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Producer Perspectives on Barriers to the Adoption of Regenerative Agriculture on the Canadian Prairies

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Table 2
Key Knowledge Gaps that Create Barriers to Prairie Producer Adoption of BMPs

List of Acronyms

4R	4R Nutrient Stewardship (Right Source, Right Rate, Right Time, Right Place)
AB	Alberta
AFSC	Agricultural Financial Services Corporation
ALUS	Alternative Land Use Services
AMP	Adaptive Multi-Paddock Grazing
B.C.	British Columbia
BMO	Bank of Montreal
BMP	Beneficial Management Practice
CANZA	Canadian Alliance for Net-Zero Agri-Food
CBA	Cost-Benefit Analysis
CCA	Certified Crop Advisor
CO_2	Carbon Dioxide
EEF	Enhanced Efficiency Fertilizer
ESMC	Ecosystem Services Market Consortium
FaRM	Farm Resilience Mentorship Program
FCC	Farm Credit Canada
FWWF	Food Water Wellness Foundation
GHG	Greenhouse Gas
GHGE	Greenhouse Gas Emissions
GIS	Geographic Information System
IPM	Integrated Pest Management
MB	Manitoba
MRV	Measurement, Reporting, and Verification
N_2O	Nitrous Oxide
NCS	Natural Climate Solutions
NGO	Non-Governmental Organization
NU	Nature United
OFCAF	On-Farm Climate Action Fund
PAg	Professional Agrologist
PAHs	Polycyclic Aromatic Hydrocarbons
PCAB	Provincial Council of Agriculture Development & Diversification Boards for Saskatchewan
PLO	Producer-Led Organization
RALL	Regenerative Alberta Living Lab
RDAR	Results Driven Agricultural Research
ROI	Return On Investment
SCIC	Saskatchewan Crop Insurance Corporation
SK	Saskatchewan
TA	Trusted Advisor
TAP	Trusted Advisor Partnership
U.S.	United States
U.K.	United Kingdom

Executive Summary

There are significant knowledge gaps in Canadian Prairie producers' perspectives of barriers to individual Beneficial Management Practices (BMPs) and to regenerative agriculture as a whole. Producer engagement facilitated by the Food Water Wellness Foundation (FWWF) has given Prairie producers opportunities to share the specific challenges and barriers they have encountered in their efforts to adopt regenerative agriculture. Clearly identifying and understanding producers' perspectives on these barriers is essential to appropriately addressing barriers and increasing the adoption of regenerative agriculture in the Canadian Prairies.

This report aims to identify key barriers to the adoption of regenerative agriculture from the perspectives of agricultural producers from the three Prairie provinces of Canada: Alberta (AB), Saskatchewan (SK), and Manitoba (MB). Detailed, descriptive Prairie producer responses from multiple FWWF engagement sessions are compiled and presented alongside findings from a scan of current literature studying producer perspectives on adoption barriers. The end result is a unique reference work that synthesizes literature findings with a large body of authentic, richly detailed producer perspectives, highlights key knowledge gaps and barriers to adoption, and presents recommendations for future direction.

Producers' Perspectives on Barriers to Adoption

Barriers to adoption are explored both in the context of whole-system regenerative agriculture and in the context of individual BMPs. Barrier responses collected from FWWF engagement sessions can be broadly categorized as economic, agronomic, socio-cultural, or awareness barriers. It is important to emphasize that barriers to adoption are dynamic, complex, and interconnected. The effects of multiple barriers can be cumulative and interact with each other, presenting even more complex challenges to producers.

For the purpose of this report, **economic barriers** are related to any economic or financial aspects of agricultural production at the producer level. The barrier most consistently reported by producers is an economic one – the lack of demonstrated return on producers' investment in BMPs. This category also includes any direct or indirect costs related to BMP adoption that producers will have to pay, such as costs of labour, as well as the profitability of BMP implementation in their farming operation, perceptions of risk and profitability, the lack of relevant and accessible markets for agricultural products, and the lack of available crop insurance coverage for BMPs.

Agronomic barriers are defined as factors related to the scientific or technical aspects of agricultural production. A very frequently reported major agronomic barrier to producers is the lack of a demonstrated soil health benefit from BMPs. Agronomic barriers also include labour or harvest timing incompatibilities, equipment incompatibilities, the lack of technical knowledge available to producers, as well as biophysical factors that affect farm production, such as inconsistent precipitation, weed issues, or the short growing season.

For this report, we define **socio-cultural barriers** as those related to time management or lifestyle commitments, social and cultural farming norms, producers' interactions with the people and communities around them, producers' resistance to change, and macro-level systems that impact producers' daily lives, such as the educational and political systems. Socio-cultural barriers include the major time and lifestyle commitment for producers, the needed paradigm shift away from conventional agriculture, the lack of Prairie-specific evidence, insufficient knowledge-sharing pathways, and producers' lack of trust toward policymakers.

Finally, **awareness barriers** are defined as those factors that interfere with a producer's awareness that a BMP exists. This includes producers' lack of awareness of the practice itself, what the practice entails, or what the terminology means. It also includes a sense of ego or underlying assumptions that lead producers to believe they are already implementing a practice and know everything about it, even if they are doing it in a way that is inconsistent with how the practice is generally defined.

Knowledge Gaps that Create Barriers to Adoption

There remain significant knowledge gaps related to regenerative agriculture in the Prairies that continue to create barriers to producer adoption.

Key Knowledge Gap 1: There are no universal definitions for regenerative agriculture or BMPs in Canada.

Key Knowledge Gap 2: There is not enough information available for producers to know their estimated costs and revenue for BMP adoption. There is also not enough data available to accurately estimate the full value of ecosystem goods and services that BMPs contribute to society.

Key Knowledge Gap 3: Prairie producers do not have access to enough knowledge or learning opportunities on how to implement BMPs on their farms, nor enough technical support from extension services or knowledgeable experts in regenerative agriculture.

Key Knowledge Gap 4: There is not enough agronomic or economic research on BMPs in Prairie agricultural contexts.

Key Knowledge Gap 5: The greenhouse gas mitigation potential for some BMPs in the Prairies is still uncertain. There are also uncertainties about the long-term future of the carbon/ecological goods and services market or compensation for GHG mitigation or reductions on farms.

Opportunities for Future Research to Identify Barriers to Producers

Based on the knowledge gaps and limitations of previous engagement research, this section presents opportunities for future work to further the identification, documentation, and understanding of barriers to adoption of regenerative agriculture from a Prairie producer perspective.

Opportunity 1: Conduct engagement research with conventional Prairie producers to more accurately identify BMP adoption barriers relevant to non-regenerative producers.

Opportunity 2: Support the development and expansion of existing participatory, producer-centered research studies that explore Prairie producers' perspectives on:

- Barriers to adoption of regenerative agriculture BMPs
- Policies and programs to promote adoption of regenerative agriculture
- Agronomic research on BMPs in the Prairies

Opportunity 3: Continue producer engagement sessions with regenerative and transitional producers to uncover barriers to producer adoption specific to Prairie regions.

Opportunity 4: Engage with Prairie producers to determine how regenerative agriculture incentives, policies, and programs should be designed, developed, and delivered to effectively meet producers' needs.

Opportunity 5: Support research that uncovers macro level barriers to producer adoption of regenerative agriculture that are not always visible from the producers' perspective.

Opportunity 6: Interface with existing soil and climate mapping initiatives of the three Prairie provinces to integrate producer-reported barriers to BMP adoption in a spatially explicit way.

Opportunity 7: Conduct retrospective research on the adoption of reduced tillage practices in the Prairies to uncover key insights that could be applied to the adoption of regenerative agriculture on a large scale.

Recommendations for Strategies to Address Producer Barriers and Drive Adoption

Based on Prairie producers' perspectives on the most critical adoption barriers, this section presents recommendations for strategies and initiatives that will be the most impactful in addressing barriers and increasing producers' capacity to adopt regenerative agriculture.

Recommendation 1: Advocate for the development of producer accepted definitions and outcomes-based monitoring, reporting, and verification (MRV) system for regenerative agriculture BMPs in Canada.

Recommendation 2: Invest in thorough cost-benefit analyses of BMPs in Prairie agro-climatic contexts to allow accurate estimations of costs and benefits to Prairie producers.

Recommendation 3: Support and advocate for the development of producer-led regenerative system demonstration sites to be located throughout the Prairies.

Recommendation 4: Facilitate and amplify a storytelling and data-sharing pathway that allows regenerative producers to tell their stories and share them with their neighbours, the agriculture industry, and the general public.

Recommendation 5: Support Prairie producers' involvement in the development and delivery of regenerative agriculture programs that are tailored to local conditions and considerations and are based on a peer-to-peer model.

Recommendation 6: Support efforts to build cost effective and efficient soil health monitoring and comprehensive soil testing and mapping tools that are accessible to Prairie producers.

This report presents an in-depth exploration of producers' perspectives on barriers to adoption of individual BMPs and also includes some discussion of higher-level barriers to regenerative agriculture as a whole. While the reductionist approach of discussing individual BMPs reveals valuable details and important barriers in producers' adoption decision-making, it conflicts with the systems approach to large-scale adoption of regenerative agriculture. Further research on barriers would benefit from the inclusion of perspectives on the complex synergies between BMPs and on the ecology of regenerative agriculture as a whole system within the context of Prairie agriculture.

1.0. Introduction

Decades of research have drawn few clear conclusions on producer perspective on the barriers to adoption of regenerative agriculture. There are significant knowledge gaps on Prairie producers' perspectives of barriers to individual Beneficial Management Practices (BMPs) and to regenerative agriculture as a whole. Producer engagement facilitated by the Food Water Wellness Foundation (FWWF) has given Prairie producers the opportunities to share the specific challenges and barriers they have encountered in their efforts to adopt regenerative agriculture. Clearly identifying and understanding producers' perspectives on these barriers is essential to appropriately addressing barriers and increasing adoption of regenerative agriculture in the Prairies.

1.1. Objective

The objective of this report is to identify key barriers to the adoption of regenerative agriculture from the perspectives of agricultural producers from the three Prairie provinces of Canada: Alberta (AB), Saskatchewan (SK), and Manitoba (MB). Detailed, descriptive Prairie producer responses from multiple engagement sessions are compiled and presented alongside findings from a scan of current literature studying producer perspectives on adoption barriers. The end result is a unique reference work that synthesizes literature findings with a large body of authentic, richly detailed producer perspectives, highlights key knowledge gaps and barriers to adoption, and presents recommendations for future direction. Highlighting the voices of Prairie producers will allow adoption barriers to be more clearly identified and thus more effectively addressed by those who have the capacity to do so.

The current regenerative agriculture knowledge base that is specific to Prairie agricultural contexts is growing but remains quite limited. This knowledge gap is a key barrier interfering with Prairie producers' adoption of BMPs on their farms. While other research works may focus on agronomic outcomes or producer perspectives, this work brings value in the compilation of research findings with a significant volume of Prairie producer perspectives collected through FWWF engagement sessions spanning the last ten years. Moreover, this report highlights key knowledge gaps and presents recommendations for future research on barriers as well as recommendations for strategies to address producer barriers. As such, this work itself fills a knowledge gap related to the identification of barriers to adoption from the perspectives of Prairie producers and in consideration of Prairie-specific agricultural contexts. With Nature United's support, this work contributes to the growing Prairie-specific knowledge base on regenerative agriculture.

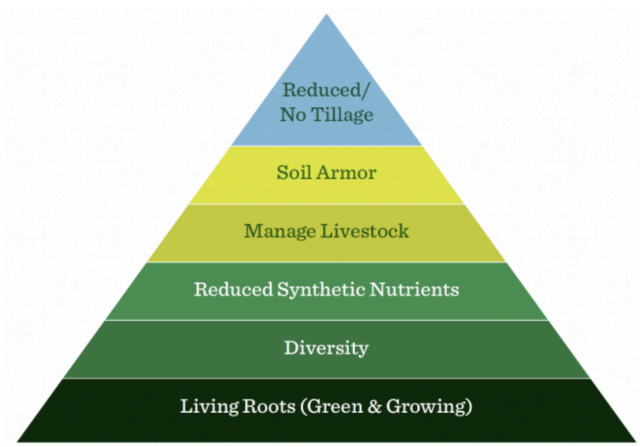
1.2. Regenerative Agriculture and Beneficial Management Practices

There is no universal definition for regenerative agriculture. In *Trusted Advisors in the Canadian Prairies* (FWWF, 2023b), FWWF defines regenerative agriculture as a "whole-systems approach that recognizes the link between plants and soil and seeks to guide agricultural practices with the goal of optimizing soil health to improve the nutritive quality of food, help to manage water, control pests and diseases, and build resilience against climatic uncertainty" (p.15). For the purposes of this report, the above definition will be used.

Many Prairie producers are aware of the term regenerative agriculture, although some may not know the practices included in a regenerative agriculture system nor how the system functions holistically. Figure 1 gives a visual representation of the six soil health principles that are integral to regenerative agriculture as a system. An in-depth explanation of these principles and a list of BMPs that contribute to each principle can be found in Appendix A.

Figure 1

Regenerative Agriculture Soil Principles



Note. From Regenerative Alberta Living Lab. (n.d.-a). *Resources – Regenerative agriculture soil principles.* https://www.regenlivinglab.org/resources

The Alberta government defines Beneficial Management Practices (BMPs) as "any management practice that reduces or eliminates an environmental risk" (Government of Alberta, n.d.-a). There are dozens of agricultural BMPs that contribute to a regenerative agriculture system through one or more of the above soil principles. It is critical to emphasize, however, that regenerative agriculture is far more than a checklist of BMPs. While individual BMPs play an important role in moving agriculture towards a regenerative paradigm, in isolation they cannot achieve the full scope of soil health and ecosystem benefits that result from a regenerative production system.

1.3. Scope and Methodology

This work presents key points from a review of current literature on producer perspectives on barriers to adoption of regenerative agriculture. It also incorporates qualitative insights and themes from producers' perspectives on adoption barriers collected from extensive engagement research conducted by FWWF on the Canadian Prairies since 2013.

The scope of this report is limited to BMPs and other agricultural practices that have the potential to mitigate greenhouse gas emissions (GHGE) in Prairie agriculture systems, especially in crop production systems. As such, agricultural practices are presented in two sections: (a) crop production BMPs and (b) agricultural land management practices that are not directly applicable to crop production but still play an important role in regenerative agriculture and GHGE mitigation across the Prairie agricultural landscape. It is important to note that while all BMPs in this report have the potential to mitigate GHG emissions, there are several that do not fall within the scope of regenerative agriculture as defined by FWWF in section 1.2.

Both formal engagement research and countless informal conversations have enabled FWWF to keep their ear to the ground on the cutting edge innovations being implemented by early adopter regenerative producers in the Prairies. Thanks to established and trusted relationships with their wide network of Prairie producers, FWWF hears directly from regenerative producers about what practices they are using or considering, and their rationales for choosing these practices.

Through grassroots experimentation, early adopter producers have recognized ways to incorporate certain practices into regenerative agriculture systems, even some that are perceived to be outside the scope of regenerative agriculture. For example, tillage is typically perceived to be incompatible with regenerative agriculture, but many early adopter producers in the Prairies have developed ways to use tillage practices strategically and still in alignment with regenerative agriculture principles. As such, all practices included in this report are relevant to Prairie producers' implementation of regenerative systems, even if formal agricultural research has not yet caught up.

Literature searches began in September 2023 and were conducted through the University of Alberta's online library search platform. As it was beyond the scope of this project, the literature search did not follow a systematic review protocol. Although search terms differed for each BMP or topic area, a non-exhaustive list of some of the search terms used is provided here: producer*, farmer*, rancher*, barrier*, adopt*, Prairie*, Canad*, "regenerative agriculture", Alberta*, Saskatchewan*, Manitoba*, BMP*, "beneficial management practice*", "cover crop*", intercrop*, economic*.

The current base of literature on producer perspectives on barriers to adoption focuses largely on producers from the United States or from low- and middle-income countries in the Global South. With the exception of one article from Pakistan, studies from the Global South were excluded from this review due to the significant differences in biophysical, socio-economic, and political variables between Canada and Global South countries that influence producers' BMP adoption decisions. Studies on tropical climates were also excluded due to the significant differences between agriculture in a tropical climate and in the Prairies' continental or subarctic climate zones.

Literature included in this review was restricted to articles that were in English, studied producers in a high-income country with a comparable climate, and were from 2007 or later (although a small number of articles older than this were included if the information was deemed still relevant and difficult to source elsewhere). The majority of adoption literature cited in this report is from Canada, along with some from the United States, and a few articles from the U.K., Australia, China, and some European countries.

Literature that has explored producers' perspectives on barriers to adoption of BMPs in Canada is quite limited. For some BMPs, research from the United States is more plentiful however it is not necessarily applicable to Prairie producers due to differences in numerous biophysical, political, and socio-economic variables between the United States and Canada, and their influential role in producer decision-making.

In their goal to capture richly detailed, authentic responses from Prairie producers, FWWF uses primarily qualitative research methodologies and prioritizes producer perspectives throughout its research initiatives. FWWF also works to foster strong researcher-participant relationships to earn the trust of their participants and to create an environment where producers feel comfortable enough to give honest and authentic responses.

Producer perspectives on barriers to adoption of regenerative agriculture were collected by FWWF through engagement sessions with Prairie producers. Engagement research for the Trusted Advisor Study – *Trusted Advisors in the Canadian Prairies* (FWWF, 2023b) – also included interviews with industry stakeholders who are closely connected to Prairie producers and regenerative agriculture, including representatives from retailers, producer-led organizations, and non-governmental organizations, as well as academics, researchers, and professional agrologists.

FWWF producer engagement research spans the last decade and includes the 2015 Needs Assessment, the 2021 Producer Engagement Sessions, the 2023 Trusted Advisor Study, and the 2023 (and ongoing) Regenerative Alberta Living Lab (RALL) surveys and roundtable discussions. Further discussion of FWWF's approach to producer engagement, past engagement initiatives, and the scopes and methodologies of these initiatives is included in Appendix D of this report, as well as in the separate report titled *Food Water Wellness Foundation: Our Approach to Producer Engagement on the Canadian Prairies (2013-2024) – A summary of research, methods, themes, and recommendations (FWWF, 2024)*.

This report prioritizes and presents barriers to adoption of BMPs from producers' perspectives and emphasizes producers' voices as often as possible. Over the last 10 years, many Prairie producers have shared their personal experiences and perspectives informally, through casual, unrecorded conversations with the FWWF team. Although subject to bias, this organic engagement provides high value to the understanding of producers' perspectives on barriers. As such, these perspectives have been paraphrased and included in this report.

Direct quotes from producers, whether from engagement research or published literature, will be italicized and in quotation marks to emphasize producers' voices. Producer responses obtained through FWWF engagement were collected either verbally through interviews or discussions, or in writing through a survey. For this reason, some producer quotes appear in a conversational speech style and others in a more organized written style. Perspectives from industry stakeholders that were collected through FWWF engagement research are included in this report as many of these individuals are also producers themselves and all have strong connections to Prairie producers and regenerative agriculture.

FWWF also benefited from the insight of a highly knowledgeable professional agrologist who contributed the collective perspectives of his network of Prairie producer contacts and provided technical advice throughout the writing and editing process. This advisor to FWWF shared the barriers he has heard through conversations with a vast client base of conventional and regenerative producers located across the Prairie provinces. These barriers will be discussed in the individual BMP sections and are summarized in table format in Appendix B.

Findings from the Bain producer engagement research (Bain, 2021) are referenced throughout this report. Bain engagement research collected perspectives from four producers (three livestock producers and one organic producer) and findings were shared internally with Nature United in February 2021. Despite the small sample size, the Bain research adds important producer perspectives on many individual BMPs that align with many of the key barriers noted in other sources. As the objective of this report is to focus heavily on emphasizing producers' perspectives, responses from the Bain research are presented throughout this work.

This report also frequently references the Viresco Solutions report, *Beneficial Management Practices (BMPs) for Reducing Greenhouse Gas (GHG) Emissions in Prairie Agriculture,* that was prepared for Nature United (Viresco Solutions, 2022). The Viresco report provides a detailed exploration of individual BMPs and other agricultural practices relevant to Prairie agriculture that carry significant GHGE mitigation potential. The strengths of the Viresco report are clear – it highlights the practices, estimates on current levels of adoption, GHG emission impacts, barriers, trade-offs, and knowledge gaps that are specific to the Prairies as often as possible. It features numerous relevant quantitative findings from Prairie-focused literature when available, including Drever et al. (2021a; 2021b)'s *Natural Climate Solutions for Canada*.

Nature United's support has enabled these research works to make a significant contribution to the available knowledge base of Prairie producer perspectives on regenerative agriculture adoption barriers. Both Bain producer research (2021) and the Viresco Solutions report (2022) are trustworthy sources of in-depth, Prairie-specific data that speak to the focus of this report. While the Viresco report (2022) provides important considerations on the outcomes of BMPs in the Prairies, its limitation is that it does not present producers' perspectives directly.

Recognizing this limitation, this report aims to provide value by building on these foundational works and creating an extensive synthesis of Prairie producer perspectives with key findings from available literature. This creates a unique, in-depth research work that presents Prairie producers' perspectives on barriers to adoption of regenerative agriculture, along with key knowledge gaps and recommendations for future direction.

1.3.1. Limitations of the Research Base

The collection of detailed, authentic perspectives from producers most frequently requires the use of qualitative research methods. While qualitative studies allow for a deep exploration of the experiences and perspectives of producers, they are typically limited by a smaller sample size and are not broadly generalizable. As selection of participants in these studies is often not randomized, selection bias or sampling bias can affect the findings. Many studies included in this report used a snowball sampling method which allows access to participants that may otherwise be hard to recruit. Snowball sampling also introduces sampling bias to the study which must be considered when interpreting the findings.

For some BMPs, research from the U.S. is more plentiful than that from Canada, however its relevance to Prairie producers is limited due to the differences in numerous biophysical, political, social, and financial variables between the U.S. and Canada, and their influential role in producer decision-making. This is consistent with findings from the few Canadian studies that have examined producer perspectives on barriers to BMP adoption. McMartin and Hernani Merino (2014) discussed the importance of regional variables in producer decision-making, and highlighted the need for producer incentives and programs to be targeted to the adoption of specific BMPs and based on research that considers the local and regional contexts.

Even within the Prairie producer population, variations in farm size and scale limit the generalizability of findings on the drivers and barriers to adoption. Indeed, a group of cattle, grain, and mixed farmers from the Qu'Appelle Watershed area of Saskatchewan told researchers that "the implementation of BMPs cannot be generalized across all farms since each farm varies in practices and size" (Bradford et al., 2020, p. 14282). Notably, these producers wanted the opportunity to observe the adoption and implementation of BMPs in a local context, at their farm's scale, and to see the benefits they could reasonably expect before they made the decision to adopt.

As the available literature base is quite limited, this report attempted to include all relevant Canadian research, including many studies that are 10-15 years old. Findings from many of these studies still have relevance and provide important insights, however some findings may be considered outdated due to significant socio-economic or technological changes in that time period. Agricultural markets can change rapidly and thus research on economic factors that influence BMP adoption from 10-15 years ago may have limited applicability to today's market conditions.

Some studies have examined BMP adoption strictly as a yes/no variable – which does not recognize adoption over time, partial adoption of some BMPs, or failed adoption (where a farmer adopts a practice but then abandons it after a period of time and returns to their previous methods) (Prokopy et al., 2008). Producers may adopt practices partially or fully and they may adapt them heavily to their farming operation and biophysical conditions.

There is also a lack of quantitative research on cultural and structural barriers to adoption (Prokopy et al., 2019). Cultural barriers including community or social norms, farmer identity and farmer values, and structural barriers including policy instruments, market conditions, financial incentives, and available research may have significant influence on producers' adoption decisions, but research in this area is insufficient to make clear conclusions (Prokopy et al., 2019).

Bain engagement research (Bain, 2021) contributes detailed and specific producer perspectives to this report that highlight important barriers to BMPs, however there are some important limitations to the Bain research. The sample size of just four producers is unquestionably small. Moreover, the participants were either livestock or organic producers and as such their responses are not representative of conventional crop producers.

Finally, the Viresco Solutions report (Viresco, 2022) also has limitations. While it provides a strong foundation of information about individual BMPs, including barriers to adoption in Prairie agricultural contexts, it does not present producers' perspectives directly. The report discusses adoption barriers at many levels of the value chain but not necessarily from the producers' perspective, nor does it include direct quotes from producers.

1.4. Why Producers' Perspectives?

Although many factors contribute to their decision-making processes, producers are the ones who ultimately decide whether or not to adopt BMPs on their farms. Producers also face the daily challenges as they work to problem-solve agronomic and economic issues in their farming operations. While regenerative agriculture brings countless benefits to the whole population through ecological goods and services, producers alone shoulder the costs, the labour, and the difficulties of sustaining agricultural productivity while implementing new production systems on their farms.

Producers must be able to tell the rest of us what they are experiencing, what they need, and what they identify as barriers. Indeed, single conversations between producers and FWWF revealed Prairie-specific major barriers to the adoption of some BMPs that failed to emerge through months of literature review. Accurately identifying and describing regenerative agriculture adoption barriers from the producer's perspective will allow researchers and policymakers to more effectively address these barriers and promote increased BMP adoption.

In their past producer engagement research, FWWF approach to questions were designed to capture producers' perspectives on barriers to regenerative agriculture as a system, not as individual BMPs. As such, FWWF producer engagement responses are largely presented in the Higher Level Barriers section as they relate to adoption of regenerative agriculture as a whole system. Producer responses that did identify barriers to specific BMPs are presented in the individual BMP sections.

Research that focuses on barriers to individual BMPs allows us to pinpoint where these barriers act on the processes of adoption and implementation for each practice. However, this type of research fails to capture the benefits and synergies of BMPs that are implemented together, or of holistic regenerative agriculture that is adopted as a system. Some BMPs must be practiced together for implementation to be successful; silvopastoral systems, for example, must also include rotational grazing for the wellbeing of both the pasture and the livestock (Gabriel, 2018). Thus, research on the barriers or challenges to adoption of rotational grazing may not delineate whether those barriers apply to producers considering it as part of a silvopastoral system, or as a grazing practice on its own.

There are other drivers for multi-BMP adoption. Saskatchewan producers in the Bradford et al. (2020) study told researchers they are likely to adopt more than one BMP around the same time to maximize the likelihood of success and minimize potential economic losses. They also highlighted that some BMPs are logistically more feasible to adopt in conjunction with other BMPs, rather than individually. This also includes consideration for the overlap between many BMPs, either in how they are defined or how they are practiced.

And while there are a few negative interactions between some BMPs, many BMPs can be implemented together to reinforce their beneficial effects (Viresco, 2022). Crop residue management is important with reduced tillage, and nutrient management BMPs are most effective when used in conjunction with practices such as zero-tillage and cover cropping (Nutrient Stewardship, n.d.). Viresco (2022) also stresses that regenerative agriculture is "a system of BMPs that are reinforcing [each other]" (p.5), the impacts of which will be beyond those of any individual BMPs. Ultimately, research, programs, and policies that consider BMPs individually may fail to capture the full scope of adoption barriers and impacts of regenerative agriculture as a whole system.

This report presents an in-depth exploration of producers' perspectives on barriers to adoption of individual BMPs and also includes some discussion of higher-level barriers to regenerative agriculture as a whole. While the reductionist approach of discussing individual BMPs reveals valuable details and important barriers in producers' adoption decision-making, it conflicts with the systems approach to large-scale adoption of regenerative agriculture. Further research on barriers would benefit from the inclusion of perspectives on the complex synergies between BMPs and on the ecology of regenerative agriculture as a whole system within the context of Prairie agriculture.

1.5. BMP Categorization

This report includes BMPs and other agricultural practices if they have GHGE mitigation potential in Prairie agriculture systems. In particular, BMPs are considered here in terms of their feasibility in crop production Prairie agriculture systems. As such, agricultural practices are presented in two sections, including crop production BMPs and agricultural land management practices that are not directly applicable to crop production but still play an important role in regenerative agriculture and GHGE mitigation.

Section 3.0 discusses regenerative agriculture BMPs that are directly applicable to crop production in the Canadian Prairies. These BMPs fall into the broader categories of cover cropping, crop rotation diversity, nutrient management, integrated crop-livestock systems, tillage, and agroforestry. All have direct impacts on crop productivity and soil health and vary in their GHGE mitigation potential.

Section 4.0 discusses agricultural land management practices that are natural climate solutions (NCS) that focus on either avoiding the conversion of land for agricultural production or on restoring current agricultural land to its naturalized state. These strategies are distinct from the BMPs in section 3.0 in that they are not directly applicable to crop production, but rather are related to agricultural land management at the landscape level. Although these practices do not have direct impacts on crop production, some have enormous GHGE mitigation potential in the Prairies and thus their importance should not be underestimated.

1.6. BMP Definitions and Terminology

There are currently no universal definitions for BMPs or for regenerative agriculture as a system, either in Canada or internationally. With no clear definitions or criteria for BMPs, there will be a significant range of variability among all cover crops currently being grown, for example, ranging from a single species to complex cocktail mixtures.

The lack of universal definitions that define regenerative agriculture and regenerative agriculture practices in Canada has become a barrier in itself. A key finding highlighted in the Trusted Advisor study is the barrier presented by the lack of consistent, universal terminology in regenerative agriculture BMPs (FWWF, 2023b). The study noted that terms that mean different things to different groups of people are being used interchangeably, and important distinctions are not being communicated. This is especially relevant when a reduction of GHG emissions is being ascribed to a specific practice, but the application of the practice is not consistent.

During the process of aligning findings from the literature review with producer responses from FWWF engagement sessions, a number of definition discrepancies emerged. These discrepancies are identified in the individual BMP discussions in sections 3.0 and 4.0. The practices are described and defined from a research and/or government policy perspective and then compared with how Prairie producers would typically define or describe them in everyday language. These practice definitions are also presented in a glossary format in Appendix C.

There are language discrepancies in what the practices are called, as well as in how the practices are implemented. Based on Drever et al. (2021a; 2021b)'s work on *Natural Climate Solutions for Canada*, cover cropping and nutrient management are the BMPs that are deemed to be the easiest to drive adoption and have the greatest GHGE mitigation impact in the Prairies. This report identifies many practices, including cover cropping and nutrient management, that are subject to language discrepancies and misunderstandings amongst the various players in the space, including producers, academic researchers, government policy-makers, agrologists, equipment manufacturers and retail sales representatives. This inconsistency in language and understanding of the BMPs is a major barrier to driving adoption of practices that carry the potential for significant climate mitigation.

Many similar practices in sections 3.0 and 4.0 share some of the same barriers, and this does result in some repetition in the barrier sections of the report. Combining similar practices and discussing their barriers together would have allowed for a more condensed report, but would have done a disservice to the understanding of the context and potential for each practice.

It is crucial to highlight that ultimately, each practice is distinct. In spite of any shared barriers, individual practices are intentionally discussed separately and not together. They have different definitions, are used in different ways or in different contexts by producers, and have some differences in barriers, even if slight. This approach reflects the intended purpose of this report, which is that each BMP or practice section can act as a stand-alone reference or resource outside of the context of the full report.

1.7. Categorization of Barriers

Barrier responses collected from FWWF engagement sessions can be broadly categorized as economic, agronomic, socio-cultural, or awareness barriers. Table 1 summarizes Prairie producers' responses on barriers to adoption that were recorded during FWWF producer engagement from 2021 to 2023.

For the purposes of this report, **economic barriers** are related to any economic or financial aspects of agricultural production at the producer level. The barrier most consistently reported by producers is an economic one – the lack of demonstrated return on producers' investment in BMPs. This category also includes any direct or indirect costs related to BMP adoption that producers will have to pay, such as costs of labour, as well as the profitability of BMP implementation in their farming operation, perceptions of risk and profitability, the lack of relevant and accessible markets for agricultural products, and the lack of available crop insurance coverage for some BMPs.

Agronomic barriers are defined as factors related to the scientific or technical aspects of agricultural production. A very frequently reported major agronomic barrier to producers is the lack of a demonstrated soil health benefit from BMPs and the resulting reduction in need for inputs (fertilizers, herbicides, and pesticides). Agronomic barriers also include labour or harvest timing incompatibilities, equipment incompatibilities, the lack of technical knowledge (know-how) available to producers, the lack of technical support from agronomists, as well as biophysical factors that affect farm production, such as inconsistent precipitation, weed issues, or the short growing season/number of frost-free days in the Canadian Prairies.

For this report, we define **socio-cultural barriers** as those related to time management or lifestyle commitments, social and cultural farming norms, producers' interactions with the people and communities around them, producers' resistance to change, and macro-level systems that impact producers' daily lives, such as the educational and political systems. Socio-cultural barriers include the major time and lifestyle commitment for producers, the needed paradigm shift away from conventional agriculture, the lack of Prairie-specific evidence, insufficient knowledge-sharing pathways, and producers' lack of trust toward policymakers.

Finally, **awareness barriers** are defined as those factors that interfere with a producer's awareness that a BMP exists. This includes producers' lack of awareness of the practice itself, what the practice entails, or what the terminology means. It also includes a sense of ego or underlying assumptions that lead producers to believe they are already implementing a practice and know everything about it, even if they are doing it in a way that is inconsistent with how the practice is generally defined.

It's important to emphasize that barriers to adoption are dynamic, complex, and interconnected. Barriers often do not fit neatly into one category, nor do they act in isolation. Many barriers are both agronomic and economic, or both economic and socio-cultural. Barriers may apply to some producers but not others, can be region-dependent, and can act directly or indirectly on producers' adoption. The effects of multiple barriers can be cumulative and interact with each other, presenting even more complex challenges to producers. This is illustrated in the following quote from a RALL producer who shared their challenges with mob grazing (adaptive multi-paddock grazing) and seeding legumes into pastures:

"*Tried mob grazing, spread some seed, hard to introduce new perennials in established forage. …Added fertilizer, but economics did not shake out. Normal soil testing is not finding the issue, [need] comprehensive testing"*

RALL producer (RALL, 2023b)

This comment highlights the interplay and complexity of barriers to the adoption of adaptive multi-paddock grazing. On the surface, this producer is sharing the specific economic, agronomic, and socio-cultural barriers that prevent them from adopting this practice. But this response also shows us how one barrier can lead into another, how the barriers can stack to make the practice far more challenging, and how some barriers are within the producer's locus of control and others are not. This quote also points to how barriers can arise at different stages of the adoption process. This producer overcame barriers to the initial adoption of mob grazing, but then struggled with barriers that prevented them from successful continuation of the practice.

While this report covers dozens of barriers that have been identified through literature or from producer engagement, there are undoubtedly additional barriers that we have not identified and thus are not discussed here. When a barrier category is absent from an individual BMP section, it means that these barriers may exist but there is not yet enough information available to accurately identify them.

Table 1

Summary of Producer Responses on Barriers to Adoption of Regenerative Agriculture, from FWWF producer engagement sessions 2021-2023

Economic Barriers	Farm Management or Scale Incompatibilities	- Farm infrastructure barriers - producer lacks necessary machinery, fencing, or water infrastructure - Hard to scale BMPs up or down to fit their farm operation
	Costs and Profitability	- Direct costs to implement and maintain BMPs - Indirect costs of lost production from converted cropland - Uncertainty around profitability and return on investment - Slim margins – risky to try something with an uncertain outcome
	Markets and Marketing	- Limited markets or processors available to them - Lack of unbiased agronomic advisors – most are also in product sales
	Crop Insurance	- No crop insurance coverage available for some BMP practices
	Personal Perceptions of Risk and Profitability	- Personal perceptions of risk and profitability - Personal level of risk tolerance
Agronomic Barriers	Biophysical	- Weeds - Short growing season - Changing weather patterns - Lack of consistent moisture
	Knowledge and Support, Data, Research, Evidence/ Demonstration	- Lack of 'how-to' knowledge and technical support - No clear protocols for BMPs in Prairie agro-climatic conditions - Unsure what species are compatible - Unsure how to establish and maintain legumes in existing stand - Unsure how manure and cover crops affect nitrogen availability - Need evidence-based guidance to implement BMPs in a whole system-based approach, relevant to Prairie agro-climatic context - Lack of research, data, or evidence to demonstrate the feasibility and optimal protocols of BMPs in the Prairie context
	Timing Incompatibilities	- Timing of planting or harvest interferes with cash crop planting or harvest
	Equipment Incompatibilities	- Farm infrastructure or equipment barriers – machines must maneuver around shelterbelts or restored wetlands

Socio-Cultural Barriers	Farm Management Incompatibilities	- Significant time and labour commitment for some BMPs, may require family lifestyle change
	Paradigm Shift and Mindset	- Mindset – change is too overwhelming - Farmer demographics (older age – too hard to change) - Dominance of conventional agriculture – need paradigm shift to regenerative agriculture - Stigma of going against farming norms
	Research Paradigm	- Lack of research, data, or evidence to demonstrate systems-based outcomes
	Education and Knowledge-Sharing	- Lack of unbiased, non-sales agronomic advisors - Lack of trusted, knowledgeable mentors and leaders - Lack of knowledge sharing among peers - Lack of practical regen ag post-secondary education - Research and academia are dominated by conventional agriculture – need paradigm shift in research
	Social and Community	- Lack of peer support, community, social network - Lack of trusted, knowledgeable mentors and leaders
	Approach to Communication and Policy	- Need better communication channels between producers, academics, and advisors - policymakers need to approach with sensitivity, no judgement, and without alienating the conventional majority of producers
	Political and Policy	- Lack of trust in policymakers and government - Lack of clear, universal definitions of regenerative agriculture and BMPs - Government regulations - Time-consuming and complex applications for funding programs - Check off system – research dollars to single crops rather than systems

Awareness Barriers	Lack of Awareness	- Producers' lack of knowledge or understanding of BMPs and how they are practiced
	Misunderstanding	- Producers' misunderstanding of BMP terminology
	Ego or Assumptions	- Producers' ego or ingrained assumptions results in them overestimating their knowledge on a practice and being resistant to new information

2.0. High Level Barriers to Adoption of Regenerative Agriculture

Through FWWF engagement sessions, Prairie producers shared many barriers to adoption of regenerative agriculture which are not necessarily associated with individual BMPs. A fair portion of the existing literature base has explored producers' perspectives on barriers to adoption of regenerative agriculture as a system rather than barriers to specific BMPs. This section presents producers' perspectives on economic, agronomic, socio-cultural, and awareness barriers to adoption of regenerative agriculture as a whole system.

2.1. Economic Barriers

During the Living Lab roundtable meeting in November 2023 (RALL, 2023b), producers discussed the factors that limited BMP adoption from their perspectives. Economics was one of the two clear themes that emerged in their responses (the other being lack of precipitation). Producers shared the following comments related to how economics limit or dictate the practices they adopt:

- *"the information is out there but economics will dictate"*
- *"the uptake of OFCAF* [On-Farm Climate Action Fund] *for things like fencing & water indicate where the margins are at - economics will dictate a lot"*

It's important to note how the producer who gave the first comment feels that information on regenerative agriculture is available but that ultimately adoption will be dictated by the economics to individual producers. Consistently, the lack of demonstration of the long-term profitability of these practices are cited as a barrier to large scale adoption.

2.1.1. Costs

Initial implementation costs for BMPs have consistently been identified by producers as not just a barrier, but their primary barrier to adoption of regenerative agriculture (Bogdan & Kulshreshtha, 2021; Liu et al., 2018; Ranjan et al., 2019). Producers and industry stakeholders interviewed in engagement sessions also mentioned costs repeatedly as a key barrier to BMP adoption (FWWF, 2021; FWWF, 2023b).

Producers in FWWF engagement sessions and RALL discussions gave the following responses related to cost as a barrier to adoption of regenerative agriculture:

- *"costs (i.e. topical product to make nutrients more available – up to $20/acre)"*
- *"costs of BMPs are too high"*
- *"costs of regenerative agriculture inputs much higher than conventional"*

- *“lack of capital & equipment to get started with new practices”*
- *“cost of freight to the North”*
- *“funding programs help with trying out new things, can offset capital but do not cover labour”*

Implementation costs of certain BMPs may be covered by funding programs or grants, but maintenance, input, and labour costs may not be. As such, cost can still be a significant barrier even to producers who are receiving grant funding to adopt a BMP.

2.1.2. Infrastructure

Infrastructure issues can also be barriers to regenerative agriculture adoption, including lack of appropriate infrastructure both at the farm-level as well as within the community and larger geographical region. Producers in FWWF engagement (FWWF, 2021) stated they had limited access to the equipment or local processors needed. Producers also mentioned the meat inspection system restriction on direct marketing at scale or across borders, as well as virtual fencing technology not yet being a viable option.

2.1.3. Crop Insurance

Crop insurance was mentioned by producers in FWWF engagement sessions (FWWF, 2021) and can act as a significant barrier to the adoption of BMPs in both direct and indirect ways. Typical Prairie crop insurance policies do not provide coverage for many BMPs or regenerative agriculture practices.

Rosenzweig et al. (2020) highlighted the upstream, indirect way that conventional crop insurance policies create a barrier for producers who are motivated to adopt BMPs on their farms, stating that “in addition to posing an economic barrier, crop insurance also serves to reinforce conventional ideologies and norms that can impose social, as well as economic, barriers on those seeking to break from historically dominant practices” (Rosenzweig et al., 2020, p. 567).

Producers who may be interested in regenerative agriculture practices have to carefully review crop insurance policy terms and conditions to find ways to get coverage for BMPs under specialty crop or diversified crop programs. Also, insurance providers may consider the implementation of a BMP such as companion cropping or relay cropping as a “practice or action taken by the Insured that would prove detrimental to or limit production of the Insured Crop” (AFSC, 2023b, p.7). This point is listed as a coverage restriction in the Agriculture Financial Services Corporation (AFSC)’s *2023 Cereal & Oilseed Crops Insuring Agreement,* and could result in AFSC limiting, restricting, excluding, or denying coverage on that crop (AFSC, 2023b). Each province in the Prairies has slightly different insurance rules and provides different amounts of coverage; in Saskatchewan, the average multi-peril coverage for 2024 is $389 per acre (Agriculture and Agri-Food Canada, 2024). Regardless of the province they farm in, producers do not want to risk having an insurance claim denied because they used a regenerative practice that is considered a coverage restriction. This system reinforces the idea that anything outside the norm is too risky.

Current crop insurance policies emphasize the perception that BMPs are risky and unorthodox and that those who adopt these practices must also have some level of peculiarity or eccentricity to engage in something so unusual. Indeed, some regenerative producers report social isolation and a loss of social capital from adopting farming practices that go against the norm (Rosenzweig et al., 2020; Sustainable Food Lab, 2023).

2.1.4. Markets and Marketing

Producers frequently reported that instabilities in market prices were a significant barrier to their ability to adopt regenerative agriculture practices (Bogdan & Kulshreshtha, 2021; Liu et al., 2018). Market price and demand is different from year to year based on commodity prices. If there was a consistent and dependable market for commodities grown using regenerative agriculture, it would allow for the development of regenerative systems on farms. Production systems take more than one year to develop, so having a short-term market that may be gone next year does not drive sustained change.

To derive profitability from their investment in regenerative agriculture practices, regenerative producers are value-adding and direct-marketing their products, as the current commodity market does not provide a premium that motivates change.

2.1.5. Perceptions of Risk and Profitability

Perceptions of risk are highly individual, shaped by a variety of social, cultural, and economic factors, and are “a key bottleneck controlling agricultural adaptation” (Rosenzweig et al., 2020, p.564). Throughout adoption literature, uncertainties around BMP outcomes, BMP profitability, and yield outcomes emerge consistently as risk perception barriers to producers’ adoption of regenerative agriculture (Liu et al., 2018; Ranjan et al., 2019; Rosenzweig et al., 2020).

Perceptions of risk are often tightly aligned with, and sometimes inextricable from, perceptions of profitability. Risks are also often a trade-off of one for the other. This may manifest as an aversion to short-term risk but a tolerance for long-term risk, for example, an intolerance to profitability risk in the short-term, but more tolerance to soil health risk in the long-term (Rosenzweig et al., 2020).

Conventional perceptions of profitability may be incompatible with the broader profitability potential of regenerative agriculture. Responses from the TA study (FWWF, 2023b) mentioned concerns about short-term profitability, and that *“regenerative agriculture [practices] do not pay off in short term and need to figure out how to do it profitably.”*

Producers’ perceptions of profitability may be a key variable through which we can foster the paradigm shift needed to normalize large-scale change to regenerative agriculture. Perceptions on what makes a farm profitable can vary significantly even within one local area where we can presume mostly consistent climate, weather, and soil factors. Indeed, Rosenzweig et al. (2020) noted that dryland farmers in Colorado and Nebraska from different social circles (subgroups) had different perceptions of what profitability means to them. Producers who used sustainable agricultural practices and continuous cropping on their farms felt that a fallow system was less profitable due to the loss of cash crop years. Those on the other end of the spectrum who used approaches that are more traditional in that area believed that farming in their region could only be profitable with a summer fallow.

Although producers may perceive the risk of uncertain BMP outcomes as a barrier to regenerative agriculture, it’s possible the actual barrier lies in misplaced perceptions of risk. Rosenzweig et al. (2020) makes an important point – the perception that poor soil health is an insignificant risk, especially among conventional producers, might actually be the greater barrier to adoption of regenerative agriculture. If these producers perceived poor soil health in the long term as a great risk to their farming operation, they would likely adopt practices now that would mitigate that risk.

Prairie producers echoed these themes of risk and uncertainty through FWWF engagement (FWWF, 2021) and RALL discussions (RALL, 2023b), stating the following reasons as barriers to BMP adoption:

- *“risky to try something uncertain, may not work, margins are slim”*
- *“ability to accommodate risk”*
- *“economic uncertainty”*
- *“lack of return & high risk to try some of the practices if you don't already understand them well”*
- *“fear or overestimation of the risk of making a change”*

The last response indicates the producer recognizes that they may overestimate the risk of making a change, which aligns with the idea that we may unintentionally exaggerate our perceptions of risk towards something unfamiliar. Risk perception may be one of the driving forces feeding the status quo bias that urges us to continue with what we know rather than change to something different.

2.2. Agronomic Barriers

Many agronomic barriers are more specific to individual BMPs, but some broad factors do influence adoption of regenerative agriculture as a system. Biophysical factors, especially those related to climate change, were the most frequently mentioned agronomic barriers in FWWF engagement sessions (2021). Producers frequently noted changing weather patterns, increasing variability of weather events, lack of consistent moisture, and the short growing season as barriers to adoption of regenerative agriculture. Indeed, numerous producers at a recent RALL roundtable discussion (RALL, 2023b) stated that the lack of precipitation is a critical limiting factor to BMP adoption, with comments such as:

- *“we can only push the land so hard – brittle landscape, water is a limitation”*
- *“drought is necessitating some other changes – like true vertical tillage to keep more trash”*
- *“no rain or limited water for irrigation dictates a lot - like if we are going to put in a cover crop before we plant potatoes”*

Historical precipitation trends in the Prairies suggest that moisture will likely continue to be a major limiting factor for producers. In Alberta, total winter precipitation, snow cover duration, and annual maximum snow depth have consistently decreased since 1950 (Mapfumo et al., 2023). Off-season precipitation is crucial to ensure soil has sufficient moisture to sustain crop growth through the growing season and shoulder seasons.

Another key barrier was mentioned in RALL discussions – producers need specific agronomic information and technical support to figure out how to implement the practices on their own farms. One producer stated they need to know *“how to actually implement BMPs - how to do logistics, equipment, experts. Focusing on the management input to make the system work”* (RALL, 2023a). Other producers stated they are *“trying to implement BMPs as a holistic system. Nothing new - but trying to improve, expand and tweak the system [we] have developed”* and want to *“get better at the things we are currently doing. Be more effective at the BMPs that are already adopted”* (RALL, 2023a).

2.3. Socio-Cultural Barriers

There are numerous socio-cultural barriers that hinder adoption of regenerative agriculture as a system, many of which relate to the dominance of the industrial, conventional agriculture paradigm in the Prairies and in Canada. Conventional agriculture dominates research and academics, post-secondary education and training, government policy, and the agriculture industry. Historically, there has been little room for alternative practices that do not align with the status quo.

Socio-cultural barriers also include barriers at the farm level or the community level, including farm management incompatibilities, lifestyle commitments for time-consuming practices, the lack of social connections, and local farming norms. Although some of these barriers do not act directly on producers at the farm level, they create systems and structures that are not conducive to the adoption of unconventional practices and thus act as indirect barriers to producers.

There is an emerging and somewhat unexpected barrier to adoption – newfound government, NGO (non-governmental organization), and corporate interest in regenerative agriculture. Some producers feel that the term has become trendy and is further convoluted through “snake oil” salespeople marketing a one-size-fits-all approach to implementation, rather than the highly contextualized and nuanced approach that early adopters sought to build in holistic regenerative systems. Some early adopters are questioning the regenerative agriculture paradigm and are also seeking, alongside their more conventional counterparts in the industry, clearly articulated return on investment from the implementation of regenerative practices.

2.3.1. Incompatibilities with Farm Management and Scale

Producers may perceive BMPs to be incompatible with their current farm management system and these perceived incompatibilities can act as barriers to adoption. In FWWF engagement sessions (2021), producers listed the following factors as barriers related to farm management and scaling of practices:

- *"labour"*
- *"time needed for monitoring and measuring, hard to get benefit out of it"*
- *"specialization"*
- *"transition away from feedlot so less access to manure"*
- *"difficulties for smaller scale intensive agriculture"*
- *"difficult to scale up to commodity level"*
- *"some BMPs require intensive management, not practical on smaller farm"*
- *"hard to do some BMPs on commodity scale and still make money"*

These incompatibilities can include the need for additional equipment or infrastructure on the farm, additional time and/or labour needed for monitoring, paperwork, independent learning, or overall management, overall lifestyle change for BMPs needing more intensive management, or difficulty scaling BMPs or regenerative agriculture as a system to their operation.

2.3.2. Paradigm Shift and Mindset

A RALL producer recently shared that age and reluctance to change act as barriers to adoption because *"more producers are aging out than are looking to re-invent their business"* (RALL, 2023b). Through FWWF's engagement research, producers mentioned similar barriers related to age, a perception that change is too hard or too overwhelming, and that maintaining the status quo is easier. Indeed, the status quo bias makes us want to continue what we are already doing rather than make a change to something different (Behavioral Economics, 2023). It feels safer and easier to carry on with what is familiar instead of risking a change to something we perceive as new and uncertain.

For a large-scale change to occur, people will need a different understanding of soil and agriculture. The conventional mindset is that soil is a medium to aid in plant growth, rather than a complex system occurring below the ground that interacts with, and depends on, green, growing plant material. Without widespread knowledge and understanding of how important this interdependence is, it will be very difficult to foster changes in beliefs, mindsets, and regenerative agriculture adoption.

The Scale Lab report (Sustainable Food Lab, 2023) highlights the crucial roles of fostering a paradigm shift in farming mindset and a systems approach to agriculture in general. Based on the work of Centola et al. (2018), the report authors hypothesize that if 30% of farmers adopt regenerative agriculture practices, we will reach a tipping point that will drive most other farmers to follow suit, and regenerative agriculture would then become the norm rather than the exception.

Changing the culture of farming will play a key role in encouraging BMP adoption; the report states "farmer culture is a barrier to change until it is an accelerant" (Sustainable Food Lab, 2023, p.11). The authors suggest that once the 30% tipping point is reached, the systems and structures will have changed enough that the majority of remaining producers will find it in their best interest to adapt to the new norms. One Living Lab producer shares this perspective, as they stated in a producer roundtable discussion:

"[We want to] get to a tipping point so shared information on changes can build momentum and be able to go somewhere"

RALL producer (RALL, 2023a)

The paradigm shift from conventional monocropping to systems-based regenerative agriculture should also include the research world. Paradigm barriers at the research level are apparent in how academic research primarily focuses on the dominant industrial agriculture system (Frison, 2016) and on economic productivism. Although research on alternative agriculture practices is gaining traction, it's worth considering that the reductionist approach of research on specific BMPs neglects the broader synergies and impacts of the regenerative agriculture system as a whole.

Rosenzweig et al. (2020) suggested that regenerative agriculture research should move towards a focus on the long-term, multi-capital approach rather than a short-term profitability view. Industry stakeholders in the *Trusted Advisor* engagement sessions (FWWF, 2023a) also pointed out that the academic mindset needs to shift to research that focuses on a systems approach to regenerative agriculture.

"Researchers and agronomists are well positioned to engage in BMPs, not foreign concepts, but putting them together in systems approach is uncomfortable"

Industry stakeholder (FWWF, 2023b).

This perspective must be explored more deeply in research to give producers an evidence-based, holistic regenerative agriculture framework applicable to Prairie farms.

2.3.3. Data, Evidence, and Research

Producers have consistently stated that there is not enough data available on regenerative agriculture practices in the Prairies, especially on the effects of BMPs on soil health and on the systems approach to regenerative agriculture (FWWF, 2021). Industry stakeholders also shared that the current evidence base is insufficient. There must be more research on regenerative agriculture *specific to the Canadian Prairie context* to develop the data that producers need to comfortably adopt these practices. Industry stakeholders and producers reiterated that they need research that clearly demonstrates the benefits of these practices in local contexts, soil testing that is easier to access, and regenerative agriculture research that is scalable to large commercial production (FWWF, 2021; FWWF, 2023b).

This dearth of data also complicates other issues related to regenerative agriculture adoption. The lack of data inhibits actuarial calculations required for crop insurance coverage, and as such, producers have very few crop insurance mechanisms that allow them to mitigate the financial risk of BMP adoption.

To ensure research meets the needs of Prairie producers, researchers and academics should include producers in their collaboration on the design, implementation, and evaluation of the research. A Canadian study on BMPs for groundwater protection in the Abbotsford-Sumas Aquifer reported that "the lack of a concerted research and development effort conducted in collaboration with growers, and the lack of objective metrics of the efficacy and adoption of BMPs, remains a major barrier to the development, demonstration and adoption of BMPs" (Zebarth et al., 2015, p.93).

A participatory or user-centered approach to research and innovation design could produce more impactful results for producers who are curious but hesitant. Particularly important is the need for feedback loops between producers and researchers – there must be channels for producers to share their field experiences with researchers who can then make appropriate modifications to research and innovation through the development process (FWWF, 2023b). This is precisely the gap that the Regenerative Alberta Living Lab is working to fill, by facilitating collaborative, producer-led research, and connecting regenerative producers with problem-solving and guidance from experts (Regenerative Alberta Living Lab, n.d.-b).

2.3.4. Education and Knowledge-Sharing

There are many education- and knowledge-related barriers to adoption of regenerative agriculture methods. FWWF engagement work revealed the following reasons why producers felt they could not adopt regenerative agriculture practices (FWWF, 2021):

- *"lack of personal knowledge about regenerative agriculture and how to implement it"*
- *"lack of demonstrations on BMPs"*
- *"not enough education on regenerative agriculture"*

- *“not enough education or advisors (who are knowledgeable on regenerative agriculture in the Canadian Prairies)”*
- *“uncertainty on how to implement a new BMP – I see things I would like to do, but I don’t know how to do them”*
- *“mentoring + practical + academic knowledge together”*

These barriers were echoed through engagement with industry stakeholders, who also felt that producers have an insufficient bank of regenerative agriculture knowledge resources to access. Engagement participants reported that there is a gap between academic and practical knowledge in university and college curriculums, leaving new graduates to become CCAs and PAgs who are unprepared to provide the regenerative agriculture knowledge that producers are seeking (FWWF, 2023b). Many producers in FWWF engagement sessions (FWWF, 2021; FWWF, 2023b) stated that whether an expert or advisor has practical farming experience is an important factor in whether they earn the trust of producers who are seeking knowledge and advice.

Producers also suggested that more connections between post-secondary students and farmers, and better practical training for students, would result in new graduates who better understand the practical experience of farming. In fact, another participant in the TA study believed that focusing on better regenerative ag training for current post-secondary students would be more influential than training current PAgs and CCAs, who may be stuck in the conventional farming paradigm they were taught (FWWF, 2023b).

Producers and industry stakeholders stated through FWWF engagement sessions (2021, 2023) their concerns about misinformation on BMPs from advisors and influencers both locally and online. Individuals with a large following, or in a position of influence, might be sharing inaccurate or contextually inappropriate information on how to implement BMPs. Misinformation with no ongoing support could lead to adoption but with poor outcomes - which is not only likely to impede further adoption, but could damage the regenerative agriculture movement in general, as one producer stated – “*bad advice is worse than no advice*” (FWWF, 2023a).

Producers also stated a need for *“education and communication for regenerative practices that don’t have money or profit attached to them as marketing of chemicals does”* (FWWF, 2021). In 2015, a Needs Assessment conducted by FWWF with Alberta producers revealed the same insight - conventional farmers who want to try something new found the advice they have access to is tied to representatives who are selling products (FWWF, 2015). Multiple farmers reported to FWWF that they need access to agricultural research, advice, and innovations that are unbiased and not linked to someone who has products to sell (FWWF, 2015). Producers in the Living Lab roundtable discussion (RALL, 2023b) also felt this was a barrier, as one stated that there were “*more people who are selling things (biological) - hard to know what is worthwhile*.”

