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Economics of mitigating greenhouse gas emissions from beef production in western Canada

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ABSTRACT

Beef production plays a vital role in the economy of western Canada; however, in the wake of global warming as a result of increasing greenhouse gas (GHG) emissions, the industry has come under some scrutiny. Although there has been encouraging scientific findings on mitigation strategies applicable to beef operations, there is a lack of economic analysis of such strategies. This study extends on the work of Beauchemin et al. (2011) and evaluates the economic impacts of greenhouse gas mitigation scenarios (GHGMS) for beef operations, and in the process identifies economic and environmental sustainable scenarios. A whole farm economic simulation model was developed and used to measure the profitability of eleven GHGMS adopted from Beauchemin et al. (2011). Whole farm present value gross margin of the eleven scenarios was measured and compared to the conversional system (baseline) of a farm in Vulcan County, Southern Alberta. The farm had 120 cows and their progeny, which was raised and finished on the farm for sale. The study farm was simulated over a period of 8 years in order to fully account for the lifetime economic activity of the breeding stock, as well as the progeny raised for sale. Simulation results estimated a whole farm present value gross margin per ha of $3.51 for the baseline. Seven of the eleven scenarios evaluated were found to increase profitability of the farm by up to 4%. However, only six of the scenarios were found to be both economically and environmentally sustainable to the farm. Four of the six sustainable scenarios were strategies applied to the breeding stock and two to the feedlot. These results suggest that beef producers can profitably implement several GHG mitigation strategies to their operations without substantial changing their operational system.

1. Introduction

The interaction of agriculture and the environment has been under scrutiny in the wake of global warming and climate change discussions. In Canada, animal agriculture accounts for more than 60% of the 69 Mt carbon dioxide equivalent GHG emissions from agricultural emissions (CCA (Canadian Cattlemen Association), 2013a). In particular, beef production is a major contributor to Canadian agricultural emissions, estimated at 42% of total agricultural GHG emissions (CCA (Canadian Cattlemen Association), 2013b).

In December 2015 at the Paris Climate Conference, Parties under the United Nations Framework Convention for Climate Change (UNFCCC (including Canada) agreed to a historic new agreement to address climate change. Collectively, the countries of the world agreed to strengthen the global response to limit global average temperature rise to well below 2°C, as well as to pursue efforts to limit the increase to 1.5° (Environment and Climate Change Canada, 2016). This now creates a challenge to reduce GHG emissions to meet this target. Beef production being a major contributor of GHG emissions is perhaps one of the areas that need attention to achieve that objective. Several scientific researchers have identified GHG mitigation scenarios that can be adopted to Canadian beef operations to reduce GHG emissions (Boadi et al., 2002; DeRamus et al., 2003; Beauchemin and McGinn, 2005; Pelletier et al., 2010; Beauchemin et al., 2011). Some of the strategies identified as having a potential to reduce GHG emissions include: managing animal diets, manure storage and application, land management, shift towards high-grain diets (Legesse et al., 2016) and change in animal husbandry practices. Producers have made changes in land use practices and tillage systems, as well as in manure management, adoption of feed management by Canadian beef farmers has been reported to be very low (MacKay, 2010).

Review of literature on adoption of new methods of production (technology or cultural practises) has suggested that their profitability is an important consideration for producers (Smith et al., 2007). It has been found that Canadian farmers may not adopt a management strategy only because of its environmental benefits, but their decision is

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revered if their economic objective is met. It is therefore, important to perform an economic analysis of greenhouse gas mitigation scenarios (GHGMS) to see how they affect profitability of beef production at the farm level as the adoption decision lies with producers.

The objective of this study is to measure the economic impacts of implementing GHGMS to Canadian beef operations, and also identify economically and environmental sustainable strategies. This study was an extension of a study by Beauchemin et al. (2011) who studied the mitigation of GHG emissions from beef production in western Canada.

2. Material and methods

2.1. Beef production and greenhouse gas emissions from beef production

A review of Canadian studies and those in other jurisdictions resulted in no study that had compared beef production economics with GHG emissions trade-off analysis. Wall et al. (2010) has explored developing better breeds of dairy cattle for reducing GHG emissions. Subak (1999) has estimated the cost of environmental degradation from global beef production. Most studies have addressed one or the other issue in beef (and in general livestock) production and their relationship with GHG emissions but have not extended their analysis to bring economic cost of mitigation measures.

Several researchers have identified management practices that reduce GHG emissions from beef operations (Beauchemin et al., 2011; Beauchemin and McGinn, 2005; Pelletier et al., 2010; Boadi et al., 2002; DeRamus et al., 2003). Most of these researchers have concluded that beef producers can reduce GHG emissions by managing the diet of animals, manure storage and application, and through land management. DeRamus et al. (2003) have argued that traditional (without improved feed and grazing management practices) production systems are generally inefficient in converting plant biomass into animal protein. In support of this argument, these authors demonstrated that controlled rotational grazing systems have the potential to reduce GHG emissions by 22% compared to traditional continuous grazing systems. The type of production system used for beef production also determines the levels of emissions produced from beef farms. The cow-calf beef production system, common in Canadian beef operations, has been found to produce 80% of total GHG emissions from beef operations, compared to a mere 20% from feedlot systems (Beauchemin et al., 2011). A recent study by Alemu et al. (2017) has reported this to be between 65 and 70%. However, one should keep in mind that the feedlot system needs the cow-calf system and therefore, such a distinction is somewhat arbitrary. A similar study in the US also found cow-calf production to emit more methane and nitrous oxide than feedlot cattle (Phetteplace et al., 2001).

Most methane gas from beef production is emitted though enteric fermentation, which results from the inefficiency of ruminants to convert feeds into milk or weight gain (CCA, 2003). Beauchemin and McGinn (2005) and Beauchemin et al. (2011) have suggested that producers can reduce the amount of GHG emissions from their farms by selection of the type of feeds used. For example, Beauchemin et al. (2011) have shown that additives, such as crushed oil seeds, can be used as part of animal diets to reduce methane emission levels, thus increasing the efficiency of feed use in animals. Beauchemin and McGinn (2005) found that corn diets fed to beef cattle in Alberta, during the backgrounding and finishing phase, resulted in less emissions compared to barley grain diets.

