Available online at www.centmapress.org

Int. J. Food System Dynamics 15 (6), 2024, 591-611

DOI: https://dx.doi.org/10.18461/ijfsd.v15i6N2

INTERNATIONAL JOURNAL ON FOOD SYSTEM DYNAMICS

Rancher adoption and perception of greenhouse gas reducing practices in Canada

Eric T. Micheels

Department of Agricultural and Resource Economics, University of Saskatchewan, Saskatoon
eric.micheels@usask.ca

Received May 2024, accepted September 2024, available online October 2024

ABSTRACT

Canada is home to over 39,000 beef farms and feedlots that are home to over 3.77 million beef cows. Beef cattle have a much larger carbon footprint compared to many other animal protein products. Given this context, it is important to understand producer mindsets regarding ranching practices and how they may help mitigate GHG emissions. Data for this paper was collected from two separate producer surveys that asked ranchers across Canada questions about their specific production practices and attitudes toward greenhouse gas emissions. Using this data, I apply cluster analysis techniques to identify four distinct groups of beef producers who vary on their willingness and ability to invest resources into changing practices to limit the production of greenhouse gasses (Willing and able, generally neutral, willing but unsure, and High Complexity Low Ability). In general, I find that there is a great deal of current adoption of management practices that have been shown to reduce greenhouse gas emissions. However, adoption is predicated on the impact of adoption on firm profitability as many respondents indicated that they would not be willing to change practices if these practices did not improve profitability. Greater adoption could be achieved through increased awareness relating to practices that have positive environmental impacts, particularly as they relate to greenhouse gas reduction and mitigation.

Keywords: *Beef production; greenhouse gas; adoption; cluster analysis; Canada.*

1 Introduction

The production of beef cattle is an important source of greenhouse gas (GHG) emissions, with cattle production (beef and dairy) globally accounting for over 70% of total livestock GHG (Cusack et al., 2021). Along with enteric methane (CH_4) production from the animals, these emissions stem from nitrous oxide (N_2O) from soils, carbon dioxide (CO_2) from feed production, along with nitrous oxide (N_2O) and methane (CH_4) from manure management (Cusack et al., 2021). However, recent studies have challenged the climate accounting relating to CO_2 and CH_4 (Liu et al., 2021), and proposed a new metric to measure GHG from cattle production, and warn that improper accounting of the effect of GHG emissions from livestock may lead to a misallocation of resources in mitigating climate change stemming from livestock production. This has contributed to an already important discussion that highlights it is not just the number of cattle and calves on the planet, but also the methods in which they are raised that affects their contribution to climate issues (Cusworth et al., 2022).

In terms of cattle numbers in Canada, recent data from Statistics Canada reports that there are over 3 million beef cows located on over 54,000 Canadian farms, resulting in an average herd size of 56 head (Statistics Canada, 2021, 2023). Globally, the FAO expects that cattle numbers will increase by two percent by 2030, while productivity for beef is expected to increase by four percent (OECD-FAO, 2022). As the agriculture industry works to meet both the needs of a growing population and a changing climate, productivity gains may be the first choice for meeting both the expected quantity of beef demand and needs of the planet. However, GHG gains through efficiency may be harder to achieve in regions where productivity is at or near the production frontier. In these instances, additional reductions in GHG production may be best achieved through changes in other aspects in the production of livestock, including pasture management (Cusack et al., 2021). In these cases, the amount of GHG production that can be reduced is dependent on the willingness of beef producers to adopt new production practices on their farms and ranches.

Prior work on GHG production in livestock systems has shown that beef has a much larger carbon footprint (as measured in CO_2 eq per kg of production) compared to pork and poultry (Clune et al., 2017; de Vries and de Boer, 2010). A recent study estimated that GHG emissions from all beef cattle produced and marketed in Saskatchewan were 8.52 x 10^9 kg CO_2-eq, and that diets were significant contributors of these GHG emissions (Chen et al., 2020). Other work from Argentina examined how farming systems and managerial decisions contributed to GHG emissions, finding that considerable differences are present if GHG are measured per hectare or per pound of production (Nieto et al., 2018). Therefore, it may follow that good animal husbandry and good land management are both important factors to consider if producers are to reduce GHG emissions on a per pound of production basis, particularly when one considers the carbon opportunity cost of land required for pasture-based or grain-finished beef (Blaustein-Rejto et al., 2023; Hayek et al., 2021).

More work in this area will contribute to our understanding of how producer mindsets may affect the adoption of different GHG mitigation strategies as outlined by Grossi et al. (2019) and Rojas-Downing et al. (2017). As the ability of a country or an industry to meet GHG reduction targets is a result of the aggregation of different mitigation strategies across the population of producers, understanding producer mindsets and how they relate to mitigation approaches is likely key to increasing the rate of adoption of these practices through more effective policy design or producer engagement strategies. This was outlined by Rojas-Downing et al. (2017, p. 157), who stated "it is important to collect information about farmers' perceptions to mitigation and adaptation." It may be, as suggested by the studies of Nieto et al. (2018) and Cusack et al. (2021), that production practices that contribute the most to economic gains are the same ones that align with a reduction in GHG emissions. Policy makers and industry stakeholders can use these findings to develop communication strategies and effective policies to encourage greater adoption of beneficial practices.

Therefore, the purpose of this paper is to explore data collected from a sample of Canadian ranchers on cost of production measures and their attitudes toward GHG mitigation strategies to examine how managerial attitudes are related to openness to adoption of different land management practices. To do so, I use factor analysis and two-stage clustering methods to identify distinct groups of ranchers across Canada who differ on their ability and willingness to change practices related to GHG production within livestock production systems. I find that while there are distinct groups of farmers based on their answers to willingness and ability to engage in greenhouse gas reducing practices, there is a wide degree of adoption of practices that have been shown to reduce greenhouse gasses across these distinct groups.

The remainder of this paper is structured as follows. The next section highlights some of the key literature on GHG production in agriculture, particularly within the livestock industry, while also highlighting recent work in mitigation strategies. The next section describes the data used in the study and the methods employed in our analysis, followed by a discussion of the results. This paper concludes with a section outlining the implications and limitations of this work, while also providing some ideas for next steps.

2 Background literature

2.1 GHG production in Agriculture

Recent research reports state that livestock production, and beef production in particular, is a significant contributor to greenhouse gas production (Bellarby et al., 2013; Cusack et al., 2021; Hayek et al., 2021). Other studies have found that on a per kilogram basis, beef production is a greater contributor to global warming potential than other animal proteins (pork, poultry, dairy) (Clune et al., 2017; de Vries and de Boer, 2010; Humpenöder et al., 2024; Xu et al., 2021). Greenhouse gas production in livestock systems includes both methane, nitrous oxide, and carbon production. Methane is produced and released through biological processes of ruminants as well as manure management, which is also a source of nitrous oxide emissions (Crosson et al., 2011). Cattle are often finished on feedlots, which can also significantly contribute to greenhouse gas production through manure storage and handling (Grossi et al., 2019). In a study of two feedlots in Alberta, Canada, McGinn and Flesch (2018) find that there can be wide variations in methane, nitrous oxide, and carbon emissions per animal per day, which can be attributed to the choice of management practices undertaken on different operations.

While many cattle are finished at the feedlot, cattle production in Canada (and in much of the world) is a largely a pastoral activity, and therefore I need to consider how pasture-based systems both contribute to and mitigate greenhouse gas production through improved pastures and sequestration attributed to undisturbed soils. How these pastures are managed can therefore contribute to economic and environmental performance of these systems. Research by Alemu et al. (2017) finds that while intensive grazing strategies can result in greater beef productivity per ha of land (which may also reduce the carbon footprint per kg of beef), pastures that were less intensively managed had higher levels of carbon sequestration, which subsequently reduced CO_2 production per kg of beef.