2.3.5. Social and Community Networks

Producers face social and cultural barriers for adopting practices that go against the accepted farming norms in their region. Burton et al. (2008) discuss the cultural perception of what a tidy, well-managed farm looks like, and it generally does not include fields full of multi-species cover crops left for grazing or decaying into the soil while the neighbours' monocropped fields are harvested neatly. They note that the cultural preference for "tidy farming" is well known and documented, and producers may indeed feel that there is a social stigma to having a "messy field" (Viresco, 2022).

The significant role of social capital in producer decision making should not be underestimated. Producers value their peers' opinions and knowledge more than anyone else's, which means that knowledge sharing is heavily intertwined with, and sometimes inextricable from, social networks. Research in Manitoba and Ontario found that producers strongly preferred learning through social networks and other resources suggested by their peers and neighbours, over any other information source (Laforge & McLachlan, 2018).

However, producers stated in FWWF engagement sessions (FWWF, 2021) that they *"have no peers or peer support"*, *"lack of opportunity to work together"* and *"not enough chili parties to build community."* Interviews with industry stakeholders (FWWF, 2023a) reinforced this with a clear pattern in the responses related to social networks and community. Multiple participants stated that producers need more opportunities for quality peer to peer learning and connecting with other producers.

"Farmers learn from each other, and from people who speak their language"

Industry stakeholder (FWWF, 2023a)

Participants also described the need for more support for grassroots organizations and improved communication between local information sources. They stated that more money was necessary to increase the capacity of farmers and smaller groups who are working to share regenerative agriculture information with other producers. Supporting these channels supports producers directly, and will encourage more effective and trustworthy communication, which is significant, as research has shown that producers tend to trust other producers more than any other information source (Ranjan et al., 2019).

In fact, a systematic review of qualitative research on BMP adoption in U.S. farmers (Ranjan et al., 2019) found that farmers always perceived other farmers as a trusted information source, and that trust acts as a driver of BMP adoption. This aligns with a finding from the same review paper – that a feeling of trust in their community actually motivates producers to adopt BMPs (Ranjan et al., 2019). Producers and industry stakeholders in FWWF engagement sessions agreed, as many responses mentioned that peers are the most trusted source of knowledge for producers (FWWF, 2021; FWWF, 2023a).

2.3.6. Approach to Communication and Policy

Another common theme that emerged from producer engagement was that of the approach to communication related to regenerative agriculture. Many producers and industry stakeholders commented on how using the right approach is critical to increasing adoption of regenerative agriculture. The Trusted Advisor Study engagement sessions (FWWF, 2023a) revealed the following insights as to how the wrong approach may act as a barrier to a producer's decision to adopt:

- *"tie sharing of knowledge to producer goals – offering info, support, tools, framework vs. more simplified recipe in conventional farming"*
- *"approach is key – sharing knowledge vs. casting judgment"*
- *"approach with goals/problems of the farmer vs. discussion of benefits of cover cropping/BMPs"*
- *"farmers are skeptical of individual BMPs – need systems approach with combined BMPs – systems thinking is a pathway in regenerative agriculture adoption"*
- *"it's a sensitive subject and need to not dismiss those farming in conventional way, they are still the main client"*
- *"need to balance hope and realism"*
- *"any change towards regenerative agriculture will need to be incremental rather than big overhaul"*

These responses show some contradictions and highlight the importance of recognizing the heterogeneity of the Prairie producer population. Change takes time and will need to be incremental, but farmers are skeptical of individual BMPs and need a systems approach to the whole philosophy. Small, incremental changes are easier and more realistic to adopt whereas the idea of changing your entire farm may be too overwhelming for most producers. A problem-solving, targeted approach that promotes BMPs is more focused on specific challenges, while a systems-based approach fosters a whole-farm perspective of regenerative agriculture. Regardless, participants agreed that the approach used must be careful to not be judgmental towards or dismissive of conventional producers. Alienating the majority is not an effective way to promote large-scale adoption of a new agricultural paradigm with significant climate mitigation and adaptation potential.

Some producers and industry stakeholders in FWWF engagement sessions felt that communications and knowledge-sharing should use a practical, problem-solving approach that focuses on helping producers understand options and practices that could benefit their farm and their specific challenges. Although this targeted approach may be more relatable to producers, it conflicts with the systems approach to regenerative agriculture.

“We used to think about technical assistance as solving for single-issue productivity challenges… now we need to think about technical assistance as a whole farm process that asks what is the limiting factor in this system, and how can we use soil health practices to solve for those issues?”

Ohio farmer Fred Yoder (Sustainable Food Lab, 2023, p.11)

Producers in FWWF engagement sessions recognized the important role of policy to bring about greater adoption of BMPs - but emphasized the need for policymakers to use the correct approach and not alienate their audience. Producers in the Trusted Advisor Study engagement sessions (FWWF, 2023a) stated that “*policy is the place to make big changes and need[s] to be positive about messages and not dump on the conventional [farmers]”* and *“it is a sensitive subject and [they] need to not dismiss the farmers farming in the conventional way.”*

Recent adoption literature seems to be prioritizing producer perceptions, producer identity and values, and producer attitudes towards regenerative agriculture practices. Prokopy et al. (2019) state that producers who are aware of, or have a positive attitude toward, a specific BMP are more likely to adopt the practice. While this may seem obvious, it highlights the importance of ensuring that producers can access the information and opportunities they need to be able to form positive attitudes about these practices (Prokopy et al., 2019). This is echoed in a recent study by Mu et al. (2023) which discusses the need for effective pathways to communicate climate change information to producers, as individual perceptions of climate change were found to act as barriers to adaptation strategies including water-saving irrigation, crop diversification, and alternative marketing channels.

2.3.7. Political and Policy Factors

Political and policy factors are significant structural barriers to producers’ willingness to adopt regenerative agriculture. In FWWF engagement sessions (2021 and 2023), producers reported several ways that political or policy issues act as barriers to adoption, including the lack of standard definitions for BMPs and regenerative agriculture, crop insurance policies, check-off system incentives, inappropriate policy approach, and a carbon tax system that does not benefit producers.

Prairie producers and industry stakeholders agree that the lack of universal language for regenerative agriculture is a barrier to adoption. In engagement sessions, producers and industry stakeholders stated repeatedly that Canada needs a clear and consistent definition of what regenerative agriculture is, what BMPs are considered regenerative agriculture practices, what the criteria are for each BMP, who is considered a regenerative agriculture producer, and what consistent language will be used to define the field (FWWF, 2021; FWWF 2023a).

In an exploration of BMP adoption by Southern Ontario producers, Lamba et al. (2009) heard from many producers who felt that the government was too heavily involved in farming and that regulations were interfering with their ability to manage their farms productively. These producers' perception of heavy government involvement and excessive regulations degraded their trust in the government. Producers interviewed in the Ontario study stated repeatedly that a more effective way to encourage greater adoption of BMPs was through voluntary, confidential programs that offered significant financial incentives (75-95% coverage) and technical support, and were implemented by local producer peers and farm leaders (Lamba et al., 2009).

"Need more resources – new programs bring money but are not reliable, and often just put more strain on [an] already stretched system."

Prairie producer (FWWF, 2023b)

The Trusted Advisors Study (FWWF, 2023b) revealed some skepticism from producers related to how helpful government funding programs are. One producer said that we should *"question current incentives - do they actually meet a need or are [they] 'just try it' money?"* (FWWF, 2023b). Still, there is optimism that these programs and financial incentives could be the tipping point needed for some producers to embrace regenerative agriculture, especially those who are curious but not yet committed. Producers in the TA study (FWWF, 2023b) believed *"OFCAF [On-Farm Climate Action Fund] may allow hesitant people on the fringes [the chance] to try some of the practices and see how they go."*

"Money available could make the paradigm shift more possible"

Prairie producer (FWWF, 2023b)

2.4. Awareness Barriers

Through FWWF engagement sessions and RALL roundtable discussions, producers made several mentions of how ego and ingrained beliefs or assumptions can be barriers to the adoption of regenerative agriculture. One producer commented that this barrier can be seen in producers' *"belief that what they're doing is working and that they understand it already."* Producers with this mindset may perceive that, for example, 'Improved Nutrient Management' is what they are already doing on their farm. They may feel that their nutrient management practices are working and as such they have no reason to learn what 'Improved Nutrient Management' as a BMP entails, nor to adopt it.

Personal ego or lack of humility presents an awareness barrier in that it limits producers' drive to seek out information on BMPs or on how their implementation of BMPs could be improved. This is explained clearly by Krumrei-Mancuso et al. (2020) who stated, "simply put, learning requires the humility to realize one has something to learn" (p. 155).

Moreover, producers may believe or assume that their way of implementing a farming practice is the correct way, although it may be significantly different from how a practice is defined by industry, technical experts, or researchers. This can be seen in the confusion over the term 'vertical tillage' which is a new practice that has not yet been precisely defined (Zeng et al., 2021) either in research, industry, or at the farm level. Section 3.5.1.5. discusses the inconsistencies between Prairie producers' practice of vertical tillage, the generally accepted consensus of the practice, and the labeling criteria used for tilling equipment.

If producers assume they understand what the practice is, and believe they are practicing it correctly with the correct equipment, there is a barrier to their awareness of the full scope of the practice. Programs or policies promoting adoption of vertical tillage may be entirely overlooked by producers who believe they already have vertical tillage in place.

3.0. Crop Production BMPs

Section 3.0 discusses regenerative agriculture BMPs that are directly applicable to crop production in the Canadian Prairies. These BMPs fall into the broader categories of cover cropping, crop diversity, nutrient management, integrated crop-livestock systems, tillage, and agroforestry. All have direct impacts on crop productivity and soil health and vary in their GHGE mitigation potential in Prairie agricultural contexts.

Through sections 3.0 and 4.0 this report discusses individual BMPs and corresponding sub-BMPs, which are more specific practices that fall under the umbrella of a more general BMP category. Barriers to the adoption of each BMP and sub-BMP will be presented within the contexts of the four broad categories: economic barriers, agronomic barriers, socio-cultural barriers, and awareness barriers.

3.1. Cover Crops

A cover crop can be defined as an additional crop grown during a period of time when no crop would normally be grown (Drever et al., 2021b; Morrison, 2021; Morrison & Lawley, 2021; Viresco, 2022). Prairie producers would generally agree with this definition, but also would consider the term cover cropping to include crops grown for grazing or other production purposes, as well as those grown and then terminated for soil health purposes. However, there is still significant inconsistency in how research defines cover cropping practices. With no single, universal definition of what a cover crop is, comparison of research findings is challenging.

Some research, like the 2020 Prairie Cover Crop Survey Report (Morrison & Lawley, 2021), and the Viresco report (2022) use a definition of cover crops that includes annual cover crops grown as forage for grazing livestock but excludes perennial grazing forage crops. Typically, winter cereals grown for harvest are not considered cover crops (Viresco, 2022). In 2015 however, the Canadian government published its Census of Agriculture and included the use of winter cereals in their reported prevalence of winter cover crop use on Canadian farms (Statistics Canada, 2015).

Viresco (2022) reports that intercrops are not considered cover crops, however the 2019 (Morrison, 2021) and 2020 (Morrison & Lawley, 2021) Prairie Cover Crop Surveys include numerous mentions of intercropping as an important and common technique used by Prairie producers for establishing cover crops. This significant difference is likely explained by different interpretations of the term intercrop. While Viresco (2022) defines intercropping based on the goal of growing two or more crops together to be harvested for grain, Morrison (2021) and Morrison and Lawley (2021) define intercropping as a method of establishing a cover crop by seeding it into a cash crop. In fact, Morrison (2021) noted that 54% of producers who responded to the 2019 Prairie Cover Crop Survey had established their cover crops through intercropping. The Viresco report (2022) identifies this practice as interseeding, not intercropping. The inconsistency in the terminology and definitions of regenerative agriculture practices surely contributes to confusion in tracking trends in practice adoption, inaccurate comparisons of research findings, and miscommunication between researchers, policymakers, and producers.

Economic Barriers

Economic barriers to cover cropping include both direct and indirect costs. Viresco (2022) and Bain (2021) report that upfront costs for seed, sowing, labour, and equipment are major barriers to cover crop adoption. Labour and equipment availability may be limited at fall harvest time, when cover crops may need to be seeded (Viresco, 2022). Cover cropping practices have a steep learning curve, and both soil health and economic benefits may not be apparent for the first few years (Bain, 2021). Prairie-specific data on benefits from cover cropping is limited, but a US study, as reported in Viresco (2022), suggested that three to five years of annual cover crop usage may be needed for producers to see tangible soil health benefits through higher crop yields and less need for inputs (Myers et al., 2019).

These American estimates may even be a bit more conservative than what the 2020 Prairie Cover Crop Survey heard from Prairie producers who grew cover crops in 2020. Of the 281 producers who completed the survey, 71% stated they saw benefits from cover crops within three years of initial adoption, and over 35% actually saw benefits within just one year, with the most common benefits being improved soil health, increased biodiversity, and increased soil organic matter (Morrison & Lawley, 2021). Researchers in Ontario conducted a study on the profitability of cover crops in sweet corn production over two years and found that fields with cover crops were just as profitable, or even more profitable, than fields without cover crops, regardless of the rate of nitrogen fertilizer used (O'Reilly et al., 2012).

There are indirect costs to producers as well, including crop insurance. FWWF engagement sessions (2021) heard that Prairie producers viewed crop insurance as a barrier to adoption of regenerative agriculture methods. A report on BMPs in the Canadian Prairies (Viresco, 2022) noted that planting a full season cover crop instead of fallow could reduce producers' insurance coverage for their subsequent cash crop. Organic lettuce farmers in California stated that terminating the cover crop in the spring could delay the ability to plant their cash crop, and they weren't able to tolerate that level of risk (Carlisle et al., 2022). Most crop insurance policies have seeding deadlines, so if producers are delayed in seeding their cash crop, they may lose their eligibility for that crop to be insured that year.

A systematic review of U.S.-based studies on farmers' behaviours relating to conservation practices and programs also noted that farmers' fears of reduced crop yield negatively impacted their adoption of many BMPs, including cover crops (Ranjan et al., 2019). In their work in the U.S. High Plains agricultural region, Rosenzweig et al. (2020) found that some producers were less tolerant to the risk of yield loss and therefore continued with the wheat-fallow system rather than adopt cover cropping and crop diversification practices. This ensured they had a more consistent wheat yield, yet being reliant on only a single crop increased their risk of losses due to market variabilities (Rosenzweig et al., 2020). These producers valued the security of consistent short-term crop yield more than profitability through long-term soil health improvements (Rosenzweig et al., 2020).

Agronomic Barriers

Producers and researchers have reported numerous agronomic barriers to producers' adoption of cover crops in the Prairies related to timing, uncertainty, and variability in cover crop practices (Bain, 2021; Viresco, 2022), weather and climate issues, and interference from weeds. Producers also report that planting fall cover crops around the same time as cash crop harvest can cause timing conflicts for availability of both labour and equipment.

During recent roundtable discussions (RALL 2023a; RALL 2023c), Alberta producer participants in the Regenerative Alberta Living Lab contributed their perspectives and personal experiences with cover crops. Comments related to cover crop-related weed problems were a common theme, as seen here in producer responses:

- *"dabbled in cover crops but weeds wrecked it"*
- *"tried broadleaf cover crops but too much manure and weed competition. Now using Italian ryegrass and regular rye"*
- *"[need help with] cover crops, especially with weed issues"*
- *"also struggle with weeds after first grazing but the ones the cattle don't like become a problem quickly so I pre-mow portions of a field before the cattle get to that area to set it back so it's at the right stage when the cattle get to it"*

A crop consultant present at the discussion also had similar issues in their work, stating "working with cover crops as a consultant. Tried some but had weed control disasters so looking to continue that and improve soil health and carbon" (RALL, 2023a).

Through FWWF engagement sessions in 2021, Prairie producers shared the following agronomic barriers to cover crops:

- *"lack of consistent moisture"*
- *"short growing season in northern Prairies"*
- *"changing weather patterns"*
- *"agroclimatic barriers i.e. how to put in a cover crop in time and terminate"*
- *"challenges with timing of grazing"*
- *"weed pressure"*
- *"high variability of rainfall"*
- *"no good protocol"*

The lack of consistent moisture and the short growing season were mentioned several times by producers in FWWF engagement sessions (FWWF, 2021) and these barriers are consistent with findings from other Prairie research on cover crops. Martins et al. (2021) report that soil moisture and growing season length are barriers to Canadian adoption of cover cropping. For the 2020 Cover Crop Survey, Callum Morrison and Dr. Yvonne Lawley noted that the most common challenges reported by producers were the short growing season and the lack of soil moisture (Morrison & Lawley, 2021).

In a separate article (Better Farming, 2020), Dr. Yvonne Lawley states that two pressing concerns that Prairie producers have regarding the timing of cover crops are: (a) how early fall cover crops should be planted and (b) when they should be terminated before the next grain crop. The 2020 Cover Crop Survey noted that many producers had problems with cash crop harvest delaying the planting of their cover crops (Morrison & Lawley, 2021). Thiessen Martens et al. (2015) suggest that using cover crops in integrated crop-livestock systems or other new methods could promote adoption, but they are clear that "finding a temporal niche for cover crops in the short growing season of the Prairies remains a challenge" (p. 1063).

Both producers and researchers report that the lack of information available to producers, especially technical advice, is one of the most significant barriers to their adoption of cover crops in the Prairies (Jeffers-Bezan, 2023; Morrison, 2021). There is a subset of the Prairie producer population who are interested and motivated to adopt cover cropping but cannot access the information or technical support that they need to get started and established. Data on successful cover cropping in the Canadian Prairies is very limited (Morrison, 2021), which brings uncertainty to the practice of cover cropping and makes it more difficult for producers to clearly see what direct benefits they will receive (Viresco, 2022). The 2020 Cover Crop Survey Report (Morrison & Lawley, 2021) identified a clear information barrier; in fact, producers stated that technical assistance would be the most important factor that would enable them to adopt cover cropping (Jeffers-Bezan, 2023).

An insufficient base of Prairie-focused research data has resulted in a lack of optimal agronomic protocols for cover cropping in Prairie agricultural contexts and this gap is a key barrier to producer adoption. There is a significant range of cover cropping practices and what works best is highly dependent on local geography and crop variety (Bain, 2021). Cover cropping practices must be tailored to producers' climate, soil, and geographical conditions, and to their type of production systems. The climatic variability seen throughout the vast Prairies means that the cover cropping protocol that works in one area is likely to fail in another area.

Thiessen Martens and Entz (2000) found that south-central Manitoba had the most ideal heat and water conditions to support production of winter wheat through relay cropping and double cropping. Southern Saskatchewan and southwestern Manitoba, however, had insufficient precipitation to support these systems, and northern and western Prairie regions did not have enough days of warmth to support winter wheat. Producers in these regions may have success in relay cropping and double cropping by growing varieties that are more suited to drought conditions or a shorter growing season (Thiessen Martens & Entz, 2000). These findings highlight how the knowledge gap in regional agronomic cover cropping protocols tailored to different agro-climatic conditions across the Prairies acts as a barrier to producer adoption of cover cropping practices.

Despite these challenges, many producers in the RALL discussions expressed continued interest in learning more about cover crops, and specific cover crop protocols for their geographic region and type of farming. One producer stated they needed *"more diverse, longer season, cover cropping, relay cropping options for producers in the longer season, irrigated areas"* (RALL, 2023a).

"[We] need more information on cover crops…everyone's environment is different. Grey wooded soils are responding differently to it and there's so many variables. Hairy vetch is supposed to be the answer, but it won't grow for [me]"

RALL producer (RALL, 2023a)

These responses from RALL producers show persistence and a desire to continue trying cover crop practices in spite of previous negative outcomes. Challenges like weed control may not be an insurmountable barrier for regen ag-motivated producers like those in the RALL program, but for producers who are less motivated, or with fewer accessible resources, weed problems could be a major barrier to cover crop adoption.

Canadian cover crop literature is limited; however, the American literature echoes these perspectives. Numerous mentions were found of producers reporting that cover crops can interfere with their cash crop production. Many of the Iowa farmers surveyed in a qualitative study on cover crop barriers (Roesch-McNally et al., 2017) stated that managing the timing of seeding and terminating a cover crop, and the risk that it would interfere with their cash crop, were significant reasons for their decision to not adopt the practice. In a systematic review of U.S.-based adoption studies, Ranjan et al. (2019) reported that producers often felt that the timing protocol for cover crops made them incompatible with their farming operations.

Socio-Cultural Barriers

These socio-cultural barriers apply to all cover crop practices in section 3.0. Socio-cultural barriers that apply to specific cover cropping practices will be mentioned in individual BMP sections below. There are numerous socio-cultural barriers that interfere with producers' adoption of cover crops, including overwhelm from a wealth of information, a lack of information available that is relevant to the Prairie context, as well as social isolation and a reluctance to adopt a practice that is viewed as alternative or experimental.

Cover cropping practices contrast sharply with conventional monocrop Prairie production systems and are therefore perceived as alternative or experimental practices. Many producers are uncomfortable adopting practices that are outside of social farming norms and that will be viewed negatively by neighbours and peers.

It is well known that rural producers have close, trusted, highly valued connections with their local peers. It is understandable then, that these close peer networks can work against those who do not follow the socially accepted norms. Social isolation which may result from going against farming norms, is a legitimate challenge for some regenerative agriculture producers. Indeed, a cover-cropping farmer in the Rosenzweig et al. (2020) study reported that he "*quit going to the coffee shop because [other farmers] look at you like you're – I mean you may as well have flown a UFO in because they think you're crazy*" (p. 567). This highlights the importance of having opportunities and platforms available for regenerative agriculture producers to form peer-to-peer connections and reduce social isolation.

"*Plant a cover crop in the middle of an area of conventional agriculture and you will be diminished in the eyes of your neighbors*"

U.S. farmer (Sustainable Food Lab, 2023, p.8)

Producers may be reluctant to learn about a new practice or to make changes to their current practices. Factors such as ingrained farming norms or the status quo bias drive producers to continue the practices they have always used and resist learning new techniques, even if they could bring greater benefits than their current practices.

Those who are motivated to learn may find barriers in the information available to them. While there is a good amount of information available on various cover cropping practices, producers may be overwhelmed and not be able to discern what is relevant and accurate information that would be helpful to them. At the same time, the lack of specific information available on how to implement cover cropping practices within a typical Prairie farm is also a barrier.

Some Prairie producers lack access to a local processing facility that will accept intercrop or polycrop harvests. Another challenge mentioned by one producer is their lack of control over their rented cropland, which limits the practices they can adopt. Producers who rent their land may have restrictions that prohibit atypical farming practices such as cover cropping or polycropping.

Awareness Barriers

Cover cropping is not an overly common practice in the Canadian Prairies. As such, many Prairie producers are unfamiliar with or unsure of both the definition and the technical details of cover cropping practices. Through FWWF's advisor, we have heard that the lack of awareness of cover crops on the Prairies is a barrier to producer adoption. Producers are likely also unaware of the full spectrum of long-term benefits of cover cropping and the lack of awareness of the on-farm, ecosystem, and societal benefits from cover cropping presents a barrier to adoption. These awareness barriers apply to all cover cropping practices discussed in section 3.1.

3.1.1. Cocktail Cover Crops

Agriculture and Agri-Food Canada (2021) defines cocktail cover crops as "the intentional co-planting of several species of plants in the same field or plot." Cocktail cover crops are also known as polyculture cover crops, or multi-species planting, and are grown from seed mixes of up to a dozen or more different species, which can either be purchased as a pre-made seed mix or created by the producer blending their own seed. Cocktail mixes are promoted as providing greater ecological services and having higher productivity and better pest suppression than monocultures (Smith et al., 2020).

In the Prairies, producers would consider any two or more species grown together, including a forage stand, to be a cocktail cover crop. Thus, a cocktail cover crop could have as few as two, or as many as a dozen or more species. There is some overlap in producers' definitions of cocktail cover crops and polycropping.

Research on producers' perspectives on cover cropping rarely distinguishes between specific cover crop subcategories such as cocktail crop mixes or fall-seeded cover crops. Although the literature is sparse, some specific barriers to producers' adoption of cocktail cover crops have emerged.

Economic Barriers

Cocktail cover crops can be grown by producers creating their own seed blends, or by purchasing commercially available pre-mixed seed blends. Producers have found that commercially available cocktail seed mixtures are often quite expensive (Stockford, 2020). A Manitoba producer who has already implemented a 15-species cover crop on his farm shares that pre-mixed cocktail blends may not be compatible with everyone's soil type, even when they are designed for local conditions (Stockford, 2020). The high cost of pre-made cocktail mixes may also reinforce the cost barrier to hesitant producers, who are then likely to see the practice as too financially risky (Stockford, 2020).

Agronomic Barriers

Some producers in the Regenerative Alberta Living Lab have adopted cocktail cover crops and have experienced some challenges in implementation, especially related to moisture and pests. In the RALL roundtable discussion (RALL, 2023c), producers mentioned the following challenges with their cocktail cover crops:

- *"moisture and pest issues affecting diversity in cocktail mixes"*
- *"hit some dry years, thought it was drought but think it's more than that, like we hit a plateau, did come back a little, but not getting the same as the first few years"*
- *"grasshoppers are a huge problem, every second year"* [Peace region of Alberta]
- *"establishment was a challenge for cocktail mix, with regard to moisture and crop competition"*

- *“lack of moisture for small and shallow seeded crops, less regrowth for grazing”*
- *“cocktail mix maturing with ryegrass seed emerging as a weed in future crops”*
- *“trying to utilize mixed species cover crops for swath grazing but weed management is becoming a problem because there aren't many options. Been doing it about four years now and the weed load seems to be getting bigger and bigger”*
- *“multispecies blend limits your options [for weed management] because of broad spectrum of species”*

A study in New Hampshire, U.S.A. (Smith et al., 2020) tested cover crop monocultures against cover crop mixtures of a variety of species including annual cool-season and warm-season grasses, legumes, and non-legume forbs. The study found that the mixtures did not suppress weeds as effectively as some monocultures did. The authors stressed that if weed suppression is a producer’s primary motivator to adopt cover crops, a cocktail cover crop blend may leave them frustrated and turned off of cover crops altogether. However, similar research in Saskatchewan found that some simple blends of cover crop species produced weed suppression equal to some monocultures (Bainard, et al., 2020).

Timing can also be a barrier to adoption of cocktail cover crops. The complex mix of species needs time to grow and is not well-suited to a fall-seeding cover crop practice (Stockford, 2020). If a producer is looking for a fall-seeded cover crop to fit into their operation, they may have expensive and disappointing results with a cocktail blend. Viresco (2022) highlights the need for further research on cover crop species, and species mixes, to determine protocols for optimal agronomic productivity under Prairie soil and weather conditions.

Socio-Cultural Barriers

While creating their own cover crop seed blend is far more economically feasible, producers then face the challenge and complexity of determining which species, and at what amounts, to use. Learning how to select the right cover crop species for your farming operation is a significant investment of time, money, and energy; full-day seminars are offered to producers just to help guide them through cover crop species selection (Stockford, 2020). They also need to invest time and money in experimenting with seed blends to determine the optimal mix for their weather and soil conditions and may experience poor outcomes along the way.

3.1.2. Fall Seeded Cover Crops

Fall-seeded cover crops are seeded after cash crop harvest in the fall and grow during the shoulder season. These crops will grow through the fall and the next spring before the next cash crop is seeded. Producers in the Prairies would also define fall seeded cover crops this way, although termination could be either late fall or the following spring, and the crop would not be grown for grain, but may be used for grazing purposes. Producers would consider this practice to be the same as relay cropping. Limited research is available on the agronomic outcomes of fall-seeded cover crops on the Canadian Prairies.

Economic Barriers

Prairie producers face economic barriers to fall-seeded cover crops that include the risk of a reduced cash crop yield, the costs for purchasing and planting seeds, and the extra time and labour involved with a second seeding process during the growing season.

Although the literature findings are inconsistent, there is some evidence that fall-seeded cover crops can reduce the yield of subsequent cash crops. Moyer and Blackshaw (2009) studied fall rye, winter triticale, barley, and oat as fall cover crops, planted after potato and dry bean crops in southern Alberta. They noted that both fall rye and triticale reduced subsequent wheat yield.

Agronomic Barriers

Producers who consider fall-seeded cover crops on their farms may encounter several agronomic barriers to adopting this practice. There is some evidence that fall rye can have an allelopathic effect that can reduce subsequent crop yield (Moyer & Blackshaw, 2009), although other research has shown this effect to cause weed suppression without reducing subsequent crop yields (Thiessen Martens et al., 2015).

Biophysical conditions including precipitation levels and growing season length can be barriers to producers' success with fall cover crops. Moyer and Blackshaw's (2009) study also found a slight reduction in soil moisture after a cover crop, and no reduction in weed density from any cover crop studied. Researchers in Manitoba and Alberta found that late-season cover crops can reduce soil moisture levels, which could be a significant barrier for producers in drier regions of the Prairies (Thiessen Martens et al., 2015).

Moisture levels in particular may be the limiting factor for fall cover crop success on Prairie farms. Indeed, Thiessen Martens et al. (2015) report that although the growing season is long enough to support cover crop production in many regions of the southern Prairies, "southern Manitoba may be the only region that consistently receives enough late-season moisture" (p.1052). A Manitoba producer shared that due to limited sunlight and moisture, and such a short growth window, cover crops seeded in the fall had a higher chance of failure than those at other times of the year (Stockford, 2020).

Moreover, producers may not experience the tangible benefits that they would expect from cover crops. Moyer and Blackshaw's (2009) study also found that fall cover crops failed to protect soil from fall and winter wind erosion. Cover crops planted after both potato and dry bean harvest did not reduce soil erosion through the fall and winter, although by the following spring they may provide enough ground cover to prevent soil erosion at that time.

Agronomic barriers to seeding cover crops in the fall also include the timing conflict for labour and equipment availability during the busy cash crop harvest time.

Awareness Barriers

In addition to the awareness barriers to all cover crop practices, listed in section 3.1., a terminology difference is also a barrier to the adoption of fall seeded cover crops. As mentioned, Prairie producers may refer to this practice as relay cropping. As such, producers may be unfamiliar with the term ‘fall-seeded cover crops’ and unaware of what the practice entails, even if they are personally familiar with relay cropping.

3.1.3. Fall Seeded Cash Crops

Producers would call this a fall seeded crop and would consider this to be the same as a fall seeded cover crop, except this would be a grain or forage crop meant for harvesting. An important discrepancy in terminology should be emphasized here. Viresco (2022) reports that typically, fall seeded cash crops would not be considered cover crops. However, Statistics Canada has classified winter cereals as winter cover crops in both their 2016 and 2021 Censuses of Agriculture (Statistics Canada, 2016; Statistics Canada, 2021). Question number 35 on the 2021 Census asks producers, “In 2020, did this operation use the following land practices? Planting winter cover crops – Include fall rye, winter wheat, and red clover” (Statistics Canada, 2021, p. 14).

Morrison (2021) suggests that the inclusion of winter cereals has resulted in an overestimation of the current adoption levels of true winter cover cropping in the Prairies. This is a clear example of how the lack of universal definitions for BMPs contributes to inaccuracy in estimating adoption levels.

Economic Barriers

FWWF’s advisor identified many economic factors that create barriers to producer adoption of fall seeded cash crops. An additional crop means additional expenses above what they are already paying, including the costs for seed, costs for increased labour and time needed for seeding and harvest, and an overall higher cost of production. The lack of crop insurance coverage for fall seeded cash crops is also an economic barrier as producers face a greater financial risk without the safety net of insurance.

A cash crop will bring additional revenue after being sold; however, producers may not be able to predict the actual profit they will earn after accounting for their additional expenses. Market availability is a barrier to many Prairie producers who may not have access to a market locally that is appropriate for their cash crop.

Agronomic Barriers

There are many agronomic barriers that interfere with producers who want to grow fall seeded cash crops. From the producers’ perspective, there is no clear agronomic protocol that helps them learn how to grow a fall seeded cash crop or how to select the most optimal species.

Many producers who want to establish a fall seeded cash crop feel that the risk of plant diseases and weeds are barriers to their success. They may also struggle with determining the appropriate application rate for fertilizer.

While the agronomic benefits of growing a fall crop can improve a farm's climate resilience, the investment of money into an extra crop is a risk if an extreme weather event were to occur. Producers may feel that the risks from drought, flood or wildfire are too high given the costs and time they put into a fall crop.

Finally, seeding an additional crop in the fall involves a significant amount of labour and equipment use. Labour and equipment resources needed for main crop harvesting may be too busy and not available for seeding a fall cash crop. This timing conflict for labour and equipment resources presents a barrier to producers.

3.1.4. Intercropping

As noted in Section 3.1, the introduction to cover cropping, there is inconsistency within the literature on the definition of intercropping. Agriculture and Agri-Food Canada (Government of Canada, 2021) and the Viresco report (2022) both define intercropping as a method of planting and growing two or more crops together, in the context of cash crops grown for harvest, rather than the monocrop field that is typical in the Prairies. Some academics, however, include cover crops in their definition of intercropping (Morrison, 2021; Morrison & Lawley, 2021), and Thiessen Martens et al. (2015) state that "the benefits of intercropping may also be realized in non-grain crops such as cover crops, green manures, and annual forages" (p.1054).

Prairie producers would tend to use the term intercropping in the same way as the Viresco report, and Agriculture and Agri-Food Canada, that is, to refer to two or more crops harvested for grain, not cover crops. In the interest of consistency with producers' perspectives, this report will focus on intercropping as it relates to two or more cash crops grown together for the purpose of harvesting. Although literature that explores direct producer perspectives on intercropping barriers is very limited, numerous barriers have been identified by researchers and agronomists, many of which align with the producer responses from Living Labs discussions.

Economic Barriers

Dr. Luke Struckman led a project (Struckman, 2021) funded by General Mills that assessed oat-pea intercropping test plots on a small sample of farms in Saskatchewan, Manitoba, and North Dakota. The researchers then interviewed participating producers who gave their perspectives on barriers and benefits to intercropping (Struckman et al., 2021), many of which aligned with the barriers mentioned in the Viresco report (2022).

Separating crops after harvest is a major economic barrier (Viresco, 2021) and Prairie producers reported that the cost of commercial grain separation can reduce profits significantly (Struckman et al., 2021). Producers in FWWF engagement sessions mentioned their lack of access to seed sorting and other equipment necessary to adopt and maintain intercropping practices (FWWF, 2021). Some producers feel that the returns they would get through the marketplace may not be sufficient for them to justify the work involved in separating grain (Beef Cattle Research Council, 2021).

Grain separation and cleaning is less costly if done on-farm with a basic rotary grain cleaner (Heppner, 2018; Struckman et al., 2021). However, additional costs may be needed for equipment modifications to allow for one-pass seeding (Heppner, 2018) and producers will then face an even greater demand for labour during the already very busy harvest season (Viresco, 2022).

Separation of harvested intercrops is typically required for commodity crop producers in the Prairies. In general, the commodity crop market will purchase only one crop at a time and will not accept a mixed intercrop. While there are some markets for unseparated intercrops available in the Prairies, they tend to be very limited and localized, and are generally not accessible to most producers. Unseparated intercrops like peas and barley can serve a purpose in some farming operations, such as for use as livestock feed (L. Fuller, personal communication, March 28, 2024). These arrangements require alignment between the scale of the marketer of the intercrop and the buyer. As a result, for most commodity crop producers, the barrier remains – their intercrops must be separated to be saleable on the commodity market.

Although the oat and pea varieties used in the General Mills project were selected because of their similar maturity dates, many producers noted that the crops did not mature evenly (Struckman et al., 2021). Intercrops that mature at different times can cause crop damage and loss of value to the earlier crop (Viresco, 2022). Producers in the oat-pea project (Struckman et al., 2021) were concerned about the risk of their green peas bleaching in the field while they waited for the oat crop to mature. Bleached peas will be downgraded at market, causing a loss of potential income on that harvest (Oosterhuis, 2017).

Producers also noted that grain buyers may refuse mixed crops for fear of potential allergen contamination or milling problems (Briere, 2021). Harvested mixed crops may also require more on-farm storage space than monocrops (Briere, 2021). Viresco (2022) reports that there is some evidence that intercropping may lower crop yields; however, they do not provide further context, nor do they cite the specific source for this point.

Producers in the Struckman et al. (2021) project stated that crop insurance policies were a significant barrier to their adoption of intercropping as the policies restrict the acreage used for each season's new cash crops. A Manitoba agrologist who evaluated canola and field pea (peaola) intercropping noted that insurance presents a barrier to this intercrop mix as crop insurance coverage is not available for peaola crops (VanKoughnet, 2015).

The uncertainty on economic outcomes and the lack of a clear economic benefit from intercropping remains a barrier to producers. VanKoughnet (2015) found peaola returns at a Manitoba test site to be greater than canola alone but less than peas alone. Struckman's oat-pea project reported inconsistent profitability outcomes, with the oat-pea intercrop being more profitable than oat monocrop at three test sites, equally profitable at three other test sites, and significantly less profitable at the remaining six test sites (Struckman, 2021).

From the perspectives of the producer participants, the oat-pea intercropping project was a success; by the project's end, only four out of twenty-five producers stated they would not continue with oat-pea intercropping (Struckman et al., 2021). These four producers cited their difficulties with harvesting and separating the mixed grains, and with marketing the final products, as their reasons for discontinuing the practice.

Agronomic Barriers

FWWF producer engagement sessions heard only a few responses directly related to intercropping, however Living Lab producers do have an interest in gaining the knowledge needed to allow them to adopt intercropping on their farms. One producer stated that they needed more information on *"intercropping and battling fear of the unknown, and how to harvest intercropped quarters"* (RALL, 2023a). Other producers want information on *"intercropping in potatoes and vegetables in organic operations*" and *"three-way intercropping – grass/cereal/legumes and broadleaf mixes"* (RALL, 2023a).

In a recent producer roundtable discussion (RALL, 2023b), Living Labs producers shared more in-depth challenges and barriers to their potential adoption of intercropping:

- *"I don't know enough to try it (and would like to talk with people who have done it successfully)"*
- *"challenge of selecting crops that work well together and then separating them at harvest"*
- *"not being able to spray to manage weeds when that is what you're used to"*
- *"challenge of having to seed at different depths or having crops ripen at different times"*
- *"challenge of moving away from traditional crops in intercropping"*
- *"to get over the mindset that it's more than one crop, having weed issues, having to separate seeds at harvest, crop share relationship building"*
- *"knowledge around water retention/use with intercropping is a barrier"*
- *"peola as an intercrop is gaining traction; how do you return to a four-year rotation when peola is used in a three-year rotation? Four-year crop rotations are ideal with disease pressure"*

Seeding intercrops can be challenging. Seeding fields with mixed seed can be done fairly easily with most common seeders, however some producers opt for variable rate seeding, or seeding different species into different rows, both of which may require equipment modifications (Struckman et al., 2021; Viresco, 2022). Often, there is limited information available to producers to guide their decisions on intercrop seeding rates (Struckman et al., 2021).

Ensuring disease breaks is another challenge in intercropping, especially in the common intercrop of peas and canola (also known as peaola). While some producer experience suggests that intercrops provide protection against soil pathogens that reduce yield, both peas and canola have associated diseases that traditionally require a four-year break. In areas where the number of crops that can be grown are limited, such as the Peace Country, integrating peaola into the rotation is a perceived risk that many producers are not willing to take. Lack of demonstration of how intercrops can provide disease mitigation is a significant barrier.

Harvesting intercrops can also bring significant challenges as the mixed crops then need to be separated after harvesting, which Viresco (2022) reports as a major barrier to producers. Some combinations of intercrops may have similar sized seeds which could be too difficult to separate, and some plant species may be too fragile to withstand the separation process (Briere, 2021). Viresco (2022) also reports that harvesting mixed crops without damaging them can be difficult. The timing of each species can be a critical determinant of intercropping success or failure. A Manitoba producer shared his timing challenge when planting lentils in an intercrop mix, stating that *"'timing the species right is so important,"* he said*, "by the time the other crop was ready for harvest, the lentils had shelled out"'* (Beef Cattle Research Council, 2021, para. 24). Producers may be forced to decide between harvesting before the later crop has matured or risking the loss of part of the mature crop (Viresco, 2022).

Weed management during the growing season also presents challenges due to the lack of appropriate herbicides that can be used on both crops at the same time (Struckman et al., 2021; Viresco, 2022). These agronomic barriers experienced by Prairie producers align consistently with the barriers reported by European producers in a literature review by Mamine and Fares (2020), who found that weed control, pest management, and the lack of technical knowledge on intercropping were barriers to wheat-pea intercropping systems.

3.1.4.1. Polycropping

Polycropping may also be known as multi-species or cocktail mixtures, companion cropping, or polyculture, especially in academic research. Agriculture and Agri-Food Canada (2021) defines polyculture as "the intentional co-planting of a variety of species of plants in one plot, particularly for use as forage, or food for livestock." In the Prairies, producers would define polycropping as more than two species of any type of crop that are seeded around the same time. This definition overlaps with what producers would define as a cocktail cover crop, however, polycropping would include cover crops, forage, and cash crops for production or harvest.

Economic Barriers

Producers in the Living Labs roundtable discussion (RALL, 2023b) shared the following economic barriers or challenges to the adoption of polycropping:

- *"poor yields due to drought (may be some agronomics too?)"*
- *"issues with insurance"*
- *"new products and processes with unknown ROI, risky to move to low/no inputs, trial and error can be costly"*

FWWF's advisor shared many costs and other factors that create economic barriers to the adoption of polycropping. The introduction of new species means additional costs for seed, as well as costs for the time and labour spent on planning, seeding, seed cleaning, separating crops, and disposing of waste material.

Market barriers are also a concern to producers. Some Prairie producers do not have a market available to them for the crops they would want to grow through polycropping. Market acceptance for crops grown and harvested together can be low due to the risk of cross contamination. This is especially an issue for buyers who need to ensure their grain remains free of certain allergens.

There may also be costs to producers for consulting with an agrologist or other advisor to help with choosing the right species and getting the crops established. Crop insurance can be a significant barrier to polycropping as some policies may exclude anything other than a conventional monocrop. Finally, the economic benefit from a polycrop is uncertain. There are many variables that can affect the outcome of a polycrop and there is insufficient research on polycropping in the Prairies to clearly define what economic benefit producers can expect from this practice.

Agronomic Barriers

There is a large variety of agronomic barriers to polycropping that have been identified by FWWF's advisor or through direct producer engagement. RALL producers shared their agronomic challenges with polycropping (RALL, 2023b):

- *"re-harvested desiccated winter triticale in wheat due to kochia pressure and loss of winter cereal; extra steps to manage seed/treatments in busy season"*
- *"lots of weeds that are proving difficult to manage"*
- *"separation at time of combining is a barrier, but interest is increasing"*
- *"can we condense diversity into fewer years? Could be a good opportunity to explore"*

From producers' perspectives, there is no guidance on selecting the best species for a polycropping system and no clear agronomic protocol for implementing this practice on Prairie farms. Producers are also unsure how to determine the appropriate fertilizer application rate or how to manage weeds in a diverse species mix. Increasing the number of species being grown also increases the risk of insect infestations and plant diseases that target certain species.

Other agronomic barriers include the management of greater amounts of waste material. Additionally, polycrops may present conflicts in the timing of crop maturity and harvestability if one crop matures and is ready to harvest while the other crop remains too immature for harvest. Producers are then left with a difficult management decision and risk damage or loss to the crop. Agronomic benefits to soil health remain uncertain as many variables can affect the agronomic outcomes of a polycrop.

3.2. Increasing Diversity Of Crop Rotations

This BMP can be defined as the temporal or spatial incorporation of new, varied crop species into pre-existing rotations of annual or perennial crops (Thiessen Martens et al., 2015; Viresco, 2022). Drever et al. (2021a) does not include diversity of crop rotations as one of their natural climate solution pathways, but does look more specifically at increasing legume crops, which could be considered a practice that increases diversity of crop rotations. Hanson et al. (2007) describes dynamic cropping systems as those which use "a long-term strategy of annual crop sequencing to optimize the outcome of production, economic, and resource conservation goals using ecologically based management principles" (p.940).

Prairie producers would consider crop rotation diversity in terms of the frequency of inclusion of different crops in their rotations. Increasing diversity in their crop rotations would involve using a greater number of crop species and a lower planting frequency for each species. Crop rotations could be diversified with perennials, forages, pulses, and more diverse grain and oil seed crops.

On-farm benefits from diversifying crop rotations can include better resistance to weeds and pests, reduced input usage, enhanced genetic diversity, and reduced occurrence of disease (Hanson et al., 2007; Thiessen Martens et al., 2015; Viresco, 2022)

Economic Barriers

Producers in British Columbia (B.C.), Canada and in Shaanxi, China were interviewed about decision-making related to planting new crop varieties and Mu et al. (2023) found that market demand exerts a strong influence on producers' decision-making and operations. Producers in B.C. told researchers that "our future planning is determined by the market" and "the market demand is not structured in a way which promotes food security and economic security for producers, and this determined our planning for the different varieties" (p.19).

It's not surprising then, that even with no other economic or technical barriers present, just the perception of a possible market risk is enough to deter some producers from committing to new, more climate-resilient crop varieties (Mu et al., 2023). This finding is consistent with a recent

U.S. study, which found that the lack of accessible and profitable markets local to producers is a clear barrier to producers' adoption of diverse crop rotations (Silva et al., 2023).

Viresco (2022) reports that the lack of a proven economic benefit is a barrier to producers and that producers are not likely to deviate from their current cropping system without a clear financial incentive.

Agronomic Barriers

Incorporating greater diversity in cropping rotations presents some agronomic barriers to producers. With each new species introduced to a cropping rotation, the system becomes more complex. The more complex the system becomes, the more challenging it is to manage successfully. Producers must have, or acquire, deeper agronomic knowledge of each species; how they may affect each other, how they are impacted by biophysical variables, and how they will fit into the overall cropping system. This creates a barrier not only to producers' adoption of crop rotation diversity but also to their continued success with the practice, especially for producers who have minimal experience with species diversity (Hanson et al., 2007). Moreover, there is a lack of research on long-term yield outcomes and optimal management practices for diverse crop rotations, especially in the context of Prairie climate and soil types (Viresco, 2022).

Although diversity in crop rotations will improve soil health, these benefits will take time. Producers may be discouraged by the time lag between adoption of crop rotation diversity and tangible soil health benefits (IPES-Food, 2016). There is at least some interest in increasing crop rotation diversity among Prairie producers, as we heard from a RALL producer that they wanted more information on what the best order of crop rotations to help reduce fertilizer requirements (RALL, 2023a). Lack of available technical advice may be a barrier to adoption even for producers who are interested and motivated to adopt this practice.

Socio-Cultural Barriers

These socio-cultural barriers apply to all crop rotation diversity practices in section 3.2. Practices that increase crop rotation diversity are viewed as alternative or experimental farming practices and thus producers must go outside of local farming norms to adopt them. Producers may avoid adopting a practice that their neighbours would consider weird or strange, as social acceptance and community cohesion are motivating factors in the farming community. Producers may also be reluctant to learn about new farming practices or change their current farming practices, especially if there is no clearly defined agronomic or economic benefit to them.

At the farm level, managing more diverse cropping systems will demand more time and knowledge from producers (Hanson et al., 2007). Producers may need to search for information and learn the knowledge needed for successful implementation of new species into their cropping rotations.

Producers who are interested in diversifying their crop rotations may find an overwhelming amount of information available and not know where to begin due to "YouTube University." At the same time, they may also find a lack of specific information on how to establish relay crops and other diverse crop rotation practices successfully on Prairie farms. These practices are uncommon in the Prairies and there is little evidence to show feasibility or agronomic outcomes of these practices in Prairie contexts. As such, there is a lack of knowledge and support available to help producers learn how to implement these crop rotation systems in Prairie agro-climatic contexts.

Finally, land rental agreements may restrict the types of cropping practices that are permitted on the land, and thus producers who rent their cropland may not be able to adopt these practices.

There are also barriers to crop rotation diversity at higher levels. Policies and regulatory mechanisms are meant to accommodate the dominant industrial agriculture system and leave little room for producers who use systems that are outside of the norm (IPES-Food, 2016). This presents a barrier to producers who try to implement agricultural practices that go against the status quo and also do not fit into current policies and regulations. This also highlights how policies, regulations, and related extension services would need to be changed significantly to align with alternative agricultural practices and especially with a new regenerative agriculture production paradigm.

Awareness Barriers

These awareness barriers apply to all crop rotation diversity practices in section 3.2. While most Prairie producers are aware of crop rotation diversity and how it is practiced, there is still an awareness barrier to producer adoption of these practices. Through FWWF's advisor we have heard that some Prairie producers likely believe they already have diversity in their crop rotations, regardless of whether or not their practice aligns with regenerative agriculture principles. Producers' assumption that they already know how to diversify their crop rotations acts as a barrier to their willingness to learn how to optimize the practice and receive the full scope of its potential soil health benefits.

The crop rotation practices in section 3.2 are not clearly or consistently defined in Canada, and as such, producer awareness of these practices is generally low.

3.2.1. Relay Cropping

Relay cropping is a specific method of intercropping where a second crop is seeded into a first crop that is already established and growing. There is a short overlap period where both crops are growing and occupying the same land, with one reaching maturity earlier than the other.

Prairie producers define relay cropping slightly differently, as they would consider relay cropping to be the same practice as planting a fall seeded or spring seeded crop, including both cover crops and cash crops. In the producers' practice, relay crops would be planted during or *after* the previous crop has been harvested, and as such there may be no, or very minimal, growth overlap between the two crops.

Economic Barriers

Economic and operational barriers to producers involve the additional costs, labour, and time required for two seeding and two harvesting processes (Viresco, 2022), as well as the purchase of additional seed. Relay crops, however, are not harvested at the same time as other intercrops, so producers should not have the high costs of seed separation and cleaning unless their relay crop is a more complex crop or polycrop .

Relay cropping can create more litter and requires investment in residue management mechanisms. The actual economic benefit to producers is uncertain due to the limited research on relay cropping and the many variables that can affect the outcomes.

Agronomic Barriers

Some agronomic barriers to producers' adoption of relay cropping have been identified in Prairie research. Thiessen Martens et al. (2015) noted that relay cover crop yields in Manitoba and Alberta research studies have varied widely, including some yields at nearly zero, depending on late fall moisture and residue management strategies to allow for germination. Some Prairie research has also found that productive cover crops can deplete soil moisture content, which could be detrimental to producers in drier regions of the Prairies, though it can also be a benefit in wet climates.

The productivity of both crops will be dependent on the availability of soil, nutrient, and water resources as well as on seeding rates and weather conditions (Thiessen Martens et al., 2015). Producers then face the challenge of testing relay crop systems and modifying the variables as needed to find the optimal balance (Thiessen Martens et al., 2015).

Awareness Barriers

In addition to the awareness barriers described in section 3.2., a terminology difference also creates a barrier to the adoption of relay cropping. As noted in the introduction of section 3.2.1., producers who are aware of relay cropping may have an understanding of the practice that is not consistent with how the practice is defined in research or extension services.

A disconnect between producers' and researchers' understandings of relay cropping poses a barrier to the advancement of producer adoption. Research may be designed to study relay cropping in a way that does not align with how relay cropping would be typically practiced by Prairie producers.

3.2.2. Increased Legume and Pulse Crops

Both Viresco (2022) and Drever et al. (2021a) are consistent in defining this practice as removing some non-legume crops from production and replacing them with legume crops. By reducing production of non-legume crops and replacing them with nitrogen-fixing legumes, producers will require less nitrogen fertilizer, thus reducing greenhouse gas emissions from N_2O. Producers would consider this BMP to involve an increased frequency of pulse or legume crops in their cropping and forage rotations.

Economic Barriers

The nature of legume production brings unique economic barriers to increasing legume crops. Viresco (2022) reports that legumes have high seeding costs, take longer to harvest than cereals or canola, and are expensive to produce in general. Legume quality is also sensitive to weather events, and if the crop is downgraded, producers can lose a significant amount of income (Viresco, 2022). Bain research (2021) reports that high initial and maintenance costs for equipment and legume production can be barriers to producers' adoption of legume crop practices.

Market pricing barriers should also be considered in promoting adoption of legume crops, considering that Canada exports more dried legumes than any other country, by far (OEC, 2021). Significant increases in legume production in Canada may result in lowered market prices and less profitability (Viresco, 2022).

Agronomic Barriers

Some legumes, including lentils and chickpeas, will only grow in drier areas of the Prairies, especially the Brown and Dark Brown soil zones (Viresco, 2022). This limits the legume options available to producers outside of these zones. Some legume crops may require fungicides (Viresco, 2022), and this can be a barrier if producers are unfamiliar with their use and application.

A shorter period of time between legume crops increases the risk of plant disease (Viresco, 2022). The Viresco report (2022) also highlighted that there is a research gap on "optimizing integrated plant disease management, including better genetic disease resistance" (p.44). Future research to decrease the risk of plant disease could make a significant impact on this barrier to increasing legume crops. In a RALL focus group, one producer cited the need for more information on *"what is good to seed before and after legumes*" to aid in managing disease associated with nitrogen-fixing plants.

3.2.3. Short-Term Rotation of Annual Crops with Perennial Forages

Viresco (2022) and Thiessen Martens et al. (2015) define this practice as the addition of perennial forages to an annual cropping rotation for a short period of time. Producers would define this BMP as the inclusion of short-term perennials in a cropping system. A real-life example of this system could be: wheat-barley-canola-alfalfa-alfalfa-alfalfa-wheat-barley-canola.

Incorporating perennial forages into an annual cropping rotation keeps living plants and root systems in the soil outside of the annual crop season, which aligns with Principle 1 of the regenerative agriculture soil health pyramid described in Appendix A. Soil that is typically used for annual crop production may have no living vegetation for months every year, whereas soil that is planted with perennial crops retains living vegetation year-round. During the years that they are part of the rotation, perennial crops typically increase soil carbon sequestration as they produce more residue and have larger, deeper roots than annual crops, storing more carbon and likely keeping it more stable from oxidation in the deep soil (Ledo et al., 2020).

The inclusion of perennial forages in annual crop rotations has been researched on Prairie farms for decades. Researchers have heavily focused on the agronomic and economic outcomes of these diverse cropping systems; very little research has considered barriers to this practice from a producer perspective. We know that Prairie producers are interested in cropping rotations, and in knowing which rotations would be most appropriate for their farming operation, soil, and climate conditions – a RALL producer stated they needed more information on *“what the best order of crop rotations would be”* (RALL, 2023a).

Economic Barriers

Numerous studies have evaluated the economic profitability of diversified cropping systems on the Canadian Prairies and annual crop/perennial forage rotations have consistently been found to be economically unfavourable to producers. Long-term and short-term trials of perennial forage-annual grain systems have typically produced low net returns compared to annual-only rotations or continuous grain systems (Zentner et al., 2011).

A Saskatchewan study reported on the economics of nine different cropping systems and determined that these systems are not economically feasible for Saskatchewan producers. (Zentner et al., 1996). Over the 12-year study period, mean annual net returns were lower for the two rotations containing perennial alfalfa hay than for any other cropping system in the study due to the price of hay in that time frame.

More recently, Zentner et al. (2011) conducted another evaluation of nine different cropping systems over a six-year period; the systems varied in species diversity and input usage and included a diversified rotation of annual canola-wheat-barley-oat and perennial bromegrass-alfalfa-hay-hay. Of all nine cropping systems, this annual-perennial crop rotation had the highest direct labour costs related to field operations and production, and the lowest net returns, regardless of the level of inputs used. This study also found the annual-perennial crop rotation to have the highest income variability of all cropping systems, and overall, the authors concluded that this system is not an economically feasible choice for producers.

These points necessitate contextualization that considers the differences between market conditions today and in 2011 for perennial hay. Currently, in Alberta, perennial hay under irrigation boasts the *"highest gross margin of any crop,"* according to a RALL producer. It is essential to note that hay production exhibits significant variability in terms of labour and is contingent upon factors such as the number of cuts and the management approach employed.

Agronomic Barriers

Viresco (2022) discusses how reduced yields of annual grain crops after perennial forages present a barrier to Prairie producers' adoption of this practice. However, this contradicts a fair amount of Prairie-based research going back to the 1990s that has clearly shown evidence for annual crop yield increases after perennial forages are introduced into the rotation, both from agronomic researchers' findings, and from producers' reported yields (Thiessen Martens et al., 2015).

Entz et al. (1995) found that 67% of the 253 Manitoba and Saskatchewan producers who were surveyed, reported grain crop yield increases after perennial forages and they report that these findings align with many other studies in the Northern Great Plains region. Thiessen Martens et al. (2015) and Entz et al. (2002) noted that yield increases of annual crops after perennial forages are a well-known and documented benefit of this system, and that some evidence has even shown annual crop yield increases many years after the forage was terminated.

There are also environmental and soil health benefits to including perennial forages in rotation with annual crops, including reduced nitrate leaching and deep root carbon sequestration (Thiessen Martens et al., 2015). Despite these benefits, there are still agronomic barriers to producers' adoption of perennial forage rotations with annual crops. The quantified impacts of these perennial-annual cropping rotations on greenhouse gas emissions in the Prairies is still largely unknown (Viresco, 2022).

Perennial forages can cause moisture depletion in soil, which in drier regions of the Prairies can reduce subsequent annual crop yields (Entz et al., 2002). Some soil nutrients can be quickly depleted by perennial forage legumes (Thiessen Martens et al., 2015). If producers incorporating this practice do not have a plan in place to replenish soil nutrients or proactively manage their soil health, soil nutrient levels could be negatively affected.

