analysis of the breakeven prices and breakeven yields for crops indicated the importance of adopting diversified crop rotations and choosing crops with high organic price premiums as means to maximize the long-term profitability of organic cropping systems.

Introduction

From 2014 to 2018, the total number of certified organic farm operations in the Canadian Prairies increased by 34%, from 1465 to 1975 (Canada Organic Trade Association, 2019). Between 2011 and 2017, the land area under organic management in Canada increased by over 45%, growing to 1.27 million ha by 2018 (Willer and Lernoud, 2019). Strong consumer demand for organic food products, both in Canada and internationally, is one of the main reasons for this growing trend. In 2017, the value of the organic market in Canada was estimated at CAN$5.4 billion, a 54% increase compared to 2012. Canadian organic exports were estimated at CAN$607 million in 2017, with lentil (*Lens culinaris* L.) and wheat (*Triticum aestivum* L.) being the most popular export grains (Canadian Organic Growers, 2019). As of 2017, organic foods had made up 2.6% of the total food sales in Canada, with 66% of Canadians buying organic products every week (Canada Organic Trade Association, 2019).

The increasing concern of producers about the continued degradation of the agricultural resource base under conventional cropping practices is often reported as another reason for the conversion to more sustainable farming methods, including organic management. Findings by Zentner *et al.* (2011a) support the tendency among farmers to use organic cropping systems as a means of reducing the reliance on non-renewable energy inputs through the non-use of inorganic fertilizers and pesticides. Organic farming methods also provide other ecosystem benefits to society including biological control of pests, soil formation, mineralization of plant nutrients, pollination, services provided by shelterbelts and hedges and so on. (Stockdale *et al.*, 2001; Sandhu *et al.*, 2008). When the economic value of these societal impacts attributed to organic agriculture are considered, the overall economic value of an organic farming system is often enhanced (Sandhu *et al.*, 2008; Crowder and Reganold, 2015).

Several studies have examined changes in the cost of production when transitioning from conventional to organic crop production. Their findings have revealed that production costs for certain organic crops can surpass production costs for crops grown under conventional management (Klonsky, 2012; Ostapenko *et al.*, 2020). This has been attributed to higher energy consumption due to the greater number of mechanical tillage operations required and to higher costs for the organic fertilizers or amendments with organic management.

Table 1. Tillage intensity × crop rotation in an organic trial at Swift Current, SK, 2010–2015

Tillage-Rotation	2010	2011	2012	2013	2014	2015
High simplified	Wheat	Forage pea	Wheat	Forage pea	Wheat	Forage pea
High simplified	Forage pea	Wheat	Forage pea	Wheat	Forage pea	Wheat
Low simplified	Forage pea	Wheat	Forage pea	Wheat	Forage pea	Wheat
Low simplified	Wheat	Forage pea	Wheat	Forage pea	Wheat	Forage pea
High diversified	Wheat	Forage pea	Flax	Lentil	Wheat	Forage pea
High diversified	Flax	Lentil	Wheat	Forage pea	Flax	Lentil
High diversified	Field pea	Wheat	Forage pea	Mustard	Field pea	Wheat
High diversified	Forage pea	Mustard	Field pea	Wheat	Forage pea	Mustard
Low diversified	Field pea	Wheat	Forage pea	Mustard	Field pea	Wheat
Low diversified	Forage pea	Mustard	Field pea	Wheat	Forage pea	Mustard
Low diversified	Flax	Lentil	Wheat	Forage pea	Flax	Lentil
Low diversified	Wheat	Forage pea	Flax	Lentil	Wheat	Forage pea

High, high tillage; Low, low tillage. Crop sequences, simplified: forage pea (for green manure)–wheat (HRSW); diversified: forage pea (for green manure)–oilseed (flax or mustard)–pulse (field pea or lentil)–HRSW, with all phases of the rotations present each year.