2.2 Producer adaptation and mitigation strategies

While the production of livestock is a significant contributor to greenhouse gas production, livestock producers can also mitigate these effects through adoption of production practices that reduce the production of greenhouse gasses or sequester higher levels of emissions. Whether or not these practices are adopted may depend on several factors. Cultural embeddedness has been shown to be one mechanism that may limit adaptation strategies, as farmers may face both structural and cultural barriers to significant change (Burton and Farstad, 2020).

Strategies that may reduce greenhouse gas emissions relate to both herd and pasture management. These strategies can include (but are not limited to) changes in pasture productivity, herd composition and management, feed composition and management, and manure management. Work by Nguyen and colleagues (Nguyen et al., 2013) found that while the adoption of a single approach to mitigating greenhouse gas production may not have large impacts on emission reduction, many of these practices can be adopted in concert, and therefore may result in more significant reductions in emissions. At the same time, research has shown that many of the strategies that can reduce greenhouse gas production per kg of beef produced are the same strategies that producers may consider for increasing production efficiency (Samsonstuen et al., 2020). For example, Samsonstuen et al. (2020) find that in Norwegian production systems, decreasing calf mortality and increasing production efficiency reduced greenhouse gas production intensity for both British and Continental breeds. Results have been similar when looking at mitigation strategies in production systems in western Canada (Beauchemin et al., 2011; Modongo and Kulshreshtha, 2018).

At the same time, it is also important to consider how land use and land use change can influence greenhouse gas emissions in livestock systems. Increases in livestock and pasture productivity through improved management and improved genetics can increase production efficiency in terms of kg of beef produced per ha. Without improvements in productivity in converting forage to kg of beef, greater numbers of animals and greater areas of land would be needed to meet beef demands of a growing population, particularly when facing environmental challenges caused by a changing climate (Terry et al., 2021). While pasture-based systems can preserve perennial grasslands that serve as a carbon sink, cattle take longer to finish in these systems which may lead to more GHG output per kg of beef. Supplementing feed through annual cropping (e.g. corn, barley) can shorten the time to finish these animals, but the carbon opportunity costs required for this type of production may increase the total costs of such systems (Blaustein-Rejto et al., 2023). While land use change is an important consideration in much of the world, within Canada the role a changing climate may have on this pressure may increase SOC sequestration in converted from forests to pastures (Jiang et al., 2023). At the same time, research in Australia has suggested that climate adaptation strategies may lead Australian farmers to increase land allocation from annual crops to pasture, and also increase stocking rates in an effort to balance financial risks. The increase in stocking rates may lead to higher CH_4 emissions through ruminant emissions as well as those attributed to increased animal waste through greater stocking rates (Ghahramani et al., 2020).

3 Data

In 2021, the Beef Cattle Research Council (BCRC) collected data from farmers and ranchers across Canada on a range of topics related to their cost of production. Sample populations were not random but were purposefully drawn to closely match the provincial distribution of farmers and ranchers across Canada (Table 1). As shown in Table 1, the proportion of respondents from western Canada closely matches the proportion of ranches across Canada, according to the 2021 Census of Agriculture, while the number of respondents from Alberta somewhat underrepresents the total number of ranches in Alberta. Cattle producers from the Maritimes and Quebec are somewhat over-represented, and Ontario is underrepresented in this data.

Table 1.
Number of respondents by Canadian Province

Province	Number of respondents	Percent	Farms in 2021 census	Percent
Alberta	19	24.68%	14,601	36.84%
British Columbia	6	7.79%	2,284	5.76%
Manitoba	9	11.69%	3,574	9.02%
Maritimes	8	10.39%	1,139	2.87%
Ontario	8	10.39%	7,986	20.15%
Québec	12	15.58%	2,395	6.04%
Saskatchewan	15	19.48%	7,610	19.20%
Total	77		39,633	

Source: Author and Statistics Canada (2021)

The data I use comes from two surveys sent to respondents, the cost of production practices survey, which focuses on different production practices and producer attitudes toward adoption, and the cost of production related to greenhouse gas emissions survey, which focuses on producer perceptions of greenhouse gas mitigation strategies. Participants were sent both questionnaires. but response rates differed across questionnaires. Consent was implied through the completion of the questionnaires and respondents were informed that they were free to not respond to any question they did not want to answer. The surveys were anonymous, however survey software stored IP address which was then used to link the two datasets. Following dataset linkage, IP address data was destroyed.

In total, 101 producers responded to the GHG emissions, and the COP mindset surveys, and 84 producers responded to the COP practices survey. As these surveys were administered in the respondents preferred language (English or French) the data was translated to English and then merged into one file for each survey. After the merger of the datasets, data from 77 respondents were used in the analysis.

3.1 Cost of Production Practices

The Cost of Production (COP) practices survey asked ranchers to respond to questions relating to production costs and approaches to measuring profitability. In addition, respondents were asked to describe their current approach to marketing their production. In this question, respondents were given a list of options (direct to consumer, preconditioning, auction market, etc.) and were asked if they had c*urrently adopted, previously adopted but no longer practiced, not interested,* or *not able to adopt that practice*. Respondents were also given the option of responding *not sure* to each of the practices listed. The full questionnaire is available in Appendix B.

3.2 Cost of Production Greenhouse Gas Emissions

The Cost of Production Greenhouse Gas Emissions (GHG) survey asked producers to respond to questions relating to their attitudes toward GHG emissions and their level of agreement with farm-level and industry-level responses to this issue. Respondents were asked if reducing GHG emissions should be a priority, and if they have attempted to reduce emissions on their operation. Respondents were then asked about their level of adoption of different practices that have been shown to reduce GHG emissions. These practices included *improving the quality of summer pasture, implementing grazing practices to improve productivity and regrowth, improving herd genetics for feed efficiency*, etc.

Respondents were asked how profitability factors into their decision to reduce emissions, with choices being *I would be willing to reduce profitability to reduce emissions* to *I would not consider changing practices even if it could increase profitability.* Likert scale questions were also included to gather data on the willingness and ability of the respondent to access and allocate financial capital, labour, and equipment to the reduction of GHG emissions, along with the perceived complexity in reducing emissions. The choices here ranged from *strongly agree* to *strongly disagree.* The full questionnaire relating to GHG emissions is available in Appendix C.

4 Methods

Using data collected in question six of the GHG emissions questionnaire, I examine the underlying factor structure of these items as they are inquiring about the producer's ability and intention to reduce GHG emissions on their farm operations.

Using confirmatory factor analysis, three different factors were identified using the items asked in question six of the GHG emissions questionnaire. These factors are GHG ability, GHG willingness, and GHG complexity. The factor GHG ability measures the ability of the respondent to access capital, equipment, and labour to manage GHG emissions, as well as if they believe they have adequate information to reduce GHG emissions on their operation. GHG willingness measures the desire for respondents to actually deploy capital, equipment, labour to reduce GHG emissions, as well as their level of agreement that 1) reducing GHG is a priority, and 2) they believe their farm can make a meaningful contribution to GHG reductions. Finally, GHG complexity measures the perceived difficulty in knowing how to reduce GHG emissions. This scale consists of only two items, namely if the respondent knows how to reduce GHG emissions on their farm and if means to reduce GHG emissions are complex.

For all items, respondents were asked to rate their agreement with the statements on a five-point Likert scale, anchored by strongly agree (coded as 5) and strongly disagree (coded as 1). In Table 2, I show mean scores, standard deviations, and item-to-total correlations for three measurement scales derived from question six of the GHG emissions questionnaire.