The processes of establishing and terminating perennial forages also present significant agronomic barriers to producers (Viresco, 2022). Perennial forage stands can be difficult to establish, especially when soil moisture or precipitation levels are low (Zentner et al., 1996).

Termination of the forage stand can be done chemically or mechanically, but this requires additional agronomic management and labour commitment from the producer.

3.2.4. Annual Crops Seeded into Existing Perennial Forages

From the producer perspective, this practice would involve stitching annual crops (for example, oats, barley, or wheat) into established perennial stands, especially those that are older or struggling, to provide sufficient ground cover and production. Depending on the producer's goals, annual crops could be planted for a single season or for multiple years in a row.

This practice is similar to Australian 'pasture cropping', which refers to the direct seeding of a crop into a perennial pasture. Present-day pasture cropping was developed and refined by Australian farmer Colin Seis (Soils for Life, n.d.), and most commonly, in Australia, involves direct drilling a winter cereal crop into a dormant pasture after the summer grazing season (Luna et al., 2020). Pasture cropping has grown in popularity in Australia over recent decades. FWWF's advisor has shared that the success rate of this practice, or similar practices, in the Canadian Prairies is very low because we do not have dormant pastures during the main growing season, and because we have snow and freezing temperatures after the summer grazing season.

As this practice is not common nor consistently defined in Canada, no relevant literature was found. Some literature is available on direct seeding legumes into degraded perennial stands but that practice is covered in another section of this report. Literature that did study annual crops in perennial forage stands assumed that the perennial stand would first be chemically terminated before annuals would be planted.

Economic Barriers

There are numerous costs producers must incur to adopt this practice; costs for the increased amount of time and labour needed, additional equipment or a custom contractor, and an overall increased cost of production all create economic barriers to producers. As there is extremely limited research on this practice in the Prairies, no clear economic benefit has been estimated. Producers thus have no guarantee of what return they will receive for their investment.

Agronomic Barriers

Limited literature on pasture cropping is available, which is mostly relevant to the temperate sub-humid or Mediterranean types of climates seen in Australia and thus has very limited application in Canadian Prairie climates. Studies on pasture cropping elsewhere have noted decreased yields in both the commercial crop and the pasture crop (Luna et al., 2020). Indeed, without supplemental irrigation, yield losses in pasture cropped fields were particularly significant under drought conditions in a Spanish study (Luna et al., 2020). With an increasing prevalence of drought events in the Canadian Prairies, there are likely significant agronomic barriers to Prairie producers successfully stitching annual crops into perennial forage stands.

3.2.5. Short-Term Rotation of Perennial Forages with Annual Crops

Producers would define this practice as a short-term introduction of annual crops into a perennial forage system. Perennial crops would first be terminated to allow annual crops to be seeded and grown. After a few years of annual crops, producers would reseed perennial crops and return to the perennial forage rotation. A real-life example of this system could be mixed pasture for years one to ten, then oats-oats-oats, then back to mixed pasture.

Economic Barriers

Economic barriers to this practice include the costs and availability of seed, the costs for increased labour and time spent on the practice, the increased overall cost of production, and the possible costs for extra equipment. Also, the profitability of this type of cropping rotation practice remains uncertain and thus producers are unable to quantify their expected economic benefit.

Furthermore, there are barriers in crop insurance and in market availability. FWWF's advisor reports that some producers may not have access to an appropriate market to sell the additional crops they've grown. Additionally, crop insurance policies may exclude diverse crop rotation practices from full coverage. Producers may face the additional financial risk of the loss of crop insurance coverage if they decide to adopt a crop rotation practice that falls outside of the conventional norm.

Agronomic Barriers

Producers are likely to face several agronomic barriers to the short-term introduction of annual crops into their perennial forage system, many of which are related to the lack of Prairie-specific research on this type of crop rotation practice.

There is no clear agronomic protocol for this practice in a Prairie agricultural context, nor is there clear guidance on what species would be most successful. Challenges with weed control and unknown fertilizer requirements for these additional crops are likely to be barriers to producer adoption and success with the practice. Finally, without quantification of a clear soil health improvement that results from this practice, the farm-level agronomic benefit to the producer remains uncertain.

3.3. Improved Nutrient Management

Improved nutrient management can be defined as using “reduced nutrient inputs and … more efficient application of nitrogen fertilizers” (Drever et al., 2021b, p.12). In academia and in the fertilizer industry, some may consider ‘improved nutrient management’ to be synonymous with the 4R Nutrient Stewardship Framework, but among Prairie producers ‘4R’ or ‘4R Nutrient Stewardship’ are not terms that are frequently used unless working with an ag retailer. Producers would use ‘nutrient management’ to refer to anything related to soil nutrients, including fertilizer, but also including manure and compost. From the producers’ perspective, the ‘stewardship’ term would be associated with the idea of land stewardship and would not likely be perceived as specifically related to nutrient management.

3.3.1. 4R Nutrient Stewardship

The 4R Nutrient Stewardship Framework was originally developed to address concerns related to negative environmental effects of nutrient runoff, water quality, and overall environmental impact of nutrients lost from agricultural fertilizer. Through the 1990s and early 2000s, increasing focus was put on the negative impacts of nitrogen leaching and cascading through surrounding ecosystems, and on the global impacts of agricultural nitrogen use (Fixen, 2020). BMPs, including 4R Nutrient Stewardship, were developed and promoted as tools to minimize the negative environmental effects of agriculture while still ensuring profitability.

In 2005, the Canadian Fertilizer Institute worked to market fertilizer management as a way to achieve sustainability, passing out brochures that featured three Rs (Right Rate, Right Time, Right Place) titled *“Fertilizer – the Path to Sustainability”* (Fixen, 2020, p. 4513). The fourth R (Right Source) was added shortly thereafter, and since 2007 the 4R Framework as we know it has been developed and refined.

The 4R Nutrient Stewardship Framework was developed through international collaboration between the scientific community and the fertilizer industry, including the Canadian Fertilizer Institute. Although the foundational principles of the 4R framework are universal, the protocols are site-specific to allow for tailoring to various soil, weather, crop, timing, and environmental conditions (Fertilizer Canada, 2023).

The 4Rs refer to the application of fertilizer from the Right Source, using the Right Rate, to the Right Place at the Right Time. There are three levels of implementation – basic, intermediate, and advanced – but the specific practices that make up each level are determined regionally and based on local conditions (Fertilizer Canada, 2019). Drever et al. (2021b) describes the three levels of 4R adoption as:

1. **Basic** matching of the nutrient supply to crop needs based on limited monitoring of N status and field-level spatial resolution

2. **Intermediate** matching through detailed monitoring of nutrient status, manipulation of the timing of nutrient supply, and sub-field spatial resolution
3. **Advanced** matching based on detailed monitoring of nutrient status and plant health, extensive manipulation of nutrient supply timing, and detailed sub-field spatial resolution (Suppl. p.12)

Prairie producers would be somewhat familiar with both 4R terminology and the different levels of adoption. While the core principles of 4R inherently contribute to sustainable agricultural practices, including reducing environmental impacts, the initial development of 4R was not explicitly centered on climate change, nor on greenhouse gas (GHG) emission reduction. Also, sustainability has become a new lens through which to market slight changes in the use of conventional agricultural inputs. While precise application of fertilizer does align with the regenerative agriculture principle of reduced synthetic nutrients, 4R, as a practice, would generally fall within the sphere of conventional rather than regenerative agriculture.

Economic Barriers

Nutrient management practices can bring a significant reduction in greenhouse gas emissions from Canadian agriculture. However, there are numerous economic barriers to producers' adoption of nutrient management practices as reported by Viresco (2022) and Bain (2021), primarily related to the costs for specialty inputs and equipment, as well as the management needed for these more specific practices.

The costs of soil testing, enhanced efficiency fertilizer (EEF), documenting within-field crop response to fertilizer, set-up and management of precision farming, specialized equipment, and skilled labour are all barriers to producers' adoption of some or all levels of 4R Nutrient Stewardship (Bain, 2021; Fertilizer Canada, 2018; L. Fuller, personal communication, January 2, 2024; Viresco, 2022).

The Viresco report on BMPs in Prairie Agriculture (2022) noted that the high cost of enhanced efficiency fertilizers (EEFs) has impeded producers from reaching the intermediate or advanced levels of 4R Nutrient Stewardship implementation. This is reflected in the 4R Canadian adoption rates estimated by Drever et al. (2021b) – basic 4R is practiced by around 50% of farms, while intermediate and advanced 4R is much less prevalent, estimated at only 8% and 2% respectively (Viresco, 2022). These figures align fairly closely with Fertilizer Canada's (2021) estimate that approximately 58% of surveyed farm acres have implemented basic 4R practices (Fertilizer Canada, 2021).

Conversely, high input costs may actually motivate some producers to seek out alternative practices (FWWF, 2023b). Conventional fertilizer costs in Canada rose significantly from 2021 to 2022 (Statistics Canada, 2023a). Although fertilizer prices went down through 2023, other input costs like pesticides and machinery increased (Statistics Canada, 2023a), while most crop commodity prices decreased (Statistics Canada, 2023b). Overall, the increasing costs of inputs continue to put pressure on producers to ensure they stay profitable, which could be a driving factor for some producers to adopt BMPs that allow them to reduce their input usage.

In 2015, Amiro et al. (2017) asked 135 Manitoba agronomists about their perspectives on nutrient management BMPs. The high cost of EEFs emerged as a barrier to agronomists' use or willingness to recommend nutrient management BMPs. Only 12% of respondents stated they would be willing to spend 25% more for enhanced efficiency fertilizer (Amiro et al., 2017). An American study (Davidson et al., 2015) noted the significant level of influence that crop consultants have on agricultural producers' decision-making, and Ulrich-Schad et al. (2017) found that this influence was consistent in the context of producer adoption of nutrient management practices. Overall, the producers in the latter study had relatively high levels of trust in crop consultants to provide nutrient management information, and this trust did have a significant motivating effect on producer adoption of soil testing and variable rate application technology (Ulrich-Schad et al., 2017). It could be suggested then that any barrier to agronomists' adoption of nutrient management BMPs also acts as an indirect barrier to producers' adoption.

The Canadian 4R Research Network (Fertilizer Canada, 2018) reported that gains in crop yield and optimized fertilizer rate may not outweigh the higher costs of specialty fertilizers and equipment needed for 4R practices. The Viresco report (2022) also notes that increased efficiency of crop nitrogen use should make up for the increased costs of 4R management at the basic level but may not be sufficient to offset the higher costs at the intermediate and advanced 4R levels. Some producers may then experience a reduction in their net income from crop production, especially when commodity crop prices are low (Viresco, 2022). Additionally, producers may not see an increased crop yield from their 4R practices if they were already in the practice of overapplying nitrogen fertilizer (Viresco, 2022). Thus, the lack of an economic benefit, and the risk of a loss of net income, are barriers to producer adoption of nutrient management practices.

Agronomic Barriers

Nutrient management practices are significantly affected by biophysical factors including weather, eco-region, and soil microbiology. These factors can shape the specific environmental benefits of nutrient management, the optimal fertilizer rates, the responsiveness of crops to fertilizer, and the overall on-farm outcomes of nutrient management practices (Fertilizer Canada, 2018). Viresco (2022) reported a knowledge gap in nutrient management research on ensuring crop production is maintained while optimizing EEF use for a variety of soil, crop, and climate contexts. A RALL producer stated they needed more information on how manure and cover crops affect nitrogen availability, how to ensure sufficient nitrogen for the next crop, and how to achieve these goals with reduced synthetics and inputs (RALL, 2023a).

Equipment and timing incompatibilities also act as agronomic barriers. Some nutrient management practices may require specialized equipment, or fertilization application at times when producers are already busy with other operations such as seeding (Fertilizer Canada, 2018).

Although Canadian research on nutrient management practices is expanding, there is still a lack of knowledge on 4R nutrient management practices specific to Canadian Prairie contexts, and producers' barriers, drivers, and needs for adoption of the practices. Challenges and uncertainties around optimal fertilizer application rates, unpredictable biophysical variables, and crop response to fertilizer, and the lack of tools to assist with customizing practices to local conditions, are barriers to producers' adoption of nutrient management BMPs (Fertilizer Canada, 2018).

Socio-Cultural Barriers

4R nutrient management includes three levels of practice: basic, intermediate, and advanced. Adoption at the basic level is less complex, however, the intermediate and advanced levels require significant time, labour, equipment, and financial commitments. Viresco (2022) reports that the management requirements for the advanced 4R level are a significant barrier to producer adoption.

The key findings of the Canadian 4R Research Network (Fertilizer Canada, 2018) report include a number of socio-cultural barriers to nutrient management adoption. Information on the full commitment of time, money, labour, and equipment needed for 4R nutrient management in the Canadian Prairies is limited and inconsistent (Fertilizer Canada, 2018). It is especially hard to measure and predict the amount of time and effort a producer will need to invest to learn, experiment, and manage the transition to 4R practices, leaving a level of risk and uncertainty that is likely to be a barrier for some producers. The report suggests that even with the potential for an economic benefit from the practice, these factors can still be a barrier to producer adoption (Fertilizer Canada, 2018).

The burden of increased management requirements needed for the intermediate and advanced levels of nutrient management adoption may be compounded by the lack of tangible benefits from reduced N_2O emissions at the farm level (Viresco 2022). Although nutrient management BMPs will have substantial environmental and ecosystem benefits, producers will see these only minimally or not at all at the farm level. The lack of an economic value placed on both the on-farm and off-farm benefits from nutrient management practices presents a significant barrier to producers' adoption of these practices.

> "These off-farm benefits tend to be disconnected from the on-farm challenges of producing a crop in a competitive market with resource limitations"
>
> (Fertilizer Canada, 2018, p. 12)

Awareness Barriers

These awareness barriers apply to all Nutrient Management practices in section 3.3. Awareness barriers do interfere with producer adoption of improved nutrient management practices. Some producers may believe or assume that they have already improved the nutrient management practices on their farm and thus have already adopted these practices.

Producers may also believe they know how to improve their nutrient management techniques and are therefore not interested in learning more about the practice. These internal assumptions create an awareness barrier that prevents producers from learning how to implement and optimize nutrient management BMPs to take advantage of the full scope of soil health benefits.

Variable rate nutrient application (VRNA) and foliar fertilization are relatively new practices in the Prairies and thus many producers may be unaware or vaguely aware of the terminology and the practices themselves. Most producers are likely unaware of the on-farm benefits of these practices, which creates a barrier to their adoption.

3.3.1.1. Variable Rate Nutrient Application (VRNA)

Variable rate nutrient application (VRNA) is a 'Right Rate' practice that fits within the 4R Framework and is defined as the application of fertilizer at different rates on the same field, based on the specific nutrient needs of each soil zone (Agriculture and Agri-Food Canada, 2020). Using soil testing data, and information on soil types and yield expectations, a customized map is created for the producer that delineates different soil management zones on the field and calculates optimal fertilizer application rates for each zone. Producers would understand this practice to be the application of fertilizer at optimal rates for different areas of the field, as opposed to a flat rate applied to the entire field.

Economic Barriers

Prairie producers have shared that the costs associated with VRNA are a barrier to adoption. Reluctance to commit to the technology required for this practice is also a significant barrier. The initial costs for technology are a barrier, but many producers also fear that glitches, outages, or technology failures will cost them time and money.

Other economic barriers include costs for increased labour and time spent on learning and implementing the variable rate method, increased cost of production, costs for a specialist agronomy consultant, and costs for additional equipment or technology required for the practice. Finally, as with many BMPs, the potential economic benefit from VRNA is still too uncertain for many producers to feel comfortable adopting this practice.

VRNA may be perceived by producers to be a riskier practice, especially in regard to the increasing variability of extreme weather events due to climate change (Agriculture and

Agri-Food Canada, 2020). The extra costs for VRNA technology carry a greater economic risk to producers in situations of drought, flooding, or wildfires.

Agronomic Barriers

Producers likely don't have access to sufficient knowledge on how to implement a variable rate application on their farm and in their agro-climatic conditions. Calculating fertilizer application rates based on numerous dynamic field and soil conditions is complex. The potential for variability in conditions such as precipitation, temperature, and the presence of pests, means that calculated rates may not reflect the actual needs of the soil (Agriculture and Agri-Food Canada, 2020).

There is also a major knowledge gap in the area of crop response to variable rate fertilizer, which creates a significant agronomic barrier to VRNA. The crop response models currently in use are based on flat rate fertilizer application for a whole field and do not account for within-field variations in crop response as seen with variable rate application (L. Fuller, personal communication, January 2, 2024).

The potential for timing conflicts for labour and equipment during busy times of the crop production season are also barriers to some producers.

Socio-Cultural Barriers

As VRNA is a BMP that involves investing in and learning new technology, many producers are reluctant to learn about the practice or to implement a new change in their farming operation.

3.3.1.2. Stabilizer

The use of nitrogen stabilizers or EEFs is considered a 'Right Source' practice within the 4R Framework. Nitrogen stabilizers are products that can be added to fertilizer to slow and stabilize its conversion in soil, reduce leaching and volatilization, and protect seeds from fertilizer burn.

Although stabilizer should allow producers to use less fertilizer and thus reduce N_2O emissions from their farms, many producers perceive stabilizer as a way to use more fertilizer and increase their production. There is likely a disconnect between researchers' promotion of stabilizer as a way for producers to reduce fertilizer usage and N_2O emissions, and producers' actual use of stabilizer to increase their fertilizer usage and in turn, increase crop production.

Economic Barriers

Cost is a barrier to producer adoption of nitrogen stabilizer. The stabilizer itself is expensive and some stabilizer products require specialized application equipment that the producer must purchase. The availability of nitrogen stabilizers may be a barrier to some producers as these specialized products are not necessarily available in all regions of the Prairies.

As there is a lack of Prairie-specific research on stabilizer, the economic benefits to the producer from incorporating nitrogen stabilizers remains uncertain.

Agronomic Barriers

FWWF's advisor identified one agronomic barrier to the use of fertilizer stabilizers: the uncertainty of soil health or ecological benefit from this practice. Prairie-specific agronomic research is lacking and has not clearly identified soil health benefits at the farm level from stabilizer use.

Socio-Cultural Barriers

For the purposes of this report, many agricultural climate solutions have been explored with an aim to maximize the understanding of adoption of these practices. As noted in the introduction, several BMPs in this report fall outside the scope of what is generally considered to be regenerative agriculture. Enhanced Efficiency Fertilizers (EEFs) and stabilizers are generally regarded as divergent from the core practices of regenerative agriculture due to their impact on the soil microbiome. Regenerative agriculture focuses on reducing inputs and prioritizes soil health and nutrient availability through plant-soil microbiome interactions. EEFs are designed for short-term nutrient optimization and will reduce N_2O emissions but do not foster long-term ecological resilience or promote biodiversity in soil microbiomes.

3.3.1.3. Foliar Fertilization

Foliar fertilization is also known as foliar feeding and can be defined as "the application – via spraying – of nutrients to plant leaves and stems and their absorption at those sites" (Kuepper, 2003, p.1). Foliar fertilization is considered a 'Right Time' practice under the 4R Framework, as fertilizer application is timed to align with the crop's nitrogen needs. This can potentially reduce the net amount of fertilizer the crop receives because fertilizer is applied at the time the plant can most readily use it. Opinions on the use of foliar fertilization in agriculture are quite variable, likely due to limited research and inconsistent results. Foliar fertilization is rarely used in Canadian crop production; in 2021, only 3% of field crops in Canada received foliar spray application of fertilizer (Statistics Canada, 2022).

Research on foliar fertilization in Prairie agricultural contexts is limited. In fact, it was difficult to find published research on foliar fertilizer from any high-income, temperate climate country comparable to Canada, although some studies from South Asian and Middle Eastern regions were found. Overall, there are inconsistent research findings on the agronomic outcomes of foliar fertilization in agriculture and no studies were found that explore producers' perspectives on this practice.

Prairie producers are familiar with foliar fertilization and some are excited by the potential of this practice to reduce the amount of fertilizer required to grow crops successfully, while also reducing input costs and GHG emissions.

Economic Barriers

Expanding the literature search to include research from South Asia revealed a Pakistani study (Khattak et al., 2017) which found that foliar nitrogen application on wheat resulted in a higher net return and a higher nitrogen use efficiency compared to soil-applied nitrogen.

Some U.K. producers report that foliar fertilizer allows them to decrease their rate of nitrogen application as well as the number of field passes needed to apply fertilizer (Jones, 2018). A small number of producers in southwestern England have achieved nearly the same wheat yield (as their previous conventional fertilizer crops) with a foliar nitrogen product that uses significantly less nitrogen and requires fewer field passes (Jones, 2018). This article also quotes an agronomist who believes that foliar nitrogen has “a big potential to replace some of the soil-applied nitrogen” (Jones, 2018, p. 38).

As the literature base is so limited, there is no clearly demonstrated economic benefit from foliar fertilization. Prairie producers may have heard anecdotal evidence that applying nitrogen via foliar spray will reduce their nitrogen usage while maintaining the same expected crop yield. With the lack of research studies in this area, much of the information on foliar fertilization available to Prairie producers comes from fertilizer vendors or sales representatives. Producers who are interested in trying foliar fertilizer will have very little unbiased information available to them on expected costs, expected savings, and effect on crop yield.

Agronomic Barriers

Findings from other parts of the world are not necessarily applicable to Prairie agriculture. In the Prairies, quick advancement of spring-seeded crops, unpredictable spring moisture levels, and lack of soil moisture are limiting factors to producers’ success with foliar fertilizer. Froese et al. (2020) studied foliar phosphorus applied to canola, wheat, and pea crops grown in phosphorus-deficient soil in Saskatchewan. Overall, there was evidence for crop absorption of foliar phosphorus, however, it was not enough to be associated with any major impacts on agronomic outcomes. The authors concluded that in general, foliar application of phosphorus is not an effective replacement for seed-placed phosphorus application.

Foliar absorption of nutrients is dependent on soil moisture levels and is generally impaired in dry conditions (Blair, 2015; Evans, 2020). When plants experience heat stress or drought stress, they develop a thicker waxy cuticle on their foliage that retains moisture but also impairs foliar absorption of nutrients (Blair, 2015; Froese et al., 2020). Dry conditions resulting from increasing temperatures, a longer growing season, and the lack of precipitation experienced in many regions of the Prairies would be a considerable barrier to producers’ adoption of foliar fertilization as a replacement for conventional fertilizer application.

Without consistent research findings, there is no agronomic protocol suitable for Prairie agro-climatic conditions that is available to producers to guide them in implementing foliar fertilization on their farms. Considering the critical role soil moisture levels play in foliar absorption of nutrients, Prairie producers will need access to expert advice on whether their moisture and weather conditions are suitable for success with foliar application.

Socio-Cultural Barriers

The lack of consistent agronomic research findings on the outcomes of foliar fertilization is a major barrier to producers' adoption of this practice. Without this research, there is not enough information available for producers to know how to implement foliar fertilization. The "fear of missing out" on potential yield due to the lack of upfront nutrition, or the risk of not applying nutrients at the correct time or stage, can be significant barriers to producer adoption of foliar fertilization.

3.3.2. Increasing Application of Organic Soil Amendments

Viresco (2022) describes organic amendments as any substance derived from organic matter that can be added to the soil to improve soil health, replenish depleted nutrients, and improve agricultural production. Products such as manure, compost, biochar, and microbial fertilizers would all be classified as organic soil amendments (Viresco, 2022). Producers in the Prairies would generally use the same terminology and definition for this practice. Although the word 'organic' in the name of this practice refers to amendments derived from biological sources (as opposed to inorganic fertilizer, for example), producers may interpret this to mean soil amendments that are certified organic products.

Drever et al. (2021a) discusses manure acidification as a specific BMP pathway for methane reduction but does not otherwise discuss organic soil amendments. There is very limited literature available that explores producers' perspectives of barriers to application of organic soil amendments, but some insights can be drawn from studies of European producers and of U.S. organic producers.

Economic Barriers

Lack of a cost-effective source of organic soil amendments is one of the most significant barriers to producers' adoption of this practice (Viresco, 2022). Some organic amendments may require higher application rates than what producers typically would use, adding cost, time, and labour to the operation, and possibly new farm machinery suitable for manure spreading (Viresco, 2022).

Organic producers in the U.S. noted that the high cost of commercially available compost products was a barrier to their usage, but on-farm manure processing was also prohibitive due to the very high costs associated with the equipment and infrastructure (Melo Ramos et al., 2019). The most common reported reason for not using organic soil amendments among French winegrowers were the high costs, although producers also noted the lack of access to necessary equipment, and difficulty in finding suppliers as other economic barriers (Payen et al., 2023).

Viresco (2022) also reports that “the biggest trade-off facing virtually all organic amendments is the cost and energy required for scaling and distributing the amendments widely across the Prairies" (p. 65). At the current high costs for producing and distributing organic soil amendments, and with the need for higher application rates than conventional fertilizers, large-scale adoption of this BMP may be unrealistic in the Prairies (Viresco, 2022).

Agronomic Barriers

Viresco (2022) reports that the availability of organic soil amendments is one of the primary barriers to producers’ adoption of this BMP. In addition to availability, the logistics of application of organic amendments at farm level can be a significant challenge to producers (Viresco, 2022). Spreading soil amendments in solid form may require specialized equipment that is not typically found on Prairie grain farms (Viresco, 2022).

By nature, some organic soil amendments may bring negative impacts to producers’ fields. Weeds may flourish on cropland if applied manure contains weed seeds, and there is a risk of pathogen and heavy metal contamination from biosolid amendments (Viresco, 2022). If organic soil amendments are not applied appropriately, there can be detrimental effects to soil health and surrounding ecosystems. Producers may need to apply a larger quantity of organic soil amendments than what they would have used if they were targeting just a single nutrient with a conventional product. Overapplication of manure in a localized area can lead to soil accumulation of nitrate or phosphorus, nitrate leaching, and nutrient runoff into surrounding bodies of water (Manitoba Agriculture, Food, and Rural Initiatives, 2009; Viresco, 2022). Heavy use of manure can also cause the accumulation of high levels of salt in soil which can have detrimental effects on crop growth (University of Nebraska-Lincoln, n.d.).

Case et al. (2017) noted that producers in Denmark perceived organic fertilizers to have a nutrient profile that was uncertain and inconsistent, especially related to nitrogen, phosphorus, and potassium content; producers stated that this uncertainty was a very important factor in their decision to use or not use organic fertilizers. The authors suggested that producers may consider organic fertilizers to be “more difficult to plan for and use than mineral fertilizers” (Case et al., 2017, p. 92). Organic farmers in a U.S. study stated they did not have a high level of trust in commercially produced compost, and perceived these products to be low quality, nutrient-poor, and possibly contain pesticide contaminants (Melo Ramos, 2019).

Winegrowers in France stated that they did not use organic soil amendments for several agronomic reasons, including that they already had good yields and did not perceive a need for soil amendments, and that they did not want to disrupt the balance of carbon and nitrogen in their soils (Payen et al., 2023).

Socio-Cultural Barriers

The following socio-cultural barriers apply to all organic soil amendment practices in section 3.3.2. Many socio-cultural barriers may negatively impact producers' adoption of the use of organic soil amendments in their farming operations. Like many other regenerative agriculture practices, some of these practices may be viewed as alternative or experimental, and don't align with conventional Prairie agriculture. This is particularly true for green manure, the roller crimper, humic and fulvic acids, and legumes in pastures. Many producers are uncomfortable or unwilling to adopt farming practices that are perceived by others as unconventional or strange. They may be reluctant to learn about new practices as well.

Many Prairie producers are second, third, or fourth generation farmers and may find it very difficult to change practices that have been in place on their farms for decades. Even if a producer is interested in learning about a new practice or changing the way they operate, their family members, neighbours, or community may not be supportive. These strong farming norms and social pressures can create a tremendous barrier to more widespread adoption of green manure, roller crimping, and other organic soil amendment BMPs. This is especially true if there is a perception in the community that the status quo is functional and "if it ain't broke, don't fix it." This also reflects how the status quo bias discussed in section 2.3.2. can act at the community level and not just the individual level.

Producers who are interested in these practices and seek out information on seeding legumes into their pastures, for example, may find a lack of Prairie-specific knowledge on the practice. The lack of knowledge available on how to incorporate organic soil amendments into Prairie farms to achieve the soil health benefits is a barrier to producers. Payen et al. (2023) noted that French winegrowers frequently reported barriers related to increased time, labour, and management needs, stating that they believed organic soil amendments are "too difficult to set up" and "too time-consuming" (p.5)

Odour is a barrier to adoption, particularly for the use of manure. Danish producers in the Case et al. (2017) study responded that odour was their primary barrier to adopting organic soil amendments.

Finally, land rental agreements can present a barrier as well. Crop producers who rent their land may not have permission from the landowner to incorporate some of these practices.

Awareness Barriers

There are awareness barriers that hinder the greater adoption of organic soil amendments in the Prairies. FWWF's advisor indicated that Prairie producers may be unaware of the term "organic soil amendments" or what the term entails. As mentioned, some producers may interpret the word “organic” to mean a certified organic product and may feel that this practice is not relevant to them if they do not use certified organic inputs.

Lack of awareness of the organic soil amendment practices among conventional Prairie producers is a barrier to widespread adoption that was identified by many producers. This lack of awareness is likely true for most practices described in section 3.3.2., but especially for manure acidification, humic and fulvic acids, green manure, the roller crimper, biochar, and legumes in pastures. Knowledge of these products and practices is slowly growing in the Prairies, especially among regenerative-minded producers.

Producers may be aware of a practice, but unaware of the practice’s potential as a BMP, or of the agronomic and ecological benefits that the practice can bring. This may be especially true for the use of legumes in pastures, as some producers are familiar with the practice of stitching legume seed into established pastures or perennial forage stands, but not necessarily familiar with the regenerative soil health benefits.

Some producers may already believe they have implemented these practices on their farm, although their methods may be inconsistent with the practice as a BMP with GHGE mitigation potential. This is particularly true for the common Prairie use of compost, as described in section 3.3.2.1. Underlying assumptions about the methods they use may present a barrier to producers’ willingness to seek out new information or to learn how to optimize the practice for the full scope of soil health and climate mitigation benefits.

3.3.2.1. Manure Acidification

For the purpose of estimating mitigation potential in their *Natural Climate Solutions* study, Drever et al. (2021a) defines this BMP as the practice of acidifying fresh slurry manure with concentrated sulfuric acid to reduce the production of methane. They restricted their potential mitigation estimation to swine and dairy farms, which typically store manure as a liquid over a sufficiently long period of time to allow for acidification.

The specific process of manure acidification as defined by Drever et al. (2021a) is mostly unheard of among Prairie producers, although some producers may treat their liquid manure in some manner. Viresco (2022) discusses manure management in general and does not cover manure acidification as a practice.

Economic Barriers

A European study (Hou et al., 2018) surveyed stakeholders, including livestock farmers, in Denmark, Italy, Spain, and the Netherlands about drivers and barriers to eight different manure management practices, one of which was acidification. Economic factors were the most common barriers given by producers, including the lack of capital for initial investment in manure treatment technologies, the high costs for manure processing, and the significant time gap before financial benefit.

Agronomic Barriers

Very little is known about manure acidification in a Prairie agricultural context. Acidified manure used on agricultural crops and soils could potentially have negative impacts on soil pH or soil biota but there is insufficient evidence to fully assess these impacts (L. Fuller, personal communication, January 2, 2024). Without clear research findings on the impacts of acidified manure on soil health and crop production, producers are likely to avoid the adoption of manure acidification.

Socio-Cultural Barriers

European livestock producers frequently reported legal constraints and a lack of knowledge of manure practices, including manure acidification, as barriers to adoption (Hou et al., 2018). Some Dutch and Danish producers noted that the lack of knowledge among local residents and policymakers on manure treatments, such as acidification, created social and political barriers to approval and licensing for manure treatment operations. Less frequently reported barriers in this study included issues with odour and with the transportation of manure.

Awareness Barriers

Drever et al. (2021b) report that manure acidification is not a well-known practice in North America, which suggests that an awareness barrier plays a significant role in producer adoption of manure acidification as a BMP. In contrast, 73% of Danish producers surveyed on manure management (Hou et al., 2018) were not only aware of manure acidification, but had prior experience with the practice, vastly higher than producers from the other European countries in the study. Further exploration would be warranted to identify the drivers of adoption of manure acidification in Denmark and their relevance to the context of Canadian Prairie producers.

3.3.2.2. Manure Application on Cropland

From Prairie producers' perspectives, manure is any animal waste matter obtained from a confined operation such as a dairy or feedlot. Application of manure on Prairie farms typically occurs by one of two methods:

- solid manure is spread onto cropland and then incorporated into the soil through harrowing or tillage
- liquid manure is injected into the soil during fall or early spring when there is no crop growth

Economic Barriers

Canadian researchers McMartin and Hernani Merino (2014), in their article based on field studies and observations in various sites including Alberta and Saskatchewan, noted that costs for manure management equipment are considerable and limit the adoption of manure BMPs, especially for small-scale farming operations. This aligns with producer perspectives from the Bain (2021) report, which stated that the high costs for equipment and infrastructure to store and distribute manure, and the costs for management and processing of manure, are significant barriers to producers' adoption of manure management.

These economic barriers are consistent with Prairie producer perspectives heard through FWWF's advisor. The significant costs associated with the freight for manure to be delivered by truck, the application of manure to cropland, and the incorporation of manure into the soil are major barriers to the adoption of manure as a soil amendment on cropland.

Producers who use manure on their land sometimes continue to use additional synthetic fertilizer as well. These producers are then incurring significant costs for the purchase, delivery, and application of manure, as well as the purchase and application of fertilizer. Lack of access to a manure source is also an economic barrier. Producers may not have a confinement operation that is close and accessible to them from which they can purchase manure.

Agronomic Barriers

The nutrient profile of manure products can be inconsistent and highly variable. The nutrient composition of manure depends on several factors including the animal type, the animals' age, the bedding type, and the feed type used (Manitoba Agriculture, Food, and Rural Initiatives, 2009). Most Prairie producers are not having their manure tested to know the nutrient profile of the products they are applying to their soils.

Not knowing the nutrient profile of manure amendments can lead to the overapplication of manure and overloading of nutrients into the soils. Excess nitrogen in the soil can then be lost to surrounding water bodies or air through leaching, runoff, or volatilization; excess phosphorus in soil can also be lost through runoff (Manitoba Agriculture, Food, and Rural Initiatives, 2009).

This problem is compounded by the additional use of synthetic fertilizer, which some producers apply after manure because they are unsure if the manure has added sufficient nutrients to effectively fertilize their crops. Adding fertilizer can potentially result in the overapplication of nutrients and increases the likelihood of nutrient loss through leaching, runoff, or volatilization.

Socio-Cultural Barriers

Several socio-cultural barriers were reported by Prairie producers through FWWF's advisor. The presence of multiple manure trucks, along with the dust and odour from delivery and application onto fields, can be a nuisance to the community. This creates a major social barrier to producers who do not want to upset their neighbours.

Producers also reported that manure usage is time-consuming. It takes time for manure to be trucked in and spreading it on cropland is a longer process than application of other types of soil amendments.

These barriers are consistent with the two socio-cultural barriers identified in the Bain (2021) report: the logistics of transporting and coordinating manure between parties and the investment of costs, time, and labour for inconsistent benefit to the producer.

Prairie producers must follow local regulations that dictate when, where, and how manure can be applied to agricultural lands. Alberta, Saskatchewan, and Manitoba each have provincial legislation on manure application to minimize the potential for environmental contamination from manure nutrients. The Agricultural Operation Practices Act (AOPA) defines regulations for manure application in Alberta, including the requirement that manure be incorporated into the soil within 48 hours of application to cultivated land, as well as minimum setback distances to keep manure away from water bodies and residences (Government of Alberta, 2015). These time constraints and restrictions may pose a barrier to some producers.

Awareness Barriers

Prairie producers are generally aware of the use of manure as a soil amendment on cropland, however, producers may be unaware of the need to test manure to determine the nutrient profile of the product and avoid overapplication of nutrients through manure and additional synthetic fertilizer.

3.3.2.3. Compost

Scientifically, compost is produced from the biological decomposition of organic matter under specific, controlled conditions. The composted material must be actively managed, have the appropriate nutrient ratio of different types of organic feedstock, and reach a high enough temperature for a period of time to produce the resulting compost product (Martin, 2005).

In practice though, agricultural composting often does not follow this process. Most Canadian producers would consider compost to be the aged mixture of manure and livestock bedding stored on their farms that has not actively been managed under the conditions needed for proper composting. Many producers may not be aware of the specific conditions of time, temperature, and feedstock components that would be necessary for the composting process to effectively kill pathogens and weed seeds.

Economic Barriers

Economic barriers to the adoption of compost as a soil amendment include increased cost of production, costs for increased labour or time needed for compost storage and application, and the potential cost of additional machinery needed for compost application.

Producers may find it difficult to use compost on their land because spreading a solid product may not be possible with the equipment that is typical for most Prairie grain producers (Viresco, 2022). Having to purchase the type of equipment needed to spread compost would present an economic barrier to producers.

Sourcing compost products can also present a barrier as not all producers in the Prairies will have access to a vendor of high-quality compost in the quantity needed. Finally, because of the high variability in compost end products, the economic benefit to the producer from compost use is difficult to define.

Agronomic Barriers

Typical Prairie machinery is often not suitable for spreading solid compost and thus producers may be unable to use compost as a soil amendment with the equipment they currently have available (Viresco, 2022). The use of compost may also require additional labour or equipment usage at the busy seeding and harvest times which creates a conflict in management of the farming operation.

Organic producers in the U.S. reported that they did not trust commercially manufactured compost, stating that they felt it was low-quality and likely contaminated with pesticides or pathogens (Melo Ramos et al., 2019). The variability of feedstock and processes that are used to produce compost means that the end product can also be highly variable. An Alberta producer in the Living Labs program shared that using compost was a challenge to them because there are *“lots of variables and protocols put forward [that] make it a hit and miss affair”* (RALL, 2023b).

This variability in compost products also presents a challenge for producers who may not know how much compost to use or how to calculate the application rate. The agronomic and soil health outcomes from highly variable compost are also uncertain and difficult to predict.

Socio-Cultural Barriers

Socio-cultural barriers to producer adoption of compost as a soil amendment include the lack of available knowledge on compost use or the added benefit of composting manure rather than spreading it uncomposted. A common Prairie farming belief is that there is limited need for the additional step of composting, as producers see compost as simply a source of nitrogen rather than as a microbial inoculant for seed or soil.

Awareness Barriers

The primary awareness barrier to producer adoption of compost as a BMP is the misunderstanding of what compost is intended to be. As mentioned, most Prairie producers are likely not aware that compost should be treated under controlled conditions, nor aware of the specific time, temperature, and feedstock components that would be required for this process.

As such, Prairie producers are not likely achieving full biological decomposition and inactivation of pathogens and weed seeds in the compost they use in their operations. This may result in negative outcomes from compost use that drive the producer to abandon the practice.

3.3.2.4. Green Manure

The Government of Manitoba (n.d.) defines green manure as “a crop [that] is grown primarily for the purpose of being plowed down to add nutrients and organic matter to the soil.” Some sources, both academic and non-academic, consider green manuring to be an interchangeable term for cover cropping. In general, cover cropping as a BMP can be defined as the practice of growing the crop itself, and green manuring as the practice of incorporating the cover crop vegetation into the soil to act as an organic soil amendment.

In the Prairies, green manure is generally more well known in organic agriculture than in conventional agriculture. Prairie producers who are aware of the practice would likely agree with the initial definition of green manure as a cover crop that is grown for the purpose of incorporating into the soil to add nutrients, organic matter, and improve soil health. The practice of mulching could be considered a subcategory of green manure. A cover crop on its own, or the practice of growing a cover crop, would not be considered green manure to producers.

Economic Barriers

The uncertainty of any farm-level economic benefit is likely a strong barrier to Prairie producers’ adoption of green manure. However, there is evidence that green manure systems can produce immediate value if livestock grazing is integrated into a green manure system (Thiessen Martens & Entz, 2011). The authors highlighted the success of the Australian wheat-sheep system, which has benefitted producers in several ways, including through increased crop and livestock productivity, reduced need for nitrogen fertilizer, improved soil structure, and more efficient crop water use.

Agronomic Barriers

Researchers have consistently found that livestock integration with green manure systems results in significant soil health benefits and there is evidence that these benefits could also drive adoption of green manure and grazing BMPs on the Canadian Prairies (Thiessen Martens & Entz, 2011). The feasibility of integrating livestock and cropping systems into large monocropping Prairie farms, however, is questionable.

3.3.2.5. Roller Crimper (Blade Roller)

Producers in the Prairies would agree with the generally accepted definition of a roller crimper as a piece of equipment including one or more drums covered with blunt blades that can be rolled over a cover crop to crimp and damage the plant stems without cutting them. The damaged vegetation falls into a thick mat that covers the ground which then terminates the cover crop, protects the underlying soil, and prevents weeds from growing through (Barrera, 2020; Legere et al., 2013). Although academic researchers often use the term 'blade roller' in the literature, Prairie producers would largely be unfamiliar with this term and would refer to it as a roller crimper.

While it is a tool typically used for cover crop termination, agricultural usage of the roller crimper is considered a BMP in its own right, as it serves many functions that align with regenerative agriculture principles. In addition to cover crop termination, the roller crimper is also used for the purposes of conserving soil moisture, managing weeds, and preventing soil erosion.

Mowing, tillage, and herbicides are also tools used for cover crop termination, however the roller crimper serves this function in a way that aligns more closely with regenerative principles. It does not cause soil disturbance, does not add synthetic inputs to the soil, retains organic matter and nutrients from the terminated crop, retains moisture, and protects the soil from erosion.

The roller crimper also expands the functionality of cover crops on Prairie farms. Cover crops may not have enough time in the short growing season to reach the late growth stage that is necessary for effective roller crimper use. Recent Canadian innovations have led to the development of an in-row roller crimper that allows producers to seed a crop while the cover crop is still growing, and then roller crimp the cover crop at maturity between the rows of new crop growth.

Economic Barriers

The additional costs for specialized equipment, increased labour, increased time and increased cost of production, overall present economic barriers to producers' adoption of the roller crimper.

Most Prairie producers do not have a roller crimper and must obtain this additional equipment before adopting this BMP. Producers can rent, purchase, or build their own roller crimper, although this introduces barriers to the practice. Producers in a Living Labs roundtable discussion (RALL, 2023b) noted that cost and time commitments are barriers to building your own roller-crimper.

They also mentioned that the lack of locally available roller-crimpers to rent presents a challenge to producers, especially those who want to trial the practice on a small scale before making a full commitment. The lack of roller crimpers available for rental may be a major barrier to producers who are interested and willing to adopt the practice but are also trying to mitigate their financial risk.

Finally, the economic benefit at the farm level is uncertain and thus producers do not have a clear financial incentive to adopt the practice.

Agronomic Barriers

Agronomic barriers should also be considered. A major barrier to the use of the roller crimper in the Prairies is the short growing season. Cover crops should reach the late reproductive stage for ideal use with the roller crimper and often the short Prairie growing season does not allow for this. Using the roller crimper too early in the plant's growth may result in the crop not being fully terminated and springing back up to continue growing (G. Singh Dhillon, personal communication, March 28, 2024).

One RALL producer (RALL, 2023b) mentioned that moisture levels present a challenge to their ability to use the roller crimper. They also pointed out that having livestock means the roller crimper may be less necessary, as livestock can graze and trample the cover crop. As such, livestock producers may be less likely to adopt the roller crimper practice.

Moreover, although literature on producer perspectives of the roller crimper is very limited, there is some evidence for decreased crop yields following roller crimper use. A Western Canada test site compared tillage with roller crimping as a cover crop termination method. The study found that although weed growth was reduced, wheat yield was also reduced following the roller crimper (Legere et al., 2013).

Roller crimping that occurs around the busy seeding or harvest seasons may cause timing conflicts for the labour and equipment needed for both purposes, creating an agronomic management barrier to producers.

Awareness Barriers

In addition to the awareness barriers listed in section 3.3.2., a terminology difference also presents an awareness barrier to adoption of the roller crimper. The use of the term 'blade roller' by researchers is inconsistent with terminology used by Prairie producers who are familiar with this equipment as a roller crimper. The disconnect in terminology between researchers and producers creates a barrier to accurate tracking of the practice, more widespread adoption of the practice, and to producers' access to knowledge about the practice.

3.3.2.6. Humic and Fulvic Acids

Humic and fulvic acids are found naturally in the humic substances of soil and are commercially available to producers as soil amendment products. These acids can be used to stimulate plant growth, act as a source of carbon and energy, chelate soil nutrients, and buffer against pH changes or other excesses in soil. Most conventional producers in the Prairies would be unaware of humic and fulvic acids, or their use as soil amendments, although knowledge of these products is now growing.

Commercial humic and fulvic acid products are frequently used and have become a popular discussion topic within the regenerative agriculture community. Regenerative producers have reported to FWWF that humic and fulvic acids seem to optimize their herbicides and fertilizers, allowing them to use those inputs more conservatively.

These products are important to highlight, as they have the potential to bridge the gap between conventional producers and regenerative agriculture. Curious producers can start with humic and fulvic acids, as they are soil inputs that can be used alongside any conventional inputs already in place and have lower barriers to entry than many other BMPs. The use of these products as soil amendments can increase soil microbial growth, soil water-holding capacity, and nutrient availability (Ampong et al., 2022), and can act as the catalyst that prompts conventional crop producers to think about farming in terms of soil carbon and regeneration.

Economic Barriers

Economic barriers to producers' use of humic and fulvic acids include the additional cost of these products, the costs for increased labour or time spent applying the products, and the potential cost for additional equipment for application or for professional consulting on how to use the products.

The availability of humic and fulvic acids may be a barrier to some producers as they may not have access to a retailer who sells the products. The potential economic benefit to producers from the use of humic or fulvic acids has not yet been proven and thus producers are unable to accurately weigh the costs and benefits of using these products.

Agronomic Barriers

As the agricultural use of humic and fulvic acids is relatively new, research on their use in the Prairies is limited. As such, there is a lack of agronomic knowledge available to Prairie producers on how to use these products on their farms or on the optimal application rate for humic or fulvic acids on cropland.

Moreover, humic and fulvic acid products that are available to producers may not have consistent formulations. They can vary in strength or quality and thus pose a challenge to producers trying to determine the optimal rate of application and may produce inconsistent or unpredictable agronomic outcomes. The additional labour or equipment needed for application of humic or fulvic acids may result in a timing conflict during the busy seeding or harvest times.

Finally, the potential benefits from humic or fulvic acids to soil health or to surrounding ecosystems remain unclear – producers may be reluctant to adopt a practice with no clearly demonstrated benefit.

3.3.2.7. Biochar

Biochar, also known as biocarbon, is consistently defined as the charcoal product formed from the pyrolysis of organic matter. Drever et al. (2021a) evaluated the mitigation potential from biochar specifically made from agricultural crop residue, thus not including biochar from manure or other sources of biomass. In the Prairies, most producers would be unaware of the term biochar, or of the practice of using it as a soil amendment.

Research on biochar has primarily focused on the agronomic and environmental outcomes of biochar addition to agricultural soil; literature on producers' perspectives of the practice is very limited. FWWF engagement sessions collected just one response directly related to biochar – a producer shared their struggles with biochar application, stating it is a *"challenge to spread timely and in right season, expensive custom rates to spread and difficult to calibrate rates, inconsistent quality"* (RALL, 2023b). With the lack of available producer perspectives on biochar, this section will present barriers to biochar usage described by researchers and scientists in current literature.

Economic Barriers

Biochar is created from pyrolysis, not combustion, of biomass and, therefore, requires specific pyrolysis equipment to produce. Producers then must have access to commercial pyrolysis facilities or mobile pyrolysis units – investment in these types of equipment or services may be costly and producers will need assurance of sufficient financial return for this practice (Viresco, 2022). Guo et al. (2016) also report that commercial biochar products are limited and expensive, and that it is more economically feasible for producers to create their own biochar using crop residue from their own farms.

Latawiec et al., 2017 examined Polish producers' awareness of, and willingness to adopt, biochar as a soil amendment. 42% of surveyed producers were not interested in adopting biochar on their farms, with the most common reasons cited as costs being too high, or a lack of information or knowledge about implementing the practice.

Technical research on biochar use in agriculture has shown inconsistent economic outcomes. Although many studies have shown crop yield increases after biochar use, some studies have shown no difference, or even reduced crop yields with biochar addition (Zheng et al., 2016). The small yield improvements and inconsistency of yield outcomes seen in biochar research reinforces the idea that economic incentives, possibly through carbon offsets, will be necessary to increase producer adoption of biochar usage as a soil amendment (Ejack, et al., 2021).

Agronomic Barriers

Literature on producer barriers to biochar usage as a soil amendment is very limited. Further research is needed to more fully understand the impacts of crop residue removal on soil health and crop yields, on biochar's capacity to reduce nitrous oxide emissions in Prairie soils, and on the effects of biochar from different types of biomass and pyrolysis conditions on Prairie soils (Viresco, 2022). Research that fills these knowledge gaps can address agronomic knowledge barriers that producers may have and should contribute to increased adoption of biochar usage on soil by Prairie producers.

Current literature largely focuses on agronomic benefits from biochar seen in laboratory-scale research and are not necessarily generalizable to large-scale or even farm-scale application (Guo et al., 2016; Zheng et al., 2016). As biochar is produced from biomass, the final product can be highly variable depending on what type of biomass was used and the conditions of the pyrolysis process. Moreover, biochar research has evaluated biochar outcomes primarily on soils that were initially hostile to agricultural production, including nutrient-depleted soils and acidic forest soils (Zheng et al., 2016). Outcomes on these soils may be significantly different than those on the fertile, agriculturally productive soils of typical Prairie farms.

There are also practical challenges of application as biochar is a lightweight material that can blow away if applied on the surface without incorporation into the soil, therefore creating soil disturbance and potential soil carbon release.

Socio-Cultural Barriers

As most Prairie producers are unaware of either the terminology or the practice of biochar in agriculture, it would likely be perceived as an alternative or experimental practice that does not align with Prairie farming norms. Interested producers may be reluctant to adopt unproven agricultural practices that are outside of the norm, such as biochar, out of fear of experiencing a disconnect from their peer community or social isolation from engaging in "fringe" farming practices.

Polish producers in the biochar study gave "no information or knowledge" as the most common reason for not being interested in pursuing biochar amendments as a practice on their farms (Latawiec et al., 2017b).

Environmental risks may present barriers to increased adoption of biochar as a soil amendment. After pyrolysis, biochar may retain polycyclic aromatic hydrocarbons (PAHs), which are phytotoxic and potentially carcinogenic compounds (Zhang et al., 2016). When biochar is spread on soil in fields, there is the potential for these compounds to become airborne and pose a health risk to animals and humans (Zhang et al., 2016). This can also become a potential food safety issue if the compounds enter into food crops through the soil (Zhang et al., 2016). By law, Canada requires commercial biochar soil additives to be certified, which includes toxicological testing for numerous heavy metals, dioxins, and furans (Bertrand & Lange, 2019). This process, however, does not include testing for PAHs, as is required by the International Biochar Initiative for safe usage and handling of biochar (International Biochar Initiative, 2015).

Awareness Barriers

As stated in the introduction to section 3.3.2.7., most Prairie producers are unaware of the term biochar, or of the practice of using it as a soil amendment. Although research on producers' perspectives on biochar is very limited, a couple of European studies on producers' perspectives on biochar (Latawiec et al., 2017a; Payen et al., 2023) give some insight into what barriers might also be relevant to Canadian Prairie producers.

Overall, Polish producers in the Latawiec et al. (2017a) study were mostly unaware of biochar, either by terminology or by function. The researchers provided a definition of the term 'biochar' on the producer survey, but of the 161 farmers who participated, 72% responded that they were unfamiliar with the term 'biochar', whether related to the provided definition, or in any other context.

This awareness barrier was echoed in the findings of a French study (Payen et al., 2023) that interviewed winegrowers on soil carbon sequestration practices. Nearly half of the 506 participating French winegrowers stated they were unaware of the practice of adding biochar to agricultural soils. Being unaware of biochar as a soil amendment was by far the most common barrier stated by winegrowers in this study. The small number of winegrowers who were familiar with biochar had limited understanding of the technical aspects and the beneficial effects of the practice due to a lack of information available to them.

Guo et al. (2016) agreed that there is a significant awareness barrier to producers' adoption of biochar as a soil BMP, stating that the majority of crop producers have never heard of biochar. They stated that those stakeholders who are aware of the term often have a poor understanding of the practice, or don't realize how different biochar end products can be, depending on the feedstock and pyrolysis conditions used (Guo et al., 2016).

3.3.2.8. Legumes in Pastures

Incorporating legume species into pasture stands brings significant benefits to soil health, including improved biological fertility in soil (Thiessen Martens et al., 2015), fixation of atmospheric nitrogen (Khatiwada et al., 2020), and increased soil organic matter (Government of Saskatchewan, n.d.-b) and as such, this practice is included in the Organic Soil Amendments section.

Drever et al. (2021b) defines this BMP as "including locally suited legumes in the species mix used in pasture establishment, managing grazing to increase the longevity of existing legumes (e.g. allowing legumes to go to seed), or seeding legumes into established pastures that have inadequate legume composition" (p. 30). Producers in the Prairies would consider this practice to involve stitching legume seed into established pastures or perennial forage stands that may be old or struggling.

There is a wide range of species that can be used when incorporating new legume forages, from simple monocultures to complex legume-grass mixtures. A sod seeding manual for producers created by the Manitoba Forage Council (Nazarko, 2008) outlines multiple methods of seeding new legumes into pasture stands:

1. Renovation involves chemical termination of the existing pasture, tillage, and then reseeding
2. Broadcast seeding deposits legume seeds directly into the existing stand without initial termination, and usually requires some mechanical force to disturb the ground to allow seed germination
3. Sod seeding or direct seeding is done with a sod seeder or a zero-till drill, to directly seed into the existing pasture without disturbing the land

Economic Barriers

Kelln et al. (2022) conducted a study on sod-seeding legumes into pasture stands in Saskatchewan (a five-year experiment) and Alberta (a three-year experiment). The study evaluated both agronomic and economic outcomes of legumes in pastures and found that the legume paddocks showed no increase in profitability over the control paddocks. Both sites showed legume yields that varied from year to year. Dry matter intake by steers was the same in legume paddocks as it was in the control paddock, until year five when legume dry matter intake exceeded the control. They also found that sainfoin needed to be reseeded after the five-year experiment and noted that the cost of reseeding should be considered against any economic benefit. Ultimately, the authors concluded that sod-seeding pastures with the studied legume plants (non-bloating cicer milkvetch and sainfoin) is financially very risky to producers and may not be economically feasible (Kelln et al., 2022). They also noted that the literature on the economic outcomes from legumes in pastures is inconsistent, with some studies showing net losses and others showing net profits (Kelln et al., 2022).

Another Alberta study (Omokanye et al., 2018) had zero establishment of cicer milkvetch or alfalfa at two separate sites using three methods of seeding; the economic returns of these methods were negative and the authors concluded that more research is needed to develop a protocol that will be economically feasible for producers.

Producers in the Bain (2021) report also noted that the initial costs needed to seed legumes into pastures, including the high cost of legume seeds and the costs of seeding them, are economic barriers to producers. In addition, they noted that there is no clear economic benefit or market incentive that would motivate producers to adopt forage legumes in their pastures (Bain, 2021). Many producers will only consider changing their farming practices if there is a clear revenue potential from the new practice that justifies the cost to implement (L. Fuller, personal communication, January 2, 2024).

One RALL producer had these same concerns and expressed a desire for help with this practice, stating *"[it's a] challenge to get pastures productive enough to get them competitive with grain production. [Need to know] how to get return for any investment (i.e. Fertility, composition, production)"* (RALL, 2023a).

Agronomic Barriers

Canadian research on successful protocols for adding legumes to pastures is limited and the findings on agronomic outcomes are inconsistent, which presents a barrier to producers' ability to confidently incorporate this practice. There are numerous biophysical variables that contribute to legume success in a pasture stand. A variety of seeding methods and legume species can be used to incorporate legumes into pastures but not all will be successful in each producer's specific farm context. Geography and weather also play a significant role in legume success – they are weather-sensitive so some species may fail in certain weather, soil, and climate conditions (Bain, 2021; Foster et al., 2014).

A recent review (Khatiwada, et al., 2020) on mixed grass-legume pastures in Western Canada shared many consistently beneficial findings, however with no information on their selection methodology, nor on the quality of the included studies, it's difficult to determine the accuracy of the findings or the overall validity of this article.

Kelln et al.'s (2022) study of legumes in Saskatchewan and Alberta also found that legumes' success in a pasture stand depends in part on what plant species is already present, as some legume crops may be incompatible with certain pre-existing pasture plants. Many pre-existing pasture grasses are highly competitive, and it can be difficult to establish new legume seedlings (Nazarko, 2008). The Manitoba Forage Council (Nazarko, 2008) strongly encourages producers to suppress the existing vegetation on pastures before seeding, to dramatically increase the percentage of legumes that will successfully establish. Suppression can be done mechanically, chemically, or via livestock (Nazarko, 2008), but this adds time, labour, and cost to the process.