However, even with higher production costs, most organic crops were profitable due to the high organic price premiums that currently exist (Zentner *et al.*, 2011a; Crowder and Reganold, 2015; Manitoba Agriculture, 2018). In the case of organic winter wheat production in Manitoba, a 260% organic price premium was highly profitable despite the higher production cost (Manitoba Agriculture, 2018). A meta-analysis of 44 scientific studies spanning 55 crops grown on five continents showed that when organic price premiums were not applied, benefit/cost ratios of organic crop production were significantly lower (−8 to −7%) compared to benefit/cost ratios with organic price premiums (20–24%) (Crowder and Reganold, 2015).

McBride *et al.* (2015) reported that even with potentially higher returns, adoption of organic production practices remained low among US field crop producers, mainly because of lower crop yields and the challenge of achieving effective weed control. According to Schneeberger *et al.* (2002), technical challenges in crop management and additional labor requirements were also important barriers to the adoption of organic methods by cash-crop farmers in Austria.

In organic agriculture, tillage method and crop rotation play important roles in management of weeds and soil fertility. Peigne *et al.* (2007) reported that the success of conservation tillage in organic farming systems depends on the choice of crop rotation to ensure weed and disease control and nitrogen availability. Further, Gruver and Wander (2020) reported that despite the heavy reliance on tillage for weed control under organic management, these farming systems typically have improved soil quality with enhanced organic matter and better soil structure than those under conventional management. One of the main reasons for improved soils in organic farming systems is the use of well-designed crop rotations that help offset the negative influences of tillage on soil structure and organic matter (Gruver and Wander, 2020).

Due to the various agronomic challenges associated with organic farming, understanding which management practices provide greater economic returns is needed. Crop rotation and soil tillage intensity are two common practices used by organic farmers in their operations. Accordingly, this study focused on the impact of two crop rotations (simplified and diversified) and two tillage intensity levels (high and low) under organic management on the costs of crop production and economic returns in the semi-arid Brown soil zone of the Canadian Prairies. Lower tillage intensity levels allow crops to be grown with less machinery input and fossil fuel costs (Baig and Gamache, 2011; Awada *et al.*, 2016). In addition, reducing tillage intensity increases soil moisture content which can lead to increased crop yields and improved soil productivity (Malhi, and O'Sullivan, 1990; Baig and Gamache, 2011; Awada *et al.*, 2016). Increasing crop rotation diversity has also been shown to enhance crop yield potential (Smith *et al.*, 2017). Therefore, we hypothesize that lower tillage intensity and a more diversified crop rotation will result in greater profitability compared to traditional high tillage intensity and a simplified crop rotation, and that the combination of tillage reduction and a diversified crop rotation will further enhance farm profitability through a synergistic effect.

Materials and methods

Agronomic trial

A field experiment was established at the Research and Development Centre of Agriculture and Agri-Food Canada, at Swift Current, SK, Canada (50.3°N, 107.7°W) in 2010, for a period of 6 years. The site was organically managed under legume green manure, with no chemical inputs, for 2 years prior to its initiation. The trial included two cropping sequences × two tillage intensity systems (Table 1). Cropping sequences were a simplified 2-year rotation: forage pea (*Pisum sativum* L.) green manure–hard red spring wheat (HRSW); and a diversified 4-year rotation: forage pea green manure–oilseed–pulse–HRSW. In the diversified rotation, the oilseed crop alternated between flax (*Linum usitatissimum* L.) and yellow mustard (*Sinapis alba* L.), while the pulse crop alternated between field pea and lentil. All phases of the rotations were present each year. In all years, at ∼50% flowering, the forage pea was incorporated with two passes of a tandem double disk in the high tillage plots, and by mowing with a 3-gang mower in the low tillage plots.

The cultivars used were 'Lillian' HRSW, 'Vimy' flax, 'Andante' yellow mustard, 'CDC Sovereign' large green lentil, 'CDC

Meadow' yellow field pea and '4010' forage pea. Plots were seeded in mid-May to early June. For all crops, seeding rates were about 25% higher than what is normally recommended for conventional systems: for wheat 121, field pea 252, lentil 192, flax 47, mustard 15.4 and forage pea 269 kg ha^{-1}.

The tillage systems were 'high tillage' and 'low tillage'. In all years, the high tillage plots were tilled at least once with a cultivator, and/or tandem double disk, while the low tillage plots were tilled either with a rotary hoe, a cultivator, or a rod weeder. Fall tillage was performed after harvest in 2013 and 2014 (Fernandez *et al*., 2019a).