Scale reliability measures the degree to which scales are free from error (Kline 2005, 58). For a scale to be reliable, it would need more of the variance to come from differences within the scale than to random error (Micheels and Gow, 2014). One of the most common means to measure the reliability of a scale is to calculate the coefficient alpha (Cronbach, 1951). For research on previously tested scales, a common threshold for alpha is 0.7, and this has been relaxed for newer or more exploratory research (Nunnally, 1978).

Scale validity examines how well measurement items used in the questionnaire measure an underlying factor (Kline, 2005). I use factor analysis to measure construct validity, as this allows us to examine how the individual items relate to a particular factor (Table 2). Goodness of fit statistics for the CFA indicate an acceptable model fit, with the Chi-Squared estimate not-significant and the comparative fit indices (CFI = 0.958; TLI = 0.943) in the acceptable range outlined by Klein (2005). At the same time, scales are shown to be reliable and consistent as item-to-total correlations are at acceptable levels. High correlations between individual items and the scale as a whole show that items are related to the underlying factor. Conversely, low or insignificant factor weights or low item-to-total correlations would indicate there are issues with the measurement of the underlying factor.

5 Results

Following the development of the measurement scales, I use cluster analysis to identify similar groups of respondents within the data. Cluster analysis is a statistical method that attempts to create homogeneous subgroups from heterogeneous data. In essence, the analysis attempts to sort data into the smallest number of groups where the distance between members within a particular group is minimized (groups are similar) while the distance across groups is maximized (groups are distinct).

Within a farming context, cluster analysis has been used in research that examined producer use of meetings and extension (Rosenberg and Turvey, 1991), the characteristics of their livestock systems (Usai et al., 2006), animal husbandry practices (Kiernan and Heinrichs, 1994), as well as the relationship between open-mindedness and experience (Micheels, 2014). Of particular interest with respect to this paper, research has also shown that producer attitudes toward sustainability and animal welfare can also be used to create distinct clusters of farm managers, with subsequent analysis on how cluster membership is related to the rate of adoption of different practices (Luhmann et al., 2016; von Hardenberg and Heise, 2018).

For this study, I use the two-step clustering technique within SPSS 28.0. The input variables I use to determine the clusters are the retained factor scores for the *GHG willingness* scale, the *GHG ability* scale, and the *GHG complexity* scale. Using the two-step clustering approach, four clusters emerge from the data. The results of the cluster analysis can be found in Table 3.

Table 2.
Descriptive statistics and item reliability

Measurement Items	Mean	Std. Deviation	Corrected Item-Total Correlation	N
GHG ability (alpha = 0.735)				
I can access business capital to invest into reducing greenhouse gas emissions.	2.95	0.944	0.578	77
I can access equipment, facilities, and land I think can help reduce greenhouse gas emissions.	3.26	0.938	0.557	77
I can access enough labour to reduce greenhouse gas emissions.	2.86	0.914	0.479	77
I have adequate access to information regarding how to reduce greenhouse gas emissions.	2.78	1.143	0.508	77
GHG willingness (alpha = 0.814)				
I want to make capital investments into reducing greenhouse gas emissions.	3.13	0.908	0.572	77
I want to use my equipment, facilities, and land to reduce greenhouse gas emissions.	3.83	0.801	0.658	77
I want to allocate labour to reduce greenhouse gas emissions.	2.86	0.914	0.553	77
Reducing greenhouse gasses is a priority for me.	3.26	0.938	0.752	77
I believe my operation could meaningfully contribute to reducing greenhouse gas emissions.	3.73	1.008	0.507	77
GHG complexity (alpha = 0.649)				
Reducing greenhouse gas emissions is too complicated.	2.92	0.839	0.481	77
I don't know how to reduce greenhouse gas emissions on my operation(s).	2.92	1.061	0.481	77
Chi Squared Statistic for CFA = 51.69 p = 0.1224; RMSEA = 0.059; CFI = 0.958; TLI = 0.943; SRMR = 0.072				

Further examination of the mean scores for the input variables across the clusters can help us characterize respondents that have been grouped into these clusters. For example, results show that respondents in cluster one have average scores slightly above three (neutral) on both the GHG ability and GHG willingness scales, and on average they disagree that reducing GHG is complicated. Respondents in cluster two have lower scores on both GHG ability and GHG willingness but have higher scores (compared to cluster one) on GHG complexity. Respondents in cluster two may be characterized as being generally neutral to the idea of making investments to reduce GHG emissions on their operation. Respondents in cluster three have similar scores on GHG ability and GHG willingness compared to respondents in cluster one, but they are almost 1.5 points higher on their perception of the complexity involved in reducing GHG emissions. Finally, respondents in cluster four have the lowest scores in GHG ability and GHG willingness and the highest scores on GHG complexity.

Table 3
Mean values of measurement scales across clusters

	Cluster Number			
	1	2	3	4
GHG Ability	3.68	2.56	3.04	1.86
GHG Willingness	3.62	2.92	3.84	2.54
GHG Complexity	2.00	2.98	3.33	4.29
Number	22	25	23	7
Characterization	Willing and able	Generally neutral	Willing but unsure	High complexity Low ability

Following the creation of the clusters, respondent membership within each cluster was recorded. This data was then used to create tables where I could explore how cluster membership is associated with decision-making around actions that may be taken to reduce greenhouse gas emissions.

One component that may limit adoption of different practices is the effect that the resulting change has on firm profitability. There may be differing willingness to adopt new practices depending on the effect that these changes will have on firm performance (Nybom, 2023). For example, farmers who are more profit driven may be unwilling to adopt if the proposed changes lower profitability, while other more community- or mission-oriented farmers may be willing to adopt regardless of how the adoption process affects profits (or at least if they are non-negative). Table 4 shows how profitability may influence reducing greenhouse gas emissions.

Table 4.

Profitability influences on GHG reduction across cluster membership

Cluster Name	I would be willing to reduce profitability to reduce emissions	I would consider changing practices if it also increases profitability	I would consider changing practices only if it does not reduce profitability	I would not consider changing practices even if it could increase profitability	Total
Willing and able	1	5	16	0	22
Generally neutral	0	12	13	0	25
Willing but unsure	2	6	15	0	23
High complexity Low ability	0	4	2	1	7
Total	3	27	46	1	77
c^2 (9, N = 77) = 18.406, p = 0.031, Cramer's V = 0.2823, Fisher's Exact = 0.071					

What I observe from this data is that most of the respondents indicated that they would be willing to change practices if these changes had a non-negative effect on profitability. It is important to note in this data, that it was not a requirement for most of the respondents that these changes have a positive impact on performance. While it is not possible to extrapolate these results to the broader population of Canadian farmers and ranchers, a reasonable starting point for considering adoption would be that implementing these changes will not negatively impact profitability. Results from the Chi-Square test and Fisher's Exact test would indicate that cluster membership is a significant predictor of their response on profitability.

As shown in Table A1 in the appendix, the current rate of adoption across cluster membership is strong for several practices that have been identified as those that reduce greenhouse gas emissions. The analysis shows that a high percentage of respondents within each cluster already adopt practices that improve the quality of summer pasture, implement grazing strategies to improve productivity and regrowth, improve the quality of winter feed, improve feed storage to reduce waste. As such, the results from the Chi-square test and Fisher's exact test are not significant, which means that cluster membership is not a strong predictor of the level of adoption of these practices. Moreover, the second highest response across for all cluster groups is *would consider*. This may be areas where further extension and outreach efforts could make further gains in adoption of these practices, as there does not seem to be much underlying unwillingness to adopt these practices on farms and ranches in Canada.