The literature on seeding methods shows inconsistent findings; mechanical methods of aeration during seeding have been shown to either increase, or have no effect, on forage yield (Kelln et al., 2022). Seeding rates and species mixtures also need to be balanced carefully to maximize productivity without causing harm to cattle. Alfalfa is easier to establish and grow in a variety of soil and water conditions (Nazarko, 2008), however if pastures become too alfalfa-heavy, the risk of pasture bloat in cattle is high (Popp et al., n.d.). Echoed from above, other legume species such as sainfoin and cicer milkvetch are non-bloating but are more difficult to establish and grow, and less likely to re-grow in following seasons (Nazarko, 2008), potentially leading to costly re-seeding being necessary in the near future.

Timing of legume seeding is another challenge. Spring seedlings may fail due to highly competitive grasses but later summer or fall seedlings may fail due to the lack of soil moisture (Nazarko, 2008; Omokanye et al., 2018).

Foster et al. (2014) conducted a Saskatchewan study on simple and complex grass-legume mixtures and noted inconsistencies even within their own findings and in comparison to other literature. Their finding that complex grass-legumes mixtures yielded less than simple grass-alfalfa blends contradicts other research showing that more complex blends increase yields (Foster et al., 2014). Their yields were also highest in the second year of production, whereas the literature findings generally show that first-year yields are typically the highest (Foster et al., 2014). Research inconsistencies like this create a barrier to producers who may adopt the practice but not see desired yield results after the first year. Hearing that the first-year yield should be the highest may lead the producer to abandon the practice, believing they will not get a higher yield next year, when in fact the opposite could be true.

Prairie producers are interested in incorporating legumes into their pastures, but their comments echoed some of the same challenges found in the literature. At a RALL discussion, a producer wanted to know *"what is the most effective way to incorporate legumes into existing/established pasture/grass stands (weather exclusive) without breaking ground. Also needs to be a reliable way to get it established"* (RALL, 2023a).

Other producers said they need help with the *"challenge of how to keep legumes in the stands without breaking up the land"* (RALL, 2023a). Another producer commented that there were *"very few protocols with success"* for legumes in pastures, although they felt that using mob grazing (also known as adaptive multi-paddock grazing) seemed to show the most promise (RALL, 2023b).

"Message to researchers – producers need information on how to get legumes into existing fields, and how to get them to stay once they are there. May need better breeding programs or species."

RALL producer (RALL, 2023a)

There is also a lack of knowledge among Prairie producers of the need to measure carbon and nitrogen in the soil when seeding legumes into their pastures. In some cases, the integration of legumes has been unsuccessful (lower productivity) or has resulted in increased weed stress. Measuring the carbon-nitrogen ratio in soil may indicate if and when legume use is successful. If this ratio is less than 20:1 in the dry Canadian Prairies, soil nitrate-nitrogen levels may be too high to allow nitrogen fixing by legume plants (K. Nichols, personal communication, February 20, 2024). High nitrate-nitrogen levels may result in increased weed growth as the soil attempts to add more carbon and convert nitrate-nitrogen to organic nitrogen in plant biomass (K. Nichols, personal communication, February 20, 2024). Legume biomass and residue provide only a limited amount of armour to the soil and may increase weed growth on a pasture.

Foster et al. (2014) concluded that there is insufficient information available to Saskatchewan producers, especially those in areas with more moisture, on incorporating complex legume mixtures into pastures. Bain (2021) also reported the lack of research on best practices and economic profitability to Prairie producers as a barrier to adoption. Khatiwada et al. (2020) highlighted specifically that "evidence-based information on creating forage mixtures by direct seeding legumes into existing pastures is limited, and information on bloat-free legumes is nonexistent" (p. 463). With insufficient and inconsistent research on best practice protocols for the Prairies, producers will continue to face agronomic barriers to successfully increasing legume production in their pastures.

3.4. Integrated Crop-Livestock Systems

An integrated crop-livestock system (ICLS) is an umbrella term that includes various BMPs that involve the integration of livestock management and crop production (Viresco, 2022). In the Canadian Prairies, these systems can include forage rotations, cover crop grazing, stubble grazing, bunch grazing, swath grazing, bale grazing and dual-purpose crop grazing, as well as multi-paddock or rotational grazing on cropland. Prairie mixed farms typically have their crop and livestock systems integrated by default, although they may not specifically use the term 'integrated crop-livestock system.' This terminology is likely known by most Prairie producers through agriculture publications, websites, or workshops, but is not typically used in everyday language.

Literature on producer perspectives of integrated crop-livestock systems has primarily studied producers in the U.S. and in Europe; literature on Canadian producers is limited. FWWF producer engagement received few responses directly related to integrated crop-livestock systems; one producer in the March 2023 RALL roundtable discussion noted that they did want more information on intensive grazing practices. Another producer at the same discussion shared that their status as a land renter was a barrier to integrating livestock into their cropland, stating that they are *"not in direct control as they rent cropland for livestock integration"* and that they would like to see *"relationships/partnership development with cropland owners for more and ease of livestock & cropland integration"* (RALL, 2023a).

Economic Barriers

Producers face significant financial barriers to adopting integrated crop-livestock practices. Adopting a crop-livestock practice often requires producers to purchase additional fencing and watering infrastructure. (Thiessen Martens & Entz, 2011). Viresco (2022) reports that the costs for such infrastructure are a major barrier to producers.

Managing a crop-livestock system also means a commitment to the high costs of both manure management and crop fertilizer, which is likely a major barrier to producer adoption (Thiessen Martens & Entz, 2011). They also report that crop-livestock systems require more labour than a crop-only system. These barriers align with a review by Schut et al. (2021) on the adoption of crop-livestock systems in European countries, who noted numerous economic barriers, but specifically state that "poor infrastructure, lack of qualified labour, and limited financial incentives are often cited by farmers as the key barriers to integrated crop-livestock system adoption" (p. 9).

Given the significant financial investment, producers must be able to see a clear economic benefit to their adoption of a crop-livestock system (Thiessen Martens & Entz, 2011). Research on the economic outcomes of integrated crop-livestock systems on Prairie farms is still quite limited.

Agronomic Barriers

Although Canadian literature on producers' experiences with integrated crop-livestock systems is limited, U.S.-based research has examined producer barriers more in-depth. Hayden et al. (2018) interviewed producers from Northern U.S. states, who managed farms ranging from certified organic to conventional, including some transitional operations. These producers mentioned several agronomic barriers to the adoption of integrated crop-livestock systems. Some farmers feared that grazing livestock would cause compaction in their soil.

Hayden et al. (2018) also noted that a key barrier to adoption is the time gap between producers implementing integrated crop-livestock practices and seeing any tangible soil health benefits. This was especially relevant to farmers who may already have depleted soil before adoption, as they believed it would be even more challenging to get robust, healthy soil from these integrated practices (Hayden et al., 2018).

As the effects of climate change and global warming increase, so does the level of variability and severity of weather events. American producers also struggled with challenges related to weather conditions affecting their crop-livestock systems (Hayden et al., 2018). Too much moisture can make the ground more vulnerable to soil compaction from livestock grazing. Hard, dried crusts on winter snow prevent livestock from accessing it as a water source.

Viresco (2022) reports that integrated crop-livestock systems can have a negative impact on nutrient and mineral levels and that monitoring of mineral levels should be in place to prevent environmental pollution. They also state that integrating crop and livestock systems can create a higher demand for agricultural land – which may come at the expense of converted grasslands or deforestation (Viresco, 2022), however, in the Canadian Prairie context this is unlikely.

Socio-Cultural Barriers

These socio-cultural barriers apply to all integrated crop-livestock practices in section 3.4. Rotational grazing and extended grazing practices are still viewed as alternative or experimental practices that do not fit into the box of conventional Prairie farming norms. For this reason, producers may be reluctant to learn about these practices or change their current practices.

They may also hesitate to adopt a practice that their peers and neighbours may perceive as “weird” or excessively complicated for “no good reason.”

Knowledge available to producers creates barriers to adoption, particularly for adaptive multi-paddock (AMP) grazing systems. There is simultaneously an overwhelming amount of information available and also not enough information available. The vast range of grazing practices that fall under the umbrella of AMP have led to a considerable amount of knowledge available to producers through research and online resources. FWWF’s advisor shared that the wealth of information on different grazing approaches is overwhelming to newly interested Prairie producers who are unsure where to start.

Despite this wealth of information, the resources on how to implement integrated crop-livestock systems successfully in Prairie agro-climatic contexts is limited. Many of the grazing resources online are intended for U.S. agricultural contexts and may have limited relevance to typical Prairie farms. As such, Prairie producers also find a lack of information that is specific to the unique considerations of Prairie agriculture.

In a recent roundtable discussion (RALL, 2023b), a RALL producer shared a quote that revealed a key social barrier, stating that it *“would be ideal to have a cow guy working with a grain guy (to exchange livestock grazing on crop residue, swaths, etc) but these [collaborations] are very very few and far between, it just doesn’t happen.”* This response is worthy of further exploration to uncover the specific barriers preventing grain producers and livestock producers from collaborating in this way. This quote also articulates the narrative within the farming community that there are “cow guys” and “grain guys” and highlights the different perspectives that each group holds towards the use of livestock in farming operations. Crop producers often view livestock in terms of the risk of soil compaction, the extra work and cost, and the hassle that livestock would bring to their farm management. Conversely, cattle producers typically view livestock as essential contributors to their operations due to the numerous benefits they bring to the land. These contrasting mindsets likely make collaboration between the two groups challenging and point to the need for more efforts to bridge the gap.

At the farm level, producers may encounter barriers in farm management and the complexity of their farming operations, especially for intensive rotational grazing practices. Hayden et al. (2018) noted that American crop farmers perceived livestock farming to require a significant commitment in time, energy, and management. Livestock farmers also perceived some integrated crop-livestock practices like intensive rotational grazing to be an intensive time and lifestyle commitment. Moving livestock frequently requires more grazing paddocks, which increases the labour, maintenance, and management demands on producers (Viresco, 2022). The need for livestock to rotate grazing areas frequently can necessitate a lifestyle change for producers and their families. The high levels of maintenance and scheduling needed for rotational grazing practices are a barrier to some producers who are unable or unwilling to make that commitment.

Successfully integrating livestock with a cropping system, balancing the needs of all sides, and ensuring economic feasibility will require producers to improve their human capital through knowledge, time, and labour. Not all producers have the capacity to make this investment and, as such, this presents a barrier to their ability to adopt integrated crop-livestock systems.

In their path towards adopting an integrated crop-livestock system, producers may also face barriers at higher levels related to the Prairie agricultural norms of monocrop grain farms that dominate producer culture, rural communities, and the regulatory system. Thiessen Martens and Entz (2011) note that producers who want to adopt integrated crop-livestock systems must work against a system that is designed to support large-scale monocrop farms.

Integrated crop-livestock systems do not fit nicely into large monocropping production systems and, as such, the feasibility of large-scale integration of livestock and crop production on the Prairies is questionable. The dominance of large monocropping production systems is a significant barrier to large-scale adoption of integrated crop-livestock systems that may only be addressed by a major paradigm shift away from conventional agriculture (L. Fuller, personal communication, January 2, 2024).

In the European context, Schut et al. (2021) are clear that "integrated crop-livestock systems will not develop without policy support and institutional incentives" (p.12). However, producers must also have the benefit of a like-minded peer community through which they can problem-solve, exchange knowledge, and share support. Hayden et al. (2018) noted that policies to address producer barriers to adoption of integrated crop-livestock systems would be effective only for producers who are interested in adopting and who have the social support to do so. They state that "without this supportive normative environment, it is unlikely that farmers intending to transition to integrated systems will be successful in doing so" (Hayden et al., 2018, p.20).

It can likely be presumed that these European insights would also apply in the Prairies. Indeed, large-scale adoption of integrated crop-livestock systems within the current conventional Prairie agriculture system will likely not happen without a significant paradigm shift along with policy changes, effective financial incentives, technical assistance, extension services, and community support.

Finally, land rental agreements may restrict the grazing of livestock on cropland, which creates a barrier to producers who rent their cropland.

Awareness Barriers

These awareness barriers apply to all ICLS systems in section 3.4. Although many Prairie producers would generally understand what integrated crop-livestock systems are, the terminology and specifics of the practices included in section 3.4. are not consistently understood by producers. Overall, there is generally low awareness of the benefits of integrated crop-livestock systems and of how they could be incorporated into Prairie farming systems. This is reflected in the very limited base of Canadian research as well as the very small number of producer comments on integrated crop-livestock systems collected through FWWF engagement.

Producers' understanding of extended grazing practices like bale grazing and swath grazing may be inconsistent with how researchers and other agricultural experts define the practice. Some producers may believe they are already implementing a grazing practice even if their understanding of the practice does not align with its full scope as a BMP. This is especially true for rotational grazing and adaptive multi-paddock (AMP) grazing, which both include a range of practices and terminology, and are not universally defined by researchers, government, or producers. The wide variety of practices that fall under the AMP umbrella means that producers who are familiar with AMP terms may also have a wide range of assumptions and understandings of what the practice involves. This disconnect in consistent understanding of the practices, and the terminology used, presents an awareness barrier to producers' access to information, and their ability to implement the practices optimally to achieve the full scope of soil health and climate mitigation benefits.

3.4.1. Bale Grazing

Bale grazing is a livestock feeding system in which forages (either annual or perennial) are baled and left on pasture or cropland for livestock to graze (Thiessen Martens et al., 2015). In general, producers in the Prairies would agree with this description of bale grazing as a practice. Viresco (2022) considers bale grazing to be a sub-BMP of Increasing Organic Soil Amendments due to the contribution of nutrients from livestock waste that is spread out over bale-grazed cropland rather than concentrated in one area.

Economic Barriers

Economic barriers to bale grazing include the costs of labour, time and fuel used for baling forage, and transporting and distributing the bales (Viresco, 2022). There may be additional costs if a producer's fencing needs upgrading to ensure livestock cannot escape. Double wire electric fencing is recommended to compensate for the insulating effects of snow on the ground that could render single wire fencing insufficient to retain cattle (Manitoba Agriculture, Food, and Rural Initiatives, 2008).

While some producers may perceive that adopting a bale grazing practice will increase their overall costs, time, and labour, there is some evidence to suggest that these perceptions are unfounded. Jungnitsch et al. (n.d.) studied winter cattle feeding systems in Saskatchewan and found that bale grazing and other infield feeding methods had higher labour costs, but lower machinery and manure removal costs, than dry lot feeding with manure spreading. Despite the higher labour costs, total feeding costs for bale grazing were significantly lower than total feeding costs for dry lot feeding.

Although Jungnitsch et al. (n.d.) found significant increases in forage yield after bale grazing, Prairie-based research findings in this area are inconsistent. Viresco (2022) notes that research has found evidence for both increased and decreased forage growth after bale grazing.

There is also a major crop insurance barrier that applies to both bale grazing and swath grazing. Alberta's Wildlife Damage Compensation Program provides insurance against wildlife damage sustained to stacked hay or greenfeed, silage and haylage in pits and tubes, and unharvested crops (AFSC, 2023a). Premiums for this program are covered by the provincial and federal governments, so this insurance coverage is available at no cost to Alberta producers. Producers who store their baled hay stacked in fields are eligible for the insurance coverage, however, producers who spread their hay for bale or swath grazing are not eligible for coverage. This presents a major barrier to producers who are unable to assume the risk of a financial loss of hay to wildlife that could have been mitigated by free insurance coverage.

Agronomic Barriers

Inconsistent research findings on forage growth (Viresco, 2022) present a barrier to producers' adoption of bale grazing. Producers are likely to be reluctant to adopt a practice with significant uncertainty of agronomic and economic productivity outcomes.

Jungnitsch et al.'s (n.d.) Saskatchewan study found that bale grazing and other infield feeding methods resulted in greater retention of soil nutrients, higher forage protein content, and significantly increased forage growth compared to the dry lot feeding and manure spreading method. While these findings are promising, the research is insufficient to demonstrate a proven benefit to soil health from bale grazing. This uncertainty creates a barrier to producers who may not be able to justify the costs and effort to adopt a practice with an agronomic benefit that remains uncertain.

Other agronomic barriers to Prairie producers' adoption of bale grazing include the lack of an agronomic protocol for producers to implement this practice in Prairie agricultural contexts, difficulties with calculating fertilizer requirements on cropland after winter grazing, difficulties with weed control, and having more waste material to dispose of.

3.4.2. Swath Grazing

Swath grazing is another livestock feeding system in which crops (typically annual crops) are harvested and laid in swaths on pasture or cropland for livestock to graze (Thiessen Martens et al., 2015). Producers would consider swath grazing to involve growing an annual crop for the purpose of swathing, whether it be a monoculture or even a cocktail mix, then harvesting and laying it in swaths to be fed to livestock through a managed process, depending on the needs of the producer.

Economic Barriers

A barrier to swath grazing shared by producers in a RALL producer discussion is the lack of a water source on the intended grazing land, as one producer stated *"is there water already there? Not going to dig a dugout for one to two years of swath grazing"* (RALL, 2023b). Producers who don't already have a water source on the intended grazing land are unlikely to put in the time, cost, and effort to develop one just for the purpose of swath grazing. Some producers perceive the need for fencing around grazing paddocks to be a barrier to adoption of swath grazing, however some RALL producers felt that this barrier is overstated. One producer said, *"some say fencing is a barrier but it is an easy barrier to overcome"* (RALL, 2023b).

Producers shared that the biggest barrier, by far, to swath grazing in the Peace region of Alberta is the local elk population. One Peace region producer stated they know of many local producers who are motivated to try swath grazing or other extended grazing practices but are unable to because of the abundance of elk in the area. Elk are known to eat and damage crops and forages, and their excrement can destroy anything remaining, leaving livestock with nothing to eat and producers with significant losses (The Canadian Press, 2015). In 2011 and 2012, wildlife caused nearly $7 million in crop damage in the Peace region (The Canadian Press, 2015). Thus, any fields used for swath grazing, or any extended grazing practices, must be surrounded with elk-proof perimeter fencing. This presents an economic barrier to producers who would need to invest the time, labour, and costs for extensive fencing. RALL producers (RALL, 2023b) mentioned that fencing like this can be done with some creativity and time investment, however this is simply not feasible for large acreage grain farms. For these producers, fencing in a smaller, dedicated swath grazing field would be more manageable.

Peace region producers noted that local deer can also be a challenge to extended grazing practices, but to a lesser extent than elk. Deer eat less, do less damage, and are generally easier for producers to manage; one producer stated *"[we] can deal with deer but [we] cannot deal with elk unless [we] do some creative perimeter fencing"* (RALL, 2023b). Recently, producers in central and southern Alberta have reported to FWWF that deer and Canada Geese are becoming problematic in their regions as well (K. Cornish, personal communication, February 1, 2024).

There is also a major crop insurance barrier that applies to both bale grazing and swath grazing. Alberta's Wildlife Damage Compensation Program provides insurance against wildlife damage sustained to stacked hay or greenfeed, silage and haylage in pits and tubes, and unharvested crops (AFSC, 2023a). Premiums for this program are covered by the provincial and federal governments, so this insurance coverage is available at no cost to Alberta producers. Producers who store their baled hay stacked in fields are eligible for the insurance coverage, however, producers who spread their hay for bale or swath grazing are not eligible for coverage under this program. This presents a major barrier to producers who are unable to assume the risk of a financial loss of hay to wildlife that could have been mitigated by free insurance coverage.

Agronomic Barriers

Alberta producers in the RALL program shared that the lack of moisture can cause issues with the implementation of swath grazing and that this may be more of a risk than many producers are willing to take on (RALL, 2023b).

RALL producers shared a major barrier to swath grazing specific to the Peace region of Northern Alberta, although it may also be relevant for other regions of the Prairies. They noted that warm periods through the late winter make swath grazing far too risky for producers in that area (RALL, 2023b). When the weather warms up, snow on the swaths will melt initially and then re-freeze as temperatures drop again. This causes a layer of ice to form over the swaths, making them completely inaccessible to grazing cows. This risk leads Peace region producers to discontinue swath grazing typically by Christmas.

Other agronomic barriers to producer adoption of swath grazing include weeds, unknown fertilizer requirements for crops after livestock grazing, the lack of a clear agronomic protocol on how to implement the practice and the most ideal species to use, and the uncertain soil health or ecological benefits from the practice. Extreme weather events such as drought, flooding, or wildfires can interfere with optimal outcomes from swath grazing and thus producers may feel that the risk of adopting this practice is too great.

3.4.3. Bunch Grazing

Bunch grazing is a winter grazing method used by some Prairie livestock producers. Producers would define bunch grazing as the practice of collecting and bunching chaff and straw at harvest to be left on cropland or pasture for cows to graze through fall and winter.

There is no clearly defined government or academic definition for bunch grazing, and no published literature on this practice was found. It is likely that bunch grazing was developed and refined by producers at the farm level in response to challenges with other winter feeding methods (Furber, 2014). While swaths risk being buried under deep snow or frozen due to freeze-thaw cycles, bunched piles seem to be more resistant to these challenges.

Economic Barriers

Economic barriers to bunch grazing as identified by FWWF's advisor include the costs of purchasing additional equipment to collect straw and chaff, and then drop it onto fields in piles. The economic benefit from bunch grazing is uncertain as it has not yet been clearly defined through research.

Agronomic Barriers

Producers who adopt this practice may experience timing conflicts for labour or equipment during busy seeding or harvest times. The soil health benefits from bunch grazing are uncertain which creates a barrier to producers who may not be able to see a tangible agronomic benefit from the adoption of this practice.

Socio-Cultural Barriers

High management demands are a barrier to bunch grazing. Monitoring livestock and nutrient testing the residues are necessary to ensure livestock stay healthy (Furber, 2014). As bunches include only the straw and chaff, without the grain, feed quality can be variable and sometimes poor. Producers will need to obtain a feed analysis on crop residues they use for bunch grazing (Alberta Agriculture and Irrigation, 2016). Depending on the nutrient profile, bunches may be insufficient to ensure livestock satiety.

Close monitoring through the winter is necessary to ensure that bunch grazing is providing sufficient nutrients and satiety to maintain health, and livestock should be supplemented with grain and minerals as needed (Alberta Agriculture and Irrigation, 2016).

3.4.4. Rotational Grazing

Rotational grazing is a general term that includes many different grazing practices that all involve moving livestock through multiple grazing paddocks instead of leaving them to graze in a single paddock (Viresco, 2022). The Viresco report (2022) categorizes rotational grazing as basic, intermediate, or intensive, and defines these categories based on the frequency of movement to a new paddock. Rotational grazing practices include adaptive multi-paddock grazing, strip grazing, and Voisin grazing among others (Tourangeau & Sherren, 2021).

Prairie producers would likely define rotational grazing as the practice of moving livestock through grazing paddocks on a prescriptive and repetitive schedule. Producers may not have a grazing plan and may graze livestock without changing or adapting the rotations to external factors.

Economic Barriers

Viresco (2022) highlights economic barriers that may also apply to many extended grazing practices. Specifically, there are initial costs for fencing and water infrastructure, which could be significant for producers with large acreage. Rotational grazing will also require more labour for assessing pastures, maintaining grazing infrastructure, and moving livestock regularly.

A producer in the RALL program discussed their negative experience with rotational grazing during a drought. In an effort to protect the forage stand, the producer reduced their stocking rate to one third of their normal, which resulted in a major economic impact to their operation (RALL, 2023b). Another RALL producer shared their success with rotational grazing, although they felt that the lack of an economic benefit through the carbon offset market is a barrier to livestock producers. The producer intended to continue rotational grazing *"...for a long time if we* *can find value and compensation for keeping the carbon in the soil. Carbon credits have typically been available to grain producers and not cattle* [producers]*"* (RALL, 2023a).

Agronomic Barriers

Through FWWF's advisor, numerous agronomic barriers to producer adoption of rotational grazing in the Prairies were identified. Producers lack an agronomic protocol to guide them in the implementation of rotational grazing. There is also a lack of information available on how to choose the most optimal species to use for grazing forage in their agro-climatic conditions.

Extreme weather events such as drought, flooding, or wildfires can hinder successful outcomes from BMPs such as rotational grazing. Producers may avoid adopting these practices if they view this risk as too great.

The additional use of labour and equipment to maintain a rotational grazing practice can cause timing conflicts for these resources at busy times on the farm. The soil health benefits and ecosystem services provided by rotational grazing are not clearly defined due to variability in the practice. This uncertainty can act as a barrier to producers who want to see a tangible benefit for their investment of time, money, and effort.

3.4.5. Adaptive Multi-Paddock Grazing

Adaptive multi-paddock (AMP) grazing practices are also known as mob grazing, holistic management, holistic planned grazing, intensive rotational strategies, or management-intensive grazing (Sherren et al., 2022). Researchers have struggled to agree on a definition due to the variety of terms and grazing practices used by producers that would be considered adaptive multi-paddock grazing. In Canada, "AMP grazing has not been well described …in terms of practice, uptake, or motivation" (Sherren et al., 2022, p.1307). The authors define it as "an umbrella term for approaches to grazing planning and management, often characterized by high-intensity, short-duration rotational grazing managed with careful planning and monitoring" (p.1305).

Prairie producers would consider AMP to be a grazing practice that is more holistic, observational, and adaptable to external factors. AMP producers would likely have a plan that considers grazing rotations and rest periods throughout the year and that gives a broader perspective on how grazing fits into their overall operation.

Economic Barriers

Several additional costs present economic barriers to producers' adoption of adaptive multi-paddock grazing. Costs for increased labour and increased time needed to set up, implement, monitor, and maintain the grazing plan can be considerable barriers to producers. Many producers will need to upgrade their fencing to build multiple paddocks for livestock rotation. Some producers may need to pay for professional contracting or consulting to help them develop the AMP plan. Overall, production costs to the producer will increase. The economic benefit at the farm level from the implementation of an AMP system is variable due to the high variability of AMP practices. Thus, producers' return on investment for this practice is uncertain, which creates a significant barrier to producer adoption.

Agronomic Barriers

There are a number of agronomic barriers to producer adoption of AMP grazing in the Prairies. There is a lack of agronomic protocols with demonstrated success for Prairie agro-climatic contexts which leaves producers unsure of how to implement AMP grazing on their farm. The range of different practices that fall under the AMP umbrella term means that the potential soil health or ecological benefit is difficult to calculate or predict. Producers will be reluctant to adopt a new practice requiring significant time and planning for an uncertain agronomic benefit.

Some AMP practices may result in a timing conflict for the availability of labour or equipment during the busiest times of the farming operation. Additionally, some producers may view AMP as high-risk practice due to its vulnerability to extreme weather events such as drought, flooding, or wildfires.

RALL producers shared a number of comments on adaptive multi-paddock grazing at a recent producer roundtable discussion (RALL, 2023b). One producer had a difficult experience with calves who were in poor condition, low weight, and malnourished after winter grazing on what they later realized was nutrient-poor forage: *"...noticed that cows were cylindrical. They were full but you could see the bones. Started taking forage samples. It was like feeding straw, very low nutrients. Had to supplement. That bit of protein made a difference"* (RALL, 2023b). This producer struggled to find the cause of the poor forage quality but did note that their cicer milkvetch had disappeared.

3.5. Reduced Tillage

Reduced tillage can also be known as conservation tillage and can include a spectrum of tillage practices from reduced tillage, to minimal tillage, to zero tillage (Awada, et al., 2014). Academically, conservation tillage can be defined very specifically as a "sustainable crop production system that leaves at least 30% of crop residue on the soil surface after crop planting, or at least 1.1 Mg ha^{-1} of small grain residue on the surface during the critical soil erosion period, uses specialized seeding equipment to place seed and fertilizer in the soil with minimal disturbance, controls weeds by herbicides or by minimal cultivation and herbicides, and uses crop rotations to help break the life cycles of pests and diseases and to control weeds" (Awada et al., 2014, p. 49).

Prairie producers would define reduced tillage more simply, meaning any reduction of tillage by one or more passes compared to the producer's typical tillage practice. This would include a spectrum of tillage practices in alignment with the academic definition above but would also include seeding practices with minimal soil disturbance, such as direct seeding or no-till seeding. Any tillage practice that does not cause total soil inversion would also be considered reduced tillage by producers.

For decades, heavily tilled farmland was the norm on the Canadian Prairies. Now, the opposite is true, with over 60% of Prairie cropland under zero-tillage and around 80% using some form of reduced tillage practice in 2016 (Awada et al., 2021). The fact that reduced tillage practices were adopted, and spread to become the norm, prompts optimism in the belief that other BMPs can also experience the same level of adoption.

A combination of factors triggered the adoption and diffusion of reduced tillage by Prairie producers through the 1980s, including severe droughts (Hurlbert et al., 2020a) that further degraded soil quality, the introduction of the commercial no-till drill and the broad-spectrum herbicide glyphosate, as well as further advancements in crop breeding which led to new crop rotation possibilities, including the new rapeseed variety called Canola (Awada et al., 2014).

A few early adopters in Alberta, Saskatchewan, and Manitoba began reduced tillage on their farms in the late 1970s. Despite experiencing profitable crops and improved soil quality, these producers also were subject to social exclusion for defying the culture of tillage and going against farming norms (Awada et al., 2014). Still, they persisted, and shared their knowledge both formally and informally, through networks of other producers, local associations, and researchers.

At the time, reduced tillage was viewed as incompatible with Prairie farming, even though scientists were starting to warn of the detrimental effects of tillage on soil health. Through the 1980s, many Prairie regions experienced significant drought, which degraded soil quality even further (Awada et al., 2014; Hurlbert et al., 2020a). Soil health research and economic assessments were published, with the hopes of increasing public awareness of the negative effects of continued traditional tillage practices (Awada et al, 2014).

Extension organizations developed to provide knowledge sharing, support, and demonstrations on reduced tillage to interested producers. Zero-tillage demonstration farm sites were established by Agriculture and Agri-Food Canada near Brandon, MB, Prince Albert, SK, and Vegreville, AB to provide observational and peer learning opportunities to curious producers (L. Fuller, personal communication, March 28, 2024).

Early adopters continued to spread their knowledge, which had a significantly positive influence on their producer peers. They shared that no-till practices allowed them to get a crop every year instead of having a fallow year every three years. Stories of economic returns and increased soil moisture from reduced tillage practices spread across the Prairies and acted as driving factors that motivated other producers. Awada et al. (2014) noted that these local social connections contributed significantly to the paradigm shift away from tillage as a necessary practice and increased adoption of reduced tillage throughout the Prairies.

Through the 1990s and early 2000s, further economic factors triggered widespread adoption of zero-tillage through Alberta and Saskatchewan. Manitoba producers were slower to adopt reduced and zero-tillage, however prevalence of traditional tillage there has been steadily dropping.

Patterns and processes that emerge from the history of reduced tillage adoption on the Canadian Prairies could inform an effective framework through which to encourage broader adoption of more BMPs, and regenerative agriculture overall. Numerous structural barriers initially prevented widespread uptake of reduced tillage, but were addressed through policy and market changes, the social influence of early adopters, and through new innovations at accessible costs to producers. Market, policy, technology, research, and social factors combined to create an environment that was conducive for producers to understand soil degradation, recognize the benefits of the new innovation, and adopt the practice.

"Change takes time but no-till proves it can be done and the regen ag stuff is creeping in"

Industry stakeholder (FWWF, 2023a)

3.5.1. Crop Residue Management

From a government perspective, crop residue management can be defined as the use of methods, tools, or techniques to manage the straw, chaff, and roots left behind after crop harvest to ensure the residue can provide benefits to the soil and not interfere with seeding or farm machinery (Alberta Agriculture, Food, and Rural Development, 2004). Prairie producers would generally agree with this definition.

A decrease in the use of conventional tillage in the Prairies came along with an increased need for producers to manage crop residue on their farms. Retaining crop residue on the field builds the armor that protects soil from erosion, retains moisture, and provides valuable organic matter and nutrients to regenerate soil health (Alberta Agriculture, Food, and Rural Development, 2004). Producers need to manage their crop residue appropriately and this section presents BMPs related to the management of crop residue at the farm level.

Economic, agronomic, and socio-cultural barriers to each crop residue practice will be discussed under individual sections below. Awareness barriers mentioned here are generally applicable to all crop residue management practices in section 3.5.1., except strategic tillage. Awareness barriers to strategic tillage practices are discussed more specifically in section 3.5.1.5.

Awareness Barriers

These awareness barriers apply to all crop residue management BMPs in section 3.5.1., except strategic tillage. As most Prairie producers are unaware of practices such as bioenergy production from crop residues, or maximizing the production of crop residues, low awareness of these practices is a significant barrier to producer adoption. Indeed, most Prairie producers would be motivated to reduce crop residue, rather than to maximize it, and would be unaware of the benefits of maximizing crop residues.

Additionally, while some producers may have heard of these practices, they may not consistently understand what the practices are. FWWF advisors also stated that producers' assumptions that they are already managing crop residues in the most optimal way is likely a barrier to their willingness to learn how to more effectively manage them.

3.5.1.1. Maximized Crop Residue Production

Viresco (2022) defines this as the practice of increasing crop residue through a variety of methods, including using crops like oats and canola which have larger amounts of root biomass, or even using crops that have been genetically altered to slow down residue decomposition. Straight cutting crops can also increase post-harvest crop residue compared to swathing crops for grazing (L. Fuller, personal communication, March 28, 2024). Some crop varieties are more conducive to straight cutting, and thus, adoption of these crops is also a method of maximizing crop residue (L. Fuller, personal communication, March 28, 2024).

Producers would be aware of this terminology and the practice of maximizing crop residues. Some regenerative agriculture-minded producers would be aware of the practice and would be motivated to maximize crop residue through one of the methods mentioned above.

However, many Prairie producers want to reduce and minimize crop residue, rather than maximize it, as crop residue can hinder future crop seeding (L. Fuller, personal communication, March 28, 2024).

Economic Barriers

FWWF's advisor shared multiple economic barriers to producers' adoption of maximized crop residue production as a BMP. These barriers include the costs of increased time, labour, and equipment to manage greater volumes of crop residue with improved straw spreading equipment on the combine, harrowing, or speed discs. The economic benefit to producers for increasing their crop residue production remains uncertain and thus producers are less likely to adopt this practice.

Some of the identified barriers to the adoption of maximized crop residue production are not directly relevant from the producer's perspective. Whether crops will be genetically modified to increase residue production may be dependent on the projected economic returns from these varieties. While this barrier is not directly applicable to producers, if maximized-residue varieties succeed on the market, producers may then have less economic or market-based uncertainty preventing them from using these varieties.

Agronomic Barriers

A number of agronomic barriers are of concern to producers who are interested in maximizing their crop residue production. As most Prairie producers would not be aware of this BMP, their lack of knowledge on how to implement this practice, the optimal protocol for their agro-climatic conditions, and what species would work best for them would be agronomic barriers to producers' adoption of the practice. There is also the possibility of timing conflicts for labour and equipment during the busiest times of the crop production season.

Biophysical barriers including the risk of non-beneficial insect infestation, the risk of plant diseases, difficulties with weed control, hindrance of future crop seeding operations (L. Fuller, personal communication, March 28, 2024), and the need to dispose of greater volumes of crop waste material all present additional challenges to Prairie producers.

As climate change brings more variability and more extremes in weather events, producers may find themselves more vulnerable to negative outcomes from drought, flooding, or wildfires. Producers who have overcome economic or socio-cultural barriers to adopt a BMP may be unwilling to risk a poor agronomic outcome from the practice that could occur from an extreme weather event. The uncertainty around weather events may be a significant agronomic barrier to producers' adoption of many BMPs, including maximized crop residue production. In regions where rainfall is uncertain and moisture is scarce, producers often prioritize maximizing their cash crop over allocating resources to maximize crop residue. This phenomenon is intriguing because crop residue plays a crucial role in moisture conservation. This exemplifies how long-term benefits can be overlooked or disregarded during short-term implementation of practices.

Finally, as with many practices, the beneficial effects on soil health from maximizing crop residue production are still uncertain and remain unquantified. This presents a barrier to producers' adoption as they cannot define what level of agronomic benefit their farm will see from adoption of the practice.

Socio-Cultural Barriers

Although research on producer perspectives in this area is very limited, a U.S. study did highlight that the lack of financial and non-financial support was a critical barrier to producers' adoption of crop residue management systems. In fact, they stated that "few farmers adopted these [crop residue management] systems without significant support from local equipment and agrochemical dealers, USDA technical assistance, credit sources and other components of the surrounding agricultural infrastructure" (Rodriguez et al., 2009, p.62).

Other socio-cultural barriers to Prairie producers include producers' resistance to change or learn a new practice. As well, many producers would view this practice as experimental or alternative, as it does not align with conventional farming norms, and thus they may be reluctant or uncomfortable adopting it.

3.5.1.2. Crop Residue Bioenergy

While the Viresco (2022) report discusses crop residue bioenergy together with carbon capture and storage for their combined GHGE mitigation potential, carbon capture and storage have limited relevance to adoption barriers from producers' perspectives, and as such this section will focus only on crop residue bioenergy. Both Viresco (2022) and Drever et al. (2021b) define this practice as the production of bioenergy specifically from agricultural crop residue. Most producers in the Prairies would be unaware of crop residue bioenergy production, or its purpose in regenerative agriculture, although some producers, especially in Manitoba, may have knowledge of it.

Economic Barriers

Loss of soil nutrients can result from the removal of crop residue from the soil surface. Producers may need to replenish these nutrients through the use of additional nitrogen fertilizer and thus higher input costs to the producer creates an economic barrier to this practice (Drever et al., 2021b).

The most significant economic barrier to crop residue bioenergy production will likely be the uncertainty around the long-term profitability of the practice (Viresco, 2022). Both businesses and crop producers will need assurance of economic returns to commit to the practice. Bain (2021) reports that the initial costs for infrastructure to produce crop residue bioenergy are a significant barrier to potential residue processors. Both Drever et al. (2021b) and Viresco (2022) report that as of 2021, Canada had no commercial facilities producing bioethanol from crop residue. Although these are not direct barriers from the producer's perspective, any barriers to bioenergy market advancement indirectly act as barriers to producers' adoption of related practices by limiting their available market options.

Agronomic Barriers

Bain producer research (2021) highlighted an agronomic barrier of potentially less healthy soil if crop residue is removed for bioenergy production. Producers who are motivated to collect their crop residue for the bioenergy market will be removing significant amounts of organic matter that would otherwise have been left to decay on the soil. This loss of decaying crop residue from the soil's surface can cause decreased soil organic carbon levels, and in turn, decreased soil health and agricultural productivity.

Although findings are inconsistent, there is evidence both from measured test sites and from models, that crop residue removal can lead to decreased soil organic carbon levels (Liska et al., 2014; Smith et al., 2012). Drever et al. (2021b) suggests that additional nitrogen fertilizer would be used to replenish lost soil nutrients; thus, another agronomic barrier would be the need for increased fertilizer use and the associated GHG emissions.

Socio-Cultural Barriers

Producers may have to modify their farm management practices to bale crop residues, which may be a barrier to some producers. Whether bioethanol is able to hold value over the long term is also questionable. As many countries, Canada included, move away from internal combustion engine powered vehicles, the uncertain long-term value of bioethanol could present a barrier to producers, although crop residue biomass can produce other types of bioenergy (Viresco, 2022).

3.5.1.3. Reduced Field-Burning of Crop Residues

Crop residues are burned in the field for various reasons, including making seeding easier, or to reduce disease in subsequent crops, or if residues cannot be removed by some other manner, due to excessive moisture or insufficient time (Viresco, 2022). This is most commonly practiced on fields with flax residue. Producers would likely agree with the definition and terminology used here. Viresco (2022) identified no barriers or knowledge gaps to reducing field-burning of crop residues, however, FWWF's advisor identified numerous barriers to reducing field-burning of crop residue.

Economic Barriers

In the Prairies, markets for flax straw are very limited. Producers have very few options for large, reliable buyers of flax residue (Cross, 2022). In some areas, local interest in flax residue has begun to increase recently and flax producers now have more selling options, which has contributed to a decrease in the prevalence of flax burning (Cross, 2022).

Producers who discontinue field-burning of residue are likely to face increased costs for production, costs for increased labour and time to manage crop residue without burning, and potential costs for additional equipment needed to manage the crop residue. Moreover, the economic benefit to producers is uncertain, as flax markets remain small and localized.

Agronomic Barriers

Some agronomic factors do act as barriers to reducing producers' field-burning of crop residue. The toughness of flax residue means that Prairie producers often burn flax residue in the field for lack of any better management option available to them (Prairie Clean Energy, n.d.-b). Without burning, producers will have to manage the crop residue in some other way, and they may lack knowledge on what agronomic methods of crop residue management are available to them. Producers may also be unaware that they can manage flax residue in a way that can bring soil health benefits to their fields (Manitoba Agriculture, 2021).

Producers who do not burn residue in-field will have to dispose or manage greater volumes of crop waste material which poses a barrier to producers.

Socio-Cultural Barriers

Producers who continue to burn residue in the field will likely have no reason to stop without some additional incentive to do so. FWWF's advisor shared that to reduce field-burning of residues, Prairie producers would need access to a better residue-removal method, especially for flax straw which is wiry, hard to remove, and interferes with subsequent planting.

Flax straw bioenergy products may contribute to the reduction of flax residue field-burning. Prairie Clean Energy is a newly established Saskatchewan business, which converts flax residue to biomass fuel pellets and animal bedding (Prairie Clean Energy, n.d.-a). Currently, they will purchase and pick up flax straw bales from producers in the Regina, SK and Gilbert Plains, MB regions, with plans to expand further in 2024. Producers are responsible for baling and storing the straw until pickup, which may continue to be a barrier for some, as these steps would require more time, fuel, labour, and storage space compared to burning the residues in-field.

Awareness Barriers

Producers' lack of awareness of other residue management options may be a barrier to their discontinuation of residue burning.

3.5.1.4. Grazing Residue

Residue grazing involves having livestock graze the crop residue left in a field after the crop has been harvested (Thiessen Martens et al., 2015). This practice would not include bale or swath grazing where the crop itself is intended for livestock. Prairie producers would generally agree that this description defines their practice of grazing residue.

Economic Barriers

Economic barriers to crop producers' adoption of grazing residue as a BMP include the costs for increased labour and time spent on managing the livestock grazing. Moreover, the economic benefit to producers from this practice is uncertain due to a lack of Prairie-specific research in this area. Without a clear economic benefit, many producers will not be interested in incorporating livestock grazing into their residue management system.

Agronomic Barriers

Conversations with FWWF's advisor identified three agronomic barriers to grazing residue. First, the soil health benefits from grazing residue remain uncertain and thus producers are not able to determine whether the tangible agronomic benefits are worth the costs, time, and labour needed to implement the practice. Second, producers may have a greater amount of waste material to dispose of after livestock have grazed the fields. Third, there is the potential for timing conflicts for labour or equipment at the busiest times of the crop production season.

Socio-Cultural Barriers

A number of socio-cultural barriers were identified by FWWF's advisor. These include the lack of Prairie-specific knowledge on how to implement this practice, producers' resistance to change and reluctance to learn a new farming practice. Additionally, producers who rent cropland may have a land rental agreement that does not permit livestock to graze crop residue.

3.5.1.5. Strategic Tillage

There is a perception that tillage has no place in a regenerative agriculture system. Strategic tillage, when applied judiciously and with careful consideration of soil health, can be integrated into regenerative agriculture practices. Strategic tillage practices become an additional option within a full suite of tools that the regenerative producer can access when solving specific problems.

Long-term adoption of no-tillage or intensive grazing systems can contribute to soil surface compaction. While there are several options available to producers that address surface compaction, strategic tillage can often be the faster, more efficient, and more cost-effective choice. A careful, precisely-planned tillage pass can release soil compaction and aerate the soil, providing a quick soil reset in preparation for crop production (K. Nichols, personal communication, April 16, 2024).

Regenerative agriculture typically emphasizes minimal soil disturbance, but strategic tillage is employed in specific situations, such as to address compaction or enhance seedbed preparation. The key lies in adapting tillage practices to align with broader regenerative principles, emphasizing a holistic approach that prioritizes soil health, biodiversity, and long-term sustainability.

Strategic tillage can give producers the benefits of tillage on soil compaction, while minimizing the negative effects of soil disturbance, damage to the soil microbiome, and release of sequestered carbon (K. Nichols, personal communication, April 16, 2024). This aligns with Principle 6 of the Regenerative Agriculture Soil Health Pyramid seen in Appendix A. The principle of Reduced/No Tillage emphasizes that tillage should be limited to minimize disturbance of the soil fungal network and release of sequestered soil carbon. Used carefully and strategically, with a targeted, problem-solving approach, tillage practices can be part of a well-balanced regenerative agriculture system.

While there is some overlap in barriers that apply to all three strategic tillage practices included here, each is intentionally discussed separately as they are distinct practices and have different potential for soil carbon release. Moreover, a key barrier to adoption is that these practices are frequently confused for each other due to their inconsistent definitions, and as such, the practices are more effectively presented separately.

Economic, agronomic, and socio-cultural barriers to each practice will be discussed under individual sections below. Awareness barriers mentioned here are generally applicable to all strategic tillage practices in section 3.5.1.5. and will be included here.

Awareness Barriers

These awareness barriers apply to all strategic tillage practices in section 3.5.1.5. Awareness barriers significantly impair widespread adoption and more consistent practice of strategic tillage in the Prairies.

There are discrepancies between producers' and government agricultural departments' understandings of deep tillage, subsoiling, and vertical tillage terminology, which creates a significant barrier to further adoption of these practices. Different terms are used by different groups to define the same practice. This contributes to considerable confusion and miscommunication between the groups and hinders the potential of strategic tillage practices as BMPs that can improve soil health and provide ecological services.

Assumptions and ingrained beliefs are also a barrier to adoption. Prairie producers may be using vertical tillage on their farms, but are unaware of how it is meant to be practiced to achieve its full scope of benefits as a BMP. If producers assume they understand what vertical tillage is and believe they are practicing it correctly, there is a barrier to their awareness of the full scope of the practice. Programs or policies promoting the adoption of vertical tillage may be entirely overlooked by producers who believe they already have vertical tillage in place.

Vertical Tillage

Vertical tillage is a new practice that has not yet been precisely defined (Zeng et al., 2021), either in research, industry, or at the farm level. Zeng et al. (2021) state that "the general consensus is that VT [vertical tillage] refers to the soil loosening in relatively vertical lines" (p. 1).

The lack of a clear definition has contributed to the major discrepancies in how vertical tillage is defined in Prairie agriculture. "True" vertical tillage should result in the shallow, slight vertical movement of air and moisture through only the top layer of soil without any horizontal soil disturbance (Lyseng, 2013).

Prairie producers will typically use the term vertical tillage for a tillage practice that uses equipment with wavy blades, penetrates the soil quite deeply, and typically causes a moderate amount of horizontal soil disturbance. Many Prairie producers are likely unaware of what "true" vertical tillage is or whether their equipment is a "true" vertical tiller or not (Lyseng, 2013).

Economic Barriers

Several economic barriers hinder the adoption of "true" vertical tillage on the Prairies. Producers likely will face additional costs for increased labour and time spent on vertical tillage. Producers may also need to purchase a dedicated vertical tiller which introduces another cost. As the practice of vertical tillage is new and not clearly defined in the research community, Prairie-specific research on the economic benefits of vertical tillage at the farm level is limited. Producers thus have no clear quantification of what economic value this practice could bring to them.

Agronomic Barriers

Agronomic barriers to the adoption of vertical tillage include the lack of a clear agronomic protocol that is suitable for Prairie agro-climatic conditions. The lack of research on vertical tillage in the Prairies also contributes to the uncertainty of soil health benefits at the farm level to producers who adopt this practice. Without clear evidence of the agronomic benefits of vertical tillage, producers may be hesitant to pursue this BMP.

Socio-Cultural Barriers

The inconsistency in definitions of vertical tillage between researchers, equipment retailers, and producers presents a substantial socio-cultural barrier to producers' adoption of vertical tillage. Without a clear definition of the practice, consistent research findings are limited and may have limited relevance to the actual practice of vertical tillage on Prairie farms. The lack of Prairie-specific research on vertical tillage results in a lack of available information for Prairie producers regarding how to implement this practice and in knowing what "true" vertical tillage is.

Many agricultural equipment manufacturers follow the "true" vertical tillage definition listed above (Lyseng, 2013), but confusion arises when some equipment manufacturers label equipment as vertical tillers which do not meet this criteria. Machinery labelled as vertical tillers can also vary widely and have different disc shapes – rippled tillage discs can cause significantly more lateral and forward soil displacement than plain discs (Zeng et al., 2021). With no consistency in the definition of the practice or in the types of tillage machinery and tillage discs available, there is likely significant heterogeneity in the actual practice of vertical tillage at the farm level in the Prairies.

Deep Tillage

Deep tillage refers to a farming practice in which soil is mechanically disturbed to a significant depth, typically exceeding 12 inches (30 centimetres). This form of tillage involves turning over or breaking up the soil at a depth that reaches beyond the root zone of most crops. Deep tillage can be achieved using various implements and is employed for different purposes, including alleviating soil compaction, improving drainage, or preparing the soil for specific crops.

There is a significant disconnect in the interpretation of tillage terminology between the producer's perspective and a government perspective. Deep tillage, as defined by the governments of both Alberta and Saskatchewan, includes the practice of deep ripping, which they describe as using a subsoiler to loosen the subsoil while leaving the soil surface relatively undisturbed (Government of Saskatchewan, n.d.-a; McKenzie, 2010). Prairie producers, however, would call this practice subsoiling, not deep ripping or deep tillage. Producers would use the term deep tillage for a practice that uses a cultivator to turn deep layers of soil, resulting in black soil to some degree and significant disturbance to the soil surface.

Economic Barriers

Cost is a major barrier to deep tillage. Equipment for deep tillage is expensive to purchase and, due to its substantial fuel use, expensive to operate. Deep tillage equipment is also not as readily available as it once was on the Prairies, due to the declining use of tillage on Prairie farms. Producers typically do not have the equipment needed for deep tillage and may have a hard time finding it.

Agronomic Barriers

As mentioned, many Prairie producers may not have access to deep tillage equipment, presenting a barrier to producers' adoption of the practice. Timing can also be a barrier to adoption, as deep tillage should be done only at certain times of the growing season. If the soil is too wet from excess moisture, deep tillage can cause soil compaction, resulting in more harm to the soil than benefit.

Socio-Cultural Barriers

Reduced tillage and no-tillage farming practices have become so normalized within Prairie agriculture that certain tillage practices that still serve a specific purpose may be abandoned entirely. Many Prairie producers understand that practices like deep tillage can be tools they reach for and use strategically in a way that still aligns with regenerative agriculture principles.

Due to the substantial decline in the use of tillage practices on the Prairies, tillage has become almost a four-letter word in current Prairie farming; it may now be viewed as a "weird" practice that does not align with typical Prairie farming norms. Producers who engage in deep tillage may be faced with questions or disbelief from their peers.

Deep tillage may result in the loss of soil through wind or water erosion, which can cause problems with neighbours, and poses a barrier to producers who do not want to upset their peers and community members.

Subsoiling

Prairie producers would use the term subsoiling for the practice that the governments of Alberta and Saskatchewan refer to as deep tillage, that is, the use of a subsoiler to loosen the subsoil while leaving the soil surface relatively undisturbed (Government of Saskatchewan, n.d.-a; McKenzie, 2010). By producers' definitions, subsoiling creates deep fracturing but not inversion of the soil and thus releases significantly less sequestered carbon than vertical tillage or deep tillage (K. Nichols, personal communication, April 16, 2024).

Economic Barriers

Economic barriers include the costs for increased labour and time needed for learning, planning, and implementing subsoiling as a BMP, as well as the costs for additional tillage machinery. Specialized equipment for subsoiling is expensive, both to purchase and to operate (McKenzie, 2010), which can present significant barriers to producers' adoption of this practice.

The economic benefit to producers from the use of subsoiling is dependent on multiple variables and difficult to quantify. Producers are unlikely to have a clear estimate of their potential return on investment for subsoiling, which is a barrier to producer adoption of the practice.

Agronomic Barriers

The inconsistency in how tillage terms and practices are defined among producers and in research means that it is difficult for producers to access a clear protocol for implementing subsoiling on their farms. The addition of subsoiling to their usual farm practices can create a timing conflict for the availability of labour or equipment during the busiest times of the growing season.

While the visible benefits from loosening compacted soil may be easily identified, more specific benefits to soil health may be harder to quantify.

Socio-Cultural Barriers

There is limited information available to producers on how to adopt the use of subsoiling as a strategic tillage practice on their farm. Again, the inconsistent definitions of the practice of subsoiling create barriers to producers' access to the information they need to implement the practice.

Producers who rent cropland may have restrictions in their land rental agreement that do not permit them to use subsoiling on the land.

3.6. Agroforestry

Agroforestry is an umbrella term used for a system that intentionally combines trees with agriculture. Canada follows the classification system of the Association for Temperate Agroforestry, which includes five general categories of agroforestry systems: windbreaks/shelterbelts, silvopasture, tree-based intercropping (alley cropping), riparian systems, and forest farming (Association for Temperate Agroforestry, n.d.; Hesselink & Thevathasan, 2014; Thevathasan et al., 2012). These generally align with both the Viresco report (2022), which includes shelterbelts, riparian areas and silvopasture in this category, and with Drever et al. (2021b), who include all of these as well as tree-based intercropping and avoided conversion of shelterbelts.

A more holistic and ecological perspective on agroforestry comes from Mark Shepard, an American farmer who has established a thriving perennial silvopastoral system in Wisconsin using what he calls “restoration agriculture” (New Forest Farm, n.d.). Shepard’s approach combines permaculture and keyline design to “replant natural ecosystems using the agroforestry techniques as the tools to make it through that transition” (Mizzou Visual Productions, 2015, 06:02). His silvopasture farm includes diverse fruit and nut trees, vines, perennial plants, fungi, grassy pastures, and grazing livestock that come together to regenerate soil health, sequester carbon, and strengthen biodiversity (New Forest Farm, n.d.).

Among Prairie producers, however, the term agroforestry is likely to be interpreted in a variety of ways. Some may interpret agroforestry as the agricultural production of trees as the end product, whether for garden centres or lumber mills, while others may interpret it as the production of an agricultural product that comes from trees, such as fruit or nuts. As such, there is likely no typical definition among Prairie producers of what the practice of agroforestry entails, nor of the term itself. The Viresco report (2022) calls this category “Increase and Manage Trees in Working Agricultural Landscapes.” While this terminology is clearer, it is also quite cumbersome and may not align with research, programs, and policy that will largely use the term agroforestry and its associated subcategory terms.

Much of the agroforestry literature base examines tropical agroforestry systems in low- and middle- income countries – this literature was excluded from this report. A limited amount of research has explored Canadian producers’ perspectives on barriers to agroforestry practices, which will be discussed in further sections.

Although agroforestry practices include tree-based intercropping (alley cropping), silvopasture, shelterbelts, riparian systems and forest farming, this report discusses regenerative practices in terms of how applicable they are to crop production systems. As such, the agroforestry practices will be separated between the two main sections. Tree-based intercropping and silvopasture are discussed in the Crop Production BMPs section while avoided conversion of shelterbelts and riparian systems will be discussed as Agricultural Land Management Practices that are not directly applicable to crop production.

Economic Barriers

The most significant barriers to producers’ adoption of agroforestry systems are the costs related to planting and maintenance of the trees (Valdivia et al., 2012; Viresco, 2022). Tree-related costs include preparation of the site, purchase and planting of trees, tree maintenance and management, the removal of dead or damaged trees, tree replacement and replanting, herbicide application, and sometimes snow removal (Viresco, 2022). Economic barriers to agroforestry also include the opportunity cost of lost income from productive cropland converted to treed areas. There is also evidence for reduced crop yields from crops grown near shelterbelt areas due to the trees' heavy use of moisture and nutrient resources (L. Fuller, personal communication, January 2, 2024).

Thevathasan et al. (2012) noted that renting farmland has become more prevalent on the Prairies, and land ownership status can be a barrier to Prairie producers' adoption of agroforestry systems as producers who rent cropland are limited in the changes they can make to the land (Nair et al., 2021; Thevathasan et al., 2012). Producers who rent farmland may not have permission to plant trees, nor would they likely be motivated to do so, for lack of any short-term benefit to them while they continue to rent the land. Producers who rent their farmland out to others may not have any economic reason to spend money on trees to benefit their renters and, in fact, it may hurt their rental income if some productive cropland is lost to trees.

Valdivia et al. (2012) surveyed rural landowners in Missouri about barriers to agroforestry. Their findings demonstrated that landowners perceived transaction costs related to agroforestry to be greater barriers than profitability concerns. Transaction costs included the financial, labour, and time investments needed for tree planting, establishment, and maintenance. Profitability concerns such as the lack of return on investment and the loss of crop yield to trees were perceived to be less important than the transaction costs related to agroforestry. It is important to note, however, that although participants in this study were all landowners of at least 10 acres in rural Missouri, only 34% self-identified as farmers. The remaining 66% self-identified as non-farmers, making it difficult to draw conclusions from these findings about producer perspectives.

Thevathasan et al. (2012) notes that Canadian federal government incentive programs are applicable to either agriculture or forestry operations, and do not address the needs of producers who want to adopt integrated agroforestry practices on their farms. The authors highlighted the need for further research on the economic impacts to producers of agroforestry systems in the context of Prairie climate and soil conditions.