The tillage–rotation systems were arranged in a randomized complete block design with four replicates, for a total of 48 plots. Further details on the agronomic practices and timing of operations are described in Fernandez *et al*. (2019a, b).

Cost of production

Annual costs of production were estimated for each tillage and crop rotation using input costs for labor, seed, fuel, repairs and maintenance of machinery for each year. Paid labor hours were estimated for pre-seeding operations, seeding, termination of forage pea, harvesting and post-harvest operations. Labor cost was estimated based on the hours spent on each machinery operation per ha, while fuel costs were estimated based on the amount of fuel used on each machinery operation. Data on labor hours and fuel used were obtained from the Supervisor of Farm Operations at the Swift Current Research and Development Centre in 2019. General farm worker wages in Saskatchewan (Government of Canada, 2019) and historical gasoline prices in Canada (Statistics Canada, 2019) were used in estimating labor and fuel costs, respectively. Seed cost was estimated based on the organic seed prices published by Organic Alberta (2019) and Hamm and Hugh (2015). Repairs and maintenance of machinery were estimated from Manitoba Agriculture (2018). Tables A1 to A5 include further details of the cost of production used in this study. The estimated annual production costs for each tillage intensity and crop rotation were used for all respective replicates. Data for 2010 were excluded from this study given that it was the establishment year of the trial.

Gross return and gross margin

Grain yield for all crops was measured annually, except for forage pea which was soil incorporated as green manure (Fernandez *et al*., 2019b). Prices of conventionally grown crops during the study period were used as reference points to compare the economic impact of the cropping systems with and without the organic price premiums. Prices were obtained from the Government of Saskatchewan (2020) and the Food and Agriculture Organization of the United Nations (1999). Table A3 shows the actual prices used in this study. Annual costs and prices were deflated to constant 2007 values using the Farm Product Price Index for Saskatchewan (2007 = 100). Gross revenue from the sale of the crops from each replicate within each cropping system (except forage pea) was computed by multiplying each crop yield by its corresponding commodity price (with and without a price premium). Gross margins were estimated by subtracting operating costs from gross returns. A 150% hypothetical organic price premium and organic price premiums published by OrganizBIZ (2019) were used to understand the impact of these price premiums.

Breakeven analysis

Breakeven prices for each crop were estimated by dividing the respective operating cost per ha by the average yield per ha of that crop in each year. This measure indicates the market price that is required to recover the respective production costs. If the actual market price is higher than the breakeven price, the farm operation earns an economic profit. These breakeven prices were also compared to the grain prices with organic price premiums, to determine their impact on the profitability. Similarly, annual breakeven crop yields were estimated by dividing the operating cost per ha by the respective market price for that crop without organic premiums. This measure indicates the average yield necessary to recover the production cost for one unit of product. If the actual yield is higher than the breakeven yield, the farm operation earns an economic profit.

Statistical analysis

The statistical analyses of the data followed the methods used by Zentner *et al*. (2011b). All data were subjected to analysis of variance on an annual basis using the Proc GLIMMIX procedure of SAS software, with the residuals tested for normality. An initial exploratory analysis of the data revealed an over dispersion issue. The gamma distribution option available in Proc GLIMMIX was used to correct this problem. Tillage and crop rotation were modeled as fixed effects. Least significant difference tests were used to determine significant differences ($P \leqslant 0.10$) among treatment means. All costs and returns are expressed in Canadian dollars.

Results and discussion

Operating cost of production

During the 2011–2015 study period, operating costs for the high tillage treatments averaged CAN$184 ha^{-1}, which was CAN$12 ha^{-1} higher than for the low tillage treatments (Fig. 1). Furthermore, operating costs for the simplified rotation averaged CAN$183 ha^{-1}, which was CAN$10 ha^{-1} higher than for the diversified rotation treatment. However, operating costs were not significantly influenced ($P \geqslant 0.10$) by tillage intensity or crop rotation, or their interaction (cropping system) in any of the years.