Data from Table A2 in the appendix was taken from the survey on management practices. Here again the results show high levels of current adoption across cluster membership, with cluster membership only being a significant predictor of adoption for the use of Cover Crops. Both the use of cover crops and crop/pasture mixes show both high levels of current adoption and low levels of unwillingness to adopt for those who have not already adopted these practices. Intercropping has a wider range of responses, which may be attributed to the fact that this innovation is more complex than the other two. The adoption process for intercropping is not the same as one would see for cover crops, so it might be expected to see a wider range of these practices. The second most common answer for the intercropping practice is *Not able to adopt*, which may stem from different investments needed to successfully adopt this innovation.

5.1 Adoption of Manure and Soil Management Practices

The rate of adoption for manure practices that have been shown to reduce greenhouse gas emissions is far lower than that observed for pasture and feed management practices. Table A3 in the appendix shows rates of adoption of different manure management practices. Results here show that for the items *composting manure*, *covering manure storage*, and *faster incorporation of manure into the soil*, there are much lower rates of adoption (compared to pasture management practices). The highest adoption among this set of practices is for composting manure, with a still high percentage currently doing or willing to consider. However, 12 respondents (out of 77) indicated they were unable or unwilling to consider this practice on their farm.

Only three respondents indicated that they have already adopted covered manure storage. Of the 74 remaining respondents, there was a was relatively even distribution between being unable (26) compared to being unwilling (24) to adopt this practice. Interestingly, cluster membership does not seem to have much of a relationship with responses to the question on covered manure storage, as respondents belonging to the "Willing and able" cluster are just as likely to view covered manure storage as a non-starter as a respondent belonging to the "Willing but unsure" cluster.

Of the producers who responded *would consider* to the manure storage and manure incorporation questions, those producers belonging to the "Willing but unsure" cluster were the plurality. Similar to the point above, this may indicate that there may be some areas where further gains in adoption could be achieved if producers could learn more about how these practices can be incorporated into their operation.

As soil disturbance contributes to greenhouse gas emissions, soil management practices that minimize soil disturbance can have positive environmental impacts. Furthermore, soil management practices may include limiting erosion which prevents the degradation of farmland and helps to maintain highly productive soils. As shown in Table A4 in the appendix, most producers across cluster groups have indicated that they currently have adopted a wide array of management practices relating to limiting soil disturbance and building organic matter within the soil. Almost all producers have indicated that they try to mitigate soil erosion and build organic matter. The adoption of zero-tillage has the highest rate of respondents who have indicated that they are not able to adopt this practice. However, as this practice has been widely adopted in Canada, this unwillingness may be due to a limitation caused by soil or climatic characteristics, not a producer unwillingness as the producers who indicated they could not adopt all belong to clusters that are generally favourable to practices that reduce greenhouse gas emissions.

5.2 Adoption of genetic and integrated practices

Table A5 in the appendix shows there to be a great deal of acceptance, either in current practice or a willingness to change practice, to genetic solutions to improve feed efficiency. As feed efficiency has been shown to be a key strategy in reducing greenhouse gas emissions attributed to the livestock sector, this may be a good opportunity for further work in outreach and extension. As many producers already spend considerable time and energy considering how genetic changes to the herd affect other areas of productivity (weaning weights, calving ease, etc.), it may be somewhat straightforward to add feed efficiency into the suite of attributes that producers consider when making decisions regarding sire selection or heifer retention.

Similar patterns emerged when considering the use of extended grazing strategies. However, in this instance cluster membership was shown to be significantly related to the difference in level of adoption. Many producers have indicated that they have already adopted these tools on their operation, and once again the second most rated option was *would consider*.

Table A6 in the appendix shows the rate of adoption of integrated practices across cluster groupings. Once again, most respondents have indicated they have currently adopted these practices. There is greater variability in the adoption of *integrated pest management*, with a significant number of producers indicating that they are unsure of the suitability of this practice to their operation. For example, a greater number of respondents in the "Willing but unsure" cluster stated they are unsure when asked about their current approach to *integrated pest management* on their operation. In this case, it may be that there may be a lack of actionable knowledge for the producer to determine if adopting this practice would provide economic returns that would cover the cost of adoption and implementation.

6 Discussion

In this paper, I used data gathered from producers participating in a broader benchmarking study conducted by the Beef Cattle Research Council on greenhouse gas mitigation strategies along with cluster analysis to examine how adoption of different greenhouse gas mitigation strategies varies across groups of producers. The cluster analysis showed there to be four distinct groups of producers (Willing and Able; Generally Neutral; Willing but Unsure; High Complexity Low Ability). The use of cluster analysis to explore producer sentiment has been done previously, and in general, my results are generally consistent with these earlier findings. For example, Hyland et al. (2016) explored Welsh producer sentiment on sources and impacts of climate change and found there to be distinct groups of producers based on responsibilities of producers as stewards of the environment, the contribution of livestock production to GHG emissions, and the impact of climate change on farming. However, as the clusters created by Hyland et al (2016) were generated based on data from questions regarding attitudes toward climate change and farmer responsibility to respond to these changes, and the questions here focused on producer willingness and ability to make investments in GHG reduction, the clusters across the papers are similar but measure distinct areas of environmental responsiveness.

Barnes et al. (2013) also used cluster analysis to explore perceptions of climate change on agriculture and found there to be three distinct groups (confused moderates, deniers, and risk perceivers). Again, the approach taken here differs slightly from that of Barnes et al. (2013) as the scale used by Barnes et al. (2013) measured the risk associated with a changing climate and not willingness and ability to invest resources in changing practices. For example, the cluster analysis results from Barnes et al. (2013) show there to be three distinct groups (confused moderates, deniers, and risk perceivers). While the work by Barnes et al. (2013) did not explore rates of GHG mitigation strategies across groups of dairy farmers, it could be that Risk Perceivers (those that believe climate change will adversely affect their farm) might be more willing to adopt mitigation strategies than we might expect from Deniers.

The results here showed that there was a proportion of the sample who would not adopt GHG mitigation strategies if they did not have a positive impact on farm performance (Table 4), but also there were some producers (Willing but Unsure, High Complexity Low Ability) who would consider adopting a number of practices if there was more confidence around how these practices would be implemented on their farm (improve quality of winter feed; improve feed storage; improve herd genetics for feed efficiency; composting manure; manure storage). This finding aligns somewhat with the work by Kipling et al. (2019) who found that among Welsh farmers, barriers to greater levels of adoption of GHG mitigation practices include practical limitations, knowledge limitations, and cognitive limitations, along with interests. For example, Kipling et al. (2019) note that knowledge limitations relate to the awareness among farmers of the benefits of a particular mitigation strategy or if the strategy will be economical in the long run. Additionally, cognitive limitations may limit a farmer's ability to tease out the different interactions within the farming system which makes it difficult to attribute any changes in benefits to a change in a particular practice.

For example, in this sample of beef producers in Canada, one might consider that if there was less uncertainty of how to improve genetics to focus on feed efficiency (as opposed to other beef attributes that generate revenue or reduce costs), there would be higher levels of adoption as farms might move from 'would consider' to 'currently adopted' as uncertainty is removed. The goal of policy makers and stakeholders who are interested in increasing adoption of GHG mitigation strategies beyond what are already observed should therefore be to develop improved methods of increasing awareness and knowledge of mitigation strategies while also reducing uncertainty surrounding the implementation of these strategies.

The idea of producer interest was also raised by Kipling et al. (2019), and this aligns with earlier work by Chen (1996) on adoption of strategic practices. One might suggest that for firms seeking to maximize profits or to maintain a rural lifestyle through farming, there is a motivation to increase revenues and reduce costs as these activities would be beneficial for both goals. It may be that implementing GHG mitigation strategies can increase profits for firms who adopt them, which would be a strong motivator to increase awareness of these practices and to invest time in developing implementation strategies to ensure that these practices have the intended effect on farm profit. For example, work by Modongo and Kulshreshtha (2018) found that within a simulation of an Alberta farm, adoption of different scenarios to reduce GHG emissions had a positive impact on farm profitability.