Agronomic Barriers

Introducing trees into agricultural systems results in the loss of a portion of productive agricultural land which is one of the most prominent barriers to producers' adoption of agroforestry systems (Viresco, 2022). Planting and maintaining the trees requires a significant investment of time and management to the farming operation. Agroforestry practices may actually bring more negative environmental impacts to some Prairie regions than positive ones. Introducing treed areas into regions of Alberta and Saskatchewan that are natural grasslands with very few native trees is problematic due to their use of water resources, vulnerability to drought, and negative impacts on local biodiversity (Viresco, 2022).

Thevathasan et al. (2012), in an overview of agroforestry practices in different regions of Canada, shared insights on producers' perspectives of the challenges and barriers to these practices. They noted that insufficient technical support on how to adopt and integrate agroforestry systems into their farming operations is a barrier to Maritime producers. They also reinforced the need for more research on the agronomic productivity of agroforestry practices that is regionally-specific and relevant to local producers, noting that differences in soil, climate, and weather mean that the generalizability of research findings from other regions is low (Thevathasan et al., 2012).

An American study (Kreitzman et al., 2022) interviewed producers who had already adopted woody perennial polyculture in the upper Midwest of the U.S, about barriers to continuing or expanding their agroforestry practice. Producers clearly differentiated between biophysical barriers that they could manage on the farm and systemic barriers related to policy, financing, and insurance that they felt were out of their control. Producers viewed agronomic and biophysical barriers with the mindset that these were challenges that just needed problem-solving, and interestingly, did not perceive these factors as barriers.

Socio-Cultural Barriers

At a structural level, one of the most influential barriers to producers' adoption of agroforestry systems is the clear separation of agriculture and forestry in research, policy, and regulatory networks (Nair et al., 2021; Thevathasan et al., 2012). Agriculture and forestry fall under separate government ministries in Canada, at both provincial and federal levels, and are often in separate departments or faculties at post-secondary institutions (Thevathasan et al., 2012). This naturally produces a separation between agriculture and forestry in university-level research and post-secondary student education. This separation results in a lack of professionals trained in agroforestry practices who can share knowledge and guide producers through the adoption and implementation of agroforestry on their farms (Thevathasan et al., 2012).

The governmental separation of agriculture and forestry could result in regulatory challenges for practices that combine aspects of both. Clare and Creed (2022) found significant regulatory barriers to producer adoption of wetland restoration, specifically related to government agents who lacked the authority to make decisions on any alternative practices that did not fall under the conventional norm. Approaching the separate ministries of agriculture or forestry to request financial and policy support that encourages producer adoption of agroforestry practices may be met with reluctance if they do not wish to deviate from standard practices.

Ultimately, the separation of agriculture and forestry in research, policy, and governance is a structural barrier to producers' access to research findings, trained advisors, regulatory processes, and policy instruments that will address barriers and allow them to adopt agroforestry practices on their farming operations.

Awareness Barriers

These awareness barriers apply to all agroforestry practices in section 3.6. There is a lack of awareness of some agroforestry practices as they are rarely practiced in Prairie agriculture. Alley cropping and silvopasture in particular are not well known by Prairie producers and many would be unaware of the potential soil health or ecological benefits, or GHGE mitigation potential of these practices.

The lack of awareness of what agroforestry practices are, and how they could be incorporated into Prairie cropping systems, is a barrier, although likely a less significant barrier to producer adoption than the equipment incompatibilities or the financial investment.

3.6.1. Tree-Based Intercropping (Alley Cropping)

Tree-based intercropping is also known as alley cropping and is defined as an agroforestry practice that involves wide alleys of agricultural crops planted between rows of trees (Thiessen Martens et al., 2015). Although alley cropping is not generally practiced in the Prairies, producers here would generally agree with this definition of the practice.

Viresco (2022) intentionally excluded tree-based intercropping, or alley cropping, from the agroforestry category of their report, due to the focus on BMPs specifically for Prairie agriculture. Both Viresco (2022) and Drever et al. (2021b) agree that tree-based intercropping is generally incompatible with the large size of typical Prairie farm machinery. Indeed, Drever et al. (2021b) included only the provinces of Ontario and Quebec in their analysis of tree-based intercropping GHGE mitigation potential.

Economic Barriers

Bain producer research (2021) reported that the economics of planting and maintaining rows of trees are also a significant barrier. For producers, these include the costs and labour for initial purchasing and planting of trees, for continued maintenance of trees, and for replacement of dead trees as needed. Thevathasan et al. (2012) highlight that the initial cost to adopt and establish an alley cropping system is out of reach for many producers.

Producers also lose a portion of their productive cropland when rows of trees are planted, presenting another economic barrier. Thevathasan et al. (2012) noted that the initial capital costs and the loss of productive cropland are major barriers to the adoption of alley cropping for Ontario producers.

Research in Quebec produced inconsistent findings on crop yields and economic returns in alley cropping systems (Thevathasan et al., 2012), but other Canadian research has clearly shown that alley cropping systems are not as profitable as monocropping systems (Thiessen Martens et al., 2015). As such, the lack of a clear economic benefit to the producer is unlikely to drive the adoption of a practice with significant financial barriers to entry.

Agronomic Barriers

Prairie farm machinery is typically very large, and cropping between rows of trees is perceived as too complicated and inefficient. In communications with FWWF, Prairie producers agreed that alley cropping is incompatible with both their machinery and their usual operational processes.

Socio-Cultural Barriers

The complexity of alley cropping systems necessitate greater planning and management demands on producers, and this is a barrier to many. Thevathasan et al. (2012) noted that "tree-based intercropping systems are undoubtedly more complex than current monocropping systems and call upon agricultural landowners to develop new practices that are adapted to their current crop production systems" (p. 253).

3.6.2. Silvopasture

The Canadian Forest Service defines silvopasture as "an agroforestry practice involving the compatible combination of tree growing with forage and livestock production in order to maximize both ecological and economic benefits" (Government of Canada, 2020). This aligns consistently with both Viresco (2022) and Drever et al. (2021a) who consider silvopastoral systems to include trees, livestock grazing, and forage. Generally, producers in the Prairies would also describe the practice of silvopasture in this way. Silvopastoral systems can also include the practice of alley grazing, in which livestock graze the pasture alleys in between rows of trees, often with the trees acting as fencing for livestock.

Economic Barriers

Both Viresco (2022) and Bain (2021) report that a primary barrier of silvopasture is the cost to producers – including expenses related to initial establishment and those for continued maintenance of the trees. Drever et al. (2021b) report that producers may need to prepare the pasture before tree planting and will need to carefully manage the site to ensure trees are established without being damaged by livestock. Viresco (2021) also identifies additional costs to producers, including preparing pasture sites, planting trees, removing and replacing dead trees, applying herbicide, and possibly removing snow. Other investments such as localized fencing may be necessary in some situations, to allow livestock access to the forage while preventing them from damaging trees (Kort et al., 2008). Producers who plan to sell timber from silvopasture trees should develop a plan detailing the production costs, market value, and potential income (Kort et al., 2008).

In the supplement to their 2021 report, Drever et al. stated "to our knowledge, no study exists for Canada that examines the farm-level financial impacts of switching from pasture-only to silvopasture, so it is unclear what the range of expected net financial impacts of such a switch may be for sites in Canada" (2021b, p.19). Research in other temperate climates has shown that well-balanced silvopasture systems with complementary tree and forage species can produce as much forage as pasture-only systems (Drever et al., 2021b).

Agronomic Barriers

In their *Natural Climate Solutions for Canada* report supplement, Drever et al. (2021b) noted that Canadian silvopasture research is quite limited; in fact, their section on estimated mitigation capacity from silvopasture systems is based on just five North American studies. Thus, the tangible agronomic benefits to producers are not clearly defined. Producers in the Bain (2021) engagement research felt that silvopasture systems bring only minimal direct benefits to producers. Silvopasture does sequester more soil carbon than untreed pasture (Drever et al., 2021b), but producers may not benefit from this unless they can see it in a tangible source of revenue associated with a carbon market.

Nair et al. (2021) reports that challenges with silvopasture systems include livestock damage to young trees, poor forage quality, and poor timber quality. When young trees are being established, livestock may need to be kept away from the pasture to prevent tree damage (Kort et al., 2008; Nair et al., 2021). Livestock producers may be reluctant to add trees to their existing pastures, even if they recognize potential benefits through timber production, and landowners with forested areas may be unwilling to allow livestock to graze for fear of damage to their timber production (Nair et al., 2021).

Developing a correctly balanced silvopasture system that provides sufficient nutrients for livestock, forage plants, and trees can be a challenging barrier to producers. Indeed, Nair et al. (2021) stated that silvopasture systems have "complex functional dynamics [that] make it comparatively more difficult to manage them [than other livestock production methods]" (p. 205).

Establishing new tree growth in an existing pasture presents challenges to producers. Young trees introduced to pastures must compete with existing forage plants for light, nutrients, and moisture (Kort et al., 2008; Lindgren & Sullivan, 2013). Some pre-existing forage and weeds may even have a detrimental effect on tree establishment through the production of allelopathic compounds that can inhibit the growth and development of some tree species (Kort et al., 2008). Tree overgrowth can block sunlight and decrease forage growth (Kort et al., 2008; Lindgren & Sullivan, 2013); this can happen within five to fifteen years of tree establishment (Nair et al., 2021).

To establish and maintain a successful silvopasture, producers must create the ideal balance and spacing of trees and forage plants for their given soil, weather, and sunlight conditions, and that will also meet the needs of their livestock.

Socio-Cultural Barriers

Transitioning from conventional pastures to a silvopasture system adds additional livestock and land management requirements to producers' operations. A group of agroforestry professionals representing non-profit and governmental organizations presented a review of silvopasture research applicable to the Saskatchewan context as part of a Soils and Crops Workshop at the University of Saskatchewan (Kort et al., 2008). Their review highlights that silvopasture systems are dynamic, and producers must be prepared to adapt their management practices as the trees grow. They suggest that a vegetation management plan is needed to allow young trees to establish on the pasture despite competition from pre-existing forage. Grazing of livestock must also be carefully managed to ensure healthy tree development. Kort et al. (2008) suggest that intensive, short-term grazing is ideal; this, again, adds additional time and labour commitment to producers' operations. Bain (2021) research echoes this perspective, stating that the management changes needed for a successful silvopasture system are a barrier to producers' adoption of this practice.

Socio-cultural barriers at the macro level can act as indirect barriers to producers' adoption of regenerative agriculture practices. Silvopasture and other grazing management practices may be perceived as being outside of, or even in conflict with, the agricultural status quo. This means that insight on the climate benefits of these practices, and even the voices of those who share these insights, may be intentionally excluded from government and policy processes.

Tourangeau and Sherren (2021) studied the final reports from the 2018 proceedings of two Canadian government committees: the House of Commons Standing Committee on Agriculture and Agri-Food and the Standing Senate Committee on Agriculture and Forestry. Key insights about grazing management practices and their benefits in climate adaptation and mitigation were presented by many individuals (including FWWF's Kimberly Cornish) throughout the proceedings, however no discussion of grazing practices was included in the Committees' final reports (Tourangeau & Sherren, 2021).

The authors noted that the final reports emphasize dominant narratives in Canadian agriculture and climate policy solutions, including productivist industrial agriculture, economic growth, and technological and scientific innovations (Tourangeau & Sherren, 2021). Indeed, the most frequently-cited actors in the reports are industry and government representatives, with most of them being experienced lobbyists. They also suggested that Canadian policy structures favour those who align with the status quo.

In regard to agroforestry systems in North America and Europe, Nair et al. (2021) suggests that "the separation of forestry from agriculture (including livestock production) is the main impediment to promoting combined systems" (p.228). This again points to silvopasture as a practice that is outside the status quo and the dominant belief that agriculture and forestry are two separate practices, creating a barrier to the adoption of integrated systems like silvopasture and other agroforestry practices. This paradigm barrier is reflected in the following statement from an Ontario producer who recently adopted silvopasture practices on her farm:

“The big a-ha for me was recognizing that on our particular farm, there are naturalized zones that we don’t traditionally think of as farmland, but that are also not thriving … I just hadn’t previously fathomed how they … could even be brought under the umbrella of agricultural production…[I] realized there were opportunities on our 40 acres to work with land that was neither ecologically nor agriculturally productive, and that we could actually improve the possibilities for both through silvopasture.”

Val Steinmann, Ontario producer (EFAO, 2022)

4.0 Agricultural Land Management Practices

Section 4.0 discusses agricultural land management practices that are not true regenerative agriculture BMPs. Instead, they are natural climate solutions that focus on either avoiding the conversion of land for the purpose of agricultural production or on restoring current agricultural land to its naturalized state. These strategies are distinct from the BMPs in section 3.0 in that these are not directly applicable to crop production, but rather are related to agricultural land management at a higher level. Although these practices do not have direct impacts on crop production, some have enormous GHGE mitigation potential in the Prairies and, thus, their importance should not be underestimated.

Economic and agronomic barriers to each practice will be discussed under individual sections below. Socio-cultural and awareness barriers included here are generally applicable to all practices in section 4.0., except organic agriculture systems. More specific socio-cultural and awareness barriers that apply to certain practices will be discussed in the practice sections below.

Socio-Cultural Barriers

These socio-cultural barriers apply to all agricultural land management practices in section 4.0, with the exception of organic agriculture systems. Some of these practices, especially riparian restoration, may be considered unproven, experimental, unnecessary, or too far outside of typical farming norms, which creates a social barrier to widespread adoption. Producers may be resistant to changing their farming practices or to learning about the rationale for conserving and restoring native ecosystems.

There may be limited information available on these practices that is relevant to Prairie agricultural contexts. Producers who are interested but cannot find information on things to consider and how to carry out the restoration may abandon the idea altogether.

Finally, producers who rent their land may not have permission to proceed with planting the types of crops or vegetation that would be needed for this practice.

Awareness Barriers

These awareness barriers apply to all agricultural land management practices in section 4.0, with the exception of organic agriculture systems. Many Prairie producers may be unaware of the rationale for avoiding the conversion of native grasslands, forests, shelterbelt areas, and wetlands to agricultural lands. They are also likely unaware of the role of these practices in regenerative agriculture, or of their potential for major positive impacts on soil health and GHGE mitigation in the Prairies. The lack of awareness of the importance of these practices is a significant barrier to producers' understanding of the rationale for land conservation and adoption of land conservation practices.

Misunderstandings of terminology and practices are also barriers to adoption. For example, the term “riparian grassland restoration” is not consistently understood by Prairie producers. As such, some producers may believe that they have restored their riparian areas or that their agricultural practices are contributing to riparian restoration, even if these practices are inconsistent with the role of riparian grassland restoration as a regenerative agriculture practice with ecological benefits. As discussed in section 4.6. below, some producers may associate the term “wetland restoration” with a significant investment of their land and money. Perceptions on what wetland restoration or conservation entails presents a barrier to producers.

There is a lack of awareness among producers that conversion to permanent cover is an option for managing marginal lands, as well as a lack of awareness of the soil health and ecological benefits from this type of conversion. Many producers are likely also unaware of how marginal lands are defined economically and that some of the less productive areas of their cropland would be more productive as permanent cover.

4.1. Avoided Conversion Of Shelterbelts

Shelterbelts are consistently defined as groupings of trees planted in rows at the edges of agricultural land primarily to reduce the negative impacts of wind and to increase snow retention on fields, and can be used around farmyards, crop fields, and livestock areas (Rempel et al., 2017). Shelterbelts are well known by Prairie producers and, in general, producers' description of this practice would align with this academic definition.

Shelterbelts have been a staple on Canadian Prairie farms since their widespread adoption in the 1930s, however, many factors continue to motivate producers to remove some, or all, of their shelterbelts and convert the area to agricultural land. Nearly 4.9% of Saskatchewan shelterbelts were lost between 2008 and 2016 (Drever et al., 2021b). Through multiple studies and surveys, Prairie producers have consistently reported the same primary reasons that prompt them to remove shelterbelts from their land (Bain, 2021; Drever et al., 2021b; Rempel et al., 2014; Rempel et al., 2017; Viresco, 2022):

- labour and costs required for continued shelterbelt maintenance

- nuisance or inefficiency from shelterbelts obstructing large farm equipment
- loss of productive agricultural land

Economic Barriers

Economic barriers include the costs and labour needed to maintain the shelterbelt areas (Bain, 2021; Viresco, 2022), and the lost production potential in the land (Viresco, 2022). Land taken up by shelterbelts is land that is not growing any productive crops, and producers will experience this as lost income (Bain, 2021; Viresco, 2022). There can be significant nuisance costs from driving farm equipment around shelterbelts, including labour, time, and the cost of extra fuel (Bain, 2021). Shelterbelt trees that fall or need to be removed are typically not saleable and, thus, are not likely to bring any revenue to producers (L. Fuller, personal communication, January 2, 2024).

Agronomic Barriers

Shelterbelts create physical obstacles through farmland that present an agronomic barrier to agricultural production at the farm level (Bain, 2021; Viresco, 2022). As both Prairie farms and farm machinery have increased significantly in size to align with the demands of the large-scale monocropping production system, the physical obstacles that shelterbelts create on the farm have likely become an even greater nuisance over time.

Shelterbelt trees also compete with nearby crops for moisture and nutrients (Viresco, 2022), which can result in lower agricultural productivity from cropland that is directly adjacent to shelterbelt areas (Bain, 2021). Shelterbelt areas on farmland can also interfere with the set-up of irrigation systems (Bain, 2021).

A major barrier to this practice is that the agronomic benefits of shelterbelts are no longer perceived to be necessary by many Prairie producers. Reduced and zero tillage practices, along with crop residue management, protect soil from wind erosion and thus the protective effects of shelterbelts are deemed unnecessary (L. Fuller, personal communication, January 2, 2024). Given the demand that shelterbelt trees place on water and nutrient resources and the lack of perceived benefit from the trees, Prairie producers often see them as bringing more harm than good.

Socio-Cultural Barriers

There are also significant socio-cultural barriers to retaining shelterbelts. Drever et al. (2021b) noted that Manitoba livestock producers were much more likely than crop producers to consider shelterbelts important, or very important, to their farming operation, and accordingly, “crop producers were more likely to have removed shelterbelts than livestock producers.” (p. 22). This aligns with the findings from Rempel et al. (2017) showing that Saskatchewan producers perceived livestock shelterbelts to bring clear positive benefit to their livestock operation and that none of the perceived shelterbelt costs had a significant negative impact on their decision-making processes.

Many producers do not fully recognize the benefits that shelterbelts provide, both to their own farms and to the greater ecosystem (Bain, 2021; Rempel et al., 2017). In 2017, Rempel et al. published findings from a survey of 61 southern Saskatchewan producers, randomly selected from a database of past shelterbelt tree orders. Producers were asked to rank benefits and costs of having shelterbelt areas on their land and, overall, producers ranked the costs of shelterbelts as greater than the benefits (Rempel et al., 2017).

The study found that producers seem to be aware that shelterbelts provide ecological services and are of benefit to society overall; however, these benefits are not tangible or observable at the farm level and thus producers tend to not consider these benefits in their shelterbelt decision-making processes (Rempel, et al., 2017). They are also not able to observe any direct economic benefit from shelterbelts at the farm level which again would impact their perception of costs and benefits of retaining shelterbelts.

Finally, Rempel et al. (2017) noted that "many of the surveyed producers felt that shelterbelts were no longer an important or necessary aspect of agricultural production mainly due to changes in the scale of production and production technologies" (p.350). This is consistent with findings shared in the Viresco (2022) report, stating that other crop management practices already in use by producers provide the same benefits as shelterbelts without the cost and maintenance needs. Thus, producers are motivated to remove their shelterbelts and do not perceive any loss in agronomic or economic benefit from this removal.

4.2. Reduced Deforestation to Agriculture

Although Drever et al. (2021a) evaluates the mitigation potential of avoided deforestation for many different land uses, the Viresco (2022) report looks strictly at deforestation for conversion to agricultural land, which is also what this report will discuss. Prairie producers would define this practice in the same way Viresco describes it here.

Economic Barriers

Overall, the loss of potential profits from conversion of forested areas to productive cropland is a major economic barrier to producers (Viresco, 2022). If there is no clear economic benefit or financial incentive to conserve forested lands, Prairie producers will likely be unwilling to accept the opportunity cost of potential crop production income.

Agronomic Barriers

The uncertainty of the potential soil health and ecological benefits from reducing deforestation for agriculture is a barrier to producers.

Socio-Cultural Barriers

Socio-cultural barriers also play a role in producers' decisions related to deforestation. Peer connections are important and influential to Prairie producers, and some producers may be more likely to engage in certain practices when all their neighbours are doing so. Viresco (2022) discusses potential social pressures for producers to participate in the sharing of tree clearing equipment rentals with neighbours. Producers who are reluctant to remove forested areas may feel uncomfortable going against farming norms that expect producers to clear their land of trees or rocks that interfere with production efficiency.

Forested areas have a unique appeal to organic producers as the land has no prior history of conventional agricultural inputs and thus organic agriculture systems can be implemented immediately without the usual three-year wait. FWWF's advisor shared that this fast-tracked pathway to adoption of organic agriculture presents a significant barrier to reducing deforestation for agricultural use.

4.3. Avoided Conversion of Grassland, Pasture, and Hayland

This practice is defined as preventing the conversion of native, perennial grasslands and managed pastures to annual-harvested cropland (Drever et al., 2021b). Viresco (2022) states that this category includes "'natural land for pasture', 'tame or seeded pasture', and 'all other tame hay and fodder crops'" as classified in the Canadian Census (p. 104). Producers in the Prairies would also define this practice as described in Drever et al. (2021b).

Avoided conversion of grasslands to cropland carries the highest GHGE mitigation potential of all Canadian natural climate solutions, based primarily on the Prairie Pothole Region of Alberta, Saskatchewan, and Manitoba (Drever et al., 2021a). Despite this major climate mitigation opportunity in the Prairies, only limited research has explored local producers' perspectives on barriers to avoided grassland conversion.

Economic Barriers

Economic barriers and the lack of sufficient financial incentives are likely the most significant barriers to producers avoiding grassland conversion. If grasslands or pasture can be converted to more profitable cropland, producers often view avoided conversion largely in terms of their opportunity cost from lost agricultural production.

The economic loss associated with the avoided conversion of suitable grassland to cropland is articulated and sustained through the differences in crop and pasture insurance coverage. For one risk area in Alberta, moisture deficiency insurance provides coverage for native grass at $53.98/acre with a 7.62% premium and improved or tame pasture at $77.62/acre with a 7.62% premium (Western Stock Growers' Association, 2023). In contrast, crop production in the form of silage or greenfeed is insurable for $291.20/acre at a 3.9% premium (Western Stock Growers' Association, 2023). Alberta producers pay higher premiums to receive less coverage on native grasslands than they do on fields that are producing crops. It is clear how current crop insurance policies encourage producers to remove native grasslands and plant crops in their place.

Bain (2021) producer engagement heard that current financial incentives to encourage producers to avoid converting grassland, actually do the opposite as they do not match the economic return of annual crops. Ben-Othmen and Ostapchuk (2023) found that, for grassland restoration on current agricultural land, French farmers needed financial compensation equal to their current income from that land. Moreover, producers in the Bain (2021) report stated that *"perpetual and sustained funding"* would be necessary to ensure grasslands were not converted in the future (slide 49).

Incomplete and inaccurate valuation of the ecosystem goods and services provided by grasslands, contributes to these economic barriers to producers. Kulshreshtha et al. (2015) attempted to estimate the value of ecosystem goods and services from native Manitoba grasslands. Although the authors were able to identify and include 21 specific goods and services in their calculations, they noted that they had to exclude numerous benefits including "genetic, medicinal, and ornamental resources, water supply, nursery function, biological value, and cultural services [which] could not be assigned monetary value due to lack of data" (p. 164). More accurate valuation of the full range of ecosystem goods and services from grasslands, and of producers' farm level costs to maintain grasslands, could inform more effective financial incentives that compensate producers fairly for conserving these native areas.

Although income from carbon offsets has been discussed in the context of incentivizing preservation of grasslands and pasture, there are a number of potential barriers to producers in this pathway. An American study shares that low carbon credit prices are a barrier to producers in the U.S., as the potential for carbon market income is still insufficient compared to the potential income from crops (Brammer & Bennett, 2022). They also share that there are significant costs to producers upon entering the carbon market program. The uncertainty around the future of the carbon market is another barrier to producers. A U.S. farmer stated, *"it's so early in its development that the concern is you sign a contract to sell carbon for a few dollars when, down the road, it could be worth much more"* (Sustainable Markets Initiative, 2022, p.18).

Agronomic Barriers

There remains significant uncertainty in the climate mitigation potential in grasslands. Many variables, including grassland management, human activities, and weather events, impact grasslands' capacity for carbon sequestration (Viresco, 2022). Estimation models and measuring methods can often produce high variability in soil carbon sequestration rates even within a very small area of soil and are, thus, heavily debated as inconsistent and unreliable (Viresco, 2022).

Socio-Cultural Barriers

The American study (Brammer & Bennett, 2022) reports that there is a lengthy process for producers to enroll their land in a carbon market program, as well as significant costs associated with the application. This may be a legitimate challenge to Canadian producers as well. The Canada Grassland Protocol is a new program developed to support Canadian producers in preserving grasslands through carbon offsets (Horsch, 2023). Landowners are encouraged to learn about the protocol, partner with a land trust and a project developer, and collect the required data for the application. They must also sign a Qualified Land Conservation Agreement and commit to reporting and compliance monitoring, which requires significant amounts of paperwork, time, and collaboration with other parties. This may be more than some producers are willing or able to commit to, especially if the potential revenue from a carbon market is less than what they could make from a cash crop.

Considering this investment of time and money, the lack of tangible benefits to avoiding grassland conversion is a barrier to producers. Bain (2021) heard that there are few observable benefits from the producer's perspective. Viresco (2022) reports that producers and policymakers may lack awareness of the ecosystem services and climate mitigation potential that avoided grassland conversion carries. Again, accurate valuation of the full range of ecosystem goods and services provided by grasslands would address this barrier by quantifying the level of financial incentive necessary for producers to avoid converting to cropland.

4.4. Riparian Grassland Restoration

Drever et al. (2021b) describes this practice as the restoration of marginal or unproductive cropland to grassland or shrubland, but also more specifically as "restoring 30 m riparian buffers with perennial grasses in cropland areas with annual harvests" (p. 45). Producers would likely use the term "buffer strip" to refer to this practice.

Economic Barriers

There are several costs involved in the restoration of riparian grassland areas, which create economic barriers to producer adoption. Producers will have to source the appropriate perennial grass seed which may be difficult to access locally; the purchase of the grass seed also adds initial costs. There are also costs for the increased labour and time spent on preparing the riparian land, seeding, and maintaining the grassland areas.

Producers may need help with planning the restoration strategy or assessing the structure of the shoreline or streambanks. Thus, further costs for services from a professional advisor or contractor may be needed to carry out the restoration. Producers may have crop insurance coverage in place that excludes riparian grassland areas. Finally, as the ecosystem services from grasslands are not accurately quantified, the economic benefit to producers is uncertain.

Agronomic Barriers

Numerous agronomic barriers hinder producer adoption of riparian grassland restoration. There is not enough specific information on the ideal agronomic protocols for restoring riparian grasslands in Prairie agro-climatic contexts. Producers need more guidance on planning the restoration and on selecting species that are optimal for their soil, climate, and moisture conditions.

Implementing, monitoring, and maintaining restored riparian grasslands will involve labour and equipment usage that may conflict with the availability of these resources during times when the farm is already busy with seeding or harvest operations. Producers may also deal with challenges in weed management during the establishment of the new grassland areas.

The actual soil health benefits from restoring riparian grasslands are uncertain and difficult to quantify due to the high variability in soil types, climate conditions, moisture levels, and agricultural contexts. Producers may not have a proven agronomic benefit to drive their adoption of this practice.

4.5. Riparian Vegetation Restoration

Riparian vegetation areas can also be known as treed riparian buffers, riparian forest buffers, riparian strips, filter strips, or simply as riparian tree planting. Producers would define this practice as riparian vegetation restoration or riparian tree planting. Both the Association for Temperate Agroforestry and Drever et al. (2021a) consider this to be an agroforestry practice, in that its climate mitigation potential aligns more consistently with the Trees in Agriculture pathway rather than with other Agricultural Land Management practices.

Drever et al. (2021a) define this practice as the planting of trees alongside, and around, water bodies within agricultural lands that are naturally forested. Drever et al. (2021b) calculated the climate mitigation potential specifically based on the "establishment of deciduous trees within 30 m of water bodies, in agricultural lands where forest is the native cover type" (p. 19). As such, this practice should be considered applicable only to regions of the Prairies that are naturally forested.

Riparian vegetation restoration and riparian grassland restoration may appear to be similar BMPs that could be discussed together, more broadly, as riparian area restoration. However, they are distinct practices that are defined and managed differently, with different carbon sequestration rates, and apply to different regions of the Prairies with different agro-climatic conditions. Moreover, Drever et al. (2021) assessed the GHGE potential of these riparian practices separately and so, to maintain clarity and consistency, the practices are also addressed separately in this report.

Economic Barriers

Bain (2021) producer research identified two economic barriers to producer adoption: initial costs and loss of productive cropland. The initial costs to restore riparian vegetation areas, as well as the investment of time and labour resources are significant, and may be out of reach for some producers. Riparian areas that are restored to vegetation also represent a loss of potentially productive, or already productive, cropland and, thus, a loss of revenue to producers.

Agronomic Barriers

FWWF's advisor identified numerous agronomic barriers to producer adoption of riparian vegetation restoration. There is no clear agronomic protocol that guides Prairie producers in implementing this practice on their farm and with their geographic region, soil type, and weather conditions.

Producers also have challenges with controlling weeds in restored riparian areas without harming the new vegetation. Restoring riparian areas improves the farm's resilience to extreme weather events and erosion, however producers may still view restoration of riparian areas as a high-risk practice due to their financial investment. Riparian areas in the early stages of restoration are vulnerable to damage during flooding, drought, wildfires, or erosion and as such, this risk is a barrier to producer adoption.

Socio-Cultural Barriers

Groups such as Cows and Fish have helped to convey the financial savings associated with avoided erosion of stream and dugout banks, as well as the health benefits of off-stream watering sites to make riparian health a much more common priority for Prairie producers (Fitch et al., 2003). The Cows and Fish booklet *Riparian Areas and Grazing Management* (Fitch et al., 2003) provides guidance to Prairie producers on holistic riparian management.

Drever et al. (2021a)'s description of riparian vegetation restoration as the agroforestry practice of planting trees near the edges of water bodies is limited and inconsistent with holistic riparian management practices used by Prairie producers. In addition to tree planting, practices such as rotational grazing, time-controlled grazing, and corridor fencing, among others outlined in the Cows and Fish booklet (Fitch et al., 2003), are in use on Prairie farms for riparian management. This highlights a disconnect between how differently producers and academics may view riparian practices and creates a barrier to Prairie producers' adoption of holistic, regenerative riparian management practices.

Awareness Barriers

In addition to the awareness barriers discussed in section 4.0., there is a terminology barrier that applies to riparian vegetation restoration. Although many Prairie producers are familiar with buffer strips, they may not be aware of the various terms that are used for this practice.

Producers generally understand buffer strips more as the practice of riparian grassland restoration than as riparian vegetation restoration, and as such there is a disconnect between producers' and academics' definitions of these practices.

4.6. Wetland Conservation and Restoration

Wetlands are land-based ecosystems that retain, or are submerged in, water, including marshes, swamps, bogs, and sloughs (Government of Canada, 2016). Wetland conservation (or avoided wetland conversion) can be defined as "the prevention of drainage, dredging, eutrophication, or other anthropogenic activities in peatlands, freshwater mineral lands, and seagrass ecosystems" (Drever et al., 2021b, p.31). Wetland restoration is defined as "restoration of hydrological function (rewetting) or topography, moss layer transfer, fertilization, nutrient management, vegetation management, or disturbance management." (Drever et al., 2021a, p. 3). Ducks Unlimited Canada, which offers a Wetland Restoration Lease Program to Alberta landowners, defines wetland restoration more plainly, stating that it can often be done through re-contouring and the use of a ditch plug (Ducks Unlimited Canada, 2020). Producers would generally agree with these definitions of wetland conservation and restoration.

Vast amounts of natural wetlands have been lost throughout the Canadian Prairies, with many of them being intentionally drained for conversion to agricultural land or urban developments (Viresco, 2022). An estimated 70% of wetlands in southern Canada have been lost (Ducks Unlimited Canada, 2022), and only about 25% of wetlands remain in Manitoba's pothole region (Government of Canada, 2016).

Wetland conservation and restoration in Canada occurs through land purchases, conservation easements, and programs for landowners in areas such as habitat management and forage conversion (Ducks Unlimited, n.d.-c). Some destroyed wetlands can be restored or re-created physically but may never reach the functional capacity of naturally occurring wetlands (Ontario Nature, n.d.).

Economic Barriers

The economic barriers to producers' adoption of wetland conservation and restoration are significant. Direct costs include the initial costs and labour required to restore wetlands, as well as the costs and labour for ongoing maintenance of the wetlands (Bain, 2021; Viresco, 2022). Research that has estimated costs for Prairie producers to conserve wetlands on their properties is limited. Economic methods used for farm-level cost calculations all have limitations and many are not able to include all relevant factors, nor accurately estimate all costs the producer would incur.

There is also evidence to suggest that producers' costs to conserve and maintain wetlands on their farms are dynamic and increase over time (Lloyd-Smith et al., 2020). Changes in farming technologies, crop prices, infrastructure costs, and the frequency of climate and weather events contribute to frequently changing costs for wetland maintenance at the farm level. As such, cost estimations done in the past have limited relevance to current contexts, and cost estimations done in the present may fail to capture the true range of costs to producers in the near future (Lloyd-Smith et al., 2020). Having no accurate estimation of costs they will incur now, and in the future, presents a major barrier to producers' adoption of wetland conservation or restoration BMPs. Without this information, producers will be unlikely to adopt wetland BMPs and financial incentives will be unlikely to adequately compensate producers for their costs.

Research on the economic valuation of non-market ecosystem goods and services provided by wetlands in the Prairies is also very limited. What research does exist, most commonly uses a value transfer or benefit transfer method for valuation which has significant limitations. Values for specific ecosystem services are borrowed from existing research and then applied to the studied context. For example, this method may assume that the economic value of pollinator habitat and services from wetlands in the northeastern U.S. is the same as it would be in southern Saskatchewan. Benefit transfer valuations reduce a complex problem to a series of simplistic assumptions, as they fail to consider important socio-economic, demographic, and biophysical variables. They also fail to account for "the large degree of heterogeneity in ecosystem service provision, valuation, and costs of conversion" (Lloyd-Smith et al., 2020, p. 31). More accurate valuation of the full range of ecosystem goods and services from wetlands could inform more effective financial incentives that compensate producers fairly for conserving these areas.

There are also indirect economic barriers to consider. Restoring former wetland areas may result in a loss of productive cropland to the producer and thus a loss of current and future income (Bain, 2021). Loss of future income is also a barrier to wetland conservation – when producers commit to conserve wetlands on their farms, they relinquish the possibility of future crop production and revenue in these areas. Ducks Unlimited Canada offers landowners a 10-year Wetland Restoration Lease Program which covers construction and maintenance costs for the restored wetland, however it does not offer any financial compensation for lost production revenue (Ducks Unlimited Canada, 2020).

In the Prairies, crop commodity prices impact rates of wetland drainage. High canola prices in the past have motivated producers to drain wetlands to increase their canola production acres and revenue (L. Fuller, personal communication, March 28, 2024). Financial incentives intended to prevent wetland drainage by producers would need to be equal to or greater than the current commodity prices that producers could receive through crop production.

Producers may be reluctant to restore wetlands on their fields for fear of interfering with equipment access and disrupting their crop production efficiency. Cagdas et al. (2016) noted that restoring wetlands on current cropland may negatively impact operational efficiency in the field as well as overall production efficiency.

Only limited research on the full climate mitigation potential for conserved and restored wetlands in the Prairies is available (Viresco, 2022). This information is difficult to quantify accurately, especially over the long-term, and as such wetland protocols through the carbon offset market are not yet available to Prairie producers (Viresco, 2022).

Agronomic Barriers

There are many agronomic barriers that can hinder producer adoption of wetland conservation or restoration practices. From the producers' perspective, there is no clear agronomic protocol on how to implement a wetland restoration or on what species are most appropriate to use in a restored wetland area. Producers experience challenges with weed control in restored wetland areas as their weed management options are limited to protect the wetland ecosystem. Timing conflicts may arise for labour or equipment if wetland restoration coincides with busy crop seeding or harvest times.

Quantification of the soil health or ecological benefits from wetland conservation or restoration is not clearly defined and producers have uncertainty over the extent of agronomic benefits they will gain from these practices.

Socio-Cultural Barriers

There are significant barriers to producers choosing to pursue wetland conservation and restoration, starting with the terminology alone. A Saskatchewan study on watershed modelling talked to 28 local producers through focus groups and workshops (Bradford, et al., 2020). The authors noted that an insightful discussion emerged on the topic of wetland restoration, stating "the term 'restoration' implied a high capital cost and a large donation of land that many agricultural producers dismissed as unrealistic" (p. 14281).

Other socio-cultural barriers include producers' perception of significant costs and labour involved in wetland conservation or restoration, with only minimal direct benefits to them (Bain, 2021). Also, many external stakeholders at multiple levels of government are involved in wetland restoration processes and this complexity acts as a barrier towards producers' involvement (Bain, 2021). Finally, producers are reluctant to lose productive farmland if they were to convert it back to a wetland area (Bain, 2021).

Some significant socio-cultural barriers arise from the political and organizational levels. Lack of trust, regulatory barriers, interorganizational conflicts, and regulators' reluctance to approve anything outside the status quo all acted as barriers in Clare and Creed's (2022) living laboratory study of wetland restoration in Alberta. Political disputes between municipalities, counties, and the delivery organization undermined productive discussions on wetland restoration policy and programs. Rural landowners felt it was unfair for them to shoulder the burden of wetland restoration to benefit the urban municipalities. Only one organization, Ducks Unlimited Canada, was approved by the Alberta government to deliver the restoration projects, but they had limited capacity to carry out the project, which resulted in tension and slow progress. Many rural landowners did not trust DUC and were not willing to work with them, and many others would not consent to restoration of their wetlands, or were unable to give consent due to their lands being rented to other producers. Some landowners did not want to allow wetland restoration for fear of losing the potential for land rental and others could not give permission without the agreement of several other co-owners of the land.

Clare and Creed (2022) also noted that the Alberta regulatory system is built to facilitate wetland drainage and that it was easier to be granted a wetland drainage permit than a wetland restoration permit. Regulators were also not comfortable modifying contracts to allow for restoration processes, or approving restoration work, because it did not fit within the accepted standards to which they were accustomed. As a result of these significant barriers, the study enrolled just four landowners in a three-year period. Ultimately, the authors reported that they underestimated the negative impacts from tension due to interorganizational conflicts, and from regulators who were unwilling to make decisions outside the accepted norm, on the adoption of wetland restoration in Alberta.

4.7. Conversion of Marginal Cropland to Permanent Cover

Lands that have no value for agricultural or industrial production due to degraded soil, poor quality soil, landscape complexity, salinity, or various other reasons are generally defined as marginal lands, and may also be known as ‘land set aside’. Producers in the Prairies would agree with this definition of marginal cropland. Prairie farms often have areas of land that are difficult to access, or consistently underperform in production. Conversion of these marginal lands to permanent cover with trees, perennial crops, or bioenergy crops can improve climate mitigation capacity and reduce producers’ use of time, labour, and inputs on unproductive areas.

Economic Barriers

Producers may not have enough information available to them to determine the economic productivity of their marginal lands, and without this information they may be unaware of their per-acre profits or losses. Producers who are currently using the same amount of inputs on their unproductive marginal lands as they are on their productive cropland are likely experiencing a net loss per acre on these lands (L. Fuller, personal communication, January 3, 2024). Accurate calculation of their per-acre profit or loss could be a key driving factor that encourages producers to convert their marginal lands to permanent cover to avoid further economic losses.

However, there is also time, cost, and labour involved in converting marginal lands to permanent cover and in managing these lands differently than the rest of their farmland (L. Fuller, personal communication, January 3, 2024). Producers need accurate estimations of the anticipated per-acre costs for conversion and maintenance of marginal lands which can then be weighed against any current per-acre net loss before they can make an informed decision about adopting this practice.

Agronomic Barriers

Viresco (2022) does not identify any specific barriers to this practice. However, lack of available knowledge may be a barrier to producers. There is currently limited research available to guide Prairie producers on how to best manage marginal lands, which species to plant, when to determine that land is not economically productive enough and should be set aside, as well as how much mitigation capacity is held by different types of marginal lands (Viresco, 2022).

RALL producers shared some of their challenges in restoring cropland to native vegetation. One producer stated they *"have continuous cover to stop erosion but weeds still come in from surrounding cropland"* (RALL, 2023b). They also stressed that the restoration is *"a delicate process, need to act when conditions are right"* and that the *"native grass environment is unique - thin crops need managing."*

Some initiatives are available to support producers through the process. Ducks Unlimited Canada's Marginal Areas Program offers a per-acre financial incentive for producers in Alberta, Saskatchewan, and Manitoba to seed and establish perennial forage on marginal lands (Ducks Unlimited Canada, n.d.-b; McCuaig, 2023). Producers are also given assistance and advice in identifying unproductive lands on their farms and establishing the forage stand (Ducks Unlimited Canada, n.d.-a).

Socio-Cultural Barriers

From producers' perspectives, there is not enough information available to them on how to accurately identify marginal lands on their property and how to convert them to permanent cover.

4.8. Organic Agriculture Systems

Organic agriculture and regenerative agriculture systems are frequently conflated and do have many underlying principles in common. As production systems, however, they are distinctly different and contrast highly in practical implementation and regulations. Organic agriculture is highly regulated in Canada, defined by the Canadian General Standards Board as "a holistic system designed to optimize the productivity and fitness of diverse communities within the agro-ecosystem, including soil organisms, plants, livestock, and people" (Canadian General Standards Board, 2018, p.ii). These standards define the inputs, monitoring, and production methods that producers should or should not use for their organic production. Prairie producers are generally aware of organic agriculture systems and would agree with this definition, although they may also perceive that in practice, organic systems are not necessarily consistent with their definition.

Organic and regenerative agriculture production systems are different enough in Canada that perspectives from organic producers should not be assumed to apply to regenerative producers, nor should we use the organic agriculture system as a proxy for regenerative agriculture. Still, insights from organic producers on the adoption of an alternative agriculture system that does not align with the dominant, conventional agriculture system may be valuable in the promotion of large-scale adoption of regenerative agriculture. Key points in the approach to organic agriculture adoption in Canada could prove to be relevant to regenerative agriculture as well.

Economic Barriers

Both organic and regenerative producers may use legumes as green manure to maintain nitrogen soil levels without synthetic fertilizers. Heavy use of legumes in this manner can result in less land available for cash crop use and, thus, a loss of income as well (Viresco, 2022). American research has highlighted the high costs for fuel and equipment repair in organic systems, however a Canadian study found that the reduced input costs for organic systems were more than enough to compensate for higher costs for seed, organic certification, and machine overheads (Zentner et al., 2011). Organic producers likely have higher insurance costs as well, as crop insurance premiums are higher for organic crop rotation systems than for non-organic systems (Zentner et al., 2011).

Transitioning a farming operation from conventional to organic is a process that typically takes at least three years for grain and produce farmers in Canada (Canadian General Standards Board, 2018). Until their organic certification process is complete, transitioning producers incur the high costs of organic production without the benefit of organic premium prices on their commodities (Viresco, 2022) and, as such, this presents a barrier to producers who would be unable to maintain profitability during this transition period.

Ultimately, achieving profitability with organic systems in Canada can be a slow and risky process for producers. In a Saskatchewan-based study, Zentner et al. (2011) found that organic cropping systems had much lower net returns during the initial organic certification period than non-organic systems. The authors estimated that after the initial three-year organic certification period, it would take an additional five to seven years before the organic system would be profitable enough to make up for these income losses. To producers considering adoption of an organic agriculture system, the potential of up to 10 years before losses can be regained presents an enormous economic barrier.

Agronomic Barriers

Prior to initial adoption, the lack of knowledge on the technical and agronomic aspects of implementing either organic or regenerative agriculture systems is a barrier to producers (Viresco, 2022). For producers who have been involved in conventional farming for decades, adopting new practices within an entirely different production system means learning the agronomic and technical details of how to make the BMPs work effectively together to optimize soil health and overall production.

Producers also encounter numerous agronomic challenges and barriers while implementing organic or regenerative agriculture systems in their farming operations. Organic producers in the

Prairies have reported that their most significant challenges in organic production are crop rotations, soil health and fertility, and weed management (Thiessen Martens et al., 2015). Without the use of conventional inputs, organic producers often struggle with weed and pest management on their crops and may need to seek alternatives like specialized weeding equipment (Viresco, 2022). From this report, we know that these are also common agronomic challenges in regenerative agriculture.

Nutrient management may also present a challenge to both organic and regenerative producers as they limit or restrict synthetic fertilizers (Viresco, 2022). Again, they may seek more appropriate alternatives such as manure or other organic soil amendments, which may be more costly and may also require more meticulous management to maintain optimal soil chemistry.

Socio-Cultural Barriers

The expensive and time-consuming process for a farm to obtain Certified Organic status is a barrier to many producers. Organic farming is definitely viewed as being outside of the conventional agricultural norms of the Prairies, creating social pressure barriers to producers who are interested in pursuing the process.

Many producers are reluctant to learn about organic systems or to change their current farming practices. Those who are interested are met with an overwhelming wealth of information on organic farming that does not necessarily guide producers in starting the process. Producers also find, however, a lack of information on organic farming specific to Prairie agricultural contexts.

Producers who rent their cropland may have land rental restrictions that do not permit conversion of the land to organic production. Thus, land rental is a barrier to producers' adoption of organic farming systems.

Awareness Barriers

While most Prairie producers are familiar with the concept of organic farming, many are unaware what an organic production system actually involves. Producers' understandings of organic farming are often inconsistent with organic farming as it is defined by the Canadian General Standards Board.

Producers may also have assumptions or ingrained beliefs about how organic farms function or what it means to grow a crop organically. These misunderstandings, perceptions, and assumptions present awareness barriers that interfere with greater adoption of organic agriculture systems on the Prairies.

5.0. Current and Ongoing Initiatives in the Prairies

There are numerous financial, research, and knowledge-sharing initiatives currently available to Prairie producers that aim to drive adoption of regenerative agriculture. Many of these initiatives address some of the knowledge gaps or barriers to adoption discussed in this report.

5.1. Agricultural Climate Solutions - Living Labs Program

RALL is part of the federal Agricultural Climate Solutions – Living Labs program, which began in 2021 and aims to create a robust network of regional living labs across Canada (Agriculture and Agri-Food Canada, 2023d). Living Labs within the federal program are designed to be producer-centered hubs for collaborative development and testing of agricultural innovations, with goals to:

- Sequester carbon
- Reduce greenhouse gas emissions
- Provide other environmental co-benefits

The **Regenerative Alberta Living Lab (RALL)**, led by FWWF and the Alberta Conservation Association, is a transdisciplinary initiative that aims to drive large-scale adoption of regenerative agricultural practices through producer-centered and producer-led learning, research, innovation, and partnerships (RALL, n.d.-b). The RALL activities address many barriers to producers' adoption of regenerative agriculture, including the lack of quality peer-to-peer learning opportunities, the lack of access to context-specific BMP research and data, the lack of soil health monitoring and evaluation, and the lack of local mentors who are knowledgeable in regenerative agriculture.

RALL operates with a base of enthusiastic producers who represent a wide variety of scales of farming production, types of commodities farmed, sizes of farming operations, and ecoregions in Alberta. The amalgamation of data, knowledge, experiences, and collaboration from this large network of producers through the RALL activities will not only advance adoption of BMPs, but also contribute to the paradigm shift that is needed for large-scale change to a regenerative agricultural norm.

In addition to the RALL, there are five other regional Living Lab programs available to Prairie producers (Agriculture and Agri-Food Canada, 2023d):

- **Peace Region Living Lab:** Serves Northern Alberta and B.C. and focuses on carbon sequestration, GHGE mitigation, and improving agro-ecosystem services in the Peace Region.

- **Alberta Agri-Systems Living Lab:** Led by Alberta Beef Producers and focuses on carbon sequestration and GHGEs in beef, forage, and crop production.

- **Bridge to Land Water Sky Living Lab:** Led by Mistawasis Nêhiyawak and Muskeg Lake Cree Nation in Saskatchewan, serving Indigenous and non-Indigenous producers. Focuses on the use of various BMPs to improve lands and resources in alignment with Indigenous values, treaties, and communities.

- **Central Prairies Living Lab:** Also known as the South of the Divide Conservation Action Program (SODCAP) and serves the Prairie ecozone of southern Saskatchewan. Focuses on avoided land use conversion, restoring biodiversity, and grazing management practices in Prairie ecoregions.

- **Manitoba Living Lab:** Serves producers in Manitoba and focuses on developing and testing a variety of BMPs as well as increasing producers' understanding and adoption of BMPs.

5.2. Sustainable Canadian Agricultural Partnership

The Sustainable Canadian Agricultural Partnership (Sustainable CAP) is a federal-provincial cost-share grant funding initiative that provides grants to producers, processors, and organizations through a variety of programs (Government of Alberta, n.d.-e). Sustainable CAP offers funding to cover portions of producers' expenses for BMP adoption through a variety of grant programs, most of which are available to producers, including:

- **Farm Technology Program:** Offers funding for soil technology including electronic soil sensors that measure salinity, organic matter, moisture, and nitrate levels, as well as soil compaction sensors, and solar powered soil sensors. Costs for the technology are shared 50/50 between the program and the producer, up to a maximum of $48,000 for farm technology (Government of Alberta, n.d.-b).

- **On-Farm Value Added Program:** Covers both capital and non-capital expenses for processing, food safety, product development and market development. Eligible non-capital expenses covered at 50% include costs for training on new technologies and equipment, market feasibility studies and plans, and other services to support producers in accessing new product markets (Government of Alberta, n.d.-c).

- **Resilient Agricultural Landscape Program**: Producers will receive a per-acre fee based on their implementation costs for selected BMPs and may also be eligible for funding for opportunity costs or additional impact adjustment payments, up to a maximum of $150,000 for a primary producer.
    - Funding is available for several BMPs including rotational grazing, conversion of annual cropland to native or tame forages, intercropping, shelterbelts, grass

waterways, pollinator strips, and construction of new wetlands (Government of Alberta, n.d.-d).

- **Water Program:** Limited funding is available to producers through a case-by-case application process and covers 25% of eligible expenses related to water BMPs that will improve water resiliency, including upgrades of irrigation systems, wells, dugouts, dams, and wetland assessments (Government of Alberta, n.d.-f).

5.3. On-Farm Climate Action Fund

In 2021, Canada's federal government promised $200 million towards the On-Farm Climate Action Fund (OFCAF) to support producers' adoption of BMPs in three streams: nitrogen management, cover cropping, and rotational grazing. Several organizations act to distribute funding to producers, although each producer can receive funding through only one organization per BMP stream (Agriculture and Agri-Food Canada, 2023c):

- Results-Driven Agricultural Research (RDAR) has up to $33 million available to Alberta producers
- Manitoba Association of Watersheds has up to $40 million available for producers in Manitoba and Saskatchewan
- Manitoba Métis Federation has up to $7.2 million specifically for Red River Métis farmers
- Canadian Forage and Grassland Association has up to $10 million available to support rotational grazing practices in BC, Alberta, Saskatchewan, and Quebec
- Ecocert Canada has up to $4.5 million available to support certified organic producers anywhere in Canada

The following two projects also distributed OFCAF funding to producers, but as of April 1, 2024, these projects are complete and funding is no longer available (Agriculture and Agri-Food Canada, 2023c):

- Alternative Land Use Service (ALUS) Canada had up to $700K to support a sustainable bison grazing program with the Woodland Cree First Nation in Northern Sunrise County in Alberta (Kienlen, 2022b)
- Canola Council of Canada had up to $22 million available to producers in Alberta, Saskatchewan, and Manitoba to achieve increased canola yields and reduced emissions from nitrous oxide

Many eligible BMP expenses are covered at 85% by the OFCAF program, others may be covered at 70%, up to a lifetime maximum of $75,000 per farm (RDAR, n.d.-c). Producers will need to pay upfront for their BMP expenses and then submit receipts to be reimbursed through their OFCAF distribution organization.

In addition to financial incentives, OFCAF offers resources to support producers' implementation of new BMPs, including education, training, knowledge sharing, and design recommendations. RDAR hopes that OFCAF will allow more Alberta producers to try BMPs that are uncommon here, like cover cropping, and intends to facilitate connections between interested producers and organizations that can offer the necessary equipment to adopt these practices (Kienlen, 2022a). This important recognition of the need to address infrastructure, knowledge sharing, and community barriers in addition to financial barriers, can only serve to enhance the effectiveness of the accompanying financial incentive program.

5.4. ALUS and General Mills Growing Roots Pilot Program

General Mills and Alternative Land Use Services (ALUS) have collaborated to launch Growing Roots, a regenerative agriculture program in Manitoba and Saskatchewan to promote producer adoption of BMPs including: cover cropping, intercropping, low- or no-tillage, livestock grazing on crop stubble, extended crop rotations, and reduced usage of nitrogen fertilizer (Native, n.d.; Sustainable Food Lab, n.d.). Producers enter data into an Ecosystem Services Market Consortium (ESMC) monitoring and verification platform, where it then calculates greenhouse gas (GHG) emission reduction values for each producer (Native, n.d.). These values are verified by SustainCERT, and farmers are paid for the amount of GHG emissions that were reduced or removed through carbon sequestration on their fields that year.

Producers in this program are also given virtual and in-person support including one-on-one consultations with knowledgeable regenerative agriculture mentors, field visits, a soil health workshop, and group zoom calls to facilitate BMP implementation (Native, n.d.). Again, this initiative recognizes that opportunities for regenerative producers to connect and share knowledge with peers and mentors are a necessary complement to the financial incentives and will give producers the best chance of BMP success.

5.5. Sustainable Food Lab and the Trusted Advisor Partnership

The Sustainable Food Lab is working towards sustainability in mainstream food systems and offers various initiatives that aim to increase producer adoption of regenerative agriculture (Sustainable Food Lab, n.d.-b).

The Trusted Advisor Partnership (TAP) is a new, place-based initiative that offers free training in local soil health to Certified Crop Advisors (CCAs), as well as financial incentives for producers (Sustainable Food Lab, n.d.-c). By training the advisors who already have an established, trusted relationship with producers, regenerative agriculture knowledge will be shared faster and more effectively to a broader producer audience. This should translate into greater BMP adoption rates as producers will have financial incentives available, as well as access to knowledgeable support through their Trusted Advisor.

The Sustainable Food Lab has recently launched the West Canada TAP with funding from PepsiCo, and in partnership with agricultural consultants, Nature United, and researchers in Saskatchewan and Manitoba (Sustainable Food Lab, n.d.-a). The program will train and educate Trusted Advisors in the Canadian Prairie provinces.

In addition, the Sustainable Food Lab has produced the Scale Lab 2023 Report, which gives a framework for normalizing producer adoption of regenerative agriculture over the next five to ten years (Sustainable Food Lab, 2023). One of the key building blocks to producer adoption of regenerative agriculture is farmer support systems that share knowledge and build networks among producer peers. American farmer Jim Moseley states *"on my farm the big change came along with an independent crop advisor who knew soil biology, so I'm convinced about the importance of influencers who are trusted by farmers. It's most helpful when influencers are close enough to have a group of farmers come together in person. And this key influencer can nurture, educate, train them into a better way"* (Sustainable Food Lab, 2023, slide 9).

Educating and training Trusted Advisors to share regenerative agriculture knowledge and build peer communities through interested producers will play an important role in contributing to this culture change. However, it is possible that some TAs are not ready for the mindset shift needed to align with the regenerative agriculture philosophy. We should consider this insight from a participant in the Trusted Advisor study, who said that *"focusing training on PAgs and CCAs won't move the needle – much of the old information hangs on with them – need to target uni[versity] and college students because then we hit the future TAs and the people going back to farm"* (FWWF, 2023b). Perhaps a future consideration for the TAP would be to also partner with post-secondary institutions and provide training to the students who will become the next generation of PAgs and CCAs.

5.6. Canada Agricultural Loans

General agricultural loans of up to $500,000 per individual are available to producers through the federal Canada Agricultural Loans program, distributed through banks and credit unions across Canada. Loan funding can be used for many farm expenses, including those related to regenerative agriculture practices, such as the purchase of machinery or livestock, the construction of fencing or drainage infrastructure, and the planting of trees and shelterbelts for soil erosion prevention (Agriculture and Agri-Food Canada, 2009).

5.7. Farm Credit Canada Sustainability Incentive Program

Farm Credit Canada (FCC) offers producers a variety of agricultural loans that can be used towards the purchase of inputs, livestock, equipment, sustainability upgrades, land, and more. Producers who currently have an FCC loan and have implemented some sustainable agriculture practices are also eligible for their Sustainability Incentive Program, which offers up to $2,000 per producer per year (Farm Credit Canada, n.d.). Sustainability metrics vary by agricultural industry; beef producers must be certified by the Canadian Roundtable for Sustainable Beef, while crop producers must have completed the requirements of the 2023 Cargill RegenConnect program (Farm Credit Canada, n.d.). Recently, FCC announced that a new sustainability metric has been added to the program; crop producers who follow the 4R Nutrient Stewardship framework will be able to apply for the incentive starting in the fall of 2024 (Wichers, 2024).