Operating costs were heavily dependent on organic seed (55% of total) and fuel (24% of total) costs. On average, seed costs increased over the course of the study, being highest in 2014 (Fig. 1). The higher seed costs for field pea and forage pea mainly accounted for the elevated production cost in 2014. The higher fuel costs for the high tillage treatment reflects the additional tillage operations. Overall, the cropping systems had minimal effect on labor requirements.

Hamm and Hugh (2015) estimated the variable cost of an organic cropping system consisting of a legume, HRSW and oat (*Avena sativa* L.), in the Brown soil zone at CAN$155 ha^{-1}. In the present study, operating costs for all cropping systems averaged CAN$176 ha^{-1}.

Gross return

Overall, tillage intensity had a significant impact on average gross returns of the cropping systems, while crop rotation diversity had little impact, with or without organic price premiums (Table 2). In 2011, gross return was significantly affected by crop rotation, while in 2012 and 2015 it was significantly affected by both tillage

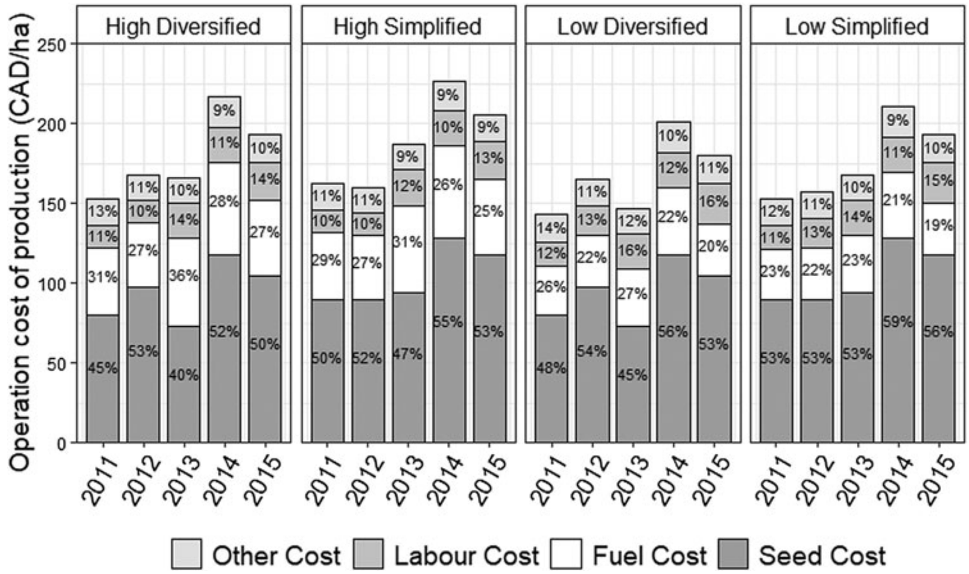

Fig. 1. Breakup of operating cost of production by cropping system, from 2011 to 2015. High, high tillage; Low, low tillage. Crop sequences, simplified: forage pea green manure–wheat (HRSW); diversified: forage pea green manure–oilseed (flax or mustard)–pulse (field pea or lentil)–HRSW, with all phases of the rotations present each year.

Table 2. Effect of tillage and crop rotation on gross return without organic price premiums, and with 150% organic price premiums in a trial in Swift Current, SK (CAN\$ ha^{-1}) (gross returns with 150% organic price premiums are in parenthesis)

Tillage/rotation	2011	2012	2013	2014	2015	Mean
Tillage						
High	695^{ns} (1042^{ns})	450^{a} (676^{a})	375^{ns} (563^{ns})	376^{ns} (564^{ns})	376^{a} (564^{a})	457^{a} (685^{a})
Low	731^{ns} (1097^{ns})	285^{b} (429^{b})	325^{ns} (488^{ns})	293^{ns} (439^{ns})	192^{b} (288^{b})	370^{b} (555^{b})
Rotation						
Diversified	644^{b} (966^{b})	284^{b} (426^{b})	354^{ns} (531^{ns})	290^{ns} (435^{ns})	318^{a} (477^{a})	382^{ns} (573^{ns})
Simplified	789^{a} (1183^{a})	453^{a} (680^{a})	345^{ns} (518^{ns})	379^{ns} (569^{ns})	227^{b} (341^{b})	443^{ns} (665^{ns})