7 Conclusions

In this paper, I used data from two surveys of Canadian cattle producers to examine producer attitudes toward the adoption of practices that can reduce greenhouse gas emissions related to the production of beef cattle. Using a cluster analysis, I find four distinct groups of producers based on their willingness and ability to make changes relating to greenhouse gas reduction. However, I also find that there is a great deal of current adoption of management practices that have been shown to reduce greenhouse gas emissions. However, respondents also indicated that they would not be willing to change practices if these practices did not improve profitability. In addition, there is room for improvement in increasing awareness on practices that could have positive environmental impacts, particularly as they relate to greenhouse gas reduction and mitigation.

In general, the results presented here show that among these respondents, there is a great deal of adoption of practices that have been shown to have positive environmental impacts. While the nature of the surveys does not enable us to know exactly which practices were adopted, the results presented above do show that for certain practice, there is greater rates of adoption across regardless of cluster membership (e.g. utilizing extended grazing). For other practices (improved genetics for feed efficiency) it may be that cluster membership is a strong predictor of level of adoption. Further inspection of the practices with high rates of *Doing* and *Would Consider* reveal that these are the practices which are more likely to have clearer economic returns to adoption (other than reduced GHG emissions). Conversely, where the economic returns are less clear, we might see more variability in adoption and willingness to consider adopting the practice.

Given that many respondents would change practices as long as income was not reduced, there is a path forward for policy makers and other stakeholder to increase adoption of other practices that might reduce GHG emissions that do not also have a clear effect on ranch profitability. In these cases, it might be possible to increase adoption through costshare arrangements or other policy frameworks that provide a wider benefit to society while not placing the full cost of adoption and implementation on the ranch, particularly when public benefits may outweigh the private benefit.

However, given the nature of the sample, I cannot be certain that the sample is representative of the broader population of Canadian livestock producers. It may be that given the nature of the topic, only respondents who were interested in GHG emissions participated in the study. Still, given that the responses came from participants in the Canfax Cost of Production network, I can assume that these data do reflect commercial-scale production practices in their geographic region, and therefore their responses are informative, if not representative.

While this is only an exploratory look at survey data, there are still some limitations to consider. First, the sample used to collect data was not representative and therefore may not accurately reflect the true population of Canadian cattle producers. Moreover, as the survey did not ask about demographic data, I was unable to explore the influence that size, experience, and producer age have on willingness and ability to reduce GHG emissions, or how these demographic variables influence adoption of individual practices.

Future research in this area may examine how sources of information relating to production practices that reduce greenhouse gas production are perceived by producers, as it may be that different sources of information are seen as more trustworthy and therefore have greater influence over future adoption decisions.

References

Alemu, A. W., Janzen, H., Little, S., Hao, X., Thompson, D. J., Baron, V., Iwaasa, A., Beauchemin, K. A., and Kröbel, R. (2017). Assessment of grazing management on farm greenhouse gas intensity of beef production systems in the Canadian Prairies using life cycle assessment. *Agricultural Systems*, **158**: 1-13. https://doi.org/10.1016/j.agsy.2017.08.003

Barnes, A. P., Islam, M. M., and Toma, L. (2013). Heterogeneity in climate change risk perception amongst dairy farmers: A latent class clustering analysis. *Applied Geography*, **41**: 105–115. https://doi.org/10.1016/j.apgeog.2013.03.011

Beauchemin, K. A., Janzen, H. H., Little, S. M., McAllister, T. A., and McGinn, S. M. (2011). Mitigation of greenhouse gas emissions from beef production in western Canada - Evaluation using farm-based life cycle assessment. *Animal Feed Science and Technology*, **166–167**: 663-667. https://doi.org/10.1016/j.anifeedsci.2011.04.047

Bellarby, J., Tirado, R., Leip, A., Weiss, F., Lesschen, J. P., and Smith, P. (2013). Livestock greenhouse gas emissions and mitigation potential in Europe. *Global Change Biology,* **19**(1): 3-18. https://doi.org/10.1111/j.1365-2486.2012.02786.x

Blaustein-Rejto, D., Soltis, N., and Blomqvist, L. (2023). Carbon opportunity cost increases carbon footprint advantage of grain-finished beef. *PLoS ONE*, December 13. https://doi.org/10.1371/journal.pone.0295035

Burton, R. J. F., and Farstad, M. (2020). Cultural Lock-in and Mitigating Greenhouse Gas Emissions: The Case of Dairy/Beef Farmers in Norway. *Sociologia Ruralis*, **60**(1): 20-39. https://doi.org/10.1111/soru.12277

Chen, M.-J. (1996). Competitor Analysis and Interfirm Rivalry: Toward a Theoretical Integration. *The Academy of Management Review*, **21**(1): 100–134.

Chen, Z., An, C., Fang, H., Zhang, Y., Zhou, Z., Zhou, Y., and Zhao, S. (2020). Assessment of regional greenhouse gas emission from beef cattle production: A case study of Saskatchewan in Canada. *Journal of Environmental Management*, **264**: 110443. https://doi.org/10.1016/j.jenvman.2020.110443

Clune, S., Crossin, E., and Verghese, K. (2017). Systematic review of greenhouse gas emissions for different fresh food categories. *Journal of Cleaner Production*, **140**: 766-783. https://doi.org/10.1016/j.jclepro.2016.04.082

Cronbach, L. J. (1951). Coefficient Alpha and the Internal Structure of Tests. *Psychometrica*, **16**(3): 297-334.

Crosson, P., Shalloo, L., O'Brien, D., Lanigan, G. J., Foley, P. A., Boland, T. M., and Kenny, D. A. (2011). A review of whole farm systems models of greenhouse gas emissions from beef and dairy cattle production systems. *Animal Feed Science and Technology*, **166–167**: 29-45. https://doi.org/10.1016/j.anifeedsci.2011.04.001

Cusack, D. F., Kazanski, C. E., Hedgpeth, A., Chow, K., Cordeiro, A. L., Karpman, J., and Ryals, R. (2021). Reducing climate impacts of beef production: A synthesis of life cycle assessments across management systems and global regions. *Global Change Biology*, **27**(9): 1721–1736. https://doi.org/10.1111/gcb.15509

Cusworth, G., Lorimer, J., Brice, J., and Garnett, T. (2022). Green rebranding: Regenerative agriculture, future-pasts, and the naturalisation of livestock. *Transactions of the Institute of British Geographers*, **47**(4): 1009-1027. https://doi.org/10.1111/tran.12555 de Vries, M., and de Boer, I. J. M. (2010). Comparing environmental impacts for livestock products: A review of life cycle assessments. *Livestock Science*, **128**(1–3): 1–11. https://doi.org/10.1016/j.livsci.2009.11.007

Ghahramani, A., Kingwell, R. S., and Maraseni, T. N. (2020). Land use change in Australian mixed crop-livestock systems as a transformative climate change adaptation. *Agricultural Systems*, **180**: 102791. https://doi.org/10.1016/j.agsy.2020.102791

Grossi, G., Goglio, P., Vitali, A., and Williams, A. G. (2019). Livestock and climate change: Impact of livestock on climate and mitigation strategies. *Animal Frontiers*, **9**(1): 69-76. https://doi.org/10.1093/af/vfy034

Hayek, M. N., Harwatt, H., Ripple, W. J., and Mueller, N. D. (2021). The carbon opportunity cost of animal-sourced food production on land. *Nature Sustainability*, **4**(1): 21-24. https://doi.org/10.1038/s41893-020-00603-4