5.8. McCain Regenerative Agriculture Framework

FCC's Sustainability Incentive Program also includes the McCain Regenerative Agriculture Framework, which offers incentives and support to McCain potato producers in the Prairies when they adopt regenerative agriculture practices. Producers who join the McCain Regenerative Agriculture Framework program will complete a soil health assessment, receive training in regenerative agriculture, and are supported in achieving up to seven BMP indicators as they work through the Framework process (McCain Foods, n.d.). Producer training was developed through the Soil Health Institute in North America and includes online sessions as well as in-field training and education on regenerative agriculture practices for potato farms (McCain Foods, 2022).

5.9. Results Driven Agricultural Research

In addition to distributing a portion of Alberta's share of OFCAF funding, Results Driven Agricultural Research (RDAR) supports producer-led, Alberta-based agricultural research projects that involve collaboration between producers, scientists, and researchers, and partnerships with educational institutions and private industry. Through transdisciplinary partnerships and research projects, they work towards adding value and profitability to farm operations and driving adoption of sustainable environmental practices (RDAR, 2022).

Ongoing producer-led, Alberta-based regenerative agriculture research projects funded by RDAR include (RDAR, n.d.-b):

- Demonstrating drought and extreme heat resilience from BMP adoption
- Comparison of traditional crop inputs and biostimulants application on wheat, canola, and peas in Alberta
- Determining specific compost blends for regenerative agriculture in central Alberta
- Managing crop residue carbon for soil health in wheat-based cropping systems
- Solutions for climate variability and adaptability: use of innovative cropping systems to improve soil water holding/drainage capacity

It is important to emphasize that these research projects are Alberta producer-led and that RDAR highlights the importance of knowledge-sharing pathways to ensure that research findings reach producers. Each project's web page states how the findings will be shared, in what RDAR calls 'The Final Mile' – research extension to producers and processors (RDAR, n.d.-a). These knowledge sharing channels include:

- Engagement with producers through outreach and stakeholder meetings
- Newsletters and magazines sent to producers
- Posting of research updates and project deliverables on websites and social media accounts
- Annual reports
- Presentations at conferences and extension events
- Extension webinars
- Workshops
- Field days inviting producers to observe the research in-person

5.10. BMO Regenerative Agriculture Donation to University of Saskatchewan

In April 2023, the University of Saskatchewan announced a $2 million donation from BMO for regenerative agriculture research, which will be used to fund the new BMO Soil Analytical Laboratory as well as the new Jarislowsky and BMO Research Chair in Regenerative Agriculture, a position that will focus on regenerative agriculture training, research, and BMP adoption (University of Saskatchewan, 2023).

The Soil Analytical Laboratory will expand capacity for soil health analysis and will allow integration of soil health data across various platforms, which will contribute to a soil database that will show relationships between soil health and crop outcomes. The research chair position will advance regenerative agriculture research and training, with a focus on assessing BMPs while still maintaining yield and profitability (Philip, 2023).

5.11. Farm Resilience Mentorship Program

The Farm Resilience Mentorship Program (FaRM) offers no-cost regenerative agriculture learning opportunities to help producers build crucial social capital that will positively impact BMP adoption in the Prairies. FaRM is based on the principle that farmers learn best from other farmers (Farmers for Climate Solutions, n.d.), and also recognizes that peers are the most trusted source of knowledge for producers, and that this trust drives BMP adoption (Ranjan et al., 2019).

The programs are funded by Farmers for Climate Solutions but are developed and delivered by regional, producer-led organizations to ensure that information is relevant to local conditions and producer needs. In the Prairies, FaRM is delivered by Organic Alberta, SaskSoil, and the Manitoba Organic Alliance.

Currently, the program is available for three BMPs: advanced nitrogen management, advanced grazing systems, and cover cropping. FaRM offers producers self-paced online courses, educational videos, one-on-one mentoring sessions, local in-person field days, and what they call a “Community of Inquiry.” The Manitoba Organic Alliance explains that “a Community of Inquiry is a meeting space that fosters learning, knowledge sharing and support among peers… [and] can help overcome isolation and build community in a meaningful way” (Manitoba Organic Alliance, n.d.). FaRM addresses social, community, and educational barriers to BMP adoption by providing a platform for producers to learn independently, to share knowledge through a peer network, and to connect with like-minded peers.

5.12. The Nature Conservancy and Louis Dreyfus Company Collaboration

A new, collaborative regenerative agriculture initiative was very recently announced by The Nature Conservancy and the Louis Dreyfus Company (The Nature Conservancy, 2024). The initiative is composed of two pillars: regenerative agriculture and deforestation- and conversion-free production. The first pillar intends to implement regenerative agriculture projects throughout the value chain, using farmer engagement and farmer collaboration to develop programs to support adoption. The second pillar will focus on incentives for farmers to conserve forested areas and avoid conversion to agricultural land. While few details are available at this point, there are early indications that some Canadian sites will be included in the regenerative agriculture pillar (The Nature Conservancy, 2024).

5.13. Canadian Alliance for Net-Zero Agri-Food and Hebert Grain Farms

Another new initiative is underway in Saskatchewan that aims to advance the carbon credit market for producers in Canada. University of Saskatchewan researchers will work with the Canadian Alliance for Net-Zero Agri-Food (CANZA) to develop a measurement, reporting, and verification (MRV) system that more accurately measures soil carbon sequestration (RealAgriculture, 2023).

The Hebert Grain Ventures farm in south-east Saskatchewan will be used as a case study site for the duration of the 12-month project. Soil carbon measurements will be based on samples from the current study as well as on data from Hebert farm soil samples dating back to the 1990s (RealAgriculture, 2023). The pilot project began in the spring of 2023 and a first prototype of the proposed MRV system could be released in 2024.

Many Prairie producers are interested in revenue from the carbon market but accurate measuring and quantifying of soil carbon remains a barrier. The project’s goal is to develop an MRV system that accurately quantifies soil carbon levels and allows Prairie producers to generate revenue through sales of high-quality carbon credits (RealAgriculture, 2023).

5.14. Saskatchewan Association of Watersheds' Climate Change Adaptation Project

The Saskatchewan Association of Watersheds has developed the Climate Change Adaptation Project which works to build capacity for climate adaptation and resilience in Saskatchewan communities (Saskatchewan Association of Watersheds, n.d.). The project began in 2023 and is supported by Environment and Climate Change Canada. One of the key objectives of the project is the implementation of six BMP demonstration sites that address a number of barriers to producers. The sites provide observable and experiential learning opportunities for producers to observe BMPs at a farm scale and learn from peers, mentors, and experts. The sites will also host field tours that are open to everyone, allowing the general public to gain a greater exposure and understanding of regenerative agriculture.

As the project is intended to build community climate resilience, it discusses BMPs in the context of climate change adaptation. Out of all regions of Canada, people in the Prairie provinces are the least likely to believe in anthropogenic climate change (Abacus Data, 2018). It is therefore important to consider the communication approach used here – the use of climate change terminology may prevent this project from reaching many Prairie producers.

It is also important to highlight that climate skepticism has not been found to negatively impact adoption of BMPs in the Prairies (Davidson et al., 2019). It would be inaccurate to assume that climate skeptic producers would be uninterested and unlikely to adopt BMPs. In fact, one study found that Alberta producers who are climate skeptics are just as likely to adopt BMPs as producers who are climate believers (Davidson et al., 2019). Framing BMPs as tools for climate adaptation is accurate but may not be the most effective communication approach to engage conventional Prairie producers.

5.15. The Canada Grassland Protocol

The Canada Grassland Protocol is a new program developed to support Canadian producers in preserving grasslands through carbon offsets (Horsch, 2023). The program states that it is "the first carbon offset opportunity for Canadian grassland managers and the first avoided conversion opportunity in Canada" (Horsch, 2023, p. 8).

Landowners must sign a Qualified Land Conservation Agreement that restricts development and ensures the grassland remains in its natural state (Horsch, 2023). Grasslands under the agreement cannot be cleared, drained, or developed, but producers can continue to use them for moderate grazing or haying, and even for intensive rotational grazing provided the vegetation and soil remains healthy (Horsch, 2023).

Interested landowners are encouraged to learn about the protocol and about land eligibility requirements, partner with a land trust and a project developer, and collect the required data for the application (Horsch, 2023). If the application is accepted, landowners must follow the appropriate monitoring, verification, and reporting guidelines, and allow compliance inspections every six years.

5.16 Nutrien Ag Solutions' Sustainable Nitrogen Outcomes Program

Nutrien Ag Solutions offers producers in the three Prairie provinces a cash incentive of at least $2/acre for adoption of 4R Nutrient Stewardship practices on canola, wheat, barley, oats, or corn crops. Actual incentive amounts vary by crop and region and are based on producers' operations and outcomes. Producers must complete an online form to determine their eligibility, have at least one year of crop data available, and sign a one-year agreement if they are accepted into the program.

Once accepted, producers need to "craft a 4R nutrient stewardship plan with a certified Crop Production Advisor or Agronomist to incorporate best management practices for nitrogen" (Nutrien Ag Solutions, n.d.-a). Producers also need to record their outcomes in Nutrien's digital platform, Agrible. Agrible uses producers' field-level data to generate "predictive agronomic forecasts and sustainability metrics" (Nutrien Ag Solutions, n.d.-a) that translate into a cash incentive.

FWWF has heard from producers who say that the program is quite lucrative for them and that they have not needed to change any of their current practices to receive the incentives. This is consistent with the messaging heard in Nutrien's promotional video *Practices,* which states "we're here to help guide field-level practices to ensure growers are being recognized for what they're already doing" (Nutrien Ag Solutions, n.d.-b, 00:28).

However, there is no information on the program website about what specific nitrogen management BMPs should be adopted, nor on what specific outcome data will be collected from producers. This makes it unclear what BMPs are being adopted and what level of positive environmental impacts and climate mitigation are occurring because of the program.

6.0. Conclusions

6.1. Key Knowledge Gaps

There remain significant knowledge gaps related to regenerative agriculture in the Prairies that continue to create barriers to producer adoption. Table 2 highlights key knowledge gaps that fall loosely into several major categories:

- Universal terminology, definitions, and evaluation metrics
- Economics and markets
- Knowledge available to producersersal terminology, definitions, and evaluation metrics
- Agronomic research and post-secondary education
- Climate mitigation potential and carbon market potential

Table 2

Key Knowledge Gaps that Create Barriers to Prairie Producer Adoption of BMPs

Key Knowledge Gaps that Create Barriers to Prairie Producer Adoption of BMPs	
Universal terminology, definitions, and evaluation metrics	**-lack of universal definitions for BMPs and regenerative agriculture** **-lack of monitoring, reporting, and verification (MRV) system for BMP outcomes** -lack of objective metrics for efficacy and adoption of BMPs -lack of affordable and comprehensive soil health monitoring
Economics and markets	**-lack of farm level cost-benefit analyses for all BMPs and related agricultural practices in Prairie contexts** **-lack of clear economic value placed on off-farm benefits of BMPs** -lack of relevant and accessible markets for agricultural products
Knowledge available to producers	**-lack of local demonstrations of BMPs in Prairie contexts at farm scale** **-lack of agronomic protocols for BMPs in Prairie contexts** -lack of PAgs and CCAs knowledgeable on regenerative agriculture in the Prairies -lack of Prairie-specific regenerative agriculture technical knowledge and support for producers -numerous knowledge gaps specific to individual BMPs
Research and post-secondary education	**-lack of in-depth feasibility studies for BMPs in Prairie contexts** **-lack of agronomic research on BMPs in the Prairies** **-lack of producer-centered research on BMPs in Prairie contexts** -lack of quantitative research on cultural and structural barriers to adoption -gap between theoretical and practical regenerative agriculture education in post-secondary programs
Climate mitigation potential and carbon market potential	-uncertain climate mitigation potential of some practices -uncertainty around future of carbon market

Note. Bolded points should be considered the highest priorities.

Key Knowledge Gap 1: There are no universal definitions for regenerative agriculture or BMPs in Canada.

The lack of universal definitions is a key bottleneck in BMP adoption that contributes to all other barriers and knowledge gaps. Policies or programs to encourage BMP adoption are not always using the same language that Prairie producers use. Producers sometimes use terms that are misunderstood by researchers and government policymakers, and vice versa.

Without consistent language, tracking of BMP adoption levels and trends in Canada is challenging and inaccurate as there are no consistent tracking metrics to follow statistical trends in BMP adoption. Viresco's (2022) report on BMPs in Prairie agriculture emphasizes the lack of universal definitions for regenerative agriculture, and the importance of monitoring, quantifying, and tracking regenerative agriculture practices in Canada for more effective research and policy-making to promote adoption.

A measurement, reporting, and verification (MRV) system for tracking the outcomes of regenerative agriculture BMPs must be developed in conjunction with universal definitions and practice terminology. The lack of consistent MRV criteria for tracking BMP outcomes remains a major barrier to the paradigm shift towards regenerative agriculture (G. Singh Dhillon, personal communication, March 28, 2024). The phrase "you can't manage what you can't measure" is a reminder of how significant this language barrier is to the forward movement of regenerative agriculture.

Inconsistent language also introduces more variability into agronomic research. Agronomic research studies on BMPs are not always consistent with each other, nor with the typical agricultural practices of Prairie producers. There is enough heterogeneity in the treatments and interventions tested in agronomic research that it can be difficult to generalize findings or to perform a meta-analysis of the current literature. Achieving reliable findings from Prairie-based research on BMPs is made far more challenging by the lack of universal definitions for these practices (Viresco, 2022).

Productive forward movement in regenerative agriculture research and policy will continue to be held back by the lack of universal practice terminology and definitions for BMPs. As long as regenerative agriculture language in Canada continues to be inconsistent, adoption of BMPs will not reach its full potential.

Key Knowledge Gap 2: There is not enough information available for producers to know their estimated costs and revenue for BMP adoption. There is also not enough data available to accurately estimate the full value of ecosystem goods and services that BMPs contribute to society.

Economic and market-related knowledge gaps have possibly the greatest potential to address barriers to producer adoption of BMPs. Producers told us that costs and profitability are the greatest barriers to their adoption of BMPs and, as such, the lack of thorough cost-benefit analyses for all BMPs and related practices in Prairie agricultural contexts is likely the most significant knowledge gap. These analyses should include full cost accounting, cost/revenue per acre analysis, and quantification of the economic value of off-farm benefits of BMPs. Producers must be able to see their potential costs and potential revenue per acre for the adoption and implementation of each BMP.

Off-farm benefits to society include ecosystem goods and services, which are difficult to accurately quantify. They are typically undervalued due to a lack of data, or a lack of understanding of the full scope of benefits provided by nature, or the tendency to not consider the increasing value of these benefits over time (Nykoluk, 2013). Research that has attempted to estimate the value of ecosystem goods and services has consistently found that the non-market ecosystem benefits from conserved native areas are considerably greater than the market benefits of conversion (Nykoluk, 2013).

Benefit transfer (value transfer) is frequently used by researchers and policymakers to value non-market goods and services – this involves borrowing the values of specific goods and services from other published sources that are comparable in context. Literature that values non-market ecosystem goods and services in North American contexts is limited and thus valuations that use benefit transfer are also limited by the small base of available data (Kulshreshtha et al., 2015). Benefit transfer valuations also assume that values from one context are applicable to another context and do not adjust for important variables that could change values considerably, such as variations in socio-economic or biophysical factors (Lloyd-Smith et al., 2020). This is a significant limitation to consider in valuations calculated by benefit transfer.

The direct and indirect benefits to society from regenerative agriculture are enormous, however limited data and limited knowledge on ecosystem goods and services result in them being consistently undervalued; their true economic value remains uncertain. This has created a disconnect between the producers who shoulder the on-farm costs of BMPs and society, who enjoys positive impacts from the off-farm benefits. This is a major barrier to large-scale adoption of regenerative agriculture in the Prairies. Society must share the costs to BMP adoption and implementation at the farm level and producers must receive a fair portion of the tangible economic benefit.

"The farmer should not be burdened with the cost when everyone will benefit."

Ontario producer (Lamba et al., 2009, p.72)

Key Knowledge Gap 3: Prairie producers do not have access to enough knowledge or learning opportunities on how to implement BMPs on their farms, nor enough technical support from extension services or knowledgeable experts in regenerative agriculture.

Both literature findings and producer engagement responses consistently showed that producers trust other producers and that they desire to learn from other producers. Currently, Prairie producers do not have enough regenerative agriculture knowledge or learning opportunities available to them. Some of this stems from the gap in agronomic BMP research in Prairie agricultural contexts. Producers have asked FWWF *"how do I do this practice?"*, *"what* *species should I use?”*, or *“what is the protocol for this practice in my region?”* The answers are either inconsistent, inaccurate, or inaccessible to them. There are not enough optimal agronomic protocols for BMPs in the Prairies and there is likely an insufficient research base on which to develop these protocols.

Also important is the lack of local, observable BMP demonstration sites on the Prairies. Producers need to see the BMPs in practice, locally, at a farm scale that is relatable to them. They want to talk to the producers who have implemented these practices and learn from them. Conventional farmers who are curious about regenerative agriculture may be looking for observable evidence that these BMPs will work in the Canadian Prairie context, but if they search and find nothing, then we’ve missed an opportunity not only in this farmer, but in all of their producer peers who will hear that the information they need just is not out there.

“Conventional farmers are curious but want to see the evidence”

Prairie producer (FWWF, 2023a)

Key Knowledge Gap 4: There is not enough agronomic or economic research on BMPs in Prairie agricultural contexts.

There are research gaps in numerous areas that create barriers to adoption of regenerative agriculture. Many knowledge gaps and producer barriers arise from the lack of agronomic BMP research in Prairie contexts that can inform optimal BMP protocols for producers. This is a major knowledge gap that continues to restrict the advancement of regenerative agriculture in the Prairies.

Key Knowledge Gap 5: The greenhouse gas mitigation potential for some BMPs in the Prairies is still uncertain. There are also uncertainties about the long-term future of the carbon market.

Finally, there are still uncertainties in the climate mitigation potential of BMPs in the Prairies. Carbon sequestration in soils is difficult to measure accurately due to high spatial variability of soil carbon levels within a small area (Melkani et al., 2023). Modelling and estimations attempt to quantify the GHG mitigation potential of BMPs in Prairie agriculture, but these are limited by the underlying uncertainties and assumptions used in their calculations.

6.2. Opportunities For Further Research

Based on the knowledge gaps and limitations of previous engagement research, this section describes opportunities for future work to further the identification, documentation, and understanding of barriers to adoption of regenerative agriculture from a Prairie producer perspective.

Opportunity 1: Conduct engagement research with conventional Prairie producers to more accurately identify BMP adoption barriers relevant to non-regenerative producers.

FWWF producer engagement research has provided immensely valuable insights on adoption barriers from regenerative Prairie producers. However, as is common with qualitative exploratory research, the findings are subject to biases arising from the selection of study participants. Producers interviewed in the engagement sessions either self-selected or were recruited by convenience sampling or purposive sampling, resulting in a sample that over-represents regenerative-minded producers. This introduces both volunteer bias and selection bias to the findings. Thus, the collected producer responses reveal barriers to adoption in regenerative Prairie producers that are not necessarily generalizable to the greater population of conventional Prairie producers.

Qualitative findings are typically not broadly generalizable nor is generalizability the desired objective of qualitative research. Still, there may be important differences between the barriers affecting conventional producers' adoption of regenerative agriculture and barriers affecting regenerative producers. Producers who consider themselves to be regenerative producers, or regenerative-minded, or are transitioning from conventional to regenerative agriculture, make up a small portion of the greater producer population in the Prairies. With the ultimate goal of large-scale adoption of regenerative agriculture as a new production paradigm, the barriers that apply to conventional producers, who make up the vast majority of the Prairie producer population, must be well understood and documented.

Framing of the subject matter in producer engagement must be carefully considered. Producers in FWWF engagement sessions were clear that the approach to communication is very important to avoid being judgmental or dismissive of conventional producers. Terms like "climate change" or "regenerative agriculture" in survey questions targeting conventional Prairie producers could evoke a negative reaction in some participants and result in them abandoning the survey before it is completed.

Opportunity 2: Support the development of participatory, producer-centered research studies that explore Prairie producers' perspectives on:

- **Barriers to adoption of regenerative agriculture BMPs**
- **Policies and programs to promote adoption of regenerative agriculture**
- **Agronomic research on BMPs in the Prairies**

Not enough Prairie BMP research has been conducted from a producer-centered approach. Using a participatory approach will include producers in the development of the research study and allow researchers to better understand producer perspectives on regenerative agriculture. This is especially important to ensure that BMPs are studied in a way that is consistent with the typical practices and terminology of Prairie producers and applicable to farm scale.

A participatory or user-centered approach to research will generate results that more accurately describe producer barriers. Particularly important is the need for feedback loops between producers and researchers – there must be channels for producers to share their field experiences with researchers who can then make appropriate modifications to research through the development process (FWWF, 2023b).

Producer-centered, participatory research will identify and document producer perspectives, promote connections and learning between producers and researchers, and will reduce the disconnect between BMP terminology and practices used in research studies and those used by producers at the farm level. Further regenerative agriculture research in the Prairies will only be effective if the research aligns with the everyday realities of how Prairie producers operate their farms.

Opportunity 3: Continue producer engagement sessions with regenerative and transitional producers to uncover barriers to producer adoption specific to Prairie regions.

Producer engagement sessions should continue, as they consistently reveal important barriers that are relevant to producers in the Prairies, sometimes including regionally-specific barriers that are easily missed in a literature scan. Indeed, a single conversation between producers and FWWF revealed that elk are a major barrier to the adoption of extended grazing practices in the Peace region of Alberta, which is an insight that failed to emerge through months of review of regenerative agriculture literature.

Engagement with producers through in-person or online channels must continue with prompts or questions designed to dig deeper to uncover specific barriers. Giving producers regular opportunities to share their perspectives will allow some of the more hidden barriers to emerge. Producer engagement, whether in-person or online, should allow for qualitative responses to ensure the most authentic and accurate information is collected. Some questions that regenerative producers could be asked in future engagement research include:

- What factors do you consider when deciding whether or not to try a new idea, method, technique, or technology on your farm?
- Do you feel that you, the producer, would receive enough benefits from BMPs to justify the costs, time, and work that you would need to put into adoption and implementation?

- Do you feel that any general groups are holding back the large-scale adoption of regenerative agriculture? (ex: conventional producers, politicians, agri-food industry, and corporations, etc.)
- What gaps in local or regional infrastructure are limiting the advancement of regenerative agriculture in the Prairies?
    - Gaps in community networks?
    - Gaps in support, financial or otherwise?
- What BMPs have you adopted or tried to adopt, but then abandoned after a short time? What are the reasons you abandoned this practice?
- In order of priority, how would you rank the barriers you are experiencing?
- How should policies or programs be designed to most effectively address barriers and encourage producer adoption of BMPs?

Opportunity 4: Engage with Prairie producers to determine how regenerative agriculture incentives, policies, and programs should be designed, developed, and delivered to effectively meet producers' needs.

A key area worthy of deeper research is on producers' perspectives on the design and implementation of regenerative agriculture interventions. A study on adaptive capacity in Saskatchewan producers noted that agri-environmental initiatives developed without producer input can create further barriers as they fail to consider important local needs and may generate skepticism or distrust in their target audience (Hurlbert, 2014). Producers in this study were clear about their distrust of government and top-down environmental programs, and many producers "expressed a sense of alienation or disconnectedness from [provincial and federal] levels of government" (p.154). Equally clear was the producers' preference for programs that are developed with local producers, tailored to local needs and conditions, and delivered locally by non-governmental organizations such as watershed groups or the Provincial Council of Agriculture Development and Diversification Boards for Saskatchewan (PCAB).

Opportunity 5: Support research that uncovers macro level barriers to producer adoption of regenerative agriculture that are not always visible from the producers' perspective.

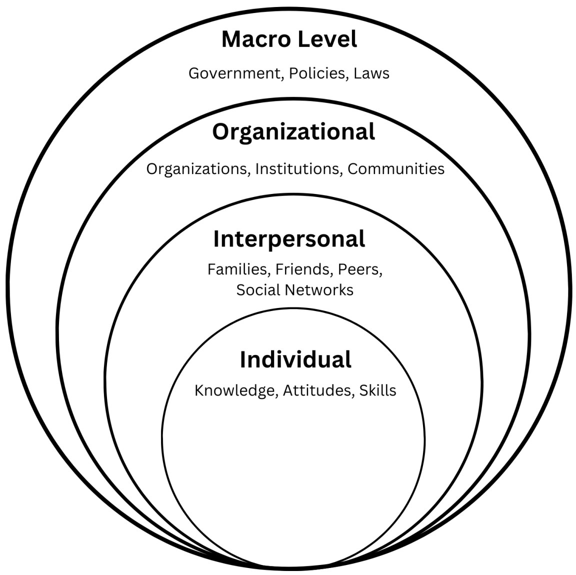
Producers' perspectives on barriers should be prioritized as they are critical to correctly defining the barriers that producers experience in the adoption of regenerative agriculture. Focusing exclusively on producers' perspectives, however, limits our understanding of the full spectrum of barriers that directly or indirectly affect producers' capacity to adopt.

Ecological models of behavioural change are based on the belief that an individual is influenced by, and interacts with, different levels of their societal environment, as seen in Figure 2. These models propose that (Salmon et al., 2020):

- There are multiple levels of influence that act on peoples' behaviour
- There are interactions between and across different levels of society
- Interventions that intend to promote change should target as many levels as possible

Figure 2

Socio-Ecological Framework of Levels of Influence on Individuals' Behaviour



Note. An ecological framework that depicts how multiple levels of influence act on an individual's behaviour as well as how an individual exists within multiple contextual levels. Adapted from Lee, B. C., Bendixsen, C. G., Liebman, A. K., & Gallagher, S. (2017). Using the socio-ecological model to frame agricultural safety and health interventions. *Journal of Agromedicine, 22*(4), 298-303. Copyright 2017 by Taylor & Francis. https://doi.org/10.1080/1059924X.2017.1356780

As such, factors at the organizational and governmental levels can act as barriers to producers, including inappropriate policies, a lack of understanding of local agricultural contexts, a lack of decision-making authority, regulatory barriers, political disputes, organizations' lack of capacity, and interorganizational conflicts. As these barriers occur within the structures and systems of society, the specifics are not always visible to producers. Producers are sometimes, but not always, aware of the details that create barriers at this level and, thus, these barriers may be underreported in producer engagement research.

Macro level barriers act as significant barriers to producer adoption of wetland conservation and restoration programs in Alberta, as was seen in the section on wetlands. Clare and Creed (2022) described political disputes, interorganizational conflicts, regulatory barriers, and a lack of decision-making authority all presented considerable barriers to producers' ability to adopt a wetland restoration project. However, these factors are so far removed from the farm level that they may be nearly invisible to producers who are not pursuing wetland restoration, and possibly not even fully visible to those who are.

Although a formal research study on macro level barriers that interfere with producers' ability to adopt BMPs in the Prairies would be especially impactful, a literature scan would be more feasible and would still provide useful findings on a shorter timeline.

Opportunity 6: Interface with existing soil and climate mapping initiatives of the three Prairie provinces to integrate producer-reported barriers to BMP adoption in a spatially explicit way.

Producer responses on barriers collected through FWWF engagement can be plotted on a GIS map to align with local and regional conditions of weather, climate, soil, and moisture, along with other relevant biophysical factors such as wildlife populations and growing season length. The integration of qualitative and quantitative data on the map will allow us to visualize how barriers align with local conditions and local ecological contexts, and to identify relevant patterns. Integrated data presented in this format will enable future programs, policies, and other initiatives to be more effectively targeted to local producer needs and agricultural contexts.

Opportunity 7: Conduct retrospective research on the adoption of reduced tillage practices in the Prairies to uncover key insights that could be applied to the adoption of regenerative agriculture on a large scale.

The adoption and diffusion of reduced tillage practices in the Prairies provides a case study which can be carefully examined to reveal key insights that may be beneficial to the widespread adoption of regenerative agriculture.

A major paradigm shift occurred in the Prairies' transition from conventional tillage to reduced- and zero-tillage as the agricultural norm. Awada et al. (2014) noted that local social connections between early adopters and their producer peers contributed significantly to the paradigm shift away from tillage as a necessary practice and increased adoption of reduced tillage throughout the Prairies. The process through which early adopters and local peer networks contributed to this major paradigm shift could be used as a model for establishing a similar social network in regenerative agriculture.

Numerous structural barriers initially prevented widespread uptake of reduced tillage, but were addressed through policy and market changes, the social influence of early adopters, and through new innovations at accessible costs to producers. An in-depth review of the history of reduced tillage adoption on the Prairies would reveal key drivers that could inform a framework through which widespread adoption of regenerative agriculture could be achieved.

6.3. Recommendations For Strategies To Address Producer Barriers

Based on Prairie producers' perspectives on the most critical adoption barriers, this section presents recommendations for strategies and initiatives that will be the most impactful in addressing barriers and increasing producers' capacity to adopt regenerative agriculture.

Recommendation 1: Advocate for the development of producer accepted definitions and outcomes-based monitoring, reporting, and verification (MRV) system for regenerative agriculture BMPs in Canada.

Prairie producers and industry stakeholders agree on this language and definition barrier. In engagement sessions, participants stated repeatedly that Canada needs clear and universal definitions of regenerative agriculture and BMPs, and consistent language to define the field of regenerative agriculture (FWWF, 2021; FWWF, 2023b).

Key stakeholders in Canadian regenerative agriculture, including producers, non-profit organizations, academics, research institutions, and the agri-food industry, together can pressure Canadian governments to collaborate with them to formally define regenerative agriculture and associated BMPs. Establishing universal definitions and practice terminology that are agreed upon by researchers, policymakers, and producers will be an important step to developing clear, effectively targeted policies and programs that address producer barriers and increase adoption.

Universal definitions in regenerative agriculture could drive BMP adoption in Canada. Clearly defined BMPs will lead to less variability of interventions tested in agronomic research. More consistent results from Prairie-specific agronomic research can then inform optimal agronomic protocols for BMPs in Prairie agricultural contexts. These protocols can then be used to create more accurate cost-benefit analyses of BMPs in Prairie contexts. Finally, cost-benefit analyses can inform more effective policies, programs, and financial incentives that meet producers' needs and compensate them fairly for their expenses, driving widespread BMP adoption in the Prairies.

Recommendation 2: Invest in thorough cost-benefit analyses of BMPs in Prairie agro-climatic contexts to allow accurate estimations of costs and benefits to Prairie producers.

Producers stated repeatedly that the economics of a practice are often the greatest barrier to its adoption. They must know the costs they will incur; they must know the benefits they will receive, and they must be assured of its profitability. Proof of profitability for BMPs in our agricultural contexts will be necessary to persuade producers who are not intrinsically motivated to farm in a more regenerative way. Accurate calculations of producers' costs to adopt BMPs can inform more effective financial incentives that will compensate producers fairly and encourage large-scale adoption on the Prairies.

"[Need a] clear cost vs. benefit rationale – if it pays people will do it"

Prairie producer (FWWF, 2023a)

A cost-benefit analysis (CBA) is one way to estimate profitability, however there are some important limitations that should be considered. Environmental and social benefits such as ecosystem services and community climate resilience are difficult to quantify. Cost-benefit analyses tend to overestimate costs and underestimate benefits to a household or corporate entity (Monahan et al., 2018; Samson, 2021). Especially in the context of climate adaptation or mitigation strategies, costs are sometimes overestimated "by at least double, and sometimes by a factor of 10 or more" (Monahan et al., 2018, p.1), and some suggest that a risk-opportunity analysis is a more appropriate tool for climate change adaptation (Samson, 2021).

A cost-benefit analysis for a BMP must be based on a defined practice within a specific context of soil, moisture, and weather conditions, production type, and production scale, and, thus, a CBA is only as accurate as the agronomic practices and conditions on which its calculations are based. There are, however, a wide range of variables and farm-level conditions of climate, weather, soil, and moisture levels that dictate how producers practice BMPs in the Prairies. Thus, the cost estimation from such an analysis may be inconsistent with the actual costs of adoption and implementation for producers whose farms and practices differ from those studied.

Moreover, cost-benefit analyses will estimate the costs and benefits producers can expect from BMP adoption but do not consider other factors relevant to producers such as the ease of adopting a practice. Feasibility studies can evaluate the economics of implementation, as well as consider important human factors, including the learning and knowledge producers require, ease of adoption from the producers' perspective, availability of needed inputs, and relevant local conditions or socio-cultural barriers.

Finally, as many uncertainties remain in the actual GHGE mitigation potential of many BMPs in Prairie contexts, valuation of the full range of off-farm benefits from BMP adoption is challenging. Drever et al.'s (2021a) extensive work on cost and benefit estimates from natural climate solutions (NCS) has provided some estimated GHGE mitigation values that could be used in a CBA. There are, however, limitations to these estimated values. The authors did not account for temporal variations in the amounts of CO_2 emissions and removals through land and oceans. They also state that the "actual mitigation potential may be even higher than what we estimated, given that there are additional actions within NCS pathways that we excluded because of limited data or high uncertainty" (Drever et al., 2021a, p. 8).

Recommendation 3: Support and advocate for the development of producer-led regenerative system demonstration sites to be located throughout the Prairies.

Demonstration farms played a pivotal role in the widespread adoption of reduced tillage practices in the Prairies and have the potential to be just as important in the adoption and diffusion of regenerative agriculture. These sites provided observable learning opportunities where Prairie producers could see that reduced tillage practices worked at the farm scale and in a local context. Once they saw how the practice worked, and that it was profitable, adoption of reduced and zero tillage spread quickly across the Prairies.

"I don't know enough to try it (and would like to talk with people who have done it successfully)"

RALL producer considering intercropping (RALL, 2023b)

With support and collaboration, regenerative agriculture demonstration farms could be developed as a joint corporate-government initiative to promote large-scale adoption by Prairie producers. Allowing these farms to be open to the general public would contribute to greater acceptance and understanding of regenerative agriculture and could help in the paradigm shift away from conventional agriculture. These farms would not only provide valuable opportunities for observational learning, they would also address numerous barriers to BMP adoption and meet several needs that producers shared with us including:

- Encourage knowledge-sharing between peers which builds trust in their community; this trust acts as a driver of BMP adoption in producers (Ranjan et al., 2019)
- Provide observable learning opportunities on how to implement BMPs in the Prairies that answer questions like "How is it done?" and "What species should I use?"
- Allow regenerative producers to tell their stories about adopting BMPs
- Provide a place for producers to connect with like-minded peers to encourage community-building, peer support, and peer-to-peer learning
- Connect producers with knowledgeable mentors
- Provide a pathway for regenerative agriculture advice that is not linked to sales representatives or retail products
- Reduce social isolation experienced by those who go against farming norms
- Reduce stigma and misinformation around alternative agricultural practices by being open to the general public for touring and learning
- Encourage experiential learning as producers may feel confident enough to try a BMP on a smaller scale on their own farm

Demonstration sites can also act as a pathway for the collection of data on soil health, crop yield, and carbon sequestration, as well as qualitative insights from producers involved, that can further contribute to the GIS map referred to in Recommendation 6.

The importance of observable and experiential learning opportunities for producers should not be underestimated. Rogers' Model of the Innovation-Decision Process notes five important characteristics that people consider before adopting innovations: Compatibility, Trialability, Relative Advantage, Observability, and Simplicity/Complexity (Rogers, 2003). According to Rogers' theory, innovations will be adopted more quickly if they meet these five characteristics (Sahin, 2006). Observability and Trialability, in particular, align with the needs we heard from producers through FWWF (2021) engagement. Indeed, trialability was mentioned in producer engagement sessions as a key factor in increasing adoption.

"The key for regen is to not get too narrow, and [to] allow more people to try it without changing or committing the whole operation"

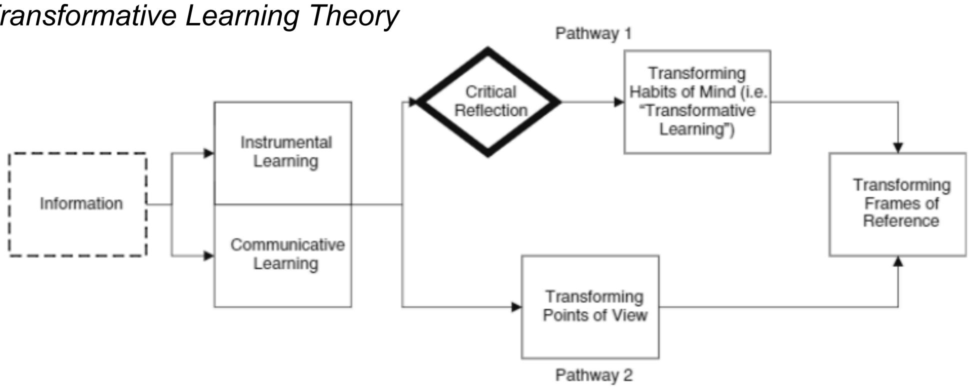
Industry stakeholder (FWWF, 2023a)

Observability is particularly critical to farmers' learning processes. Alberta and Manitoba producers told researchers (Tarnoczi & Berkes, 2009) that observable and experiential knowledge was essential for learning about BMPs that could be implemented on their own farms. The authors also noted that producers were "more open to new practices when they could learn them through observation, trials, and two-way dialogue" (p. 299). Finally, an important point noted by the authors of this study is that learning about soil and water conservation practices through observation and experimentation appeared to reduce producers' perceived economic risk of adopting the practices. Although it would be inappropriate to generalize this statement to the broader Prairie producer population, it does highlight how influential these demonstration learning opportunities can be.

Tarnoczi (2011) studied how Prairie producers learn about climate adaptation practices and concluded that new information was most likely to lead to adaptation and transformative learning when it was gained through observable and experiential learning opportunities such as observing neighbours, crop tours, and conservation group demonstrations. Importantly, he found that some producers who learned about BMPs through observation and from peers began to question conventional farming norms and their own personal beliefs or assumptions on conventional farming. This aligns with the Transformative Learning Theory seen in Figure 3, which suggests that critical reflection on social norms and personal beliefs is an important step towards transformative learning (Tarnoczi, 2011).

Figure 3

Transformative Learning Theory



Note: Adapted from Tarnoczi, T. (2011). Transformative learning and adaptation to climate change in the Canadian Prairie agro-ecosystem. *Mitigation and Adaptation Strategies for Global Change, 16*, 387-406. https://doi.org/10.1007/s11027-010-9265-7. Copyright 2010 by Springer Science+Business Media B.V.

Recommendation 4: Facilitate and amplify a storytelling and data-sharing pathway that allows regenerative producers to tell their stories and share them with their neighbours, the agriculture industry, and the general public.

Through the Regenerative Alberta Living Lab program (RALL), producers have shared the areas in which they need help to address barriers to adoption. In one roundtable discussion (RALL, 2023a), storytelling was mentioned repeatedly by producers, as seen here in responses to the question "What do you want help with?":

- *"how to help tell our story to others in the industry to find support instead of criticism"*
- *"more people to tell our story and support us as we try the 'crazy' things"*
- *"telling our story, having the data to back the benefits of BMPs/regen agriculture, showing how we are making a difference and improvements (both to consumers and to naysaying neighbours)"*
- *"ability to tell our stories and have a positive effect on public perception"*

They want to share their regenerative agriculture stories with their conventional producer neighbours, with producers across the Prairies, and with the general public. Numerous comments related to storytelling reveal how important this is to regenerative producers and how much potential this pathway carries for knowledge-sharing not only with other producers but also with the entire agriculture industry and the public in general.

These same producers also mentioned themes of isolation, being criticized, and perceived as "crazy" because their practices go against farming norms, and of needing to find support not only from peers, but also from consumers, the agriculture industry, and the general public. Being able to share their stories publicly would help regenerative producers connect with like-minded peers, explain their operations to their neighbours, reduce the stigma and misunderstandings around regenerative agriculture, and show others that these practices are bringing significant benefits to producers at the farm level.

Recommendation 5: Support Prairie producers' involvement in the development and delivery of regenerative agriculture programs that are tailored to local conditions and considerations and are based on a peer-to-peer model.

Agri-environmental initiatives developed without producer input can create further barriers as they fail to consider important local needs and may generate skepticism or distrust in their target audience (Hurlbert, 2014). Producers' distrust and skepticism towards government agencies and government programs was consistent through producer engagement and literature (FWWF, 2021; FWWF, 2023a; Hurlbert, 2014; Lamba et al., 2009). Hurlbert (2014) also noted that Saskatchewan producers felt alienated or disconnected from government and were very skeptical that provincial and federal governments were listening to their needs.

Lamba et al. (2009) suggest that trust between farmers and conservation stakeholders (government, academic, or NGO representatives) must precede successful adoption of BMPs. For farmers to trust government agencies and BMP funding programs, they must feel that the agents are intent on creating a reciprocal relationship and are committed to supporting farmers through BMP adoption and implementation (Lamba et al., 2009).

Still, there is optimism that funding programs developed by producers to meet producer needs and delivered by a trusted local organization could be instrumental in addressing economic and other barriers to BMP adoption in the Prairies. The success of such programs is determined in part by how effectively they meet producers' needs and how much trust producers hold in the program itself and the agency through which it is delivered.

Hurlbert's (2014) Saskatchewan study compared two agri-environmental initiatives meant to build producers' climate resilience and their distinct models of program development and delivery. The Farm Stewardship Program was meant to consider producers' input and allow for necessary changes to meet producers' needs, however decisions on program changes were made by provincial and federal governments, not by producers. Some individuals involved with the program reported that in reality, producers' input was rarely considered by government decision-makers and would not result in any program changes. Moreover, one participant stated that "the government employees were not even allowed to talk to the producers" (p. 153).

Conversely, the Water Infrastructure Program was led and initiated by local producers who developed and refined the program with support from provincial and federal governments (Hurlbert, 2014). Program development was an iterative process that considered producers' input and was led by producers, with frequent evaluation and revision to ensure needs were met. Once stakeholders were satisfied that the program was effective, it was passed on to the provincial government to administer, with continued audits on a yearly basis by all key stakeholders. The program has been very well received by producers. All producers interviewed by Hurlbert (2014) supported the program and wanted it to continue, and notably "not one producer expressed the sentiment that the Water Infrastructure Program was not useful" (p. 153). Overall, producers and key policy stakeholders all agreed that the program is responsive to the public's needs.

Producers in the study (Hurlbert, 2014) expressed a clear preference for programs that are developed with local producers, tailored to local needs and conditions, and delivered locally by non-governmental organizations. Local delivery of programs allows for (Hurlbert, 2014):

- More responsiveness – programs can respond more quickly to producers' needs and to local climate events
- More flexibility – programs can be changed more easily to meet changing needs or environmental factors
- Faster timelines and processing of claims
- Circumvention of the skepticism and distrust of government

Through consultation and public engagement, local producers should be involved in every stage of program planning, from the needs assessment to the evaluation stage. When programs are implemented with no or minimal public involvement, producers are more likely to be skeptical and believe the program does not meet their needs (Hurlbert, 2014).

"Regen ag people need to work together to unite & capitalize on synergies"

Prairie producer (FWWF, 2023a)

Local groups of producers need support to initiate and develop programs that will address barriers to BMP adoption while still meeting the needs of local producers. To promote large-scale BMP adoption through the Prairies, funding programs must earn producers' trust, be largely producer-led, and be delivered locally.

Recommendation 6: Support efforts to build cost-effective and efficient soil health monitoring and comprehensive soil testing and mapping tools that are accessible to Prairie producers.

Current data collection, monitoring, and soil testing methods are often inefficient or expensive. Producers may be reluctant to collect data or use soil health monitoring if they cannot see any clear benefit to themselves.

Standard soil testing is often insufficient to detect the full range of soil health metrics producers need to see. Comprehensive soil testing is available but is quite expensive, and thus remains inaccessible to producers and is rarely used on Prairie farms (Viresco, 2022). A RALL producer discussed their struggles to introduce new perennials into an established forage stand and how comprehensive soil testing would have helped them problem-solve the process more quickly, stating *“normal soil testing is not finding the issue, [need] comprehensive testing”* (RALL, 2023b).

With more efficient and affordable data collection and monitoring methods, producers could gain more specific information on their farm’s soil and vegetation conditions that could drive more targeted adoption of BMPs (Viresco, 2022). In addition, effective monitoring would quantify a BMP’s GHGE mitigation impact at the farm level and allow the producer to access the carbon market.

Accurate monitoring of BMP adoption would provide valuable information to policymakers and investors that would allow the creation of more effective policy instruments and funding programs to drive further adoption of regenerative agriculture practices (Viresco, 2022).

6.4. Closing

This report presents an in-depth synthesis of a decade of producer engagement research by FWWF with findings from a scan of current literature on BMPs in Prairie agricultural contexts. Producers’ perspectives are prioritized and aligned with literature findings to identify and discuss barriers to the adoption of regenerative agriculture. Barriers to adoption are explored both in the context of whole-system regenerative agriculture and in the context of individual BMPs.

Key knowledge gaps that create barriers to producer adoption of BMPs are highlighted. These knowledge gaps inform two robust sections to guide future direction: opportunities for further research to identify barriers and recommendations for strategies to address barriers and drive adoption. This report itself fills a knowledge gap related to the identification of barriers to adoption from the perspectives of Prairie producers and in Prairie-specific agricultural contexts.

Moving forward, findings from this report can inform Prairie-specific research that more effectively describe barriers to producer adoption of BMPs as well as policies and initiatives that more appropriately address producer barriers, meet producers’ needs, and motivate adoption of BMPs. With Nature United’s support, this work contributes to the growing knowledge base on regenerative agriculture in the Canadian Prairies.

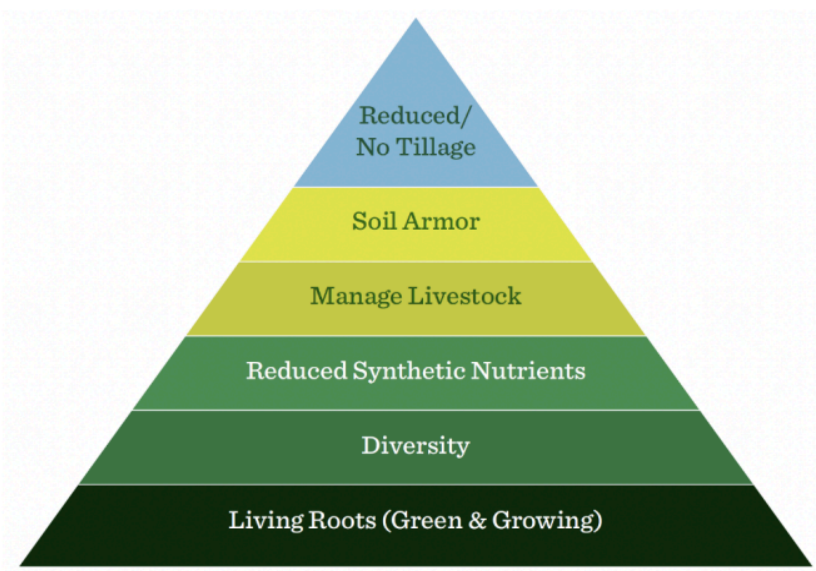
Appendix A – Regenerative Agriculture Soil Principles

Appendix A presents the soil principles of regenerative agriculture, featured in the *Trusted Advisors in the Canadian Prairies* (FWWF, 2023b) report and originally from the Resources section of the Regenerative Alberta Living Lab website:
https://www.regenlivinglab.org/resources

We are taking a whole-systems approach that recognizes the link between plants and soil. This guides agricultural practices with the goal of optimizing soil health to improve the nutritive quality of food, help to manage water, control pests and diseases, and build resilience against climatic uncertainty, as opposed to studying a set list of individual BMPs.

Regenerative agriculture is not synonymous with soil conservation. Although many of the same Beneficial Management Practices (BMPs) may form part of the approach to achieve 'regeneration' of the soil, in isolation they will not achieve regenerative soil goals.

The following graphic of a regenerative soil pyramid illustrates how all principles must be integrated to maintain the structure and integrity of the soil. As with the structure and integrity of a pyramid, all layers are integral. If we look to regenerative agriculture as a climate solution, all elements must be incorporated to have the maximum climate mitigation effect and serve to 'regenerate' or 'recarbonize' the soil through carbon sequestration.



Principle 1 – Living Roots (Green & Growing)

Maintaining living roots for as many days of the year as possible enables plants to allocate photosynthetically derived carbon to the microbial community. This soil carbon sequestration process mitigates climate change while helping crops to thrive under climatic uncertainty. Improved soil carbon increases or improves biological activity, water infiltration, soil structure, natural fertility, adsorption of pesticides and reduces soil erosion and compaction.

BMPs include:

- Cover cropping
- Crop rotation, including integration of pulses and small grains
- Relay/poly/intercropping
- Perennials in annual production
- Annuals in pasture for cattle feeding strategies
- Strategies for marginal land and wetlands (including prairie potholes); riparian tree planting
- Shelterbelts

Principle 2 – Diversity

Diversifying and lengthening crop rotations, using carefully chosen cover crops and compost adds diversity to soil. Different plants allow for longer periods of time in the year when carbon can be allocated below ground to increase carbon sequestration and support a diverse microbial community that plays a significant role in making nutrients available to plants and in soil carbon sequestration.

BMPs include:

- Annuals in perennial systems
- Perennials in annual systems
- Diverse crop rotations that include, for example, combinations of grains, legumes, oilseeds

Principle 3 – Reduced Synthetic Nutrients

Optimizing soil organisms (especially mycorrhizal fungi) is critical for regeneration of soil due to the role that mycorrhizal fungus plays in making nutrients available to plants and stabilizing carbon in soil aggregates. The application of soluble phosphorus fertilizer removes the need for a symbiotic relationship between plants and mycorrhizae. It is not possible to regenerate soil to its full potential when using conventional rates of synthetic fertilizers.

BMPs include:

- Strategies to increase biological nutrient cycling
- Incorporate more compost/manure

Principle 4 – Manage Livestock

Managing livestock and grazing patterns benefit the soil through increased organic matter, rejuvenation of microorganisms, and restoration of water cycles leading to an exponential increase in the land's ability to sequester carbon. Animals of all types and sizes, including insects, play a crucial role in regenerative agriculture - grasslands evolved out of a symbiotic relationship with large, grazing herbivores.

BMPs include:

- Animal integration with cropping
- Integrate animals into cropping systems (for example post-harvest or swath grazing)
- Adaptive planned grazing strategies
- Agroforestry
- Alley grazing

Principle 5 – Soil Armour

Crop residue, living plants, mulches, and/or compost on the soil surface are valuable sources of armour or protection, helping to avoid carbon loss from soil.

BMPs include:

- Maintain soil cover, cover cropping
- Mulching
- Compost
- Increased litter, trash, chaff left on field after harvest
- Perennials
- Relay/poly/inter cropping
- Cover cropping

Principle 6 – Reduced/No Tillage

Tilling causes the fungal network to be broken up and moves the organic matter that adds richness to the soil to the surface, where the soil carbon is released into the atmosphere.