High, high tillage; Low, low tillage. Crop sequences, simplified: forage pea green manure–wheat (HRSW); diversified, forage pea green manure–oilseed (flax or mustard)–pulse (field pea or lentil)–wheat (HRSW), with all phases of the rotations present each year.
LS-means with the same letters within each treatment in each column are not significantly different ($P \geqslant 0.10$); ns, not significant.

and rotation. As shown in Table 2, the gross returns were highest in 2011, reflecting the higher crop yields in that year. However, after the initial year, gross returns declined sharply. The decrease in wheat yields over the study period (Fernandez *et al*., 2019b) was the main reason for the declining gross returns given that product prices were generally stable during this period (Table A3). However, lentil and mustard yields also declined over time when compared to the first year of the study. Only field pea and flax yields showed a slight increase over time. Fernandez *et al*. (2019b) attributed the wheat and mustard yield declines to the low growing season precipitation and spring soil NO_3-N, while flax yields were affected mainly by available soil NO_3-N levels and increased weed competition.

Gross returns with the low tillage treatment were higher than for the high tillage treatment in 2011, but the opposite was true in the following 4 years (Table 2). Significantly higher gross returns were earned with high tillage in 2012 (CAN\$450 ha^{-1}) and 2015 (CAN\$376 ha^{-1}) compared to low tillage (CAN\$285 ha^{-1} and CAN\$192 ha^{-1}, respectively) (without organic price premiums). The simplified rotation treatments produced significantly higher gross returns in 2011 than the diversified rotations (CAN\$789 ha^{-1} vs CAN\$644 ha^{-1}, respectively) (also without organic price premiums). This trend was consistent through to 2014. In 2015, however, the diversified rotations earned CAN\$318 ha^{-1} compared to CAN\$227 ha^{-1} for the simplified rotations.

By comparison, Hamm and Hugh (2015) estimated the average gross return of a legume-HRSW-oat system at CAN\$637 ha^{-1}. The organic price premiums used in their study were 389% for HRSW and 200% for oat. In the present study, the average gross return in 2015 for all the cropping systems with 150% price premiums was CAN\$417 ha^{-1}, compared to CAN\$278 ha^{-1} without organic price premium (Table 2). In 2011, gross returns with the 150% organic price premiums were significantly affected by crop rotation, while in 2012 and 2015 it was significantly affected by both tillage and rotation. Gross return for the high tillage treatment averaged CAN\$685 ha^{-1}, which was CAN\$130 ha^{-1} higher than for the respective low tillage treatment (Table 2). When compared to the average gross returns without a price premium, the 150% organic price premiums increased the average gross returns by about 50% in both tillage treatments.