A comprehensive study of a beef farm in southern Alberta by Beauchemin et al. (2011) has shown that different management strategies that include dietary supplements, land management, timing of moving calves from pasture to feedlot to market has the potential to reduce total farm GHG emissions by 8%, and if some strategies are combined reduction may be up to 17% of total beef production GHG emissions.

2.2. The study farm

Since this study is an extension of Beauchemin et al. (2011), to keep consistency with the findings of GHG emission levels of the study farm, information on resources and activities of the farm (i.e. farmland area, crop and pasture production, beef herd dynamics, feed requirements) were adopted from that study. In addition to this information, industry data and expert information were also used to build the study farm. However, the size of the farm was made to reflect the average cattle farm in the study region.

The study farm was located in Vulcan County in Southern Alberta. Agriculture is the largest economic industry in Vulcan County, employing 52% of the labour force (City-Data, 2013). In 2011, there were a total of 603 farms in Vulcan County, of which 355 reported having mixed farming with grain and oilseed, and 105 reported beef cattle ranching and farming, including feedlots (Statistics Canada, 2011). Of the total farmland area of 548,120 ha in the county, annual cropping (wheat, barley, oats and rye) occupied the largest land area, followed by native pasture, at 65 and 20%, respectively (Statistics Canada, 2011). Availability of annual crops and pasture supports livestock production (beef, dairy, pigs, sheep, goats, horses, llamas, and alpacas). The dominant livestock was cattle production reported by 277 farms with a total of 197,851 cattle and calves (Statistics Canada, 2011). This represents almost 4% of Alberta's total cattle and calves (Statistics Canada, 2011).

The study farm had a land area of 2334.8 ha for livestock feed production. Farmland was divided into annual cropping (293.2 ha) and native pasture (2041.6 ha). Annual cropping land was used for production of barley grain, barley silage, and alfalfa-grass hay. The land area under any annual crop was determined by first meeting livestock feed requirements. Any excess land not needed for meeting livestock feed requirements was put into cash crop for sale to boost the revenues of the farm. Hay production was chosen to be the cash crop as farmers tend to produce more hay than required as a buffer for droughts in the preceding years and some of it end up in the market. Any unused pasture was used for renting.

The farm kept 120 breeding cows, 4 bulls and their progeny. Table 1 shows the cattle numbers and the basic farm management variables used for the study farm which were adopted from Beauchemin et al. (2010). Beef cattle have different nutritional needs at different stages, and also have different feed intake capacity. For this reason, all cattle were divided into different classes: breeding stock, calves, backgrounders (feeders), and finishers. The breeding stock (cows and bulls)

Table 1
Cattle numbers and basic farm management of the study farm (from Beauchemin et al., 2010).

Particulars	Value
Breeding cattle	
Cows (head)	120
Bulls (head)	4
Calves (head)	120
Management	
Weaning rate per year	85%
Heifer replacement[a] per year	15%
Backgrounding death loss per year	3%
Finishing death loss per year	1%
Backgrounding feedlot days per year	110
Finishing feedlot days per year	170
Native pasture stocking rate (AUM[b]/ha)	0.113
Animal live weights (kg)	
Feeder finishing weight	606
Mature cow weight	601
Mature bull weight	821

[a] Heifer replacement The replacement heifer becomes the genetic building block for the cow herd to produce calves in the future (Troxel and Gadberry, 2018).
[b] Animal unit months.

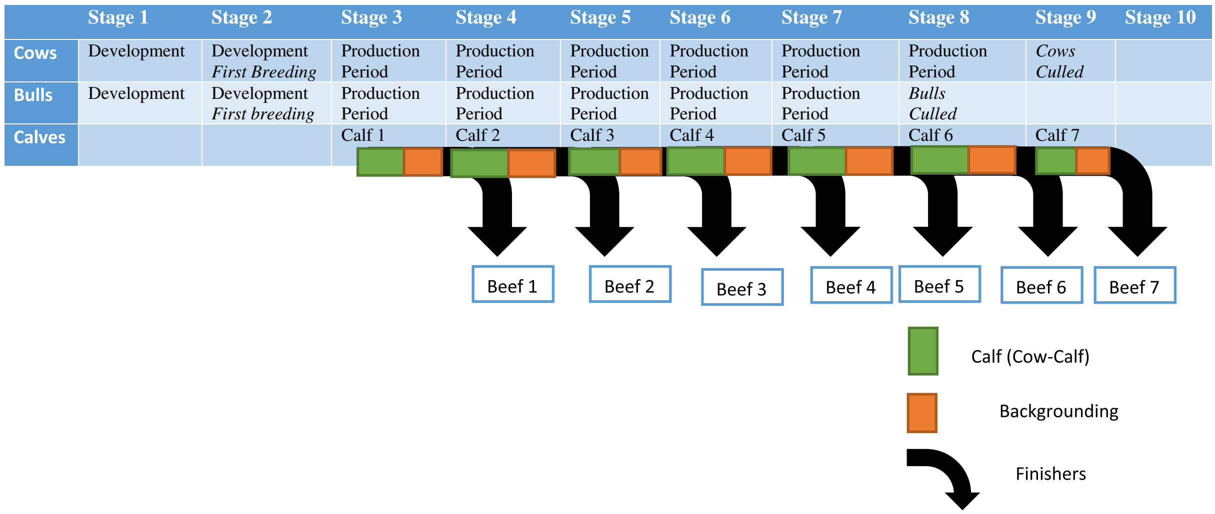

Fig. 1. Timeline and dynamics of the beef herd.

fed on native pasture in the summer and on harvested alfalfa-grass hay in the winter. Calves relied on milk from nursing cows in the early stages after birth and were separated from cows in September of the year they reached a body weight of 529 pounds. Backgrounders and finishers were fed on barley silage and grain at different formulations (Beauchemin et al., 2011). All feed for the animals was produced on the farm.

The breeding stock was brought onto the farm at birth. The bulls and cows were kept in the farm for a complete 8-year production cycle, thus going through 7 breeding periods and producing 7 calf crops (see Fig. 1). Bulls were sent to the market after they bred the 7th calf, and cows were sent to the market after their 7th calf was weaned. Calves born in the farm were raised and finished in the farm before being marketed.

Calves were raised to finish in the farm, going through a three development-stage system common in western Canadian beef operations (cow-calf, backgrounding, and finishing). The cow-calf operation comprised of cows, bulls, and their progeny. Livestock feed requirements were determined based of feed rations from Beauchemin et al. (2011) and energy and protein requirements of beef cattle (NRC (National Research Council), 2000). Any annual cropland left unused, after livestock feed requirements were met, was put into production of cash crops, and unused native pasture was rented out to other livestock producers.