Minimal tillage keeps soils covered, holding carbon in the soil rather than releasing it into the atmosphere.
BMPs include:

- Reduce frequency of tillage and minimize soil disturbance
- Minimum tillage/no-till cropping
- Use of tools (roller crimper and/or high residue cultivator)

Appendix B – Producer Barriers by Individual BMP *See page 173 for note

	Economic Barriers											
	Cost & Availability of seed	Availability of product	Uncertainty of economic benefit	Cost of increased labour	Cost of production	Cost of increased time spent on the practice	Cost & Availability of additional equipment or custom contractor	Cost of increased processing (seed cleaning, separation)	Lack of market acceptance or low value at market	Market availability (physically accessible and relevant to their product)	Crop insurance	More waste material to dispose of, cost & time to dispose
Cover Cropping	Y		Y	Y	Y	Y	Y				Y	Y
Cocktail cover crops	Y		Y	Y	Y	Y	Y				Y	Y
Fall seeded cover crops	Y		Y	Y	Y	Y	Y					
Fall seeded cash crops	Y		Y	Y	Y	Y			Y	Y		
Intercropping	Y		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Polycropping	Y		Y	Depends on complexity	Y	Y	Y	Depends on complexity	Y	Y	Y	Depends on complexity
Crop rotation diversity	Y		Y	Depends on complexity	Y	Y	Y	Depends on complexity	Y	Y	Y	Y
Relay cropping	Y		Y	Depends on complexity	Y	Y	Y	Depends on complexity	Y		Y	Y
Increased legume & pulse crops			Y				Y			Y		
Short-term rotation of annual crops with perennial forages			Y	Y	Y	Y	Y					
Annual crops seeded into existing perennial forages			Y	Y	Y	Y	Y				Y	
Short-term rotation of perennial forages with annual crops	Y		Y	Y	Y	Y	Y			Y	Y	
Improved Nutrient Management												
4R Nutrient Stewardship			Y	Y	Y	Y	Y					
Variable Rate Nutrient Application			Y	Y	Y	Y	Y					
Stabilizer		Y	Y		Y							
Foliar fertilization			Y									
Organic Soil Amendments											Possible	
Manure management		Y	Y	Y	Y	Y	Y					
Compost		Y	Y	Y	Y	Y	Y					

	Economic Barriers (continued)											
	Cost & Availability of seed	Availability of product	Uncertainty of economic benefit	Cost of increased labour	Cost of production	Cost of increased time spent on the practice	Cost & Availability of additional equipment or custom contractor	Cost of increased processing (seed cleaning, separation)	Lack of market acceptance or low value at market	Market availability (physically accessible and relevant to their product)	Crop insurance	More waste material to dispose of, cost & time to dispose
Green manure			Y	Y	Y	Y					Y	Y
Roller crimper			Y	Y	Y	Y	Y					
Humic & fulvic acid amendments		Y	Y	Y	Y	Y	Y				Possible	
Biochar		Y	Y	Y	Y	Y	Y				Possible	
Legumes in pastures	Y		Y	Y	Y	Y	Y					
Integrated Crop-Livestock systems			Y	Y	Y	Y	Y					
Bale grazing		Y	Y	Y		Y					Y	Y
Swath grazing			Y	Y	Y	Y					Y	Y
Bunch grazing			Y				Y					Y
Rotational grazing			Y	Y	Y	Y	Y					
Adaptive multi-paddock grazing			Y	Y	Y	Y	Y					
Reduced Tillage			Y	Y	Y	Y	Y					Y
Crop Residue Management			Y	Y	Y	Y	Y					Y
Maximized crop residue			Y	Y	Y	Y	Y					Y
Crop residue bioenergy			Y	Y	Y	Y	Y			Y		
Reduced burning of crop residue			Y	Y	Y	Y	Y					Y
Grazing residue			Y	Y		Y						Y
Strategic tillage												
Vertical tillage			Y	Y		Y	Y					
Deep tillage					Y		Y					
Subsoiling			Y	Y		Y	Y					
Agroforestry			Y									
Alley cropping/tree-based intercropping			Y	Y	Y	Y	Y			Y	Y	
Silvopasture			Y		Y	Y	Y			Y	Y	
Avoided conversion of shelterbelts			Y	Y	Y	Y				Y	Y	

	Economic Barriers (continued)											
	Cost & Availability of seed	Availability of product	Uncertainty of economic benefit	Cost of increased labour	Cost of production	Cost of increased time spent on the practice	Cost & Availability of additional equipment or custom contractor	Cost of increased processing (seed cleaning, separation)	Lack of market acceptance or low value at market	Market availability (physically accessible and relevant to their product)	Crop insurance	More waste material to dispose of, cost & time to dispose
Reduced deforestation to agriculture			Y		Y	Y				Y	Y	
Land conservation and restoration												
Avoided conversion of grassland, hayland and pasture			Y	Y	Y	Y					Y	
Riparian grassland restoration	Y		Y	Y	Y	Y	Y				Y	
Riparian vegetation restoration	Y		Y	Y	Y	Y	Y				Y	
Wetland conservation and restoration	Y		Y	Y	Y	Y	Y				Y	
Conversion of marginal cropland to permanent cover	Y		Y	Y	Y	Y	Y				Y	
Organic agriculture systems			Y	Y	Y	Y	Y		Y	Y	Y	

	Agronomic Barriers											
	Protocol for my region, soil type, weather conditions (includes "How do I do this practice?")	What species will work in my region, soil type, weather conditions	Drought, flooding, erosion, extreme weather events	Insects	Risk of plant diseases	Unknown fertilizer requirements or application rate	Weed Control	Crop Maturity and Harvestability (crops being mature at the same time, cannot harvest when too wet or green)	Uncertainty of soil health or ecological benefit	More waste material to dispose of	Timing conflict for labour	Timing conflict for equipment
Cover Cropping	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y	Y
Cocktail cover crops	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y	Y
Fall seeded cover crops	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y	Y
Fall seeded cash crops	Y	Y	Y		Y	Y	Y		Y		Y	Y
Intercropping	Y	Y	Y	Depends on species grown	Depends on species grown	Y	Y	Y	Y	Y	Y	Y
Polycropping	Y	Y	Y	Depends on species grown	Depends on species grown	Y	Y	Y	Y	Y	Y	Y

	Agronomic Barriers (continued)											
	Protocol for my region, soil type, weather conditions (includes "How do I do this practice?")	What species will work in my region, soil type, weather conditions	Drought, flooding, erosion, extreme weather events	Insects	Risk of plant diseases	Unknown fertilizer requirements or application rate	Weed Control	Crop Maturity and Harvestability (crops being mature at the same time, cannot harvest when too wet or green)	Uncertainty of soil health or ecological benefit	More waste material to dispose of	Timing conflict for labour	Timing conflict for equipment
Crop rotation diversity	Y	Y	Y	Y	Y	Y	Y				Y	Y
Relay cropping	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Increased legume & pulse crops	Y	Y	Y	Y	Y	Y	Y		Y			
Short-term rotation of annual crops with perennial forages	Y	Y	Y			Y			Y		Y	Y
Annual crops seeded into existing perennial forages	Y	Y	Y			Y			Y		Y	Y
Short-term rotation of perennial forages with annual crops	Y	Y	Y			Y	Y		Y		Y	Y
Improved Nutrient Management												
4R Nutrient Stewardship	Y		Y			Y			Y		Y	Y
Variable Rate Nutrient Application	Y		Y			Y			Y		Y	Y
Stabilizer									Y			
Foliar fertilization	Y		Y			Y						
Organic Soil Amendments												
Manure management	Y					Y	Y		Y		Y	Y
Compost	Y					Y			Y		Y	Y
Green manure	Y	Y	Y	Y	Y	Y			Y		Y	Y
Roller crimper	Y		Y					Y	Y	Y	Y	Y
Humic & fulvic acid amendments	Y					Y			Y		Y	Y
Biochar	Y					Y			Y		Y	Y
Legumes in pastures	Y	Y	Y			Y			Y		Y	Y
Integrated Crop-Livestock systems	Y								Y	Y	Y	Y
Bale grazing	Y					Y	Y		Y	Y		
Swath grazing	Y	Y	Y			Y	Y		Y	Y	Y	
Bunch grazing									Y	Y	Y	Y
Rotational grazing	Y	Y	Y						Y		Y	Y

	Agronomic Barriers (continued)											
	Protocol for my region, soil type, weather conditions (includes "How do I do this practice?")	What species will work in my region, soil type, weather conditions	Drought, flooding, erosion, extreme weather events	Insects	Risk of plant diseases	Unknown fertilizer requirements or application rate	Weed Control	Crop Maturity and Harvestability (crops being mature at the same time, cannot harvest when too wet or green)	Uncertainty of soil health or ecological benefit	More waste material to dispose of	Timing conflict for labour	Timing conflict for equipment
Adaptive multi-paddock grazing	Y	Y	Y						Y		Y	Y
Reduced Tillage	Y		Y	Y	Y		Y		Y	Y	Y	Y
Crop Residue Management	Y			Y	Y		Y		Y	Y	Y	Y
Maximized crop residue	Y	Y	Y	Y	Y		Y		Y	Y	Y	Y
Crop residue bioenergy		Y				Y			Y		Y	Y
Reduced burning of crop residue	Y		Y						Y	Y	Y	Y
Grazing residue									Y	Y	Y	Y
Strategic tillage												
Vertical tillage	Y		Y						Y			
Deep tillage											Y	
Subsoiling	Y		Y						Y		Y	Y
Agroforestry	Y								Y			
Alley cropping/tree-based intercropping	Y	Y					Y		Y			
Silvopasture	Y	Y					Y		Y			
Avoided conversion of shelterbelts	Y	Y	Y				Y		Y			
Reduced deforestation to agriculture	Y								Y			
Land conservation and restoration												
Avoided conversion of grassland, hayland and pasture	Y		Y						Y			
Riparian grassland restoration	Y	Y	Y				Y		Y		Y	Y
Riparian vegetation restoration	Y	Y	Y				Y		Y		Y	Y
Wetland conservation and restoration	Y	Y	Y				Y		Y		Y	Y
Conversion of marginal cropland to permanent cover	Y	Y	Y				Y		Y		Y	Y
Organic agriculture systems	Y	Y	Y	Y	Y	Y	Y		Y		Y	Y

	Socio-Cultural Barriers						Awareness Barriers		
	Too much information available - overwhelm	Not enough information available - lack of knowledge/know how	Producers' resistance to change or learn	Accessibility of processing facilities	This practice is too weird - outside farming norms	Land tenure - landlord may not approve practice	Producers not aware of this term	Definition of this practice is not consistently understood by producers	Arrogance - adoption is already achieved in their eyes
Cover Cropping	Y	Y	Y		Y	Y	Y	Y	
Cocktail cover crops	Y	Y	Y		Y	Y	Y	Y	
Fall seeded cover crops	Y	Y	Y		Y	Y	Y	Y	
Fall seeded cash crops			Y						
Intercropping	Y	Y	Y	Y	Y	Y	Y	Y	
Polycropping	Y	Y	Y	Depends on complexity	Y	Y	Y	Y	
Crop rotation diversity	Y	Y	Y	Depends on complexity	Y	Y			Y
Relay cropping	Y	Y	Y	Depends on complexity	Y	Y	Y	Y	
Increased legume & pulse crops		Y		Y					
Short-term rotation of annual crops with perennial forages		Y	Y		Y	Y			
Annual crops seeded into existing perennial forages		Y	Y			Y	Y	Y	
Short-term rotation of perennial forages with annual crops		Y	Y			Y			
Improved Nutrient Management									Y
4R Nutrient Stewardship		Y	Y					Y	Y
Variable Rate Nutrient Application		Y	Y				Y		
Stabilizer									
Foliar fertilization		Y						Y	
Organic Soil Amendments							Y	Y	
Manure management			Y			Y			
Compost		Y	Y		Y		Y		
Green manure		Y	Y		Y	Y	Y	Y	
Roller crimper		Y	Y		Y	Y	Y	Y	

	Socio-Cultural Barriers (continued)						Awareness Barriers (continued)		
	Too much information available - overwhelm	Not enough information available - lack of knowledge/know how	Producers' resistance to change or learn	Accessibility of processing facilities	This practice is too weird - outside farming norms	Land tenure - landlord may not approve practice	Producers not aware of this term	Definition of this practice is not consistently understood by producers	Arrogance - adoption is already achieved in their eyes
Humic & fulvic acid amendments		Y	Y		Y		Y	Y	
Biochar		Y	Y		Y		Y	Y	
Legumes in pastures		Y	Y			Y	Y	Y	Y
Integrated Crop-Livestock Systems		Y	Y		Y	Y		Y	
Bale grazing		Y	Y		Y	Y		Y	
Swath grazing			Y		Y	Y		Y	
Bunch grazing		Y	Y		Y	Y	Y	Y	
Rotational grazing	Y	Y	Y		Y		Y	Y	Y
Adaptive multi-paddock grazing	Y	Y	Y		Y		Y	Y	Y
Reduced Tillage		Y	Y						Y
Crop Residue Management		Y	Y						Y
Maximized crop residue		Y	Y		Y		Y		Y
Crop residue bioenergy		Y		Y	Y	Y	Y	Y	
Reduced burning of crop residue			Y						Y
Grazing residue		Y	Y			Y			
Strategic Tillage									
Vertical tillage		Y						Y	Y
Deep tillage					Y		Y	Y	
Subsoiling		Y				Y	Y	Y	
Agroforestry		Y			Y	Y	Y	Y	
Alley cropping/tree-based intercropping		Y			Y	Y	Y	Y	
Silvopasture		Y			Y	Y	Y	Y	Y
Avoided conversion of shelterbelts		Y					Y	Y	Y
Reduced deforestation to agriculture		Y					Y	Y	Y
Land conservation and restoration									
Avoided conversion of grassland, hayland and pasture		Y				Y	Y	Y	Y
Riparian grassland restoration		Y	Y		Y		Y	Y	Y

	Socio-Cultural Barriers (continued)						Awareness Barriers (continued)		
	Too much information available - overwhelm	Not enough information available - lack of knowledge/know how	Producers' resistance to change or learn	Accessibility of processing facilities	This practice is too weird - outside farming norms	Land tenure - landlord may not approve practice	Producers not aware of this term	Definition of this practice is not consistently understood by producers	Arrogance - adoption is already achieved in their eyes
Riparian vegetation restoration		Y	Y		Y		Y	Y	Y
Wetland conservation and restoration		Y	Y		Y	Y	Y	Y	Y
Conversion of marginal cropland to permanent cover		Y	Y		Y	Y	Y	Y	Y
Organic agriculture systems	Y	Y	Y		Y	Y	Y	Y	Y

Note. Y= Yes. This chart summarizes categories of barriers and specific barriers that apply to each BMP or agricultural land management practice discussed in this report, based on the perspectives of Prairie producers interviewed by FWWF and an advisor who provided his insight. A box with Y indicates that producers believe this barrier does apply to this practice. Some barriers apply to some practices depending on the complexity of the practice, the species grown, or other specific variables, and these are identified in the chart with appropriate wording.

A box that is blank indicates that, based on the producer perspectives this report had access to, this barrier does not apply to this practice at this time. While this report covers many barriers identified through producer engagement, there are undoubtedly additional barriers that we have not identified and thus are not included here.

Appendix C – Glossary of BMP and Agricultural Practice Definitions

BMPs and agricultural land management practices are defined here in the same order as they appear in sections 3.0 and 4.0. As often as possible, and based on the information that was available, practices are defined from an academic and/or government perspective, as well as from Prairie producers' perspectives, to highlight differences and important distinctions in how these practices are viewed by different groups.

3.1. Cover crops: A cover crop is commonly defined as an additional crop grown during a period of time when no crop would normally be grown (Drever et al., 2021b; Morrison, 2021; Morrison and Lawley, 2021; Viresco, 2022). Prairie producers would generally agree with this definition, but would consider the term cover cropping to include crops grown for grazing or other production purposes, as well as those grown and then terminated for soil health purposes.

> **3.1.1. Cocktail cover crops:** Agriculture and Agri-Food Canada (2021) defines cocktail cover crops as "the intentional co-planting of several species of plants in the same field or plot." Cocktail cover crops are also known as polyculture cover crops, or multi-species planting, and are grown from seed mixes with many species and plant varieties. which can either be purchased as a pre-made seed mix, or created by the producer blending their own seed. In the Prairies, producers would consider any two or more species grown together, including a forage stand, to be a cocktail cover crop. Thus, a cocktail cover crop could have as few as two, or as many as a dozen or more species. There is some overlap in producers' definitions of cocktail cover crops and polycropping.
>
> **3.1.2. Fall seeded cover crops:** Fall-seeded cover crops are grown through the shoulder season; they are seeded after cash crop harvest in the fall, and grow through the fall and then again into the spring before the next cash crop is seeded. Producers in the Prairies would also define fall seeded cover crops this way, although termination could be either late fall or the following spring, and the crop would not be grown for grain, but may be used for grazing purposes. Producers would consider this practice to be the same as relay cropping.
>
> **3.1.3. Fall seeded cash crops:** Producers would call this a fall seeded crop, and would consider this to be the same as a fall seeded cover crop, except this would be a grain or forage crop meant for harvesting.

Cash crop: This term is not commonly used by producers in Western Canada. Producers would call it a grain crop or a forage crop.

3.1.4. Intercropping: There is inconsistency within the literature on the definition of intercropping. Agriculture and Agri-Food Canada (Government of Canada, 2021) and the Viresco report (2022) both define intercropping as a method of planting and growing two or more crops together, in the context of cash crops grown for harvest, rather than the monocrop field that is typical in the Prairies. Some academics, however, include cover crops in their definition of intercropping (Morrison, 2021; Morrison and Lawley 2021), and Thiessen Martens et al. (2015) state that "the benefits of intercropping may also be realized in non-grain crops such as cover crops, green manures, and annual forages" (p.1054). Prairie producers would tend to use the term intercropping in the same way as the Viresco report, and Agriculture and Agri-Food Canada, that is, to refer to two or more crops harvested for grain, not cover crops.

3.1.4.1. Polycropping: Polycropping may also be known as multi-species or cocktail mixtures, or as polyculture, especially in academic research. Agriculture and Agri-Food Canada (2021) defines polyculture as "the intentional co-planting of a variety of species of plants in one plot, particularly for use as forage, or food for livestock." In the Prairies, producers would define polycropping as more than two species of any type of crop that are seeded around the same time. This definition overlaps with what producers would define as a cocktail cover crop, however polycropping would include both cover crops and crops for production or grain harvest.

3.2. Increasing diversity of crop rotations: This BMP can be defined as the temporal or spatial incorporation of new, varied crop species into pre-existing rotations of annual or perennial crops (Thiessen Martens et al., 2015; Viresco, 2022). Producers would consider crop rotation diversity in terms of the frequency of inclusion of different crops in their crop rotations. This could include forages, silages, short-term perennials and more diverse grain crops, and would result in their crop rotations including a greater number of species, and a lower frequency for each crop.

3.2.1. Relay cropping: Relay cropping is a specific method of intercropping where a second crop is seeded into a first crop that is already established and growing. There is a short overlap period where both crops are growing and occupying the same land, with one reaching maturity earlier than the other. Prairie producers define relay cropping slightly differently, as they would consider relay cropping to be the same practice as planting a fall seeded or spring seeded crop, including both cover crops and cash crops. Relay crops would be planted *after* the previous crop has been harvested, and as such there is no, or very minimal, growth overlap between the two crops.

3.2.2. Increased legume and pulse crops: Both Viresco (2022) and Drever et al. (2021a) are consistent in defining this practice as removing some non-legume crops from production and replacing them with legume crops. Producers would consider this BMP to involve an increased frequency of pulse or legume crops in their cropping and forage rotations.

3.2.3. Short-term rotation of annual crops with perennial forages: Viresco (2022) and Thiessen Martens et al. (2015) define this practice as the addition of perennial forages to an annual cropping system for a short period of time. Producers would define this BMP as the inclusion of short-term perennials in a cropping system. (For example: wheat-barley-canola-alfalfa-alfalfa-alfala-wheat)

3.2.4. Annual crops seeded into existing perennial forages: From the producer perspective, this practice would involve stitching annual crops (for example: oats, barley, or wheat) into established perennial stands, especially those that are older or struggling to provide sufficient ground cover and production.

3.2.5. Short-term rotation of perennial forages with annual crops: Producers would define this practice as a short-term introduction of annual crops into a perennial forage system. Perennial crops would first be terminated to allow annual crops to be seeded and grown. After a few years of annual crops, producers would reseed perennial crops and return to the perennial forage rotation. (For example: mixed pasture in years one to ten, then oats-oats-oats, then back to mixed pasture)

3.3. Improved nutrient management: Improved nutrient management can be defined as using "reduced nutrient inputs and … more efficient application of nitrogen fertilizers" (Drever et al., 2021b, p.12). In academia and in the fertilizer industry, some may consider 'improved nutrient management' to be synonymous with the 4R Nutrient Stewardship framework, but among Prairie producers '4R' or '4R Nutrient Stewardship' are not terms that are well known or frequently used. Producers would use 'nutrient management' to refer to anything related to soil nutrients, including fertilizer, but also including manure and compost.

3.3.1. 4R Nutrient Stewardship: The 4Rs refer to the application of fertilizer from the Right Source, using the Right Rate, to the Right Place at the Right Time. Drever et al. (2021b) describes the three levels of 4R adoption as "1) basic matching of the nutrient supply to crop needs based on limited monitoring of N status and field-level spatial resolution, 2) intermediate matching through detailed monitoring of nutrient status, manipulation of the timing of nutrient supply, and sub-field spatial resolution, 3) advanced matching based on detailed monitoring of nutrient status and plant health, extensive manipulation of nutrient supply timing, and detailed sub-field spatial resolution" (Suppl. p.12). Prairie producers would be somewhat familiar with the both 4R terminology and the different levels of adoption.

3.3.1.1. Variable Rate Nutrient Application (VRNA): Variable rate nutrient application (VRNA) is defined as the application of fertilizer at different rates on the same field, based on the specific nutrient needs of each soil zone (Agriculture and Agri-Food Canada, 2020). Using soil testing data, and information on soil types and yield expectations, a customized map is created for the producer that delineates different soil management zones on the field and calculates optimal fertilizer application rates for each zone. Producers would understand this practice to be the application of fertilizer at optimal rates for different areas of the field, as opposed to a flat rate applied to the entire field.

3.3.1.3. Stabilizer: Stabilizer is a product that is added to fertilizer to slow and stabilize its conversion in soil. Stabilizer on fertilizer can reduce leaching and volatilization, and protects seeds from fertilizer burn. Although stabilizer should allow producers to use less fertilizer and thus reduce N_2O emissions from their farms, many producers perceive stabilizer as a way to use more fertilizer and increase their production. There is likely a disconnect between researchers' promotion of stabilizer as a way for producers to reduce fertilizer usage and N_2O emissions, and producers' actual use of stabilizer to increase their fertilizer usage and in turn, increase crop production.

3.3.1.4. Foliar fertilization: Foliar fertilization is also known as foliar feeding and can be defined as "the application – via spraying – of nutrients to plant leaves and stems and their absorption at those sites" (Kuepper, 2003, p.1). Most Prairie producers are familiar with foliar fertilization.

3.3.2. Organic soil amendments: Viresco (2022) describes organic amendments as any substance derived from organic matter that can be added to the soil to improve soil health, replenish depleted nutrients, or improve agricultural production. Products such as manure, compost, biochar, and microbial fertilizers would all be classified as organic soil amendments (Viresco, 2022). Producers in the Prairies would generally use the same terminology and definition for this practice. Although the word 'organic' here refers to amendments derived from biological sources (as opposed to inorganic fertilizer, for example), producers may interpret this to mean soil amendment products that are certified organic.

3.3.2.1. Manure acidification: Drever et al. (2021a) defines this as the practice of acidifying fresh slurry manure with concentrated sulfuric acid to reduce the production of methane. The specific process of manure acidification as defined by Drever et al. (2021a) is mostly unheard of among Prairie producers, although some producers may treat their liquid manure in some manner.

3.3.2.2. Manure application: Prairie producers would define manure as any animal waste matter obtained from livestock production; this definition overlaps with producers' reference to aged manure as compost. In the Western Prairies, manure is typically broadcast or spread onto the soil surface and then incorporated into soil through tillage or harrowing.

3.3.2.3. Compost: Scientifically, compost is produced from the biological decomposition of organic matter under specific, controlled conditions. The composted material must be actively managed, have the appropriate nutrient ratio through different types of organic feedstock, and must reach a high temperature for a period of time to produce the resulting compost product (Martin, 2005). In practice though, agricultural composting often does not follow this process. Most Canadian producers would consider compost to be the aged mixture of manure and livestock bedding stored on their farms that has not actively been managed under the conditions needed for proper composting. Many producers may not be aware of the specific conditions of time, temperature, and feedstock components that would be necessary for the composting process to effectively kill pathogens and weed seeds.

3.3.2.4. Green manure: The Government of Manitoba (n.d.) defines green manure as "a crop [that] is grown primarily for the purpose of being plowed down to add nutrients and organic matter to the soil." Some sources, both academic and non-academic, consider green manuring to be an interchangeable term for cover cropping. In general, cover cropping as a BMP can be defined as the practice of growing the crop itself, and green manuring as the practice of incorporating the cover crop vegetation into the soil to act as an organic soil amendment. In the Prairies, green manure is generally more well known in organic agriculture than in conventional agriculture. Prairie producers who are aware of the practice would likely agree with the initial definition of green manure as a cover crop that is grown for the purpose of incorporating into the soil to add nutrients, organic matter, and improve soil health. A cover crop on its own, or the practice of growing a cover crop, would not be considered green manure to producers.

3.3.2.5. Roller crimper (blade roller): Producers in the Prairies would agree with the generally accepted definition of a roller crimper as a piece of equipment including one or more drums covered with blunt blades that can be rolled over a cover crop to crimp and damage the plant stems without cutting them. This tool can be purchased or rented commercially, or can be built DIY-style by producers. Although academic researchers often use the term ‘blade roller’ in the literature, Prairie producers would largely be unfamiliar with this term and would refer to it as a roller crimper.

3.3.2.6. Humic and fulvic acids: Humic and fulvic acids are found naturally in the humic substances of soil, and are commercially available to producers as soil amendment products. These acids can be used to stimulate plant growth, act as a source of carbon and energy, chelate soil nutrients, and buffer against pH changes or other excesses in soil. Most conventional producers in the Prairies would be unaware of humic and fulvic acids, or their use as soil amendments, although knowledge of these products is now growing. Regenerative agriculture-minded producers likely know about them and would agree with the above definition and uses.

3.3.2.7. Biochar: Biochar is consistently defined as the charcoal product formed from the pyrolysis of organic matter. Drever et al. (2021a) evaluated the mitigation potential from biochar specifically made from agricultural crop residue, thus not including biochar from manure or other sources of biomass. In the Prairies, most producers would be unaware of the term biochar, or of the practice of using it as a soil amendment.

3.3.2.8. Legumes in pastures: Drever et al. (2021b) defines this BMP as “including locally suited legumes in the species mix used in pasture establishment, managing grazing to increase the longevity of existing legumes (e.g. allowing legumes to go to seed), or seeding legumes into established pastures that have inadequate legume composition” (p. 30). Producers in the Prairies would consider this practice to involve stitching legume seed into established pastures or perennial forage stands that may be old or struggling.

3.4. Integrated crop-livestock systems: An integrated crop-livestock system is another umbrella term that includes various BMPs that involve the integration of livestock management and crop production (Viresco, 2022). In the Canadian Prairies, these systems can include forage rotations, cover crop grazing, stubble grazing, and dual-purpose crop grazing, as well as grazing practices such as multi-paddock or rotational grazing, complementary grazing, and reducing stock density (Viresco, 2022). Prairie mixed farms typically have their crop and livestock systems integrated by default, although they may not specifically use the term 'integrated crop-livestock system'. This terminology is likely known by most Prairie producers through agriculture publications, websites, or workshops, but is not typically used in everyday language.

3.4.1. Bale grazing: Bale grazing is a livestock feeding system in which forages (either annual or perennial) are baled and left on pasture or cropland for livestock to graze (Thiessen Martens et al., 2015). In general, producers in the Prairies would agree with this description of bale grazing as a practice. Viresco (2022) considers bale grazing to be a sub-BMP of Increasing Organic Soil Amendments due to the contribution of nutrients from livestock waste that is spread out over bale grazed cropland rather than concentrated in one area.

3.4.2. Swath grazing: Swath grazing is another livestock feeding system in which crops (typically annual crops) are harvested and laid in swaths on pasture or cropland for livestock to graze (Thiessen Martens et al., 2015). Producers would consider swath grazing to involve growing an annual crop for the purpose of swathing, whether it be a monoculture or even a cocktail mix, then harvesting and laying it in swaths to be fed to livestock through a managed process, depending on the needs of the producer.

3.4.3. Bunch grazing: Bunch grazing is a winter grazing method used by some Prairie livestock producers. Producers would define bunch grazing as the practice of collecting and bunching chaff and straw at harvest to be left on cropland or pasture for cows to graze through fall and winter.

There is no clearly defined government or academic definition for bunch grazing, and no published literature on this practice was found. It is likely that bunch grazing was developed and refined by producers at the farm level in response to challenges with other winter feeding methods (Furber, 2014). While swaths risk being buried under deep snow or frozen due to freeze-thaw cycles, bunched piles seem to be more resistant to these challenges.

3.4.4. Rotational grazing: Rotational grazing is a general term that includes many grazing practices that all involve moving livestock through multiple grazing paddocks instead of leaving them to graze in a single paddock (Viresco, 2022). The Viresco report (2022) categorizes rotational grazing as basic, intermediate, or intensive, and defines these categories based on the frequency of movement to a new paddock. Prairie producers would likely define rotational grazing as the practice of moving livestock through grazing paddocks on a prescriptive and repetitive schedule. Producers may not have a grazing plan, and may graze livestock without changing or adapting the rotations to external factors.

3.4.5. Adaptive Multi-Paddock (AMP) grazing: Adaptive multi-paddock grazing practices may also be known as mob grazing, holistic management, holistic planned grazing, intensive rotational strategies, or management-intensive grazing (Sherren et al., 2022). Researchers have struggled to agree on a definition due to the variety of terms and grazing practices used by producers that would be considered adaptive multi-paddock grazing. In Canada, "AMP grazing has not been well described …in terms of practice, uptake, or motivation" (Sherren et al., 2022, p.1307). The authors define it as "an umbrella term for approaches to grazing planning and management, often characterized by high-intensity short-duration rotational grazing managed with careful planning and monitoring" (p.1305).

Prairie producers would consider AMP to be a grazing practice that is more holistic, observational, and adaptable to external factors. AMP producers would likely have a plan that considers grazing rotations and rest periods throughout the year, and that gives a broader perspective on how grazing fits into their overall operation.

3.5. Reduced tillage: Reduced tillage is also known as conservation tillage, and can include a spectrum of tillage practices from reduced tillage, to minimal tillage, to zero tillage (Awada, et al., 2014). Academically, conservation tillage can be defined very specifically as a "sustainable crop production system that leaves at least 30% of crop residue on the soil surface after crop planting, or at least 1.1 Mg ha^{-1} of small grain residue on the surface during the critical soil erosion period, uses specialized seeding equipment to place seed and fertilizer in the soil with minimal disturbance, controls weeds by herbicides or by minimal cultivation and herbicides, and uses crop rotations to help break the life cycles of pests and diseases and to control weeds" (Awada et al., 2014, p. 49).

Prairie producers would define reduced tillage more simply, that is it would mean any reduction of tillage by one or more passes compared to the producer's typical tillage practice. This would include a spectrum of tillage practices in alignment with the academic definition above, but would also include seeding practices with minimal soil disturbance, such as direct seeding or no-till seeding. Any tillage practice that does not cause total soil inversion would also be considered reduced tillage by producers.

3.5.1. Crop residue management: From a government perspective, crop residue management can be defined as the use of methods, tools, or techniques to manage the straw, chaff, and roots left behind after crop harvest to ensure the residue can provide benefits to the soil and not interfere with seeding or farm machinery (Alberta Agriculture, Food, and Rural Development, 2004). Prairie producers would generally agree with this definition.

3.5.1.1. Maximized crop residue production: Viresco (2022) defines this as the practice of increasing crop residue through a variety of methods, including the use of high-residue crops like oats and canola, using crop varieties with more roots, or even using crops that have been genetically altered to slow down residue decomposition. Most Prairie producers would be motivated to reduce crop residue, rather than to maximize it, and would be unaware of this terminology or the practice of maximizing crop residues. Some regenerative agriculture-minded producers would be aware of the practice and would be motivated to maximize crop residue through one of methods mentioned above.

3.5.1.2. Crop residue bioenergy: Both Viresco (2022) and Drever et al. (2021b) define this practice as the production of bioenergy specifically from agricultural crop residue. Most producers in the Prairies would be unaware of crop residue bioenergy production, or its purpose in regenerative agriculture, although some producers, especially in Manitoba, may have knowledge of it.

3.5.1.3. Reduced field-burning of crop residue: Crop residues are burned in the field for various reasons, including making seeding easier, or to reduce disease in subsequent crops, or if residues cannot be removed by some other manner, due to excessive moisture or insufficient time (Viresco, 2022). Producers would likely agree with the definition and terminology used here.

3.5.1.4. Grazing residue: Residue grazing involves livestock grazing the crop residue left in a field after the crop has been harvested (Thiessen Martens et al., 2015); this practice would not include bale or swath grazing where the crop itself is intended for livestock. Prairie producers would generally agree that this definition defines their practice of grazing residue

3.5.1.5. Strategic tillage: Tillage practices, when applied judiciously and with careful consideration of soil health, can be strategically integrated into regenerative agriculture practices. Regenerative agriculture typically emphasizes minimal soil disturbance, but strategic tillage is employed in specific situations to address compaction, enhance seedbed preparation, or facilitate cover crop incorporation.

Vertical tillage: Prairie producers use the term vertical tillage to refer to a practice that is quite different from true vertical tillage. True vertical tillage should result in the shallow, slight vertical movement of air and moisture through only the top layer of soil without any horizontal soil disturbance (Lyseng, 2013). Prairie producers however, are often practicing tillage that uses wavy blades, may penetrate the soil quite deeply, and typically does cause a moderate amount of horizontal soil disturbance; producers will refer to this practice as vertical tillage, although this is not consistent with true vertical tillage. Many producers may not know what true vertical tillage is as a practice, or even whether their equipment is doing vertical tillage correctly or not (Lyseng, 2013).

Deep tillage: There is a significant disconnect in the interpretation of tillage terminology between the producer's perspective and a government perspective. Deep tillage, as defined by the governments of both Alberta and Saskatchewan, includes the practice of deep ripping, which they describe as using a subsoiler to loosen the subsoil while leaving the soil surface relatively undisturbed (Government of Saskatchewan, n.d.-a; McKenzie, 2010). Prairie producers, however, would call this practice subsoiling, not deep ripping or deep tillage. Producers would use the term deep tillage for a practice that uses a cultivator to turn deep layers of soil, resulting in black soil to some degree and significant disturbance to the soil surface.

Subsoiling: Prairie producers would use the term subsoiling for the practice that the governments of Alberta and Saskatchewan refer to as deep tillage, that is, the use of a subsoiler to loosen the subsoil while leaving the soil surface relatively undisturbed (Government of Saskatchewan, n.d.-a; McKenzie, 2010).

3.6. Agroforestry: Agroforestry is an umbrella term used for a system that intentionally combines trees with agriculture. Canada follows the classification system of the Association for Temperate Agroforestry, which includes five general categories of agroforestry systems: windbreaks/shelterbelts, silvopasture, tree-based intercropping (alley cropping), riparian systems, and forest farming (Thevathasan et al., 2012; Association for Temperate Agroforestry, n.d.). The term agroforestry is likely to be interpreted in numerous different ways by those in the agriculture industry, whether producers and non-producers. Some may interpret agroforestry as the agricultural production of trees as the end product, whether for garden centres or lumber mills, while others may interpret it as the production of an agricultural product that comes from trees, such as fruit or nuts. As such, there is likely no typical definition among Prairie producers of what the practice of agroforestry entails, nor of the term itself.

3.6.1. Tree-based intercropping (alley cropping): Alley cropping is also known as tree-based intercropping, and is defined as an agroforestry practice that involves wide alleys of agricultural crops planted between rows of trees (Thiessen Martens et al., 2015). Although alley cropping is not widely practiced in the Prairies, producers here would generally agree with this definition of the practice.

3.6.2. Silvopasture: The Canadian Forest Service defines silvopasture as “an agroforestry practice involving the compatible combination of tree growing with forage and livestock production in order to maximize both ecological and economic benefits” (Government of Canada, 2020). This aligns consistently with both Viresco (2022) and Drever et al. (2021a) who consider silvopastoral systems to include trees, livestock grazing, and forage. Generally, producers in the Prairies would also describe the practice of silvopasture in this way. Silvopastoral systems can also include the practice of alley grazing, in which livestock graze the pasture alleys in between rows of trees, often with the trees acting as fencing for livestock.

4.0. Agricultural land management practices: Agricultural land management practices are not true regenerative agriculture BMPs. Instead, they are natural climate solutions that focus on either avoiding the conversion of land for agricultural production or on restoring current agricultural land to its naturalized state. These strategies are not directly applicable to crop production, but rather are related to agricultural land management at a higher level. Although these practices do not have direct impacts on crop production, some have enormous GHGE mitigation potential in the Prairies and, thus, their importance should not be underestimated.

4.1. Avoided conversion of shelterbelts: Shelterbelts are consistently defined as groupings of trees planted in rows at the edges of agricultural land primarily to reduce the negative impacts of wind and moisture loss, and can be used around farmyards, crop fields, and livestock areas (Rempel et al., 2017). Shelterbelts are well known by Prairie producers, and in general, producers’ description of this practice would align with this academic definition.

4.2. Reduced deforestation to agriculture: Although the Drever et al. (2021a) review includes forest conversion to numerous types of industry uses, the Viresco report (2022) looks strictly at deforestation for conversion to agricultural land. Prairie producers would define this practice in the same way Viresco describes it here.

4.3. Avoided conversion of grassland, pasture, and hayland: This is defined as preventing the conversion of native, perennial grasslands and managed pastures to annual-harvested cropland (Drever et al., 2021b). Viresco (2022) states that this category includes “‘natural land for pasture’, ‘tame or seeded pasture’, and ‘all other tame hay and fodder crops’” as classified in the Canadian

Census (p. 104). Producers in the Prairies would also define this practice as described in Drever et al. (2021b).

4.4. Riparian grassland restoration: Drever et al. (2021b) describe this practice as the restoration of marginal or unproductive cropland to grassland or shrubland, but also more specifically as “restoring 30 m riparian buffers with perennial grasses in cropland areas with annual harvests” (p. 45). Producers would also define this practice as riparian grassland restoration.

4.5. Riparian vegetation restoration (or riparian tree planting): Riparian vegetation areas can also be known as riparian buffers, riparian forest buffers, riparian strips, filter strips, or buffer strips. Riparian vegetation restoration can also be known simply as riparian tree planting. Both the Association for Temperate Agroforestry and Drever et al. (2021a) consider this to be an agroforestry practice, in that its GHG mitigation potential aligns most consistently with the Trees in Agriculture pathway rather than with Land Restoration and Conservation practices.

Drever et al. (2021a) define this practice as the planting of trees alongside, and around, water bodies within agricultural lands that are naturally forested. Drever et al. (2021b) calculated the GHG mitigation potential based specifically on the “establishment of deciduous trees within 30 m of water bodies, in agricultural lands where forest is the native cover type” (p. 19). Producers would also define this practice as riparian vegetation restoration or riparian tree planting.

4.6. Wetland conservation and restoration: Wetland is an umbrella term that includes a variety of land-based ecosystems that retain, or are submerged in, water, including marshes, swamps, bogs, and sloughs (Government of Canada, 2016). Wetland conservation (or avoided wetland conversion) can be defined as “the prevention of drainage, dredging, eutrophication, or other anthropogenic activities in peatlands, freshwater mineral lands, and seagrass ecosystems” (Drever et al., 2021b, p. 31). Wetland restoration is defined as “restoration of hydrological function (rewetting) or topography, moss layer transfer, fertilization, nutrient management, vegetation management, or disturbance management.” (Drever et al., 2021a, p. 3). Producers would agree with these definitions of wetland conservation and restoration, although some of these practices would be recognized as being above the farm level.

4.7. Conversion of marginal cropland to permanent cover: Lands that have no value for agricultural or industrial production due to degraded soil, poor quality soil, landscape complexity, salinity, or various other reasons are generally defined as marginal lands. Producers in the Prairies would agree with this definition of marginal cropland. Although Viresco (2022) reports that the term ‘land set aside’ is often used to refer to agricultural land that has been converted to permanent cover, most Prairie producers would not use that term in everyday language, and may associate it with a research or policy context.

4.8. Organic agriculture systems Organic agriculture is highly regulated in Canada, defined by the Canadian General Standards Board as “a holistic system designed to optimize the productivity and fitness of diverse communities within the agro-ecosystem, including soil organisms, plants, livestock, and people” (Canadian General Standards Board, 2018, p.ii). Producers are generally aware of organic agriculture systems and would agree with this definition.

Appendix D – Food Water Wellness Foundation and Their Approach to Producer Engagement

Appendix D is an excerpt of the separate report titled *Food Water Wellness Foundation: Our Approach to Producer Engagement on the Canadian Prairies (2013-2024) – A summary of research, methods, themes, and recommendations*. These sections summarize Food Water Wellness Foundation's approach to producer engagement, their past producer research initiatives, and the scopes and methodologies of each engagement initiative.

Food Water Wellness Foundation

Food Water Wellness Foundation (FWWF) has played an important role in sustainability-focused producer research and engagement in the Prairies over the last decade. Guided by the leadership of Executive Director Kimberly Cornish, FWWF works with agricultural producers and researchers to encourage the use of Beneficial Management Practices (BMPs) and to understand the barriers that are preventing their widespread adoption. With a focus on growing widespread adoption of regenerative agriculture in the Prairies and throughout Canada, at its core, FWWF believes (FWWF, n.d.-a):

- Any problem can be overcome when an innovative approach is used to tackle it.
- When the natural functioning and interconnectedness of a healthy ecosystem is understood it opens the door to innovative approaches for regenerating even the most imbalanced systems.
- All people of the world deserve the dignity of having access to abundant nutrition, clean water and healthcare.

Since 2013, FWWF has developed relationships with agricultural producers, industry stakeholders, Trusted Advisors (TAs), professional agrologists (PAgs), Certified Crop Advisors (CCAs), researchers, and Producer-Led Organizations (PLOs) across the Prairie provinces. FWWF has fostered these trusted relationships to build a network of innovative stakeholders who are motivated to grow regenerative agriculture in the Prairies.

FWWF is uniquely positioned to leverage this network of established relationships through their use of "kitchen table conversation" methodology to engage with Prairie producers and collect meaningful, authentic perspectives. Building upon this vast volume of engagement research, FWWF has been instrumental in facilitating the grassroots regenerative agriculture movement in the Prairies and in scaling this movement to higher levels.

In their work with producers, FWWF follows a Theory of Change approach, starting by identifying long-term goals and then working backwards to uncover the variables and barriers that are key determinants of achieving these goals (Center for Theory of Change, n.d.). After defining the conditions needed to reach the long-term goals and the connections between these conditions, interventions are identified that will allow people to reach the desired outcomes.

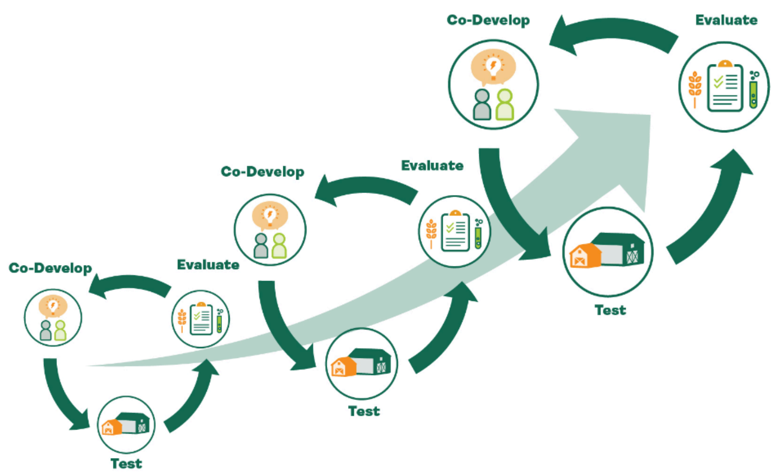
To encourage behaviour change, FWWF believes in showing producers the benefits in soil health (including increased yield, reduced need for inputs, and returns on investment) that regenerative agriculture brings at the farm level while benefiting the surrounding ecosystems and environment. FWWF also believes that incentivizing producers to voluntarily adopt BMPs or regenerative agriculture systems on their farms is more effective at encouraging large-scale adoption than top-down mandatory regulations or restrictions on what producers can and cannot do.

Recognizing that peer-to-peer learning is the most effective and trusted learning pathway for producers (FWWF, 2023b), FWWF places a high priority on supporting peer connections in their regenerative agriculture initiatives. They work to provide access to data needed to successfully adopt and implement BMPs as well as facilitate support platforms that allow producers to benefit from robust peer knowledge-sharing networks.

Feedback mechanisms are an essential and strategic part of FWWF's research and programs. FWWF's Regenerative Alberta Living Lab (RALL) program employs a producer-centered innovation feedback loop, seen in Figure 4, that incorporates producer feedback as it tests, evaluates, and improves innovations in regional agro-climatic contexts (FWWF, 2023b). Producers' insights, challenges, and needs are listened to and highly valued throughout the innovation process.

Figure 4

Living Labs Innovation Cycle



Note. From Agriculture and Agri-Food Canada. (2023b, July 24). *About the Living Laboratories approach.* https://agriculture.canada.ca/en/science/living-laboratories-initiative/about-living-laboratories-initiative

FWWF also recognizes the potential that carbon sequestration holds in driving BMP adoption. Accurate quantification and monetization of carbon sequestration in agricultural soil will reward regenerative producers with tangible compensation and drive greater adoption of BMPs in the Prairies (FWWF, n.d.-b). FWWF understands the limitations of current carbon sequestration models and recognizes the need for accurate soil carbon data that quantifies the impacts of BMPs in Prairie agricultural contexts. Partnered with a network of scientists, PLOs, applied research associations, post-secondary institutions, and other industry stakeholders, FWWF has developed the Alberta Soil Quantification Project. Soil samples collected through the Living Lab will provide a large dataset which will be used to accurately quantify soil carbon sequestration outcomes from BMPs in Prairie soils (FWWF, n.d.-b).

FWWF Producer Engagement Research Initiatives

Over the past decade, FWWF has conducted five major research initiatives with Prairie producers, which are briefly summarized in this section, and then discussed in greater depth in the sections on Scope and Methodologies, and on Key Themes. Table 1 presents a summary of the scopes, key attributes, and outcomes of the four research projects.

FWWF engagement research began with a 2015 Needs Assessment (FWWF, 2015) of Alberta producers that included focus groups and personal interviews with individuals or single-family units. Prior to the Needs Assessment, Alberta Agriculture and Rural Development identified a number of problems in the Alberta agriculture sector (FWWF, 2015):

- The lack of a systematic and effective conduit for agricultural information distribution to Alberta producers
- A broad range of agricultural information available with varying levels of research quality
- The lack of connections between farmers, agricultural researchers, markets, consumers, support vendors, and consultants
- The presence of a dominant paradigm of how and what farmers in Alberta should be growing

An online resource-sharing platform was proposed, and the Needs Assessment was then conducted to gain feedback on how producers use online technology, whether the resource platform would be an effective tool to manage these problems, and to determine accurate terminology for platform content.

Starting in 2016, FWWF began a feasibility study, market analysis, and producer needs assessment for a proposed online regenerative agriculture portal (FWWF, 2017). FWWF aimed to advance the adoption of regenerative agriculture in Alberta by educating and connecting local producers and consumers through a direct online market and knowledge hub. The objective of this report was to determine if this online portal would meet producers’ needs and fit into the Alberta market.

Subsequently, FWWF conducted Producer Engagement sessions in 2021 (FWWF, 2021), which focused on gathering information about regenerative agriculture practices on Alberta farms. Information collected through these sessions helped to inform the Regenerative Alberta Living Labs application. These engagement sessions asked 158 producers a variety of questions, including the following:

- Which BMPs do you use on your farm, and which BMPs do you intend to use within the next five years?
- What are you fearful of in trying new BMPs?
- If you could direct research dollars, where would they go?
- Do you have the resources and support you need when you have questions and need assistance with problem solving on your operation?

In early 2023, FWWF conducted engagement for the Trusted Advisor Study (FWWF, 2023a), this time with a group of 92 industry stakeholders based in Alberta (AB), Saskatchewan (SK), and Manitoba (MB), including producers, representatives from retailers, producer-led organizations, non-governmental organizations (NGOs), academics, and professional advisors. Engagement occurred through focus groups and individual interviews, and findings from these sessions were compiled in a summary report in April 2023 (FWWF, 2023b). Engagement participants had the opportunity to provide any feedback related to regenerative agriculture and were also asked open-ended questions such as the following:

- What is needed to support Prairie agricultural producers in implementing regenerative agriculture practices?
- Where do producers go for general agronomic advice?
- How do you decide a source is trustworthy?

Currently, FWWF is focused on their ongoing, and most recent initiative, the Regenerative Alberta Living Lab (RALL), which they operate in conjunction with the Alberta Conservation Association. After years of hearing producers' perspectives, FWWF recognized the need for a collaborative project for producers and researchers to create effective, producer-led research and innovations on regenerative agriculture in the Prairies.

The RALL is a network of Alberta producers, researchers, and partner organizations that addresses the need for soil data linked to practical, hands-on regenerative agriculture experience within Alberta geographical contexts. Producers want data on the soil health of their land, especially on carbon sequestration and storage, and the Living Lab uses soil carbon mapping to meet this need. Data collected from RALL producers will be compiled to create a range of tools and resources to build producers' capacity to successfully adopt regenerative agriculture practices in Alberta (FWWF, n.d.-b).

Table 1

Summary of Past Research Initiatives Conducted by Food Water Wellness Foundation

FWWF-led Project	Date	Scope and Key Attributes	Outcomes
Needs Assessment (FWWF, 2015)	2013 to 2015	Conducted a focus group with eight industry professionals as well as 23 on-farm personal interviews to gain insight into the development of an online resource sharing platform.	Collected producer perspectives on producers' use of online technology, the effectiveness of the proposed resource platform, and the appropriate terminology for platform content.
Feasibility Study for Online Regenerative Agriculture Portal (FWWF, 2017)	2016 to 2017	Needs Assessment was conducted with 21 local producers who were extensively interviewed. Market analysis was conducted to understand the online Alberta market and its competitors.	Findings from the market analysis and producer needs assessment were used to develop the freshlygrown.ca online platform to serve as a direct market and knowledge hub for producers and consumers.
Producer Engagement Sessions (FWWF, 2021)	2021	Over 150 producer engagements through interviews and focus groups to gather information about regenerative agriculture practices and barriers to adoption of regenerative agriculture on Alberta farms.	Collected producer perspectives on barriers to regenerative agriculture that informed the RALL application and the *Producer Perspectives on Barriers to Adoption of Regenerative Agriculture* report.
Trusted Advisor Study Engagement Research (FWWF, 2023a; 2023b)	2023	92 industry stakeholders spread across AB, SK, MB were interviewed and engaged through focus groups to understand the role of Trusted Advisors, including producers, retailers, producer-led organizations, NGOs, academics, and professional advisors.	Informed *Trusted Advisors in the Canadian Prairies* Report, which identified gaps and opportunities and provided recommendations, including: 1. Invest in Prairie-specific data and research 2. Support peer-to-peer learning and sharing with educational institutions 3. Collaborate with trusted and established service-based consultants 4. Invest in scaling existing initiatives and coordinate with other organizations to share information

FWWF-led Project	Date	Scope and Key Attributes	Outcomes
Regenerative Alberta Living Lab (FWWF, n.d.-b; RALL 2023a; 2023b; 2023c)	2023 and ongoing	Collaborative project for producers and researchers to create effective, producer-led research and innovations on regenerative agriculture in the Prairies.	Generates valuable soil data linked to land health, including carbon sequestration and storage linked to practical, hands-on regenerative ag experience. Collects qualitative responses from producers on barriers to adoption and challenges in implementation of BMPs. Data collected has been incorporated in the *Producer Perspectives on Barriers to Adoption of Regenerative Agriculture* report.

Scope and Methodologies

FWWF has prioritized producer perspectives throughout its research initiatives. In their goal of capturing richly detailed, authentic responses from Prairie producers, FWWF has used primarily qualitative research methodologies. All engagement research was guided by FWWF's detailed policy on the collection, use, and privacy of engagement participants' information. Participants were informed that the information collected from them would be used for the purpose of the research project, kept private and anonymized, presented in public documents in an anonymous, aggregate format, and stored securely.

Before the engagement sessions began, FWWF described the research project, informed participants of the benefits and risks of participating in the study, reminded them that participation is voluntary, and that they may decide to stop participating at any time with no negative consequences. Participants were then asked to give their informed consent, either verbally or in writing, to the collection and use of their information in FWWF research before proceeding with the interview or focus group.

2015 Needs Assessment

Engagement for the 2015 Needs Assessment (FWWF, 2015) began in late 2013. Producers at the Local Food Workshop event in Olds, Alberta were invited to participate in this upcoming research project. Relevant stakeholders from the prior Knowledge Network project were also invited to participate. Potential participants included farmers, researchers, and representatives of related agricultural associations, and nearly all of those who were contacted agreed to be involved in the Needs Assessment.

Participants were of different age groups, came from a range of geographic regions in Alberta, represented various types of farming (conventional, holistic, natural, organic, U-pick, community supported agriculture (CSA), large-scale, ranchers, mixed) and produced a variety of agricultural products (grains, vegetables, fruit, protein, oil, and forest products) on farms ranging from one acre to 10,000 acres in size. A questionnaire was chosen as the survey instrument, and FWWF used a participatory, collaborative approach in the design and development of the questions, seeking input from producers and associations throughout the process.

Researchers loosely followed a participant observation, place-based qualitative research methodology, using conversational interviews for data collection. In-person focus groups of five to eight participants proved to be logistically difficult to schedule, and instead, on-farm, individual interviews were chosen as the format for most data gathering. Personal interviews were held on 23 farms, often lasting three to five hours, with an average time of 2.75 hours. One focus group did proceed as originally planned, involving eight industry association representatives. The focus group lasted 3.5 hours, and researchers noticed that the responses shared in the group lacked depth compared to those from the individual interviews.

The one-on-one, kitchen table conversation-style interviews in producers' own homes allowed them to feel comfortable enough to share honestly and gave them the time to reflect and provide thoughtful feedback. Researchers reported that producers "had much to share and were deeply reflective in answering the questions" (FWWF, 2015, p.4).

2016-17 Feasibility Study for Online Regenerative Agriculture Portal

FWWF recognized an opportunity to strengthen the local Alberta food system, improve food security, connect producers and consumers, and promote regenerative agriculture. A market analysis was conducted which included a detailed competitive analysis, a competitor canvas, and a summary of collaborative opportunities (FWWF, 2017). Market research also assessed consumer perspectives on products, pricing, delivery, and knowledge about regenerative farming; these included consumer focus groups, network polling, packaging research, and consultation with the Canada Centre for Beef Excellence (FWWF, 2017).

A comprehensive needs assessment was conducted through engagement with a group of 21 local producers; two-thirds of producers were aged 25-49 years and one-third were over 50 years. Participating producers were in contact with the FWWF Executive Director and the project team and had opportunities to participate in holistic management workshops or at FWWF events. FWWF assessed producers' needs through this ongoing engagement as well as through extensive surveys and interviews.

Findings from the market analysis and the producer needs assessment were compiled and presented in a report titled *Feasibility study, market research, and strategic planning for the development of online regenerative agricultural portal* (FWWF, 2017). The report also included strategic planning for the proposed freshlygrown.ca platform.

2021 Producer Engagement Sessions

Producer engagement continued in 2021, but now with a more specific focus on hearing producers' perspectives on barriers to regenerative agriculture (FWWF, 2021). FWWF collaborated with local applied research & forage associations to develop the survey questions, as well as the scope, methodology, and format of engagement research sessions.

Engagement sessions were hosted at various locations throughout Alberta and were often held in conjunction with a soil health workshop. Producers were invited to the event through the local applied research & forage associations; however, the events were also open to the public and anyone who wanted to attend was included. Producer participants were primarily grain and cattle farmers, as well as a few market garden and vegetable growers.

Prior to the survey questions and discussion, a short presentation was given to participants describing the Regenerative Alberta Living Lab, the purpose of the engagement research, and that the responses collected would be used to inform initiatives through the Living Lab. Informed consent was then collected through FWWF's data collection and privacy policy as mentioned above.

Data was collected through focus groups of up to 35 participants, including those who attended in person as well as those who attended through an online video platform. Through the use of open-ended questions, a semi-structured format, and the opportunity for discussion among participants, researchers were able to gather detailed and thoughtful responses. Responses were recorded on a screen that was visible to participants, to ensure accuracy in data collection, and participants were free to correct or make clarifications to their recorded responses. Focus group discussions were also audio recorded with participants' informed consent.

All participants were asked four primary questions related to their Goals, Practices, Barriers/Fears, and Interests. With the open-ended, discussion format of the sessions, some follow-up questions and discussions emerged from the four primary questions. Producer engagement responses were compiled and used to inform the creation of the Regenerative Alberta Living Lab initiative.

2023 Trusted Advisors Study

The qualitative, participant observation methodology continued with the Trusted Advisors (TA) study in 2023. Through their broad, existing network of stakeholders, FWWF identified key individuals who could contribute valuable feedback related to producers' perspectives on the barriers to regenerative agriculture in the Canadian Prairies. These individuals were contacted and invited to participate in the TA engagement project (FWWF, 2023a). The final group of participants in the Trusted Advisors study included individuals representing 86 organizations and institutions (including 12 producer-led organizations) from 13 sectors and five geographical regions.

Data collection involved five focus groups and 59 individual interviews, as well as networking and informal engagement at three conferences. Overall, responses were drawn from a knowledge base of 130+ producers. Participants had existing, trusted relationships with FWWF, and through the use of open-ended questions, researchers were able to gather detailed and thoughtful responses. Findings from the TA study were compiled in the *Trusted Advisors in the Canadian Prairies* report in April 2023 (FWWF, 2023b).

Regenerative Alberta Living Lab – 2023 and Ongoing

Starting in 2023, the Regenerative Alberta Living Lab (RALL) began collecting data from Alberta producers through a Simple Survey online questionnaire, which was advertised to potential participants through the mailing lists of the Alberta Environmental Farm Plan and partner organizations. The initial questionnaire provides a baseline of information from participating producers, including basic demographics, as well as questions on their farm operations, and the BMPs they currently use or plan to use in the next five years (RALL, 2023b). It also included the questions below, asking about the resources they have access to, and who they go to for farming operation support:

- Do you feel you have the resources and support you need when you have questions and need assistance with problem solving on your operation?
- How would you describe your experiences with finding the information you need to make a decision about changing your farm management practices?
- Where do you go for information and support when you need it for running your operation?

The responses from this baseline questionnaire will inform the Knowledge and Technology Transfer (KTT) component of the RALL. Responses were anonymized and aggregated, encrypted and stored on Canadian servers, and shared with partnered researchers and organizations. Informed consent was obtained through participants' actions of reading survey instructions, completing the survey, and submitting it. At the end of the five-year RALL program, producers will complete a similar questionnaire to track changes in BMP adoption over the course of the program.

RALL Quarterly Producer Discussions – 2023 and Ongoing

RALL producers have access to regional, in-person, core producer co-development sessions, where small discussion groups can engage on priorities for research and pressing issues that producers are working to overcome. Throughout the year, RALL producers also have the opportunity to participate in quarterly producer roundtable discussions.

Roundtable discussions typically use a breakout room format, creating a smaller number of participants in each group that allows each participant to have more speaking time. FWWF facilitators will ask one or more open-ended questions, such as the following:

- What BMPs do you need more info on?
- What practices would you like to try?
- What BMPs have you already implemented?

Producers can use these discussions as opportunities to talk about what's working and what's not working for them, to share knowledge and ideas with each other, and to report their needs and challenges to the FWWF team. Agronomists and scientists also participate in the discussions and can provide knowledge and expertise to producers when appropriate. At the most recent producer roundtable discussion in November 2023, producers were given the following prompt for discussion (RALL, 2023c):

Please share what you see or have experienced as barriers to adoption of regenerative agriculture beneficial management practices. Is it a lack of awareness, agronomic know how, expenses, equipment or that for most people it's too out there?

Producers are encouraged to share barriers to specific BMPs, as well as barriers to regenerative agriculture as a whole system. Responses are collected on a spreadsheet that categorizes all barriers by specific BMP. Asking producers to speak about specific BMPs allowed some key barriers to emerge that had not previously been recorded in past FWWF producer engagement sessions.

Upon joining the Living Lab program, producers give informed consent for data collection in Living Lab events and discussions, and for their personal responses to be recorded and used in FWWF research. Insights and perspectives from RALL producers are collected at these producer discussions and used to inform further development of the RALL program and further research initiatives on regenerative agriculture in the Prairies.

Limitations

It should be noted that there are limitations to the methodologies used in FWWF engagement sessions. As is common with qualitative exploratory research, the findings are subject to biases arising from the selection of study participants. Producers interviewed in FWWF engagement sessions either self-selected or were recruited by convenience sampling or purposive sampling, resulting in a sample that over-represents regenerative-minded producers. This introduces both volunteer bias and sampling bias to the findings. Thus, the collected producer responses reveal barriers that apply to regenerative Prairie producers but are not necessarily generalizable to the greater population of conventional Prairie producers.

While the generalizability of the engagement research is low, qualitative findings are typically not broadly generalizable, nor is generalizability the desired objective of qualitative research. Rather, these engagement sessions were meant to deeply explore the experiences and perspectives of Prairie producers who have encountered barriers in their journeys to adopt regenerative agriculture.

To counteract these selection biases, FWWF has worked to build rigour into their research. They have sought diversity in their sample populations, with producer participants representing a wide variety of geographic regions, farm sizes, farming methods, and farmed products. They have also replicated the engagement research with different groups of participants, in online formats through Simple Survey and Huxly, as well as in-person through the 2021 Producer Engagement, the 2023 Trusted Advisor Study, and the ongoing RALL producer roundtable discussions. FWWF also fostered strong researcher-participant relationships to earn the trust of their participants and to create an environment where producers felt comfortable enough to give honest and authentic responses.

Finally, FWWF used a systems approach lens to regenerative agriculture in the majority of their producer engagement research. Engagement questions and discussion prompts were intended to reveal barriers to regenerative agriculture adoption as a whole system. While some questions did aim to determine which BMPs had been adopted or which BMPs producers needed help with, questions were not designed to uncover specific barriers to individual BMPs. Thus, FWWF producer responses on barriers to individual BMPs are limited. Framing regenerative agriculture through the systems approach is not itself a limitation, however, it misaligns somewhat with the *Producer Perspectives on Barriers to Adoption of Regenerative Agriculture* report, which uses a reductionist approach to discuss barriers to individual BMPs.