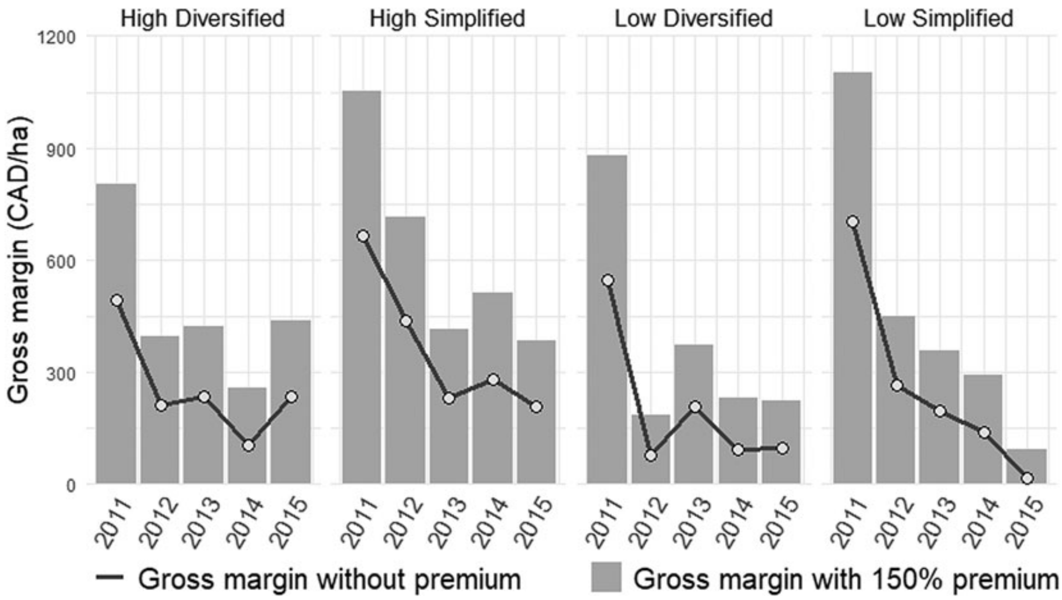

Fig. 2. Gross margin with and without organic price by cropping system from 2011 to 2015. High, high tillage; Low, low tillage. Crop sequences, simplified: forage pea green manure–wheat (HRSW); diversified, forage pea green manure–oilseed (flax or mustard)–pulse (field pea or lentil)–HRSW, with all phases of the rotations present each year.

Table 3. Effect of tillage and crop rotation, and their interaction (cropping system) on gross margin without organic price premium, and with 150% organic price premiums in a trial in Swift Current, SK (CAN\$ ha^{-1}) (gross margins with 150% organic price premiums are in parenthesis)

Tillage/rotation	2011	2012	2013	2014	2015	Mean
Tillage						
High	571[ns] (919[ns])	412[a] (673[a])	292[a] (438[ns])	250[a] (464[a])	221[a] (409[a)])	354[a] (585[a])
Low	618[ns] (984[ns])	198[b] (334[b])	201[b] (364[ns])	155[b] (290[b])	68[b] (152[b])	269[b] (441[b])
Rotation						
Diversified	517[ns] (839[b])	239[b] (396[b])	277[a] (414[ns])	197[ns] (348[ns])	177[a] (334[a])	299[ns] (486[ns])
Simplified	683[ns] (1078[a])	340[a] (577[a])	212[b] (386[na])	197[ns] (388[ns])	85[b] (187[b])	319[ns] (531[ns])

High, high tillage; Low, low tillage. Crop sequences, simplified: forage pea green manure–wheat (HRSW); diversified: forage pea green manure–oilseed (flax or mustard)–pulse (field pea or lentil)–wheat (HRSW), with all phases of the rotations present each year.
LS-means with the same letters within each treatment in each column are not significantly different ($P \leq 0.10$); ns, not significant.

Gross margin

Gross margins, with and without organic price premiums, displayed a declining trend over time (Fig. 2). Increasing operating costs and decreasing crop yields with advancing years were the main factors contributing to this decline. Except for the first year of the study, the high tillage treatments had higher gross margins than the low tillage treatments (Table 3). Higher wheat yields under high tillage than under low tillage intensity was the main reason for the higher gross margins. Average gross margins were not significantly affected by the rotation sequences. In 2011 and 2012, the simplified rotation had a higher gross margin than the diversified rotation (with and without organic price premiums); however, this effect was reversed in 2013 and 2015. In 2015, the diversified rotation had a 108% higher gross margin compared to the simplified crop rotation without organic price premiums (Table 3). This was due mainly to the high prices for mustard and lentil during that year.

Without organic price premiums, average gross margins were reduced by 65% for the high tillage and 63% for the low tillage treatments (Table 3). These results suggest that there is considerable potential to increase the profitability of organic crop production systems under the higher price premiums if the productivity of the system can be maintained. The major constrains which can limit the productivity of organic crop production are lower nutrient availability, higher weed competition and limited options to enhance soil productivity (Kirchmann *et al.*, 2008).