2.3. The economic model and GHG emissions

The different GHGMS were modelled and assessed using a whole farm simulation model (based Excel software). The economic variable of interest was whole farm gross margin, which is the difference between farm revenues and variable costs of production. Gross margin values were converted into present values for comparison of scenario results since the model generated value over an eight year period.

The model contained three components: annual cropping, a beef herd, and native pasture production. Nutritional requirements of the beef herd were the linkage between this components. All farm activities were linked and bounded by different constraints: structural (useable area, cropping land, and pastureland), agronomic (cropping plan, preceding use, etc.), zootechnical (replacement rate, mortality and numerical productivity, feed requirements, etc.) (Veysset et al., 2010), and economic variables (cost of production, crop and livestock prices, pasture rental rates, etc.) as shown in Fig. 2. It was postulated that implementation of a GHGMS to the farm may change the farm resource allocation affecting all three components of the farm in a systematic manner. These changes were accounted for in the estimation of GHG emissions.

Gross margin of the farm was a sum of four components (Eq. (1)): that from beef enterprise, sale of cash crops, renting out of native pastures, and income from other sources. Each of these was estimated as the difference between its gross revenue and cost of production.

$$\mathrm{WFPVGM}_k = \underbrace{\sum_{t=1}^{n}\left(\frac{\left(\sum_i (W_{ikt} * P_i) - (FC_{cc,t} + FC_{fd,t} + OVC_{cc,t} + OVC_{fd,t})\right)_k}{(1+r)^t}\right)}_{\text{Beef gross margin}} + \underbrace{\sum_{t=1}^{n}\left(\frac{\sum_{CS} (Q_{cs,kt} * P_{cs} - L_{cs,kt} * VC_{cs})}{(1+r)^t}\right)}_{\text{Cash crop gross margin}} + \underbrace{\sum_{t=1}^{n}\left(\frac{AUM_{Rkt} * J - L_{Rkt} * VC_p}{(1+r)^t}\right)}_{\text{Rented-out native pasture gross margin}} + \underbrace{\sum_{t=1}^{n}\left(\frac{(L_{jkt} * N_j + L_{jkt} * A_j)}{(1+r)^t}\right)}_{\text{Other revenues}} \quad (1)$$

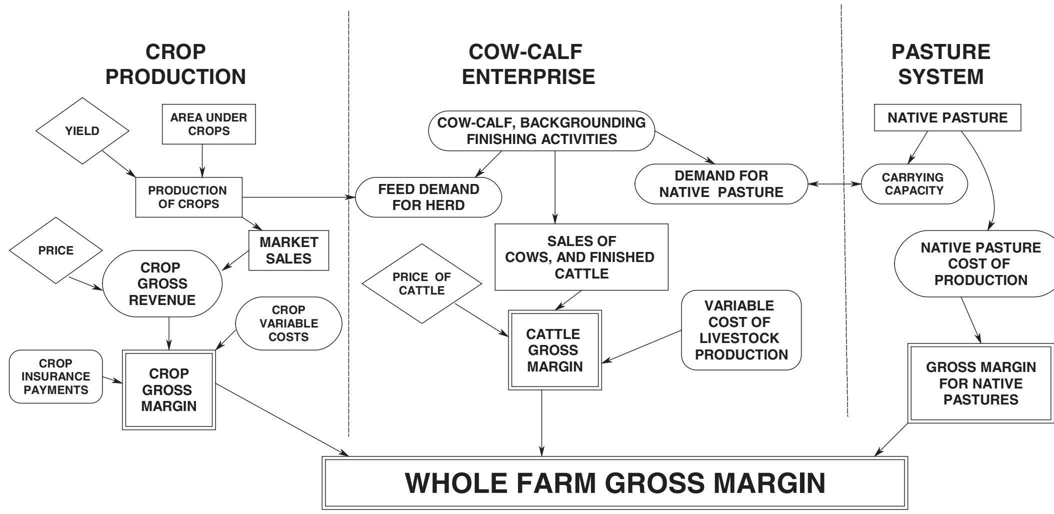

Fig. 2. Components and linkages of the farm simulation model.

where, *WVWFGM* is present value of whole farm gross margin, k is study scenarios ($k = 1, \ldots, 11$); t is the time in years from 1…. n ($n = 9$ for the full production beef cycle); i is the type of animal sold ($i = 1, 2, 3, 4$, being steers, heifers, cull cows, and cull bulls, respectively); cs is cash sale crops (=1, 2, 3, 4 for feed barley, barley silage, mixed hay, and native pasture, respectively); R is rented out pasture; j is other income sources; and r is the rate of discount.

In this study a discount rate of 5% was used following other economic studies of beef operations in western Canada (Koeckhoven, 2008; Conestoga-Rovers and Associates, 2011). The equation has two sections 1 and 2, representing revenues and costs of the farm, respectively. In the revenues section; W_i is the live weight of the ith type of animal sold (kg), P_i is the price of animals being sold ($/kg). Q_{cs} is the quantity of cash crop produced (tonnes), P_{cs} is the price of the cash crop ($/tonne), AUM_R is the total animal unit months available to be rented out, J is the pasture rental rate ($/AUM), L_j is land under crop j, N_j is the insurance compensation rate, and A_j is the rental rate of aftermath grazing rented out.

The second section is the variable costs of production associated with the activities of the farm (i.e. feed production costs, animal health, transportation and marketing). Cost of production data used for this model are shown in Appendix A. The fixed costs of the farm were omitted since the farm did not need any structural change for any of the scenarios evaluated and thus remained the same for all study scenarios. Although their manufacturing may generate GHG emissions, that was considered beyond the scope of this study. Housing costs were excluded in the model since this is not a standard practice as supported by data collection agencies. Labour cost included paid workers wages and were modified as labor use change under various scenarios.