Humpenöder, F., Popp, A., Merfort, L., Luderer, G., Weindl, I., Leon Bodirsky, B., Stevanović, M., Klein, D., Rodrigues, R., Bauer, N., Philipp Dietrich, J., Lotze-Campen, H., and Rockström, J. (2024). Food matters: Dietary shifts increase the feasibility of 1.5°C pathways in line with the Paris Agreement. In *Science Advances,* **10**(13). https://www.science.org

Hyland, J. J., Jones, D. L., Parkhill, K. A., Barnes, A. P., and Williams, A. P. (2016). Farmers' perceptions of climate change: identifying types. *Agriculture and Human Values*, **33**(2): 323–339. https://doi.org/10.1007/s10460-015-9608-9

Jiang, R., Jayasundara, S., Grant, B. B., Smith, W. N., Qian, B., Gillespie, A., and Wagner-Riddle, C. (2023). Impacts of land use conversions on soil organic carbon in a warming-induced agricultural frontier in Northern Ontario, Canada under historical and future climate. *Journal of Cleaner Production*, **404**: 136902. https://doi.org/10.1016/j.jclepro.2023.136902

Kiernan, N. E., and Heinrichs, A. J. (1994). Identification of farm manager types through cluster analysis of calf and heifer management practices. *Preventive Veterinary Medicine*, **18**(3): 225–236. https://doi.org/10.1016/0167-5877(94)90078-7

Kipling, R. P., Taft, H. E., Chadwick, D. R., Styles, D., and Moorby, J. (2019). Challenges to implementing greenhouse gas mitigation measures in livestock agriculture: A conceptual framework for policymakers. *Environmental Science and Policy*, **92**: 107–115. https://doi.org/10.1016/j.envsci.2018.11.013

Kline, R. B. (2005). *Principles and Practice of Structural Equation Modeling* (Second Edi). The Guilford Press.

Liu, S., Proudman, J., and Mitloehner, F. M. (2021). Rethinking methane from animal agriculture. *CABI Agriculture and Bioscience*, **2**(22). https://doi.org/10.1186/s43170-021-00041-y

Luhmann, H., Schaper, C., and Theuvsen, L. (2016). Future-oriented dairy farmers' willingness to participate in a sustainability standard: Evidence from an empirical study in Germany. *International Journal on Food System Dynamics*, **7**(3): 243–257. https://doi.org/10.18461/ijfsd.v7i3.735

McGinn, S. M. and Flesch, T. K. (2018). Ammonia and greenhouse gas emissions at beef cattle feedlots in Alberta Canada. *Agricultural and Forest Meteorology*, **258**: 43-49. https://doi.org/10.1016/j.agrformet.2018.01.024

Micheels, E. T. (2014). Experience and learning in beef production: results from a cluster analysis. *International Journal of Agricultural Management*, **3**(3): 154–163. https://doi.org/10.5836/ijam/2014-03-04

Micheels, E. T., and Gow, H. R. (2014). The effect of market orientation on learning, innovativeness, and performance in primary agriculture. *Canadian Journal of Agricultural Economics,* **63**/2): 209-233. https://doi.org/10.1111/cjag.12047

Modongo, O., and Kulshreshtha, S. N. (2018). Economics of mitigating greenhouse gas emissions from beef production in western Canada. *Agricultural Systems*, **162**: 229–238. https://doi.org/10.1016/j.agsy.2017.12.008

Nguyen, T. T. H., Doreau, M., Eugène, M., Corson, M. S., Garcia-Launay, F., Chesneau, G., and Van Der Werf, H. M. G. (2013). Effect of farming practices for greenhouse gas mitigation and subsequent alternative land use on environmental impacts of beef cattle production systems. *Animal*, **7**(5): 860-869. https://doi.org/10.1017/S1751731112002200

Nieto, M. I., Barrantes, O., Privitello, L., and Reiné, R. (2018). Greenhouse gas emissions from beef grazing systems in semi-arid rangelands of central Argentina. *Sustainability (Switzerland)*, **10**(11): 4228. https://doi.org/10.3390/su10114228

Nunnally, J. C. (1978). *Psychometric theory*. McGraw-Hill.

Nybom, J. (2023). *Quantifying internal and external influences on Swedish farmers' strategic choices and performance outcomes. Doctoral thesis, Vol. 2023:52*. Swedish University of Agricultural Sciences. https://doi.org/10.54612/a.3ll97ltqev

OECD-FAO. (2022). *6. Meat | OECD-FAO Agricultural Outlook 2021-2030 | OECD iLibrary*. OECCD -FAO Agricultural Outlook 2021-2030.

Rojas-Downing, M. M., Nejadhashemi, A. P., Harrigan, T., and Woznicki, S. A. (2017). Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management,* **16**: 145-163. https://doi.org/10.1016/j.crm.2017.02.001

Rosenberg, A., and Turvey, C. G. (1991). Identifying Management Profiles of Ontario Swine Producers Through Cluster Analysis. *Applied Economic Perspectives and Policy*, **13**(2): 201–213. https://doi.org/10.2307/1349637

Samsonstuen, S., Åby, B. A., Crosson, P., Beauchemin, K. A., and Aass, L. (2020). Mitigation of greenhouse gas emissions from beef cattle production systems. *Acta Agriculturae Scandinavica A: Animal Sciences*, **69**(4): 220-232. https://doi.org/10.1080/09064702.2020.1806349

Statistics Canada. (2021). *Table 32-10-0231-01, Farms classified by farm type*. Census of Agriculture.

Statistics Canada. (2023, August 23). *Number of cattle, by class and farm type (x 1,000)*. 32-10-0130-01 (Formerly CANSIM 003-0032). https://doi.org/10.25318/3210013001-eng

Terry, S. A., Basarab, J. A., Guan, L. L., and McAllister, T. A. (2021). Strategies to improve the efficiency of beef cattle production. *Canadian Journal of Animal Science*, **101**(1). https://doi.org/10.1139/cjas-2020-0022

Usai, M. G., Casu, S., Molle, G., Decandia, M., Ligios, S., and Carta, A. (2006). Using cluster analysis to characterize the goat farming system in Sardinia. *Livestock Science*, **104**(1–2): 63–76. https://doi.org/10.1016/j.livsci.2006.03.013

von Hardenberg, L., and Heise, H. (2018). German pig farmers' attitudes towards animal welfare programs and their willingness to participate in these programs: An empirical study. *International Journal on Food System Dynamics*, **9**(3): 289–301. https://doi.org/10.18461/ijfsd.v9i3.937

Xu, X., Sharma, P., Shu, S., Lin, T. S., Ciais, P., Tubiello, F. N., Smith, P., Campbell, N., and Jain, A. K. (2021). Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods. *Nature Food*, **2**(9): 724-732. https://doi.org/10.1038/s43016-021-00358-x

Appendix A

Table A1.
Adoption of pasture and feed practices that reduce greenhouse gas emissions

	Doing	*Not able*	*Not sure*	*Not willing*	*Would Consider*	*Total*
Cluster Name	**Improving quality of summer pasture**					
Willing and Able	19	0	0	0	3	22
Generally neutral	15	2	0	0	8	25
Willing but unsure	19	0	0	0	4	23
High complexity Low ability	4	0	0	0	3	7
Total	57	2	0	0	18	77
	Implementing grazing strategies to improve productivity and regrowth					
Willing and Able	19	0	0	1	2	22
Generally neutral	17	1	0	0	7	25
Willing but unsure	19	0	0	0	4	23
High complexity Low ability	4	0	0	0	3	7
Total	59	1	0	1	16	77
	Improving quality of winter feed					
Willing and Able	18	1	0	1	2	22
Generally neutral	20	1	1	0	3	25
Willing but unsure	12	0	1	0	10	23
High complexity Low ability	3	0	0	1	3	7
Total	53	2	2	2	18	77
	Improving feed storage to reduce waste					
Willing and Able	15	1	0	2	4	22
Generally neutral	16	0	0	1	8	25
Willing but unsure	15	1	0	0	7	23
High complexity Low ability	6	0	0	0	1	7
Total	52	2	0	3	20	77