Breakeven prices and yield

Figure 3 shows the breakeven prices of crops necessary to recover the respective production costs. Field pea was the only crop with higher breakeven prices compared to no organic premium over conventional prices, indicating that it was not an economically profitable crop in this study. The breakeven prices for lentil, flax, mustard and wheat were lower than the base prices indicating that these crops were economically profitable even without an organic price premium. Compared to mustard, lentil and flax, the gap between the breakeven price and the 150% price premium

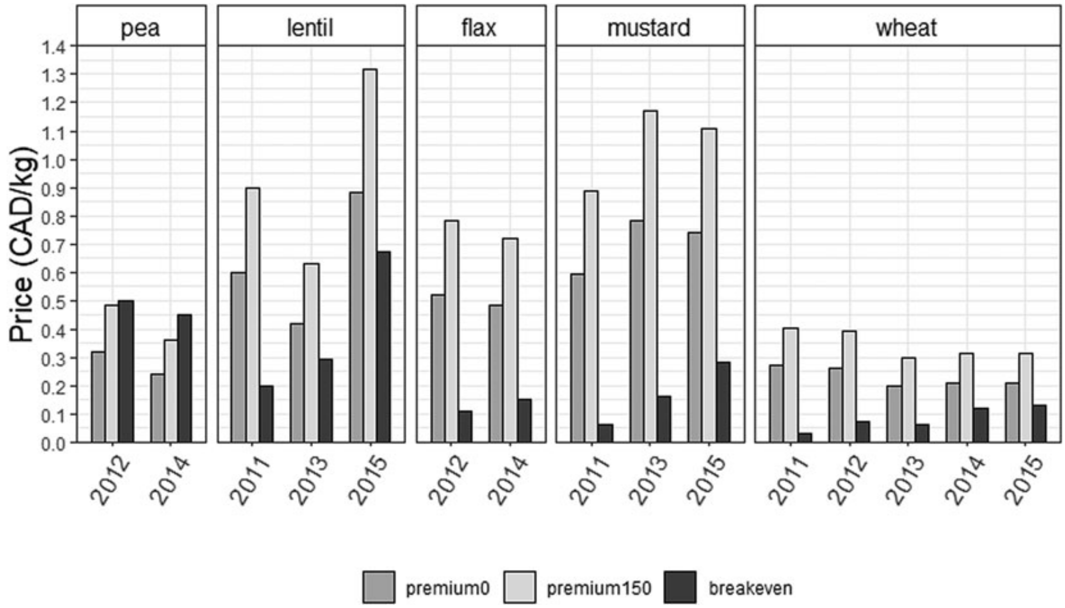

Fig. 3. Comparison of breakeven price by crop from 2011 to 2015.

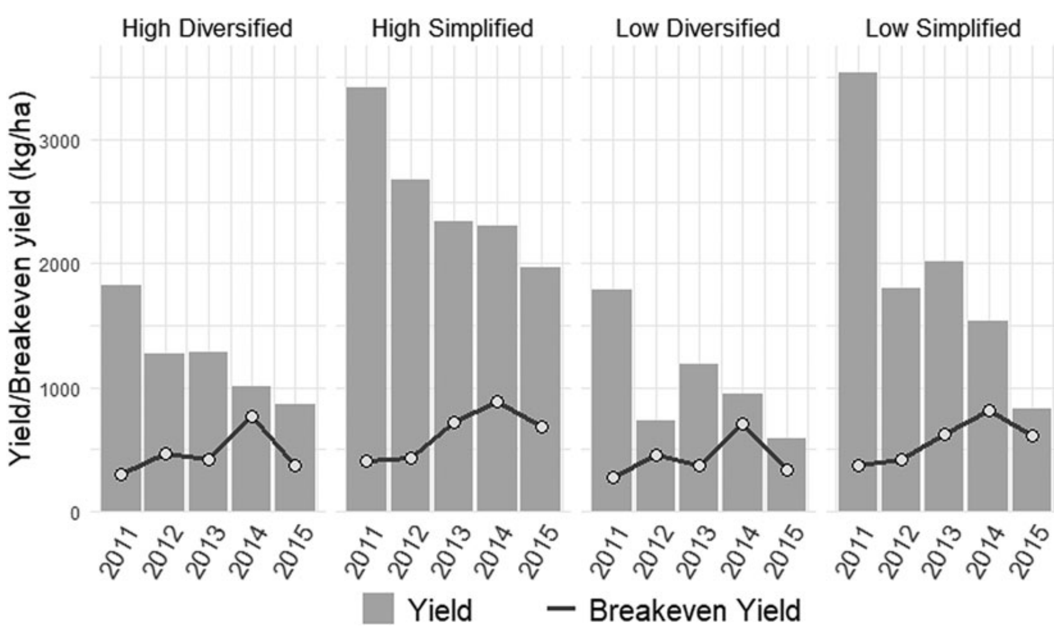

Fig. 4. Comparison of breakeven yield by cropping system from 2011 to 2015. High, high tillage; Low, low tillage. Crop sequences, simplified: forage pea green manure–wheat (HRSW); diversified: forage pea green manure–oilseed (flax or mustard)–pulse (field pea or lentil)–HRSW, with all phases of the rotations present each year.