References

Abacus Data. (2018, February). *Perceptions of carbon pricing in Canada.* Canada's Ecofiscal Commission. http://ecofiscal.ca/wp-content/uploads/2018/04/Ecosfiscal_Polling_February2018_FINAL_RELEASE.pdf

AFSC. (2023a). *Canada-Alberta Wildlife Damage Compensation Program.* https://afsc.ca/wp-content/uploads/2023/04/2023-Wildlife-Damage-Compensation-Program.pdf

AFSC. (2023b). *Cereal and oilseeds crops insuring agreement: For 2023 annual crops.* https://afsc.ca/wp-content/uploads/2023/03/2023-Cereal-and-Oilseeds-Insuring-Agreement.pdf

Agriculture and Agri-Food Canada. (2009, June). *Canadian Agricultural Loans Act (CALA) Lenders' Guidelines.* https://agriculture.canada.ca/sites/default/files/legacy/resources/prod/doc/prog/cala-lcpa/pdf/cala-lcpa_info_e.pdf

Agriculture and Agri-Food Canada. (2020, January 31). *Variable rate nutrient application: Should I consider it for my farm?* https://agriculture.canada.ca/en/agricultural-production/soil-and-land/soil-nutrients/variable-rate-nutrient-application-should-i-consider-it-my-farm

Agriculture and Agri-Food Canada. (2021, June 25). *Polycultures: A cocktail mix for the semiarid prairies.* https://agriculture.canada.ca/en/science/story-agricultural-science/scientific-achievements-agriculture/polycultures-cocktail-mix-semiarid-prairies

Agriculture and Agri-Food Canada. (2023a, June 9). *Regenerating hope*. https://agriculture.canada.ca/en/sector/canadian-food-system/taste-commitment/regenerating-hope

Agriculture and Agri-Food Canada. (2023b, July 24). *About the Living Laboratories approach.* https://agriculture.canada.ca/en/science/living-laboratories-initiative/about-living-laboratories-initiative

Agriculture and Agri-Food Canada. (2023c, December 18). *Agricultural Climate Solutions – On-Farm Climate Action Fund.* https://agriculture.canada.ca/en/programs/agricultural-climate-solutions-farm-climate-action-fund#find

Agriculture and Agri-Food Canada. (2023d, December 19). *Agricultural Climate Solutions – Living Labs.* https://agriculture.canada.ca/en/environment/climate-change/agricultural-climate-solutions/agricultural-climate-solutions-living-labs

Agriculture and Agri-Food Canada. (2024, March 5). *Governments of Canada and Saskatchewan announce 2024 Crop Insurance Program enhancements.* https://www.canada.ca/en/agriculture-agri-food/news/2024/03/government-of-canada-and-saskatchewan-announce-2024-crop-insurance-program-enhancements.html

Alberta Agriculture and Irrigation. (2016, March 15). *Winter grazing systems: Feed quality in bunch grazing* [Video]. YouTube. https://www.youtube.com/watch?v=AjrjLnbjTv4

Alberta Agriculture, Food, and Rural Development. (2004). *Beneficial Management Practices: Environmental manual for crop producers in Alberta.* https://open.alberta.ca/publications/3033430

ALUS Canada. (n.d.) *Regenerative Agricultural Practices.* https://alus.ca/growing-roots/

Amiro, B., Tenuta, M., Hanis-Gervais, K., Gao, X., Flaten, D., Rawluk, C. (2017). Agronomists' views on the potential to adopt beneficial greenhouse gas nitrogen management practices through fertilizer management. *Canadian Journal of Soil Science, 97*, 801-804. https://doi.org/http://dx.doi.org/10.1139/cjss-2017-0062

Ampong, K., Thilakaranthna, M. S., Gorim, L. Y. (2022). Understanding the role of humic acids on crop performance and soil health. *Frontiers in Agronomy, 4*, 848621. https://doi.org/10.3389/fagro.2022.848621

Association for Temperate Agroforestry. (n.d.). *What is agroforestry?* https://www.aftaweb.org/about/what-is-agroforestry.html

Awada, L., Lindwall, C.W., Sonntag, B. (2014). The development and adoption of conservation tillage systems on the Canadian Prairies. *International Soil and Water Conservation Research*, *2*(1), 47-65. https://doi.org/10.1016/S2095-6339(15)30013-7

Awada, L., Nagy, C., & Phillips, P. W. B. (2021). Contribution of land use practices to GHGs in the Canadian Prairies crop sector. *PLoS ONE, 16*(12), e0260946. https://doi.org/10.1371/journal.pone.0260946

Bain. (2021, February). *Producer Engagement Research*. [Unpublished report].

Bainard, J. D., Serajchi, M., Bainard, L. D., Schellenberg, M. P., & Lamb, E. G. (2020). Impact of diverse annual forage mixtures on weed control in a semiarid environment. *Frontiers in Sustainable Food Systems, 4*, 92. https://doi.org/10.3389/fsufs.2020.00092

Barrera, L. (2020, March 2). *How to get effective cover crop termination with roller-crimping.* Cover Crop Strategies. https://www.covercropstrategies.com/articles/994-how-to-get-effective-cover-crop-termination-with-roller-crimping

Beef Cattle Research Council. (2021, January 8). *Intercropping can be a win win for mixed operations.* Alberta Farmer Express. https://www.albertafarmexpress.ca/livestock/intercropping-can-be-a-win-win-for-mixed-operations/

Behavioral Economics. (n.d.). *Status quo bias.* BehavioralEconomics.com https://www.behavioraleconomics.com/resources/mini-encyclopedia-of-be/status-quo-bias/

Ben-Othmen, M. A. & Ostapchuk, M. (2023). How diverse are farmers' preferences for large-scale grassland ecological restoration? Evidence from a discrete choice experiment. *Review of Agricultural, Food, and Environmental Studies.* 1-35. https://doi.org/10.1007/s41130-023-00200-x

Bertrand, S. & Lange, S. (2019, February 14). *Biochar registration in Canada for energy, soil, and horticultural use.* Pyrolist. https://pyrolist.com/blog/post/biochar-registration-Canada

Blair, J. (2015, July 8). *Check your numbers. Is it worth spending money on a foliar fertilizer?* Alberta Farmer Express. https://www.albertafarmexpress.ca/crops/run-the-numbers-again-is-it-worth-spending-the-money/

Bogdan, A.-M., & Kulshreshtha, S. N. (2021). Canadian horticultural growers' perceptions of beneficial management practices for improved on-farm water management. *Journal of Rural Studies*, *87*, 77-87. https://doi.org/10.1016/j.jrurstud.2021.08.020

Bradford, L., Thapa, A., Duffy, A., Hassanzadeh, E., Strickert, G., Noble, B., & Lindenschmidt, K.-E. (2020). Incorporating social dimensions in hydrological and water quality modeling to evaluate the effectiveness of agricultural beneficial management practices in a Prairie River Basin. *Environmental Science & Pollution Research*, *27*(13), 14271–14287. https://doi.org/10.1007/s11356-019-06325-1

Brammer, T. A. and Bennett, D. E. (2022). Arriving at a natural solution: Bundling credits to access rangeland carbon markets. *Rangelands, 44*(4), 281-290. https://doi.org/10.1016/j.rala.2022.04.001

Briere, K. (2021). *Intercrop no "home run" but has potential.* The Western Producer. https://www.producer.com/crops/intercrop-no-home-run-but-has-potential/

Burton, R. J. F., Kuczera, C., & Schwarz, G. (2008). Exploring farmers' cultural resistance to voluntary agri-environmental schemes. *Sociologia Ruralis*, *48*(1), 16-37. https://doi.org/10.1111/j.1467-9523.2008.00452.x

Cagdas, A. D., Jeffrey, S. R., Boxall, P. C., & Smith, E. G. (2016). Environmental Stewardship and Technical Efficiency in Canadian Prairie Canola Production. *Canadian Journal of Agricultural Economics*, *64*(3), 455-477. https://doi.org/10.1111/cjag.12087

Canadian General Standards Board. (2018, March). *Organic production systems – General principles and management standards*. https://cog.ca/wp-content/uploads/2023/08/032_0310_2015-e_Amended-in-2018.pdf

Carlisle, L., Esquivel, K., Baur, P., Ichikawa, N. F., Olimpi, E. M., Ory, J., Waterhouse, H., Iles, A., Karp, D. S., Kremen, C., & Bowles, T. M. (2022). Organic farmers face persistent barriers to adopting diversification practices in California's Central Coast. *Agroecology and Sustainable Food Systems, 46*(8), 1145-1172. https://doi.org/10.1080/21683565.2022.2104420

Case, S. D. C., Oelofse, M., Hou, Y., Oenema, O., & Jensen, L. S. (2017). Farmer perceptions and use of organic waste products as fertilisers – A survey study of potential benefits and barriers. *Agricultural Systems, 151.* 84-95. http://dx.doi.org/10.1016/j.agsy.2016.11.012

Center for Theory of Change. (n.d.) *How does theory of change work?* Center for Theory of Change, Inc.
https://www.theoryofchange.org/what-is-theory-of-change/how-does-theory-of-change-work/

Centola, D., Becker, J., Brackbill, D., & Baronchelli, A. (2018). Experimental evidence for tipping points in social convention. *Science*, *360*(6393), 1116-1119.
https://doi.org/10.1126/science.aas8827

Clare, S. & Creed, I.F. (2022). The Essential Role of Wetland Restoration Practitioners in the Science-Policy-Practice Process. *Frontiers in Ecology and Evolution*, *10*.
https://doi.org/10.3389/fevo.2022.838502

Cowan, N., Adams, E. J., Bhangal, S., Corcoran, M., Decker, R., Doctor, C. E., Eubank, A. T., Gann, C. L., Greene, N. R., Helle, A. C., Lee, N., Nguyen, A. T., Ripley, K. R., Scofield, J. E., Tapia, M. A., Threlkeld, K. L., & Watts, A. L. (2019). Foundations of Arrogance: A broad survey and framework for research. *Review of General Psychology, 23*(4), 425-443.
https://doi.org/10.1177%2F1089268019877138

Cross, B. (2022, November 10). *Less flax straw burned as local demand grows.*
https://www.producer.com/news/less-flax-straw-burned-as-local-demand-grows/

Davidson, D. J., Rollins, C., Lefsrud, L., Anders, S., & Hamman, A. (2019). Just don't call it climate change: Climate-skeptic farmer adoption of climate-mitigative practices. *Environmental Research Letters, 14,* 034015. https://doi.org/10.1088/1748-9326/aafa30

Davidson, E.A., Suddick, E.C., Rice, C.W., and Prokopy, L.S. (2015). More food, low pollution (Mo Fo Lo Po): A grand challenge for the 21st century. *Journal of Environmental Quality, 44*, 305-311. https://doi.org/https://doi.org/10.2134/jeq2015.02.0078

Doran, E. M. B., Doidge, M., Aytur, S., & Wilson, R. S. (2022). Understanding farmers' conservation behavior over time: A longitudinal application of the transtheoretical model of behavior change. *Journal of Environmental Management, 323*, 116136. https://doi.org/10.1016/j.jenvman.2022.116136

Drever, C. R., Cook-Patton, S. C., Kroeger, T., Leavitt, S. M., Yeo, S., Akhter, F., Soolanayakanahally, R. Y., Badiou, P. H., Chmura, G. L., Davidson, S. J., Strack, M., Desjardins, R. L., Worth, D. E., Dyk, A., Fellows, M., LeClerc, M.-E., Neilson, E., Smyth, C., Kurz, W. A., … Woodbury, P. B. (2021a). Natural climate solutions for Canada. *Science Advances*, *7*(23). https://doi.org/10.1126/sciadv.abd6034

Drever, C. R., Cook-Patton, S. C., Kroeger, T., Leavitt, S. M., Yeo, S., Akhter, F., Soolanayakanahally, R. Y., Badiou, P. H., Chmura, G. L., Davidson, S. J., Strack, M., Desjardins, R. L., Worth, D. E., Dyk, A., Fellows, M., LeClerc, M.-E., Neilson, E., Smyth, C., Kurz, W. A., … Woodbury, P. B. (2021b). Natural climate solutions for Canada. *Science Advances*, *7*(23, Suppl.), S1-81. https://doi.org/10.1126/sciadv.abd6034

Ducks Unlimited Canada. (n.d.-a). *Farm less, make more.* https://ag.ducks.ca/wp-content/uploads/2022/04/AB-MAP-PF.NAWMP_04.2023.pdf

Ducks Unlimited Canada. (n.d.-b) *Marginal areas program.* https://www.ducks.ca/resources/landowners/marginal-areas-program/

Ducks Unlimited Canada. (n.d.-c). *Wetland Restoration.* https://www.ducks.ca/resources/landowners/wetland-restoration/

Ducks Unlimited Canada. (2020, January). *FAQs about DUC's wetland restoration lease program.* https://ag.ducks.ca/wp-content/uploads/2022/04/AB-WR-2020.pdf

Ducks Unlimited Canada. (2022). *What's happening to Canada's vanishing wetlands? Without a proper inventory, we won't truly know*. What's happening to Canada's vanishing wetlands? — Ducks Unlimited Canada

EFAO – Ecological Farmers Association of Ontario. (2022, February 10). *Forays into silvopasture*. Ecological Farmers Association of Ontario. https://efao.ca/forays-into-silvopasture/

Ejack, L., Whalen, J. K., Major, J., and Husk, B. R. (2021). Biochar application on commercial field crops using farm-scale equipment. *Canadian Biosystems Engineering*, *63*(1), 6.1-6.8. https://doi.org/10.7451/CBE.2021.63.6.1

Entz, M. H., Bullied, W. J., & Katepa-Mupondwa, F. (1995). Rotational benefits of forage crops in Canadian Prairie cropping systems. *Journal of Production Agriculture, 8*(4), 521-529. https://doi.org/10.2134/jpa1995.0521

Entz, M. H., Baron, V. S., Carr, P. M., Meyer, D. W., Smith, S. R., Jr., & McCaughey, W. P. (2002). Potential of forages to diversify cropping systems in the Northern Great Plains. *Agronomy Journal, 94*, 240-250. https://doi.org/10.2134/agronj2002.2400

Evans. I. (2020, May 19). *The facts and fallacies of foliar feeding and other mistaken beliefs.* Grainews. https://www.grainews.ca/columns/the-facts-and-fallacies-of-foliar-feeding-and-other-mistaken-beliefs/

Farm Credit Canada. (n.d.). *Sustainability Incentive Program.* https://www.fcc-fac.ca/en/financing/agriculture/sustainability-incentive-program.html

Farmers for Climate Solutions. (n.d.). *Farm Resilience Mentorship FAQs*. https://farmersforclimatesolutions.ca/learning-hub

Fertilizer Canada. (2018). *Key Findings of the Canadian 4R Research Network.* https://fertilizercanada.ca/wp-content/uploads/2018/08/fc_4R-key-findings2018_en_vf-digital.pdf

Fertilizer Canada. (2019). *4R Practices Guidance Document.* https://fertilizercanada.ca/wp-content/uploads/2019/06/4R-Guidance-Tables.pdf

Fertilizer Canada. (2021). *4R Nutrient Stewardship Grower Adoption across Canada.* https://fertilizercanada.ca/wp-content/uploads/2022/08/SPARK-FERTILIZER-USE-IN-CANADA-REPORT-2022-VF_08_04_2022.pdf

Fertilizer Canada. (2023). *4R's Across Canada.* https://fertilizercanada.ca/our-focus/stewardship/4rs-across-canada/

Fitch, L. Adams, B., O'Shaughnessy, K. (2003). *Riparian areas and grazing management.* Cows and Fish Program. https://www.google.com/url?q=https://cowsandfish.org/wp-content/uploads/greenzone3rd.pdf&sa=D&source=docs&ust=1709601294055682&usg=AOvVaw2BHtFtx4rqhueEi3MWW6rv

Fixen, P. E. (2020). A brief account of the genesis of 4R nutrient stewardship. *Agronomy Journal, 112*, 4511-4518. https://doi.org/10.1002/agj2.20315

Food Water Wellness Foundation. (n.d.-a). *Core beliefs that guide our work.* http://www.foodwaterwellness.org/core-beliefs.html

Food Water Wellness Foundation. (n.d.-b). *Regenerative Alberta Living Lab Application.* [Unpublished report]

Food Water Wellness Foundation. (2015). *Needs Assessment Report.* [Unpublished report].

Food Water Wellness Foundation. (2017). *Feasibility study, market research, and strategic planning for the development of online regenerative agricultural portal.* [Unpublished report].

Food Water Wellness Foundation. (2021). *Producer Engagement Sessions.* [Unpublished dataset].

Food Water Wellness Foundation. (2023a, January 27). *Nature United Interview Summary.* [Unpublished dataset].

Food Water Wellness Foundation. (2023b, April 30). *Trusted Advisors in the Canadian Prairies.* [Unpublished report].

Food Water Wellness Foundation. (2024). *Food Water Wellness Foundation: Our Approach to Producer Engagement on the Canadian Prairies 2013-2024.* [Unpublished report].

Foster, A., Vera, C.L., Malhi, S.S., and Clarke, F.R. (2014). Forage yield of simple and complex grass legume mixtures under two management strategies. *Canadian Journal of Plant Science, 94*, 4150. https://doi.org/10.4141/cjps2013-095

Frison, E. A. (2016). *From uniformity to diversity: A paradigm shift from industrial agriculture to diversified agroecological systems.* International Panel of Experts on Sustainable Food Systems. https://www.ipes-food.org/_img/upload/files/UniformityToDiversity_FULL.pdf

Froese, S., Wiens, J. T., Warkentin, T., Schoenau, J. J. (2020). Response of canola, wheat, and pea to foliar phosphorus fertilization at a phosphorus-deficient site in eastern Saskatchewan. *Canadian Journal of Plant Science, 100*, 642-652. http://dx.doi.org/10.1139/cjps-2019-0276

Furber, D. (2014, January 9). *Bunching saves a bundle.* Canadian Cattlemen – The Beef Magazine. https://www.canadiancattlemen.ca/features/bunching-saves-a-bundle/

Gabriel, S. (2018, June 28). *Six key principles for a successful silvopasture*. Cornell College of Agricultural and Life Sciences. https://smallfarms.cornell.edu/2018/06/six-key-principles-for-a-successful-silvopasture/

General Mills. (n.d.). *Farmers and General Mills are two peas in a pod.* https://www.generalmills.ca/how-we-make-it/healthier-planet/environmental-impact/regenerative-agriculture/for-farmers

Government of Alberta. (n.d.-a). *Beneficial management practices.* https://www.alberta.ca/beneficial-management-practices

Government of Alberta. (n.d.-b). *Farm Technology Program.* https://www.alberta.ca/farm-technology-program

Government of Alberta. (n.d.-c). *On-Farm Value-Added Program.* https://www.alberta.ca/on-farm-value-added-program

Government of Alberta. (n.d.-d). *Resilient Agricultural Landscape Program.* https://www.alberta.ca/resilient-agricultural-landscape-program

Government of Alberta. (n.d.-e). *Sustainable Canadian Agricultural Partnership in Alberta.* https://www.alberta.ca/sustainable-cap

Government of Alberta. (n.d.-f). *Water Program*. https://www.alberta.ca/water-program

Government of Alberta (2015, September). *Manure spreading regulations.* https://open.alberta.ca/dataset/2e2b118d-9289-47ba-813e-866f7033df78/resource/7de30eb8-e959-4cbc-9a2b-879cab04a031/download/2015-096-5-web.pdf

Government of Canada. (2016). *Water sources: Wetlands*. https://www.canada.ca/en/environment-climate-change/services/water-overview/sources/wetlands.html

Government of Canada. (2020). *Forestry glossary: Silvopasture*. https://cfs.nrcan.gc.ca/terms/read/1058

Government of Canada. (2021). *Intercropping – a new planting method for large-scale Prairie agriculture?* Intercropping – a new planting method for large-scale Prairie agriculture? - agriculture.canada.ca

Government of Manitoba. (n.d.). *Green manure*. https://www.gov.mb.ca/agriculture/crops/crop-management/forages/green-manure.html

Government of Saskatchewan. (n.d.-a). *Deep Tillage*. https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/soils-fertility-and-nutrients/deep-tillage

Government of Saskatchewan. (n.d.-b). *Soil Improvements with Legumes.* https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/soils-fertility-and-nutrients/soil-improvements-with-legumes

Guo, M., Minori Uchimiya, S., & He, Z. (2016). Agricultural and environmental applications of biochar: Advances and barriers. In M. Guo, Z. He, and S. Minori Uchimiya (Eds.), *Agricultural and environmental applications of biochar: Advances and barriers.* (pp.495-504). Soil Science Society of America, Inc. https://doi.org/10.2136/sssaspecpub63.2014.0054

Hanson, J. D., Liebig, M. A., Merrill, S. D., Tanaka, D. L., Krupinsky, J. M., & Stott, D. E. (2007). Dynamic cropping systems: Increasing adaptability amid an uncertain future. *Agronomy Journal, 99*(4), 939–943. https://doi:10.2134/agronj2006.0133

Hayden, J., Rocker, S., Smith, A., Phillips, H., Heins, B., & Delate, K. (2018). The importance of social support and communities of practice: Farmer perceptions of the challenges and opportunities of integrated crop-livestock systems on organically managed farms in the Northern U.S. *Sustainability (Switzerland)*, *10*(12). https://doi.org/10.3390/su10124606

Heppner, K. (2018). *Intercropping for rookies: Overcoming the unknown.* Real Agriculture. https://www.realagriculture.com/2018/01/advice-for-getting-into-intercropping/

Hesselink, B. & Thevathasan, N. V. (2014, July 31). *Agroforestry.* The Canadian Encyclopedia. https://www.thecanadianencyclopedia.ca/en/article/agroforestry

Horsch, C. (2023). In G. Gilchrist (Ed.), *The Canada Grassland Protocol: A backgrounder*. Canadian Forage and Grassland Association. https://www.canadianfga.ca/uploads/source/Grace/CGP_Final_Web.pdf

Hou, Y., Velthof, G. L., Case, S. D. C., Oelofse, M., Grignani, C., Balsari, P., Zavattaro, L., Gioelli, F., Bernal, M. P., Fangueiro, D., Trindade, H., Jensen, L. S., Oenema, O. (2018). Stakeholder perceptions of manure treatment technologies in Denmark, Italy, the Netherlands, and Spain. *Journal of Cleaner Production, 172*, 1620-1630. http://dx.doi.org/10.1016/j.jclepro.2016.10.162

Hurlbert, M. (2014). Adaptive institutional design in agri-environmental programs. *International Journal of Climate Change Strategies and Management, 6*(2), 145-165. https://doi.org/10.1108/IJCCSM-12-2012-0076

Hurlbert, M., Fletcher, A., Sauchyn, D., Diaz, H. (2020a). Climate Change, Agriculture and Communities in the South Saskatchewan River Basin. In P. Mussetta and M. Hurlbert (Eds.), *Vulnerability studies in the Americas : extreme weather and climate change* (pp.22-52). Cambridge Scholars Publishing.

Hurlbert, M., Wheaton, E., Sauchyn, D. (2020b). Integrating Canadian Components of the Vulnerability and Adaptation to Climate Extremes in the Americas (VACEA) Project – Canada. In P. Mussetta and M. Hurlbert (Eds.), *Vulnerability studies in the Americas : extreme weather and climate change* (pp.53-76). Cambridge Scholars Publishing.

International Biochar Initiative. (2015, November 23). *Standardized product definition and product testing guidelines for biochar that is used in soil.* https://biochar-international.org/wp-content/uploads/2019/01/IBI_Biochar_Standards_V2.1_Final1.pdf

IPES-Food. 2016. *From uniformity to diversity: a paradigm shift from industrial agriculture to diversified agroecological systems*. International Panel of Experts on Sustainable Food systems. https://ipes-food.org/_img/upload/files/UniformityToDiversity_FULL.pdf

Jeffers-Bezan, M. (2023, December 5). *Surveyed producers report soil health benefits to cover cropping.* Canadian Cattlemen. https://www.canadiancattlemen.ca/research/surveyed-producers-report-soil-health-benefits-to-cover-cropping/

Jones, D. (2018, March 13). *Foliar fertiliser could benefit farmers in post-Brexit world.* Farmers Weekly. https://www.fwi.co.uk/arable/crop-management/nutrition-and-fertiliser/foliar-fertiliser-could-benefit-farmers-in-post-brexit-world

Jungnitsch, P., Lardner, H. A., & Schoenau, J. J. (n.d.). *The effect of winter cattle feeding systems on soil nutrients, forage growth, animal performance, and economics.* Mackenzie Applied Research Association. https://www.mackenzieresearch.ca/wp-content/uploads/2021/04/The-Effect-of-winter-cattle-feeding-systems-on-soil-nutrients-forage-growth-animal-performances-and-Economics.pdf

Kelln, B. M., Penner, G. B., Acharya, S. N., McAllister, T. A., Larson, K., McKinnon, J. J., Biligetu, B., & Lardner, H. A. (2022). Effect of sod-seeding bloat-free legumes on pasture productivity, steer performance, and production economics. *Canadian Journal of Animal Science, 102*, 352-367. https://doi.org/http://dx.doi.org/10.1139/cjas-2021-0098

Khatiwada, B., Acharya, S.N., Larney, F.J., Lupwayi, N.Z., Smith, E.G., Islam, M.A., & Thomas, J.E. (2020). Benefits of mixed grass-legume pastures and pasture rejuvenation using bloat-free legumes in western Canada: a review. *Canadian Journal of Plant Science, 100,* 463-476. https://doi.org/10.1139/cjps-2019-0212

Khattak, S. I., Baloch, M. S., Naveed, K., Khan, E. A. (2017). Improving farmer's income and nitrogen use efficiency of dry land wheat through soil and foliar application of N-fertilizer. *Sarhad Journal of Agriculture, 33*(3), 344-349. http://dx.doi.org/10.17582/journal.sja/2017/33.3.344.349

Kienlen, A. (2022a). *Cover cropping program looks to encourage innovation.* Alberta Farmer Express. https://www.albertafarmexpress.ca/crops/cover-cropping-program-looks-to-encourage-innovation/

Kienlen, A. (2022b). *For the first time in generations, bison have returned to traditional lands.* Alberta Farmer Express. https://www.albertafarmexpress.ca/news/for-the-first-time-in-generations-bison-have-returned-to-traditional-lands/

Kort, J., White, L., Svendsen, E. (2008) Silvopasture principles and potential in Saskatchewan. *Harvest.* Retrieved November 15, 2023, from http://hdl.handle.net/10388/9316

Kreitzman, M., Chapman, M., Keeley, K. O., & Chan, K. M. A. (2022). Local knowledge and relational values of Midwestern woody perennial polyculture farmers can inform tree-crop policies. *People and Nature, 4*, 180-200. https://doi.org/10.1002/pan3.10275

Krumrei-Mancuso, E. J., Haggard, M. C., LaBouff, J. P., & Rowatt, W. C. (2020). Links between intellectual humility and acquiring knowledge. *The Journal of Positive Psychology, 15*(2), 155-170. https://doi.org/10.1080/17439760.2019.1579359

Kuepper, G. (2003). *Foliar Fertilization.* Appropriate Technology Transfer for Rural Areas (ATTRA). https://attra.ncat.org/wp-content/uploads/2022/10/foliar.pdf

Kulshreshtha, S., Undi, M., Zhang, J., Ghorbani, M., Wittenberg, K., Stewart, A., Salvano, E., Kebreab, E., & Ominski, K. (2015). Challenges and opportunities in estimating the value of goods and services in temperate grasslands – A case study of Prairie grasslands in Manitoba, Canada. In V. Pilipavicius (Ed.), *Agroecology* (pp. 147-169). IntechOpen. https://www.intechopen.com/chapters/48163

Laforge, J. M. L. & McLachlan, S. M. (2018). Learning communities and new farmer knowledge in Canada. *Geoforum, 96*, 256-267. https://doi.org/10.1016/j.geoforum.2018.07.022

Lamba, P., Filson, G., & Adekunle, B. (2009). Factors affecting the adoption of best management practices in southern Ontario. *The Environmentalist*, *29*(1), 64–77. https://doi.org/10.1007/s10669-008-9183-3

Latawiec, A. E., Krolczyk, J. B., Kubon, M., Szwedziak, K., Drosik, A., Polanczyk, E., Grotkiewicz, K. & Strasbourg, B. B. N. (2017a). Willingness to adopt biochar in agriculture: The producer's perspective. *Sustainability, 9*(4), 655. https://doi.org/10.3390/su9040655

Latawiec, A. E., Krolczyk, J. B., Kubon, M., Szwedziak, K., Drosik, A., Polanczyk, E., Grotkiewicz, K. & Strasbourg, B. B. N. (2017b). Willingness to adopt biochar in agriculture: The producer's perspective. *Sustainability, 9*(4), 655(Suppl.) https://www.mdpi.com/2071-1050/9/4/655/s1

Lawley, Y. (2020, February). Cover crop research across the Prairies. *Better Farming, Prairie edition,* 53-56. https://www.betterfarming.com/magazine/better-farming-prairies-magazine-february-2020

Ledo, A. Smith, P., Zerihun, A., Whitaker, J., Vicente-Vicente, J. L., Qin, Z., McNamara, N. P., Zinn, Y. L., Llorente, M., Liebig, M., Kuhnert, M., Dondini, M., Don, A., Diaz-Pines, E., Datta, A., Bakka, H., Aguilera, E., Hillier, J. (2020). Changes in soil organic carbon under perennial crops. *Global Change Biology, 26*, 4158-4168. https://doi.org/10.1111/gcb.15120

Lee, B. C., Bendixsen, C. G., Liebman, A. K., & Gallagher, S. (2017). Using the socio-ecological model to frame agricultural safety and health interventions*. Journal of Agromedicine, 22*(4), 298-303. https://doi.org/10.1080/1059924X.2017.1356780

Legere, A., Shirtliffe, S. J., Vanasse, A., & Gulden, R. H. (2013). Extreme grain-based cropping systems: When herbicide-free weed management meets conservation tillage in Northern climates. *Weed Technology, 27*(1), 204-211. https://doi.org/10.1614/WT-D-12-00074.1

Lindgren, P.M.F. & Sullivan, T.P. (2013). Response of forage yield and quality to thinning and fertilization of young forests: implications for silvopasture management. (2013). *Canadian Journal of Forest Research*, *44*(4), 281–289. https://doi.org10.1139/cjfr-2013-0248

Liska, A. J., Yang, H., Milner, M., Goddard, S., Blanco-Canqui, H., Peloton, M. P., Fang, X. X., Zhu, H., & Suykey, A. E. (2014). Biofuels from crop residue can reduce soil carbon and increase CO_2 emissions. *Nature Climate Change, 4*, 398-401. https://doi.org/10.1038/NCLIMATE2187

Liu, T., Randall J. F. Bruins, & Matthew T. Heberling. (2018). Factors Influencing Farmers' Adoption of Best Management Practices: A Review and Synthesis. *Sustainability*, *10*(2), 432. https://doi.org/10.3390/su10020432

Lloyd-Smith, P., Boxall, P., & Belcher, K. (2020, May). *From rhetoric to measurement: The economics of wetland conservation in the Canadian Prairies.* Smart Prosperity Institute. https://institute.smartprosperity.ca/sites/default/files/wetlandeconreview.pdf

Luna, I. M., Fernandez-Quintanilla, C., & Dorado, J. (2020). Is pasture cropping a valid weed management tool? *Plants, 9*(2), 135. https://doi.org/10.3390/plants9020135

Lyseng, R. (2013, July 19). *When vertical tillage isn't vertical tillage.* The Western Producer. https://www.producer.com/crops/when-vertical-tillage-isnt-vertical-tillage/

Mamine, F. & Fares, M. (2020). Barriers and levers to developing wheat-pea intercropping in Europe: A review. *Sustainability, 12*(17), 6962. https://doi.org/10.3390/su12176962

Manitoba Agriculture. (2021, August). *Managing Flax Straw.* https://www.manitoba.ca/agriculture/crops/crop-management/pubs/flax-straw-management-factsheet.pdf

Manitoba Agriculture, Food, and Rural Initiatives. (2008, February). *The Basics and Benefits of Bale Grazing.* https://www.gov.mb.ca/agriculture/livestock/beef/pubs/baa05s04j.pdf

Manitoba Agriculture, Food, and Rural Initiatives. (2009, January). *Manure management facts – Manure nutrients and their behaviour in soil*. https://www.gov.mb.ca/agriculture/environment/nutrient-management/Pubs/mmf_manurenutribehaviour_factsheet.pdf

Manitoba Organic Alliance. (n.d.) *Farm Resilience Mentorship Program (FaRM).* https://manitobaorganicalliance.com/farm-program-landing-page/

Mapfumo, E., Chanasyk, D. S., Puurveen, D., Elton, S., & Acharya, S. (2023). Historic climate change trends and impacts on crop yields in key agricultural areas of the Prairie provinces in Canada: A literature review. *Canadian Journal of Plant Science, 103*, 243-258. http://dx.doi.org/10.1139/CJPS-2022-0215

Martin, H. (2005, March). *Factsheet: Agricultural composting basics*. Ontario Ministry of Agriculture, Food, and Rural Affairs. https://omafra.gov.on.ca/english/engineer/facts/05-023.pdf

Martins, F., Atleo, T., Mbazima, G. & Israelit, S. (2021, December 2). *Helping Farmers Shift to Regenerative Agriculture*. Bain & Company. https://www.bain.com/insights/helping-farmers-shift-to-regenerative-agriculture/

McCain Foods. (n.d.). *McCain's Regenerative Agriculture Framework.* https://www.mccain.com/media/4036/mccain-foods-regenag-framework.pdf

McCain Foods. (2022). *McCain Sustainability Report 2022.* https://www.mccain.com/media/4060/mccain-foods-sustainability-report-2022.pdf

McCuaig, A. (2023, November 23). *Farmers urged to use marginal land for forage.* The Western Producer. https://www.producer.com/news/farmers-urged-to-use-marginal-land-for-forage/

McKenzie, R. H. (2010, October). *Agricultural soil compaction: Causes and management.* Alberta Agriculture and Rural Development. https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex13331/$file/510-1.pdf

McMartin, D.W. and Hernani Merino, B.H. (2014). Analysing the links between agriculture and climate change: Can 'best management practices' be responsive to climate extremes? *International Journal of Agricultural Resources, Governance and Ecology, 10*(1), 50-62. https://doi.org/10.1504/IJARGE.2014.061042

Melkani, S., Manirakiza, N., Baker, S. M., Bhadha, J. H. (2023). Current and emerging protocols for carbon measurement in agricultural soils. *IFAS Extension, University of Florida.* https://doi.org/10.32473/edis-SS721-2023

Melo Ramos, T., Jay-Russell, M. T., Millner, P. D., Shade, J., Misiewicz, T., Sorge, U. S., Hutchinson, M., Lilley, J. and Pires, A. F. A. (2019). Assessment of biological soil amendments of animal origin use, research needs, and extension opportunities in organic production. *Frontiers in Sustainable Food Systems, 3*, 73. https://doi.org/10.3389/fsufs.2019.00073

Mizzou Visual Productions. (2015, January 23). *Restoration agriculture: The role of trees* [Video]. YouTube. https://youtu.be/A1vW7WomC2k?si=sSxrSS20576k3RkQ

Monahan, K., McFatridge, S., & Whittaker-Cumming, A. I. (2018, December). Policy Brief – Do environmental regulations cost as much as we think they do? *Smart Prosperity Institute.* https://institute.smartprosperity.ca/sites/default/files/regulations-2018december-10.pdf

Morrison, C. (2021). *Cover cropping on the Prairies.* The Canadian Agri-Food Policy Institute. https://capi-icpa.ca/wp-content/uploads/2021/06/2021-06-10-Callum-Morrison-Individual-Report-1-2.pdf

Morrison, C.L., and Lawley, Y. (2021). *2020 Prairie Cover Crop Survey Report.* Department of Plant Science, University of Manitoba. https://umanitoba.ca/agricultural-food-sciences/make/make-ag-food-resources#crops

Moyer, J. R., and Blackshaw, R. E. (2009). Fall-seeded cover crops after dry bean and potato in southern Alberta. *Canadian Journal of Plant Science, 89*, 133-139. https://doi.org/10.4141/CJPS08038

Mu, L., Janmaat, J., Taylor, J., & Arnold, L. (2023). Attitudes and opportunities: comparing climate change adaptation intentions and decisions of agricultural producers in Shaanxi, China, and British Columbia, Canada. *Mitigation and Adaptation Strategies for Global Change*, *28*(8). https://doi.org/10.1007/s11027-022-10040-7

Myers, R., Weber, A., Tellatin, S. (2019, June). *Cover crop economics: Opportunities to improve your bottom line in row crops*. Sustainable Agriculture Research & Education. https://www.sare.org/wp-content/uploads/Cover-Crop-Economics.pdf

Nair, P. K. R., Kumar, B. M., Nair, V. D. (2021). Agroforestry Systems in The Temperate Zone. In P. K. R. Nair, B. Mohan Kumar & V. D. Nair (Eds.) *An Introduction to Agroforestry*: *Four decades of scientific developments* (2nd ed., pp.195-232). Springer. https://doi.org/10.1007/978-3-030-75358-0_10

Native. (n.d.). *Regenerative Farming in the Canadian Prairies.* https://native.eco/project/regenerative-farming-in-the-canadian-prairies/

Nature United. (n.d.). Regenerative Agriculture in the Prairies. [Slide Deck]. Google Drive. https://docs.google.com/presentation/d/1KFsgTunMrQ5kLf4Y8bb8xcBgOJpAz34Y/edit?usp=sharing&ouid=112703178710712024378&rtpof=true&sd=true

Nazarko, O. (2008). *Sod Seeding: Seeding forages into existing stands using minimal tillage*. Manitoba Forage Council. https://www.gov.mb.ca/agriculture/crops/crop-management/forages/pubs/sod_seeding_manual.pdf

New Forest Farm. (n.d.). *Redesigning agriculture in nature's image.* https://newforestfarm.us/

Nutrien Ag Solutions. (n.d.-a). *Investing in sustainable practices pays*. https://info.nutrienagsolutions.ca/sno

Nutrien Ag Solutions. (n.d.-b). *Practices* [Video]. https://www.nutrienagsolutions.ca/sustainable-ag

Nutrient Stewardship. (n.d.) *What are the 4Rs.* The Fertilizer Institute. https://nutrientstewardship.org/4rs/

Nykoluk, C. (2013). *What are native prairie grasslands worth? Why it pays to conserve this endangered ecosystem.* Ranchers Stewardship Alliance Inc. https://www.pcap-sk.org/rsu_docs/documents/Native_Grassland_EGS_RSA-sm.pdf

O'Reilly, K, A., Lauzon, J, D., Vyn, R, J. and Eerd, L, L, V. (2012). Nitrogen cycling, profit margins and sweet corn yield under fall cover crop systems. *Canadian Journal of Soil Science, 92*, 353–365. https://doi.org/10.4141/cjss2011-065

OEC. (2021). *Dried legumes.* Observatory of Economic Complexity. https://oec.world/en/profile/hs/dried-legumes

Omokanye, A., Yoder, C., Sreekumar, L., Vihvelin, L., & Benoit, M. (2018). Forage production and economic performance of pasture rejuvenation methods in Northern Alberta, Canada. *Sustainable Agriculture Research, 7*(2), 94-110. https://doi.org/10.5539/sar.v7n2p94

Ontario Nature. (n.d.). *Wetland Restoration and Rehabilitation.* https://ontarionature.org/wp-content/uploads/2017/11/wetland_restoration.pdf

Oosterhuis, K. (2017, August 11). *Pulse school: Avoiding bleaching in peas.* RealAgriculture. https://www.realagriculture.com/2017/08/pulse-school-avoiding-bleaching-in-green-peas/

Payen, F. T., Moran, D., Cahurel, J.-Y., Aitkenhead, M., Alexander, P., & MacLeod, M. (2023). Why do French winegrowers adopt soil organic carbon sequestration practices? Understanding motivations and barriers. *Frontiers in Sustainable Food Systems, 6,* 994364. https://doi.org/10.3389/fsufs.2022.994364

Philip, C. (2023, April 12). *BMO donates $2 million to University of Saskatchewan.* CTV News Saskatoon.
https://saskatoon.ctvnews.ca/bmo-donates-2m-to-university-of-saskatchewan-1.6353171

Popp, J., McAllister, T., Majak, W., & Berg, B. (n.d.). *Prevention of Pasture Bloat in Cattle Grazing Alfalfa*. Government of Manitoba.
https://www.gov.mb.ca/agriculture/livestock/beef/prevention-of-pasture-bloat-in-cattle-grazing-alfalfa.html

Prairie Clean Energy. (n.d.-a). *Products*. https://www.prairiecleanenergy.com/products/

Prairie Clean Energy. (n.d.-b). *Unlocking value from unutilized ag residue.*
https://www.prairiecleanenergy.com/

Prokopy, L. S., Floress, K., Baumgart-Getz, A., & Klotthor-Weinkauf, D. (2008). Determinants of agricultural best management practice adoption: Evidence from the literature. *Journal of Soil and Water Conservation*, *63*(5), 300-311. https://doi.org10.2489/63.5.300

Prokopy, L. S., Ranjan, P., Floress, K., Arbuckle, J. G., Church, S. P., Eanes, F. R., Gao, Y., Gramig, B. M., & Singh, A. S. (2019). Adoption of agricultural conservation practices in the United States: Evidence from 35 years of quantitative literature. *Journal of Soil and Water Conservation*, *74*(5), 520-534. https://doi.org/10.2489/jswc.74.5.520

Ranjan, P., Prokopy, L. S., Church, S. P., & Floress, K. (2019). Synthesizing Conservation Motivations and Barriers: What Have We Learned from Qualitative Studies of Farmers' Behaviors in the United States? *Society and Natural Resources*, *32*(11), 1171-1199.
https://doi.org/10.1080/08941920.2019.1648710

RealAgriculture. (2023, May 4). *Saskatchewan farm joins national carbon sequestration measurement study.*
https://www.realagriculture.com/2023/05/saskatchewan-farm-joins-national-carbon-sequestration-measurement-study/

Regenerative Alberta Living Lab. (n.d.-a). *Resources – Regenerative agriculture soil principles.*
https://www.regenlivinglab.org/resources

Regenerative Alberta Living Lab. (n.d.-b). *What is the Regenerative Alberta Living Lab?* https://www.regenlivinglab.org/

Regenerative Alberta Living Lab. (2023a, March). *Breakout Group Summary Data*. [Unpublished dataset].

Regenerative Alberta Living Lab. (2023b, June). *Total RALL survey responses*. [Unpublished dataset].

Regenerative Alberta Living Lab. (2023c, November). *Breakout Group Summary Data*. [Unpublished dataset].

Rempel, J., Kulshreshtha, S., van Rees, K., Amichev, B. (2014). Factors that influence shelterbelt retention and removal in Prairie agriculture as identified by Saskatchewan producers. *Harvest*. Retrieved November 3, 2023 from http://hdl.handle.net/10388/8944

Rempel, J. C., Kulshreshtha, S. N., Amichev, B. Y., & Van Rees, K. C. J. (2017). Costs and benefits of shelterbelts: A review of producers' perceptions and mind map analyses for Saskatchewan, Canada. *Canadian Journal of Soil Science, 97*(3), 341–352. https://doi.org/10.1139/cjss-2016-0100

Results Driven Agriculture Research. (n.d.-a). *Funded Projects.* https://rdar.ca/projects

Results Driven Agriculture Research. (n.d.-b). *Research Priorities.* https://rdar.ca/our-work/research-priorities

Results Driven Agriculture Research. (n.d.-c). *OFCAF Funding and Expenses.* https://rdar.ca/funding-opportunities/funding-and-expenses#maximum-amounts-for-eligible-expenses

Results Driven Agriculture Research. (2022). *Strategic Framework 2022-2027.* https://a-us.storyblok.com/f/1016551/x/65ef7b9444/2023-framework-update.pdf

Rodriguez, J. M., Molnar, J. J., Fazio, R. A., Sydnor, E., & Lowe, M. J. (2009). Barriers to adoption of sustainable agriculture practices: Change agent perspectives. *Renewable Agriculture and Food Systems*, *24*(1), 60–71. https://doi.org/10.1017/S1742170508002421

Roesch-McNally, G. E., Basche, A. D., Arbuckle, J. G., Tyndall, J. C., Miguez, F. E., Bowman, T., Clay, R. (2017). The trouble with cover crops: Farmers' experiences with overcoming barriers to adoption. *Renewable Agriculture and Food Systems, 33*(4), 322-333. https://doi.org/10.1017/S1742170517000096

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.

Rosenzweig, S. T., Carolan, M. S., & Schipanski, M. E. (2020). A Dryland Cropping Revolution? Linking an Emerging Soil Health Paradigm with Shifting Social Fields among Wheat Growers of the High Plains. *Rural Sociology*, *85*(2), 545–574. https://doi.org/10.1111/ruso.12304

Sahin, I. (2006). Detailed Review of Rogers' Diffusion of Innovations Theory and Educational Technology-Related Studies Based on Rogers' Theory. *Turkish Online Journal of Educational Technology - TOJET*, *5*(2), 14–23. http://www.tojet.net/articles/v5i2/523.pdf

Salmon, J., Hesketh, K. D., Arundell, L., Downing, K. L., & Biddle, S. J. H. (2020). Changing behavior using ecological models. In M.S. Hagger, L. D. Cameron, K. Hamilton, N. Hankonen, & T. Lintunen (Eds.), *The handbook of behavior change.* (pp. 237-250). Cambridge University Press. https://doi.org/10.1017/9781108677318.017

Samson, R. (2021). *Cost-benefit analysis is the wrong tool for tackling climate change.* Canadian Climate Institute. https://climateinstitute.ca/cost-benefit-analysis-is-the-wrong-tool-for-tackling-climate-change/

Saskatchewan Association of Watersheds. (n.d.). *Climate Change Adaptation Project.* https://saskwatersheds.ca/ccap/

Schut, A. G. T., Cooledge, E. C., Moraine, M., Van De Ven, G. W. J., Jones, D. L., & Chadwick, D. R. (2021). Reintegration of Crop-Livestock Systems in Europe: An Overview. *Frontiers of Agricultural Science and Engineering*, *8*(1), 111–129. https://doi.org/10.15302/J-FASE-2020373

Sherren, K., Hodbod, J., MathisonSlee, M., Chappell, E., & King, M. (2022) Adaptive multi-paddock grazing and wellbeing: uptake, management practices and mindset among Canadian beef producers. *Agroecology and Sustainable Food Systems, 46*(9), 1304-1329. https://doi.org/10.1080/21683565.2022.2107597

Silva, E. M., Wezel, A., Stafford, C., Brives, J., Bosseler, N., Cecchinato, N., Cossement, C., Ranaldo, M., & Broome, M. (2023). Insights into agroecological farming practice implementation by conservation-minded farmers in North America. *Frontiers in Sustainable Food Systems*, *7*. https://doi.org/10.3389/fsufs.2023.1090690

Smith, R. G., Warren, N. D., Cordeau, S. (2020). Are cover crop mixtures better at suppressing weeds than cover crop monocultures? *Weed Science*, *68,* 186–194. https://doi.org/10.1017/wsc.2020.12

Smith, W. N., Grant, B. B., Campbell, C. A., McConkey, B. G., Desjardins, R. L., Krobel, R., & Malhi, S. S. (2012). Crop residue removal effects on soil carbon: Measured and inter-model comparisons. *Agriculture, Ecosystems, and Environment, 161*, 27-38. http://dx.doi.org/10.1016/j.agee.2012.07.024

Soils For Life. (n.d.). *'Winona' – Pasture cropping for the way to health*. https://soilsforlife.org.au/winona-pasture-cropping-the-way-to-health/

Statistics Canada. (2015). *Proportion of farms reporting field crops that used winter cover crops by census division.* https://www150.statcan.gc.ca/n1/pub/95-634-x/2017001/article/54903/catm-ctra-245-eng.htm

Statistics Canada. (2016). *2016 Census of Agriculture*. https://www.statcan.gc.ca/eng/statistical-programs/instrument/3438_Q1_V4-eng.pdf

Statistics Canada. (2021). *2021 Census of Agriculture*. https://www.statcan.gc.ca/eng/statistical-programs/instrument/3438_Q1_V6-eng.pdf

Statistics Canada. (2022). *Methods of fertilizer application, by crop production type, Canada, 2021.* https://www150.statcan.gc.ca/n1/daily-quotidien/221215/cg-b004-eng.htm#shr-pg0

Statistics Canada. (2023a, October 6). *Farm input price index, quarterly.* https://doi.org/10.25318/1810025801-eng

Statistics Canada. (2023b, December 4). *Farm product price index, monthly.* https://doi.org/10.25318/3210009801-eng

Stockford, A. (2020, January 9). *A cover crop cocktail?* Manitoba Co-Operator. https://www.manitobacooperator.ca/news-opinion/news/a-cover-cropcocktail/

Struckman, L. (2021, June). *Oat-Pea mixed grain intercropping on the Canadian and Northern U.S. Prairies*. Manitoba Pulse & Soybean Growers. https://www.manitobapulse.ca/2021/06/oat-pea-mixed-grain-intercropping-on-the-canadian-and-northern-u-s-prairies/

Struckman, L., Patel, I., Shaw, L., Eckberg, J., Rabaey, T., Eichten, S., Seed, J. (2021). *Oat-pea mixed grain intercropping on the Canadian Prairies and U.S. Northern Plains.* South East Research Farm. https://oatnews.org/oatnews_pdfs/2020/Oat-Pea%20Report_May%202021.pdf

Sustainable Food Lab. (n.d.-a). *Farmer Support.* [Slide Deck]. Google Drive. https://drive.google.com/file/d/1u7d3qrWz-0coZ512vZDiRHBL0XZiyu5n/view?usp=sharing

Sustainable Food Lab. (n.d.-b). *Regenerative & Climate-Smart Agriculture.* https://sustainablefoodlab.org/regenerative-agriculture/

Sustainable Food Lab. (n.d.-c). *The Trusted Advisor Partnership.* https://sustainablefoodlab.org/initiative/the-trusted-advisor-partnership/

Sustainable Food Lab. (2023). *Scale Lab 2023.* https://sustainablefoodlab.org/wp-content/uploads/2023/09/Scale-Lab-Report-2023-091823-.pdf

Sustainable Markets Initiative. (2022). *Scaling regenerative farming: An action plan.* https://a.storyblok.com/f/109506/x/7b102e6831/agribusiness-task-force-white-paper.pdf

Tarnoczi, T. (2011). Transformative learning and adaptation to climate change in the Canadian Prairie agro-ecosystem. *Mitigation and Adaptation Strategies for Global Change, 16*, 387-406. https://doi.org/10.1007/s11027-010-9265-7

Tarnoczi, T. J., & Berkes, F. (2009). Sources of information for farmers' adaptation practices in Canada's Prairie agro-ecosystem. *Climatic Change, 98*(1), 299-305. https://doi.org/10.1007/s10584-009-9762-4

The Canadian Press. (2015, March 15). *Ranchers vs. elk in Western Alberta.* Maclean's. https://macleans.ca/news/canada/ranchers-vs-elk-in-western-alberta/

The Nature Conservancy. (2024, January 12). *Louis Dreyfus Company and The Nature Conservancy Announce Collaboration on Regenerative Agriculture and Deforestation- and Conversion-Free Production.* *https://www.nature.org/en-us/newsroom/ldc-tnc-announce-collaboration/*

Thevathasan, N. V., Gordon, A. M., Bradley, R., Cogliastro, A., Folkard, P., Grant, R., Kort, J., Liggins, L., Njenga, F., Olivier, A., Pharo, C., Powell, G., Rivest, D., Schiks, T., Trotter, D., Van Rees, K., Whalen, J., & Zabek, L. (2012). Agroforestry research and development in Canada: The way forward. In P.K.R. Nair and D. Garrity (Eds.), *Agroforestry - The Future of Global Land Use* (pp.247-283). Springer. https://link.springer.com/chapter/10.1007/978-94-007-4676-3_15

Thiessen Martens, J. R., & Entz, M. H. (2000). Availability of late-season heat and water resources for relay and double cropping with winter wheat in prairie Canada. *Canadian Journal of Plant Science, 81*, 273-276. https://www.umanitoba.ca/outreach/naturalagriculture/articles/pdf/thiessen-martens-entz-2001_late-season-resources.pdf

Thiessen Martens, J. R., and Entz, M. H. (2011). Integrating green manure and grazing systems: A review. *Canadian Journal of Plant Science, 91*, 811-824. https://doi.org/10.4141/CJPS10177

Thiessen Martens, J.R., Entz, M.H., Wonneck, M.D. (2015). Review: Redesigning Canadian prairie cropping systems for profitability, sustainability, and resilience. *Canadian Journal of Plant Science, 95*(6), 1049-1072. https://doi.org/10.4141/CJPS-2014-173

Tourangeau, W., & Sherren, K. (2021). Why is grazing management being overlooked in climate adaptation policy? *Agroecology and Sustainable Food Systems, 45*(6), 843-867. https://doi.org/10.1080/21683565.2020.1870645

Ulrich-Schad, J. D., Garciá De Jalón, S., Babin, N., Pape, A., & Prokopy, L. S. (2017). Measuring and understanding agricultural producers' adoption of nutrient best management practices. *Journal of Soil and Water Conservation*, *72*(5), 506-518. https://doi.org/10.2489/jswc.72.5.506

University of Nebraska-Lincoln. (n.d.). *Crop planning – Manure nutrient analysis and application.* https://water.unl.edu/article/animal-manure-management/crop-planning-manure-nutrient-analysis-and-application#:~:text=Manure%20may%20contain%20high%20levels,salts%20burning%20the%20plant%20tissue.

University of Saskatchewan. (2023, April 12). *BMO's $2 million donation to University of Saskatchewan to accelerate research critical to the future of food in Canada.* https://news.usask.ca/articles/research/2023/bmos-2-million-donation-to-university-of-saskatchewan-to-accelerate-research-critical-to-the-future-of-food-in-canada.php

Valdivia, C., Barbieri, C., Gold, M.A. (2012). Between forestry and farming: Policy and environmental implications of the barriers to agroforestry adoption. *Canadian Journal of Agricultural Economics, 60*(2), 155-175. https://doi.org/10.1111/j.1744-7976.2012.01248.x

VanKoughnet, B. (2015). *On-farm evaluation of peaola intercropping.* Manitoba Pulse & Soybean Growers. https://www.manitobapulse.ca/wp-content/uploads/2018/02/On-Farm-Evaluation-of-Peaola-Intercropping-2015.pdf

Viresco Solutions. (2022). *Beneficial Management Practices (BMPs) for Reducing Greenhouse Gas (GHG) Emissions in Prairie Agriculture.* Nature United. https://www.natureunited.ca/content/dam/tnc/nature/en/documents/BMPs-for-Reducing-GHG-Emissions-in-Prairie-Agriculture.pdf

Western Stock Growers' Association. (2023, August 30). *Standing Senate Committee on Agriculture and Forestry Tour.* https://docs.google.com/document/d/1-WK0cITSPregT7ih7ggWr2TsKpfMuQok/edit?usp=sharing&ouid=112703178710712024378&rtpof=true&sd=true

Wichers, G. (2024, January 10). *FCC announces new 4R incentive*. AGCanada.com. https://www.agcanada.com/daily/fcc-announces-new-4r-incentive

Wu, Q. & Congreves, K.A. (2022). A soil health scoring framework for arable cropping systems in Saskatchewan, Canada. *Canadian Journal of Soil Science, 102*(2), 341-358. https://doi.org/10.1139/cjss-2021-0045

Zebarth, B. J., Ryan, M. C., Graham, G., Forge, T. A., & Neilsen, D. (2015). Groundwater monitoring to support development of BMPs for groundwater protection: The Abbotsford-Sumas Aquifer case study. *Groundwater Monitoring & Remediation, 35*(1), 82-96. https://doi.org/10.1111/gwmr.12092

Zeng, Z., Thoms, D., Chen, Y., & Ma, X. (2021). Comparison of soil and corn residue cutting performance of different discs used for vertical tillage. *Scientific Reports, 11*, 2537. https://doi.org/10.1038/s41598-021-82270-9

Zentner, R. P., Brandt, S. A., & Campbell, C. A. (1996). Economics of monoculture cereal and mixed oilseed-cereal rotations in west-central Saskatchewan. *Canadian Journal of Plant Science, 76*(3), 393-400. https://doi.org/10.4141/cjps96-070

Zentner, R. P., Basnyat, P., Brandt, S. A., Thomas, A. G., Ulrich, D., Campbell, C. A., Nagy, C. N., Frick, B., Lemke, R., Malhi, S. S., Olfert, O. O., & Fernandez, M. R. (2011). Effects of input management and crop diversity on economic returns and riskiness of cropping systems in the semi-arid Canadian Prairie. *Renewable Agriculture and Food Systems, 26*(3), 208-223. https://doi.org/10.1017/S1742170510000591

Zheng, W., Holm, N., & Spokas, K. A. (2016). Research and application of biochar in North America. In M. Guo, Z. He, and S. Minori Uchimiya (Eds.), *Agricultural and environmental applications of biochar: Advances and barriers.* (pp.475-494). Soil Science Society of America, Inc. https://doi.org/10.2136/sssaspecpub63.2014.0054

Food Water Wellness Foundation is advancing the practice of regenerative agriculture that nurtures a robust ecosystem and healthy soil. We are working with farmers, ranchers and researchers to understand how soil can be used to mitigate climate change, drought and flood, increase biodiversity and, most importantly, produce healthy food.