Imp Summer Pasture: c^2 *(6, N = 77) = 8.9521, p = 0.176, Cramer's V = 0.2411, Fisher's Exact = 0.174*
Grazing Strategies: c^2 *(9, N = 77) = 9.3921, p = 0.402, Cramer's V = 0.2016, Fisher's Exact = 0.235*
Imp Qual Winter Feed: c^2 *(12, N = 77) = 18.776, p = 0.094, Cramer's V = 0.2851, Fisher's Exact = 0.020*
Imp Feed Storage: c^2 *(9, N = 77) = 5.934, p = 0.747, Cramer's V = 0.1603, Fisher's Exact = 0.799*

Table A2.
Adoption of cropping related management practices

	Currently adopted	*Not able to adopt*	*Not interested*	*Not sure*	*Previously adopted but no longer practiced*	*Total*
Cluster Name	**Cover Crops (e.g. multiple species grown for grazing purposes)**					
Willing and able	13	5	0	4	0	22
Generally neutral	13	3	4	4	1	25
Willing but unsure	16	1	0	6	0	23
High complexity Low ability	2	0	3	1	1	7
Total	44	9	7	15	2	77
	Crop/pasture mixes					
Willing and able	16	4	1	1	0	22
Generally neutral	19	1	2	3	0	25
Willing but unsure	12	2	1	6	2	23
High complexity Low ability	5	0	1	1	0	7
Total	52	7	5	11	2	77
	Intercroppings, polycultures (e.g. multiple species grown for combine), crop rotation incorporating cover crops.					
Willing and able	8	6	3	5	0	22
Generally neutral	10	5	4	6	0	25
Willing but unsure	7	6	4	4	2	23
High complexity Low ability	2	2	2	1	0	7
Total	27	19	13	16	2	77

Cover Crops: c^2 (12, N = 77) = 25.935, p = 0.011, Cramer's V = 0.3351, Fisher's Exact = 0.018
Crop Pasture Mix: c^2 (12, N = 77) = 14.049, p = 0.298, Cramer's V = 0.2466, Fisher's Exact = 0.327
Intercropping: c^2 (12, N = 77) =6.601, p = 0.883, Cramer's V = 0.1690, Fisher's Exact = 0.970

Table A3.
Adoption of manure management practices that reduce greenhouse gas emissions

	Doing	*Not able*	*Not sure*	*Not willing*	*Would Consider*	*Total*
Cluster Name	**Composting manure**					
Willing and Able	10	2	2	3	5	22
Generally neutral	12	3	1	1	8	25
Willing but unsure	12	0	2	0	9	23
High complexity Low ability	2	1	0	2	2	7
Total	36	6	5	6	24	77
	Covering manure storage					
Willing and Able	0	8	5	7	2	22
Generally neutral	3	6	4	9	3	25
Willing but unsure	0	7	4	4	8	23
High complexity Low ability	0	5	0	1	1	7
Total	3	26	13	21	14	77
	Faster incorporation of manure into the soil					
Willing and Able	4	7	2	6	3	22
Generally neutral	11	6	2	0	6	25
Willing but unsure	9	2	2	1	9	23
High complexity Low ability	1	1	1	1	3	7
Total	25	16	7	8	21	77

Composting Manure: c^2 (12, N = 77) = 12.625, p = 0.397, Cramer's V = 0.2338, Fisher's Exact = 0.359
Cover Manure Storage: c^2 (12, N = 77) = 18.840, p = 0.092, Cramer's V = 0.2856, Fisher's Exact = 0.186
Faster Manure Incorp: c^2 (12, N = 77) =19.803, p = 0.071, Cramer's V = 0.2928, Fisher's Exact = 0.046

Table A4.
Adoption of soil related management practices

	Currently adopted	*Not able to adopt*	*Not interested*	*Not sure*	*Previously adopted but no longer practiced*	*Total*
Cluster Name	**Soil erosion mitigation**					
Willing and able	18	0	1	3	0	22
Generally neutral	21	1	2	1	0	25
Willing but unsure	22	1	0	0	0	23
High complexity Low ability	5	0	0	1	1	7
Total	66	2	3	5	1	77
	Build soil organic matter, enhance soil biodiversity, and generate new topsoil					
Willing and able	22	0	0	0	0	22
Generally neutral	24	0	1	0	0	25
Willing but unsure	22	0	0	1	0	23
High complexity Low ability	6	0	0	0	1	7
Total	74	0	1	1	1	77
	Limits soil disturbance, maintain soil cover, keep living roots in the ground and active as much of the year as possible.					
Willing and able	19	1	0	1	1	22
Generally neutral	18	3	1	3	0	25
Willing but unsure	21	0	0	1	1	23
High complexity Low ability	4	1	0	1	1	7
Total	62	5	1	6	3	77
	No-tillage					
Willing and able	15	5	0	1	1	22
Generally neutral	19	4	2	0	0	25
Willing but complicated	11	3	2	4	3	23
High complexity Low ability	3	0	1	1	4	7
Total	48	13	4	6	6	77

Soil Erosion Mitigation: c^2 (12, N = 77) = 18.083, p = 0.113, Cramer's V = 0.2798, Fisher's Exact = 0.160
Build Soil OM: c^2 (9, N = 77) = 14.542, p = 0.104, Cramer's V = 0.2509, Fisher's Exact = 0.223
Limit Soil Disturbance: c^2 (12, N = 77) =11.194, p = 0.512, Cramer's V = 0.2201, Fisher's Exact = 0.268
No-Tillage: c^2 (12, N = 77) = 18.664, p = 0.097, Cramer's V = 0.2842, Fisher's Exact = 0.050

Table A5.
Adoption of genetic and grazing strategies that reduce greenhouse gas emissions

	Doing	*Not able*	*Not sure*	*Not willing*	*Would Consider*	*Total*
Cluster Name	**Utilizing extended grazing strategies to reduce use of fossil fuels**					
Willing and able	16	0	0	1	5	22
Generally neutral	14	1	1	0	9	25
Willing but unsure	16	0	1	0	6	23
High complexity Low ability	4	2	0	1	0	7
Total	50	3	2	2	20	77
	Improving herd genetics for feed efficiency					
Willing and able	9	0	0	0	13	22
Generally neutral	15	0	2	0	8	25
Willing but unsure	14	0	0	0	9	23
High complexity Low ability	1	0	0	0	6	7
Total	39	0	2	0	36	77

Ext Grazing: c^2 (12, N = 77) = 22.687, p = 0.031, Cramer's V = 0.3134, Fisher's Exact = 0.065
Herd Genetics: c^2 (6, N = 77) = 11.744, p = 0.068, Cramer's V = 0.2762, Fisher's Exact = 0.062

Table A6.
Adoption of integrated management practices

	Currently adopted	***Not able to adopt***	***Not interested***	***Not sure***	***Previously adopted but no longer practiced***	***Total***
Cluster Name	**Integrated crop/livestock production**					
Willing and able	12	5	2	3	0	22
Generally neutral	18	2	1	3	1	25
Willing but unsure	13	2	1	4	3	23
High complexity Low ability	6	0	0	0	1	7
Total	49	9	4	10	5	77
Cluster Name	**Integrated pest management**					
Willing and able	9	3	1	8	1	22
Generally neutral	12	2	2	9	0	25
Willing but unsure	8	3	1	11	0	23
High complexity Low ability	2	1	1	2	1	7
Total	31	9	5	30	2	77

Int Crop/Livestock: c^2 (12, N = 77) = 11.086, p = 0.522, Cramer's V = 0.2191, Fisher's Exact = 0.607
IPM: c^2 (12, N = 77) = 8.258, p = 0.765, Cramer's V = 0.1891, Fisher's Exact = 0.809

Appendix B: Cost of Production Practices Survey

This brief survey should take about 5 minutes to complete. It is designed to identify similarities and differences among producer practices within in production systems. Please do not hesitate to ask you coordinator for clarification at any time.