situation was lower for wheat. However, this does not include consideration of the high wheat protein concentrations obtained in our study (except in 2014) which often earn an additional market premium, indicating that our breakeven prices for wheat are indeed conservative as are those for most other crops. According to OrganicBIZ (2019), the actual organic price premiums as of August 2019 in Western Canada were: HRSW 200%, flax 271% and yellow peas 164%.

Actual crop yields and average breakeven yields of crops are presented in Figure 4. Each bar represents the actual annual yield averaged across all the crops grown under each cropping system. For example, in 2011 in the simplified cropping system, the actual yield averaged across wheat, mustard and lentil was 1824 kg ha^{-1}. The solid lines represent the annual breakeven yield averaged across all the crops grown within the rotation. For example, in 2011 the breakeven yield for the simplified rotation, averaged across wheat, mustard and lentil, was 272 kg ha^{-1}. Comparing the breakeven yield with the actual yield under each cropping system for the 5-year period at conventional market prices (no organic price premium) showed that all the systems produced enough yield to recover the operating costs. From 2014 to 2015, there was a declining trend in the breakeven yields in all systems, with the decline being more prominent in the diversified cropping system. High market prices for mustard and lentil and lower operation costs were attributed to the low breakeven yield in the diversified systems in 2015. Compared to the diversified systems, the simplified systems showed higher breakeven yields in 2015. Higher costs for forage pea seed and lower wheat prices were the main reasons for this higher breakeven yield in that year. In 2015, the diversified cropping systems had a significantly higher gross margin compared to the simplified cropping systems even with the comparatively low yield levels. Therefore, selecting rotation crops with high price levels could help mitigate the adverse impact on profitability, especially when crop productivity declines over time.

Conclusion

Our hypothesis that a diversified crop rotation would result in greater farm profitability than a simplified crop rotation was supported by the findings. However, our hypothesis that reducing tillage intensity, and the combination of reduced tillage intensity and a diversified crop rotation, would further enhance farm profitability was not supported by the findings. Five-year average gross returns and gross margins, with and without organic price premiums, were significantly higher for the high tillage compared to the low tillage treatments. Gross returns for low tillage were higher than for high tillage only in the first year of the study. Gross returns for all the cropping systems displayed a declining trend over time, mainly reflecting the steady decline in crop yields. Low growing season precipitation and soil NO_3-N levels and increased weed competition were the main reasons for the declining crop yields (Fernandez *et al*., 2019b). In contrast, operating costs increased over time, but were not significantly influenced by any of the treatments. Rising costs for seed over the course of the study was the main reason for the increased operating cost. Gross margins also displayed a decreasing trend over time mainly due to increasing operating cost of production and decreasing crop yields. Except for the first year of the study, the high tillage treatments had higher gross margins than the low tillage treatments, both with and without organic price premiums. In contrast, the 5-year average gross margins were not significantly affected by the rotation sequences. During the first 2 years of the study, the simplified rotation had higher gross margins than the diversified rotation; however, this effect was reversed in later years. Analysis of the breakeven prices showed the large impact that organic price premiums have on the profitability of lentil, mustard and flax. Field pea was the only crop with higher breakeven prices compared to conventional crop prices, and thus was not an economically profitable crop in this study. Higher seed cost and low yields of field pea had limited its suitability as a rotation crop in this study.

The results from our study highlighted a future challenge. Because profitability was positively linked to higher tillage intensity, profitability may come at the expense of soil health. Future research studies focusing on how to increase profitability of organic cropping systems while using better weed control mechanisms and improved options to maintain or enhance soil health would be valuable information to further encourage the adoption of organic agriculture.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1742170521000120.

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