Greenhouse gas emissions for the study farm for the baseline and study scenarios were estimated as follows: (i) For the livestock sector activities coefficients provided in Beauchemin et al. (2011) were used. (ii) For activities for which GHG emission coefficient was not reported by Beauchemin et al. (2011), IPCC default coefficients were used. (iii) For the crop production activities, coefficients were obtained from Canadian Economic and Emissions Model (Sobool and Kulshreshtha, 2005). Activities for the cop sector included: direct as well as indirect emissions. Included in these coefficients were carbon sequestration as well as reduction in emissions from land use changes. Land use change emissions were only applied if under a given scenario some of the grain area was converted into tame hay (Scenarios 5 and 8 in Table 3).

2.4. Trade-off analysis

The concept of trade-off is derived from the notion that resources are limited; that is, to obtain more of one good, some amount of another good will have to be given up. MacLeod and McIvor (2008) have argued that the reliance on production economics to inform resource use decisions on rangeland enterprises might not be appropriate, given a second feature of livestock production that has an ecological aspect. Trade-off analysis recognizes that complex interactions between environmental and economic indicators are a key aspect of production systems, and quantifies the inter-relationship of these interactions as a joint distribution (Stoorvogel et al., 2004). Trade-off curves are used to represent the joint distribution of indicators (Stoorvogel et al., 2004; Vos et al., 2003).

In this study, changes in emission levels of the farm were plotted against changes in whole farm present value gross margin. The graph was used to identify sustainable (environmentally and economic) GHGMS. Trade-off analysis was further expanded for performance ranking of scenarios. The performance of scenarios was based on profits/costs dollars per tonne of carbon dioxide equivalent of GHG emissions brought about by implementing a GHGMS, mathematically expressed as:

$$\text{Profit/Cost (\$) per tonne GHG emissions} = \frac{\Delta WFGM_{ghgms}}{\Delta WFGHG_{ghgms}} \tag{2}$$

where $\Delta WFGM_{ghgms}$ and $\Delta WFGHG_{ghgms}$ is the incremental change in whole farm present value gross margin and GHG emissions, respectively, compared to the baseline. The scenario with the highest positive ratio was ranked highest given it reduced greenhouse gas emissions of

Table 2
Growth rates and time on feed during backgrounding and finishing of beef calves for the various scenarios.

Scenario	Stage	Location	Days	ADG (kg/day)
Baseline	Backgrounding	Feedlot	110	1.0
	Finishing	Feedlot	170	1.5
Increased use of forage for	Backgrounding	Feedlot	150	0.7
backgrounding cattle	Backgrounding	Pasture	120	0.7
(Scenario 1)	Finishing	Feedlot	120	1.6
Extended grain finishing of cattle	Backgrounding	Feedlot	40	1.0
(Scenario 2)	Finishing	Feedlot	210	1.5

ADG = Average daily gain.
Source: Beauchemin et al. (2011).

Table 3
Diets composition for the dietary mitigation scenarios (Scenarios 3–9).

	Baseline	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7	Sc 8	Sc 9
		Canola Seed			Corn Distillers Grains			Increased Forage Quality
Backgrounding Ingredients, g/kg DM								
Barley grain	400	301	400	400	50	400	400	400
Barley silage	600	600	600	600	600	600	600	600
Canola seed	0	99	0	0	0	0	0	0
Distillers dried grain	0	0	0	0	350	0	0	0
CP, g/kg DM	125	133	125	125	188	125	125	125
DC	0.7	0.744	0.7	0.7	0.711	0.7	0.7	0.7
Days	110	110	110	110	110	110	110	110
Finishing Ingredients, g/kg DM								
Barley grain	900	900	801	900	900	550	900	900
Barley silage	100	100	100	100	100	100	100	100
Canola seed	0	0	99	0	0	0	0	0
Distillers dried grain	0	0	0	0	0	350	0	0
CP, g/kg DM	120	120	129	120	120	184	120	120
DC	0.81	0.81	0.849	0.81	0.81	0.816	0.81	0.81
Days	170	170	170	170	170	170	170	170
Breeding stock[1] Ingredients, g/kg DM								
Legume-grass hay	1000	1000	1000	900		1000	800	1000
Canola seed	0	0	0	100		0	0	0
Distillers dried Grain	0	0	0	0		0	200	0
CP, g/kg DM	120	120	120	129		120	156	140
DC	0.55	0.55	0.55	0.618		0.55	0.61	0.6

Sc , scenario; DM, dry matter; CP, crude protein; DC, digestibility coefficient. The ingredients of feed is measured in g/kg, which shows the portion of an ingredient in the whole rationThe grey shading shows the diet that changed in implementing the scenario.
[1] diet fed to breeding stock during winter.
Source: Beauchemin et al. (2011)

Sc, scenario; DM, dry matter; CP, crude protein; DC, digestibility coefficient. The ingredients of feed is measured in g/kg, which shows the portion of an ingredient in the whole ration. The grey shading shows the diet that changed in implementing the scenario.
[1]Diet fed to breeding stock during winter.
Source: Beauchemin et al. (2011).

the farm. A comparison of these results with those in the literature was not attempted since no similar study was found for Canada or other jurisdictions.

3. Greenhouse gas mitigation scenarios

Economic performance of eleven study scenarios was evaluated. The scenarios were divided into two general categories: feed management (Scenarios 1–9), and animal husbandry management (Scenarios 10–11). Feed management scenarios explored the economics of changing animal feed rations by either improving the quality of feed, introducing a different ingredient, or adjusting the period that animals are fed a particular diet. Farm management scenarios explored the economics of improving the efficiency of the breeding stock. All of these scenarios were adopted from Beauchemin et al. (2011), who evaluated GHG mitigation potential of the scenarios in the same farm setting. To evaluate the economic impacts of GHGMS, a baseline scenario (Tables 2 and 3) was developed for use as a point of reference for performance of the other scenarios. Baseline scenario is the state of the farm under the current system of beef production in the Vulcan County. The performance of the other scenarios was measured in terms of the incremental impact they had on the whole farm gross margin (in present value terms) to that of the farm under the baseline. Thus, a scenario leading to an increase in profitability of the farm over and above the level for the baseline scenario was considered economically desirable.

3.1. *Increased use of forage in backgrounding cattle (Scenario 1)*

This scenario evaluated the economic value of increasing the use of forages in backgrounding cattle. Market cattle were fed in a two-stage backgrounding system: first on a high forage diet and then moved to graze on native pasture before being transitioned into a finishing lot (Table 2). Backgrounders were kept in the feedlot for 150 days on a high forage diet, followed by 120 days of grazing native pasture, and finished in the feedlot on a high grain diet for 120 days. Under this scenario animals finished with higher weights (621 versus 605 kg) compared to the baseline (Beauchemin et al., 2011); however the number of days between weaning and marketing increased by 110 days. Increase in animal weights implied more revenues for the farm; however, the prolonged stay of animals on the farm also meant increase in variable costs.