1. Do you consistently aim to optimize profits?
    a. Yes
    b. No
    c. If no, why not? __________________________________
2. How do you typically measure profitability?
    a. I do not typically measure profitability.
    b. Return on investment.
    c. Gross margin.
    d. Return on assets.
    e. Net margin.
    f. Net revenue.
    g. Other (please specify) ________________________________

3. Do you retain enterprises/activities (e.g. forage production) that are unprofitable?
    a. Yes, they have longer profit cycles that balance out other enterprises.
    b. Yes, critical inputs are retained and used in other enterprises.
    c. No, resources are reallocated elsewhere.
    d. Other (please specify) __________________________________
4. How do you typically address problems (e.g. repeatable or persistent irritants) on your farm/ranch?
    a. Deliberation.
    b. Revise numbers to satisfy someone.
    c. Increased productivity.
    d. Sacrifice (choose to go without).
    e. Money.
    f. Avoidance.
    g. Put in more hours.
    h. Trade-offs.
    i. Diversify.
    j. Services from outside farm advisors.
    k. Variable based on the problem.
    l. None of the above.
5. Please rank the order of importance in which the following statements apply to your operation. One is the most important and 10 is the least important.
    a. Focus on low winterfeeding costs.
    b. Focus on reducing the number of winter feeding days.
    c. Focus on low levels of investment in machinery and buildings.
    d. Have larger herd size to capture economies of scale.
    e. Have high weaning percentages.
    f. Have robust herd health and nutrition.
    g. Have a robust bull management program.
    h. Focus on grass management.
    i. Focus on grazing period to avoid overgrazing, suitable rest periods, appropriate stock density and preserve soil cover.
    j. Focus on weaning weight.

6. Please describe your current approach to the following marketing practices on your operation. *[Respondents chose among the following for each listed practice: Currently adopted, Not interested, Not able to adopt, Previously adopted but no longer practiced, Not sure]*
    a. Use of cost of production in developing marketing strategy.
    b. Direct to consumer.
    c. Reviewing price reports published or by phone.
    d. Preconditioning.
    e. Marketing uniform truckloads of cattle.
    f. Auction market.
    g. Satellite/video/electronic auctions.

   h. Reputation sale (i.e. advertised farm name).
   i. Private treaty.
   j. Retained ownership.
   k. Branded beef/certification programs.
7. Please describe you current approach to the following practices on your operation. *[Respondents chose among the following for each listed practice: Currently adopted, Not interested, Not able to adopt, Previously adopted but no longer practiced, Not sure]*
   a. Electronic records.
   b. Cover crops (e.g. multiple species grown for grazing purposes).
   c. Crop/pasture mixtures.
   d. Intercroppings, polycultures (e.g. multiple species grown for combine), crop rotation incorporating cover crops.
   e. Soil erosion mitigation.
   f. Build soil organic matter, enhance soil biodiversity, an degenerate new topsoil.
   g. Limits soil disturbance, maintain soil cover, keep living roots in the ground and active as much of the year as possible.
   h. Earn additional income from ecosystem services (e.g. carbon sequestration, pollination, etc.).
   i. No-tillage.
   j. Integrated crop/livestock production.
   k. Integrated pest management.
8. Please once again indicate your province/region of residence so that we can keep production systems organized.
   a. Maritimes
   b. Quebec
   c. Ontario
   d. Manitoba
   e. Saskatchewan
   f. Alberta
   g. British Columbia

Appendix C: Greenhouse Gas Emissions Survey

This brief survey should take about 5 minutes to complete. It is designed to identify similarities and differences among producer practices within production systems. Please do not hesitate to ask your coordinator for clarification at any time.

1. Should reducing greenhouse gas emissions be a priority for the beef industry?
   a. Yes
   b. No

2. Regarding your response to question 1 above, why, or why not?

3. Have you attempted to reduce greenhouse gas emissions on your operation?
   a. No, I am not aware of how to reduce emissions on my farm.
   b. No, I am aware of changes I could make but do not have a reason to do so.
   c. No, I am aware of changes I want to make but I am unable to make them.
   d. Yes, I have a clear goal and a plan in action to reduce emissions on my farm.
   e. Yes, I have done so in the past but emissions reduction is not currently a priority.

4. The following practice changes have been shown to reduce greenhouse gas emissions. Please select the ONE best option to describe each practice on your operation. *[Respondents chose among the following for each practice: Doing, Would consider, Not willing, Not able, Not sure]*
   a. Improving quality of summer pasture.
   b. Implementing grazing strategies to improve productivity and regrowth.
   c. Improving the quality of winter feed.
   d. Improving feed storage to reduce waste.
   e. Composting manure.
   f. Covering manure storage.
   g. Faster incorporation of manure into the soil.
   h. Improving herd genetics for feed efficiency.
   i. Utilizing extended grazing strategies to reduce use of fossil fuels.

5. How might profitability factor into your decision about reducing greenhouse gas emissions?
   a. I would be willing to reduce profitability to reduce emissions.
   b. I would consider changing practices only if it does not reduce profitability.
   c. I would only consider changing practices if it also increases profitability.
   d. I would not consider changing practices even if it could increase profitability.
   e. None of the above.

6. Do you agree or disagree with the following statements? *[Respondents were asked to choose among the following options: Strongly agree, Agree, Neutral, Disagree, Strongly disagree]*
   a. I can access business capital to invest into reducing greenhouse gas emissions.
   b. I want to make capital investments into reducing greenhouse gas emissions.
   c. I can access equipment, facilities and land I think can help reduce greenhouse gas emissions.
   d. I want to use my equipment, facilities and land to reduce greenhouse gas emissions.
   e. I can access enough labour to reduce greenhouse gas emissions.
   f. I want to allocate labour to reduce greenhouse gas emissions.
   g. I have adequate access to information regarding how to reduce greenhouse gas emissions.
   h. Reducing greenhouse gas emissions is too complicated.
   i. I don’t know how to reduce greenhouse gas emissions on my operation(s).
   j. I believe reducing greenhouse gas emissions improves the industry image.
   k. Reducing greenhouse gas emissions is a priority for me.
   l. I believe reducing greenhouse gas emissions will negatively affect my profits and/or productivity.
   m. I believe my operation could meaningfully contribute to reducing greenhouse gas emissions.
7. Do you currently receive grants and/or funding for greenhouse gas emissions?
   a. Yes.
   b. No.

8. In your estimation, how much of your greenhouse gas reduction goals are covered by monies from grants/funds that you receive? *[Respondents used a slider to choose a percentage between 0% and 100%]*

9. One last time, again, to enhance production system record keeping, please enter your Province/region of residence.
    a. Maritimes
    b. Quebec
    c. Ontario
    d. Manitoba
    e. Saskatchewan
    f. Alberta
    g. British Columbia

10. If public funding money was provided, would your operation use it to try new best management practices to reduce greenhouse gas emissions?
    a. Yes.
    b. No.
    c. Not sure.