3.2. *Extended grain finishing of cattle (Scenario 2)*

Compared to the baseline, this scenario increased the amount of time market cattle spent in the finishing stage by 40 days and reduced the time spent in the backgrounding stage by 70 days (Table 2). Increasing the number of days animals spent on a high grain diet meant animals gained more weight in a shorter period of time (due to higher ADG), making them ready for the market earlier than in the baseline scenario (15.3 versus 16.3 months of age). However, market cattle finished with lighter weights compared to the baseline scenario (595 Vs 605 kg).

Table 4
Dry matter intake of hay cut at an early stage versus late stage.

Cattle class	Late cut hay Dry matter intake (kg) at DC = 0.55	Early cut hay Dry matter intake (kg) at DC = 0.60	Percentage change
Dry cow (4 months)	12.02	10.47	12.9
Lactating cow (2 months)	18.18	15.84	12.9
Bull	15.35	13.38	12.8

Source: Beauchemin (2014).

3.3. Feeding crushed canola seed (Scenarios 3–5)

The economics of supplementing feed diets with canola seed was evaluated by incorporating crushed canola seed in backgrounding (Scenario 3), finishing (Scenario 4) and breeding stock rations (Scenario 5) as shown in Table 3. Canola seed was substituted for barley grain in backgrounding and finishing feedlot diets, and for mixed hay in the winter diets of the breeding stock. The model accounted for changes in nutritive value of diets. According to Beauchemin et al. (2011) canola seed increased crude protein content and digestibility of feed in all rations, meaning animals ate less feed to maintain the same daily weight gain as the baseline scenario. All the canola required for animal rations was grown in the farm.

3.4. Feeding corn distillers dried grains (Scenarios 6–8)

Economic impacts of feeding corn distiller dried grains (CDDG) to beef cattle was assessed by incorporating CDDG in diets of backgrounding (Scenario 6), finishing (Scenario 7), and breeding stock (Scenario 8). CDDG were imported from Lawrenceburg, Indiana in the United States (Boaitey and Brown, 2011). The total costs (product cost plus shipping costs) for the product was set at $197.29 (Boaitey and Brown, 2011; SAAEP (Southern Alberta Alternate Energy Partnership), 2008). CDDGs replaced barley grain in backgrounding and finishing feedlot diets, and mixed hay in the winter diets of the breeding stock. Since CDDGs were purchased, cropland was freed up from the reduction of feed requirements of grains and hay from the farm. This land was put towards a cash crop to generate revenues for the farm.

3.5. Improved forage quality of breeding cattle (Scenario 9)

Under the baseline scenario, hay was assumed to be of medium quality with a digestible energy coefficient of 0.55, whereas in this scenario, hay was cut at an early stage to have a digestible energy coefficient of 0.60 (Beauchemin et al., 2011). This means cattle fed on less early cut hay to maintain the same body weight gain as when fed on medium quality hay. The amount of alfalfa grass hay to be fed the breeding stock under these different hay quality situations was obtained from Beauchemin (2014), and is shown in Table 4.

3.6. Increased number of calves weaned (Scenario 10)

The weaning rate under the baseline was set at 85%, consistent with the average rate for Alberta, Saskatchewan, and Manitoba operations (Beauchemin et al., 2011); however, weaning rates can be improved with better management of the herd. Bailey (1991) has shown that breed and timing of birth plays a pivotal role on the variation of number of weaned calves. Beauchemin et al. (2011) also argued that a high calf crop could be increased by increased conception rate, fewer abortions and increased number of live births. This scenario measured the profitability response of increasing the weaning rate from 85 to 90% for western beef operations. The number of calves weaned increased from 102 to 108 per annum compared to the baseline. This meant more animals were marketed generating more revenues for the farm; however, the farm also incurred additional costs of raising a bigger herd.

3.7. Increased longevity of the breeding stock (Scenario 11)

In this scenario the breeding stock was kept in the farm for one additional year allowing one additional calving season. The farm resources remained in the same state as for the baseline scenario, such that there were no additional resources employed but just an additional production year costs increased.

4. Results and discussion

For each scenario economic returns (measured as gross margin) were estimated and compared against change in GHG emissions provided by Beauchemin et al. (2011). Economic results were based on change in the land use for crops and pasturelands. All unused crop land was allocated to sale of crops, and any unused pastureland was used for renting. These details are shown in Table 5. Economic indicators making up gross margin for beef are shown in Table 6 along with other sources of income to the farm. Effectiveness of the scenario for the beef enterprise was compared on the basis of per unit of production (kg of meat produced), whereas that for the whole farm was using gross margin per unit of land. All values in the tables are annual values.

4.1. Economics of greenhouse gas mitigation scenarios

4.1.1. Baseline scenario

Whole farm simulation of the study farm estimated a whole farm present value gross margin of $84,098 per annum (Table 5). Activities directly linked to beef production were the main economic components of the farm; generating 64% of whole farm discounted revenues and also accounting for 87% of whole farm discounted costs. Livestock feed costs were the major costs of producing beef, accounting for 47% of total beef production costs. This is consistent with other studies that have looked at costs of producing beef in western Canadian operations (Larson, 2010; Kaliel, 2004). Under the baseline scenario a total of 293.2 ha were put under crop production annually (of which 96.8 ha were for market sales). Similarly of the total pasture area of 2041.6 ha, only 1306 ha were needed for the farm herd, the remaining 735.6 ha were rented out for a cash return. The beef enterprise's gross margin was $0.56 per kg of beef produced. Similarly, for the whole farm, estimated gross margin was $3.61 per ha per annum. All study scenarios were compared against this benchmark.

4.1.2. Increased use of forage in backgrounding cattle (Scenario 1)

Increasing the use of forage increased the amount of native pastureland required for livestock grazing to 1793.9 ha (36.59% over the baseline level) per annum. However, as a result, annual cropping land required for feed supply decreased by 10 ha (5.12% relative to baseline level). Implementation of this scenario led to a feed cost savings of $615 per annum relative to the baseline. This showed that raising animals on native pasture has a lower cost. In fact, maintaining the western Canadian cow herd on forage for one more day in the fall has been estimated to save the western beef industry at least $3.1 million (Saskatchewan Forage Council, 2011). Increasing the use of forage in backgrounding cattle also led to heavier finished animals compared to the baseline. The increase in animal weights led to an increase of $2174 annually in revenues (in discounted value) from marketed beef animals. Despite the costs savings from feeds and increased revenues from heavier animals, whole farm profitability showed a small but positive economic improvement compared to the baseline. The economic gains were offset by increases in other variable costs associated with keeping market animals longer in the farm before being sold. Profitability per ha of land under production showed a very small increase over the baseline.

Table 5
Simulation results for annual land use and production of live weight under study scenarios.

Scenarios	Annual cropland (ha)						Native pasture area (ha)			Live weight produced (kg)			
	Barley for grain	Barley silage	Alfalfa/ grass	Canola	Total cropland area for feed production	Total unused cropland area	Grazed pasture land	Unused pasture land	Total pasture land	Finished cattle	Cull cows	Cull bulls	Total quantity of beef produced
Baseline	613.2	111.2	847.0	0.0	1571.3	1067.9	10,448.3	7926.8	18,375.1	51,853.3	17,100.2	410.0	69,363.4
One	513.7	130.1	847.0	0.0	1490.8	1148.4	14,271.3	4103.8	18,375.1	53,225.6	17,100.2	410.0	70,735.7
Two	654.7	71.7	847.0	0.0	1573.4	1065.8	10,448.3	7926.8	18,375.1	50,994.1	17,100.2	410.0	68,504.3
Three	600.6	103.1	847.0	26.3	1576.9	1062.3	10,448.3	7926.8	18,375.1	51,853.3	17,100.2	410.0	69,363.4
Four	518.2	108.9	847.0	51.0	1525.1	1114.1	10,448.3	7926.8	18,375.1	51,853.3	17,100.2	410.0	69,363.4
Five	613.2	111.2	78.4	76.8	879.6	1210.5	10,448.3	7926.8	18,375.1	51,853.3	17,100.2	410.0	69,363.4
Six	610.3	109.3	847.0	0.0	1566.6	1072.6	10,448.3	7926.8	18,375.1	51,853.3	17,100.2	410.0	69,363.4
Seven	424.2	110.8	847.0	0.0	1382.0	1257.2	10,448.3	7926.8	18,375.1	51,853.3	17,100.2	410.0	69,363.4
Eight	613.2	111.2	571.9	0.0	1296.2	1343.0	10,448.3	7926.8	18,375.1	51,853.3	17,100.2	410.0	69,363.4
Nine	613.2	111.2	818.6	0.0	1542.9	1096.1	10,448.3	7926.8	18,375.1	51,853.3	17,100.2	410.0	69,363.4
Ten	647.5	926.7	894.9	0.0	2469.1	980.1	10,448.3	7926.8	18,375.1	54,903.4	12.858.0	410.0	68,171.4
Eleven	696.6	124.4	970.2	0.0	1791.2	1141.2	10,498.7	7876.4	18,375.1	52,914.7	16,474.3	410.0	69,799.0

4.1.3. Extended grain finishing of cattle (Scenario 2)

Extended grain finishing cattle shortened the number of days between weaning and marketing animal which also meant animals were marketed with smaller weights (595 kg vs 605 kg). The total live weight of marketed beef dropped by 859.1 kg every year, lowering revenues of the herd from $97,794 to $96,425 per annum – a decrease of 1.4% over the baseline level. Shorter days between weaning and marketing resulted in a decrease of $141annually in variable costs, although feed costs increased by $372 per annum. The decrease in costs did not compensate for lost revenues, yielding a decrease in whole farm present value gross margin from $3.51 to $3.46 per ha.

4.1.4. Feeding crushed canola seed (Scenarios 3–5)

Simulation results showed that replacing canola seed for barley grain in backgrounding cattle (Scenario 3) is a costly practice in western Canadian beef operations. Even though canola seed has higher energy content compared to barley grain, replacing canola seed for barley grain in backgrounding resulted in $644 increase in annual feed costs. This is mainly due to the high production costs of Canola in the region. The data used for this analysis showed that the cost of producing feed barley was $43.79 compared to $72.97 per ha for producing canola. Furthermore, the Canola seed needed to be crushed which further increased its cost. Overall profitability of the farm under this scenario decreased by a discounted gross margin value of $870 (1.2%).

In contrast, including canola seed in finishing cattle (Scenario 4) improved profitability of the whole farm per ha by 1.7%. The model estimated a 1.05% decrease in feed costs, with a slight increase (0.04%) in other variable costs. This is explained by the fact that canola seed is a high energy diet and is best utilized when fed to produce a high daily gain in finishing animals than backgrounding animals which are grown slowly.

Finally, canola seed was fed to the breeding stock (Scenario 5). Simulation results under this scenario showed that whole farm present value gross margin increased by 2.89%; however, profitability of beef production as a single enterprise (without including unused land into marketed forage) decreased by 6.8%. The increase in whole farm profitability was mainly as a result of canola seed replacing a large amount of hay in the breeding stock ration, leading to $219.3 ha (25.91%) of land seeded to hay being freed, and a total of $142.5 ha going into production of marketed forage, which increased whole farm revenues.

4.1.5. Feeding corn distillers dried grains (Scenarios 6–8)

Corn dried distillers grains were brought from off-farm sources to replace feed that could have been otherwise produced on the farm. This freed up land which was put into a marketed forage. In the backgrounding operation (Scenario 6), CDDG replaced some barley silage, freeing up 0.6 ha of annual cropping land into marketed forage production. Replacing barley silage for CDDG in the backgrounding operation increased beef feed costs by $4010 (14.65% increase over baseline). Revenues from land put into marketed forage did not compensate for the increases in feed costs leading to a whole farm present

Table 6
Simulation results for discounted annual economic indicators for study scenarios.

Scenario	Production costs per annum			Revenues per annum				Beef gross margin per annum		Other gross margin of farm per annum	Whole farm gross margin of the farm per annum	Whole farm gross margin per ha per annum
	Feed cost	Other variable costs	Total variable costs	Finished cattle	Cull cows	Cull bulls	Total revenues	Total	Per kg of marketed beef			
Baseline	$27,364	$30,690	$58,054	$82,597	$14,796	$401	$97,794	$39,739	$0.57	$44,359	$84,098	$3.51
One	$26,749	$31,318	$58,067	$84,783	$14,796	$401	$99,980	$41,913	$0.59	$42,126	$84,039	$3.52
Two	$27,736	$30,178	$57,913	$81,228	$14,796	$401	$96,425	$38,512	$0.56	$44,432	$82,943	$3.46
Three	$28,008	$30,727	$58,735	$82,597	$14,796	$401	$97,794	$39,059	$0.56	$44,169	$83,228	$3.47
Four	$27,076	$30,702	$57,778	$82,597	$14,796	$401	$97,794	$40,015	$0.58	$45,335	$85,350	$3.57
Five	$29,298	$30,751	$60,049	$82,597	$14,796	$401	$97,794	$37,744	$0.54	$48,490	$86,234	$3.61
Six	$31,374	$30,844	$62,218	$82,597	$14,796	$401	$97,794	$35,576	$0.51	$44,478	$80,054	$3.32
Seven	$30,586	$30,814	$61,400	$82,597	$14,796	$401	$97,794	$36,394	$0.52	$48,953	$85,346	$3.57
Eight	$32,232	$30,752	$62,984	$82,597	$14,796	$401	$97,794	$34,810	$0.50	$52,298	$87,108	$3.66
Nine	$27,180	$30,688	$57,868	$82,597	$14,796	$401	$97,794	$39,925	$0.58	$45,174	$85,099	$3.56
Ten	$28,628	$28,097	$56,725	$87,455	$12,177	$401	$100,033	$43,308	$0.64	$41,992	$85,300	$3.57
Eleven	$30,373	$34,298	$64,671	$92,258	$15,556	$382	$108,196	$43,525	$0.62	$46,886	$90,411	$3.45

value gross margin per ha loss of $0.19 compared to the baseline scenario.

Similarly, CDDGs were used to replace barley grain in finishing cattle rations (Scenario 7). In this scenario 23.6 ha of annual cropping land was freed, increasing non-beef revenues by a discounted value of $7940. Feed costs of the beef herd increased by 11.78%. Annual whole farm present value gross margin per ha increased by $0.06 compared to the baseline scenario.

Finally, CDDGs were used to replace mixed hay for the breeding stock (Scenario 8). A total of 274.88 ha of mixed hay shifted from being fed to marketed hay; increasing non-beef revenues by $46,133. Feed costs increased by 17.79%. The overall impact was an increase in profitability of the whole farm by a discounted value of $0.19 (4.08%) per ha.

4.1.6. Improved forage quality of breeding cattle (Scenario 9)

Using good quality hay increased whole farm profits by a discounted value of $8005, which is a 1.36% increment compared to the baseline scenario. The breeding stock consumed less forage, freeing up land towards production of a marketed forage. Feed costs decreased by $1468, and revenues from marketed forage increased by a discounted value of $7986. This scenario proved to be economical feasible in the context of western Canadian beef production.

4.1.7. Increased number of calves weaned (Scenario 10)

Under the increased number of calves weaned, the model estimated a $38,869 increase in marketed cattle revenues as a result of increasing the weaning rate from 85% to 90% (Table 6). Raising a bigger herd meant animals needed more feed, increasing the amount of land required for feed production by 87.79 ha (5.6%), leading to a $10,110 (4.62%) increase in feed costs. Under this scenario since less marketed forage was produced compared to the baseline, non-beef revenues decreased by $23,397; however, gains in beef revenues offset this losses, resulting finally in 1.63% increase in whole farm present value gross margin per ha.

4.1.8. Increased longevity of the breeding stock (Scenario 11)

Prolonging the breeding stock for one additional year increased whole farm present value gross margin by $46,886 (Table 6); however, on a per ha basis, whole farm gross margin showed a decrease of $0.05, which is 1.74% less than the baseline scenario. The fact that some transactions of this scenario appear one year later compared to the baseline led to lower economic gain per ha put into production because of discounting. It therefore, makes this scenario economically unattractive for the study farm.

4.2. Environmental-economic trade off analysis results

Trade-off analysis was performed from GHG emission intensity results from Beauchemin et al. (2011) and profitability results in Section 4.1 of the GHGMS. The results of the analysis are shown in Fig. 3 categorised into four outcomes for the environmental and profitability of the farm, respectively: loss-loss (I), loss-win (II), win-loss (III), and win-win (IV). Details on sources of these GHG emissions can be found in Beauchemin et al. (2010, 2011).

Table 7
Ranking of GHGMS based on profits/costs per tonne GHG emissions.

Study scenarios		Discounted whole farm gross margin ($/tonne of GHG)	Rank
Win-win scenarios[a]			
7	CDDG in finishing	238.11	1
4	Canola seed in finishing	115.30	2
8	CDDG in breeding stock	78.66	3
10	Increase weaning rates	47.25	4
5	Canola seed in breeding stock	37.25	5
9	Improved hay for breeding stock	30.31	6
Win-loss scenarios[b]			
3	Canola seed in backgrounding	(90.41)	7
2	Extended grain finishing	(96.39)	8
11	Add 1 prod cycle	(475.52)	9
6	CDDG in backgrounding	(582.46)	10
Loss-win scenario[c]			
1	Increased forage for backgrounding cattle	1.45	11

[a] Scenario results in lower GHG emissions and positive gross margin.
[b] Scenario results in lower GHG emissions but negative gross margin.
[c] Scenario results in higher GHG emissions but positive gross margins.

Trade-off analysis places 6 scenarios into the win-win category – scenarios that are economically and environmentally desirable sustainable if implemented on a mixed farm in the Vulcan County of Alberta, Canada. Performance ranking of all scenarios is shown in Table 7. The top 6 performing GHGMS are identified in Fig. 3. The highest performing scenario was the use of CDDGs for finishing cattle, increasing the net profit of the farm by $238.11 per tonne of carbon dioxide equivalent of GHG emissions reduced. This was followed by use of canola seed for finishing cattle, use of CDDG for breeding stock, and increasing the weaning rate. Among the win-loss scenario, the worst case was the use of CDDG in backgrounding, and adding one extra production cycle. The lowest ranked scenario was the increased use of forages in backgrounding cattle. Even though this scenario increased economic returns, it is the only scenario that did not reduce GHG emissions of the farm, hence being ranked the lowest.

5. Conclusions

Beef production has come under fire for its role as a drive of global warming through its high production of methane gas. In response to this troubling issue scientific work has focused on identifying different

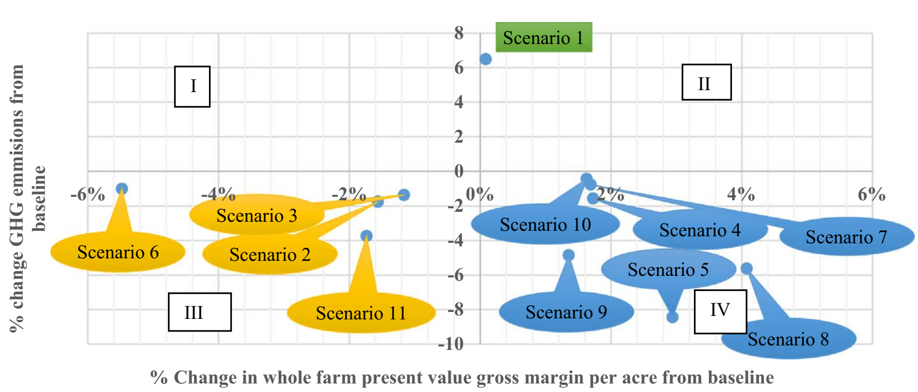

Fig. 3. Environmental-economic trade-off analysis of GHGMS.

techniques that can be implemented in beef operations to reduce GHG emissions. Although many techniques have been found to be helpful in reducing GHG emissions, their adoption depends on their effect on producers' pocketbook. Simply the knowledge of the said techniques' effect on reducing GHG emission, and thus being environmentally friendly, may not be enough to convince producers as they may be more focussed on protecting their investment than the environment. This has been evident over the years, the protection of revenues has hinged on increasing farm size and labour productivity (Veysset et al., 2010). It is therefore important to reduce GHG emissions and still maintain economically viability of the farm.

This study was an extension of the work by Beauchemin et al. (2011) who studied the environmental impacts of different GHGMS in Vulcan County in western Canada. Eleven GHGMS were adopted from that study and evaluated for their economic impacts for the same farm at the same location. Whole farm economic analyses showed that six of the eleven scenarios can be profitably implemented on the farm and at the same time reduce GHG emissions. Beauchemin et al. (2011) found that the biggest reductions in GHG emissions are achieved when mitigation practices target reducing enteric CH_4 from the breeding herd. This study found that four of the sustainable GHGMS were directly applied to the breeding stock. They included: one, the use of canola seed in breeding stock rations; two, CDDG in breeding stock rations; three, feeding improved hay to the breeding stock; and four, increased number of calves weaned. Profitability of these scenarios were $78.66, $37.81, $30.31, and 47.25 per tonne of GHG reduced, respectively. Also, some of the scenarios found to reduce GHG emissions in Beauchemin et al. (2011) were not economic for producers. One such scenario was the use of CDDG in backgrounding cattle with a loss $582.46 per tonne GHG reduced. Such scenarios would only be adopted if there is policy measures that compensate producers for such losses.

The findings of this study suggest that there are GHGMS that can be sustainably applied to western Canadian beef operations to reduce greenhouse gas emissions. However, it is important to perform profitability analysis at individual farm levels since there is variability in land use, soil type, weather, etc. Furthermore, since prices also have a tendency to vary over time, some sensitivity analysis need to be conducted to make robust recommendations. Similarly, animal productivity and costs of production were assumed constant due to lack of annual data. This sacrificed the dynamic nature of agronomic and economic realities of agricultural production with a risk element. Even though sensitivity analysis showed that there is little impact on results obtained, it is important to have realistic data that producers can associate with and more likely influence their adoption decision. In the future, if such data can be made available it will be a major step to have a model that is dynamic, and which can capture the real changes in prices and costs of the beef industry with time.

Besides the economic factors, there are other factors that affect the adoption of environmental management practices. A study of Canadian farms has pointed to the importance of information availability to be very crucial in adoption of environmental friendly practices (Jayasinghe and Weersink, 2004). A similar study in the US has shown that government involvement in educating farmers about new management practices has a positive influence on adoption of environmental management practices on beef operations (Kim et al., 2005). Diversification of the farm has also been found to be strongly correlated with adoption of environmental management practices in beef (Jayasinghe and Weersink, 2004; Kim et al., 2005). Operations with both livestock and crop production will more likely adopt environmentally friendly management practices as compared to operations that specialize in either crop or livestock production (Jayasinghe and Weersink, 2004; Kim et al., 2005), although Veysset et al. (2014) has suggested that there could be variations in this relationship. Other factors that have a positive influence on the adoption of environmental friendly management practices in beef operations are: large farm size, high household and cattle income, presence of purebred cattle on the farm, and having a family member to take over the farm when the operator retires (Kim et al., 2005). These factors show that the closer the operator is personally attached to the farm, there is more willingness to improve/maintain the farm for a longer period through the adoption of environmental friendly management practices.

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Appendix A

Table A.1
Beef herd costs of production (COP): cow-calf and feedlot.

Cow-calf COP		Feedlot COP	
Feed costs	Cost	Feed costs	Cost
1. Pasture	A[a]	1. Barley grain	C[a]
2. Mixed hay	B[a]	2. Barley silage	D[a]
Other variable costs	$/cow	Other variable costs	$/feeder
3. Bedding	2.04	4. Backgrounding death loss	20.83
5. Veterinary medicine and supplies	15.35	6. Finishing death loss	9.63
7. Fuel, oil and lube	9.33	8. Vet and medicine	21.71
9. Repairs: machinery and building	14.81	10. Interest	14.04
11. Herd replacement @ 15%	158.40	12. Labour (paid and unpaid)	35.56
13. Utilities	11.15	14. Yardage costs (excluding labour)	24.64
15. Marketing and transportation	2.48	16. Marketing	2.00
17. Custom work and specialized labour	5.07		
18. Interest	14.15		
19. Paid labour and benefits	18.09		
20. Breeding costs	25.47		
21. Unpaid labour & benefits	20.81		
Total other variable costs	297.15	128.41	

Sources: AARD (Alberta Agriculture and Rural Development) (2010) and Canfax Research Services (2011).
[a] Indicates the cost of producing animal feed. These were determined within the model for each scenario.

Appendix B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2017.12.008.

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