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Regenerative Agriculture in Canada: Considerations for Standardization

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Authors

Karina Lopez Ivich, M.Sc., M.A., Smart Prosperity Institute

Elizabeth Daigle, M.Sc., Smart Prosperity Institute

Olivia Richardson, M.A., Smart Prosperity Institute

Ryan Tougas-Cooke, M.Sc., Smart Prosperity Institute

Michael Twigg, M.Sc., Smart Prosperity Institute

Grace Kamba, BBiomedSc. & B.A. Psy., Smart Prosperity Institute

Project Advisory Panel

Asim Biswas, University of Guelph

Bryan Gilvesy, ALUS Canada

Emma Holmes, British Columbia Ministry of Agriculture and Food

Jordan Sinclair, ALUS Canada

Jury Gualandris, University of Western Ontario

Ross MacDonald, Regeneration Canada

Ana-Maria Tomlinson, CSA Group

Rocío Morales Rayas, CSA Group

Catherine Tays, CSA Group (Project Manager)

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Table of Contents

Executive Summary 4

1. Introduction 6

2. Methods 7

3. Results and Discussion 8

3.1 Definitions and Principles 8

3.1.1 Definitions 8

3.1.2 On-Farm Principles 9

3.1.3 Other Production Principles 11

3.1.4 Social Principles and Concepts 12

3.2 Common Practices in Regenerative Agriculture 15

3.2.1 Regional Implementation in Canada 15

3.3 Common Outcomes in Regenerative Agriculture 18

3.3.1 Minimizing Soil Disturbance, Keeping Soil Covered, and Enhancing Crop Biodiversity Outcomes 18

3.3.2 Incorporating Farm Animals Outcomes 20

3.4. Measuring Performance of Regenerative Agriculture Principles 20

3.4.1 Quantification of Outcomes 24

3.5 Practice Change in Regenerative Agriculture 24

3.6 Enabling a Regenerative Agriculture Transition in Canada 26

3.6.1. Barriers 26

3.6.2 Enabling Conditions 28

3.6.3 Engaging all Parties in the Regenerative Agriculture Transition 31

3.7 Standards, Protocols, and Certifications 33

3.7.1 Gaps and Challenges in Standardization 35

4. Conclusion and Recommendations 40

References 42

Appendix A. Regenerative Agriculture Practices and Outcomes in Canada 59

Executive Summary

Regenerative agriculture has the potential to drive economic growth in Canada's agri-food sector while delivering substantial environmental, economic, and social benefits. However, regenerative agriculture remains ill-defined in Canada, and has limited adoption and impact compared to other jurisdictions. Without a clear definition, it is difficult to develop a transition agenda for regenerative agriculture that includes the right set of financial, knowledge, and social supports. To respect the diversity in management practices and production systems, regenerative agriculture is best defined through a set of principles that help guide its implementation and objectives.

Through a literature review and focus groups with farmers, government, academia, farm groups, and other relevant parties, this report found agreement on the following five key principles of regenerative agriculture in the Canadian context:

1. Minimize soil disturbance;
2. Keep soil covered year-round;
3. Keep live plants and living roots in the soil;
4. Enhance biodiversity above and below ground; and
5. Incorporate farm animals.

The research conducted for this report also identified the following emerging principles and concepts of regenerative agriculture, which are growing in popularity but have yet to reach the same level of agreement as the five key principles:

- Efficient input use and reduce synthetic inputs;
- Conserve and protect water;
- Understand the farm context;
- Enhance and restore natural landscapes; and
- Respect for human and non-human life and for the environment.

The research also revealed an ongoing debate around the inclusion of the following social principles and concepts as determinants of regenerative agriculture:

- Supporting farm livelihoods and food system resilience;
- Community revitalization, health, and empowerment;
- Capacity building and knowledge transfer; and
- Advancing equality, safe work, and fair business practices.

These socially oriented principles were identified as nascent in the Canadian context, and more common in the international landscape. However, supporting farm livelihoods and food system resilience was mentioned more frequently in both domestic and international regenerative agriculture programs. Those in favour of including social principles and concepts identified them as an integral part of regenerative agriculture and recognized their value in a food system transition. Others viewed these principles as belonging to agroecology and noted that focusing on soil health principles was essential to catalyze action to support producers in building dynamic, regenerative production systems. Because socially oriented principles are present in international regenerative agriculture frameworks, it is important to consider their role and impact from an alignment perspective, given the export-driven nature of Canada's agriculture sector and the need to navigate competing international sustainable agriculture terminologies, standards, certifications, and frameworks.

This report presents five recommendations for diverse organizations seeking to advance a regenerative agri-food system in Canada:

1. **Invest in knowledge sharing networks to ease transitions:** Establish diverse and regional peer farming networks that share resources.
2. **Expand access to education and resources:** Increase access to regenerative agriculture extension services and develop demonstration projects or other practical knowledge resources.
3. **Explore innovative funding mechanisms:** Mitigate financial risks and revise existing risk management programs to remove barriers in transitioning to regenerative practices.
4. **Implement outcome-based programs:** Develop programs, with appropriate and streamlined measurement, reporting, and verification (MRV) processes, that compensate farmers for the ecosystem services they generate when using regenerative practices.
5. **Advance standards that are flexible and inclusive:** Continue advancing agreement around regenerative principles through extensive consultations, including farmers, Indigenous communities, and value chains, that explore regional or production system differences and continuous improvement processes.



"Concerted efforts that support systems change throughout the agri-food sector are key to building more sustainable and resilient production systems across Canada."

1. Introduction

In the mid-1900s, the Green Revolution transformed agricultural systems, reshaping landscapes, economies, and societies around the world through the use of technologies that dramatically increased agricultural productivity [1]. Production systems became reliant on chemical fertilizers and pesticides, irrigation systems, and machinery, as well as practices such as tillage, large crop monocultures, and intensive livestock systems [1], [2]. These industrial agriculture practices and technologies remain common in Canada, and have supported increased food production for a growing population, lowered consumer costs, created employment opportunities, and enhanced food availability [2]. Despite these important outcomes, the Green Revolution also had unintended environmental impacts. The industrial production practices and technologies popularized during this period have been linked with a depletion of natural capital (e.g., treed areas, wetlands, and grasslands), biodiversity loss, agrochemical runoff into watercourses, reductions in natural habitats, and soil health degradation [2], [3], [4]. Intensive production has also increased greenhouse gas (GHG) emissions and fertilizer use, with fertilizer consumption in Canada increasing from 1.2 megatonnes in 1990 to over 2.8 megatonnes in 2022 [5]. The unintended effects of industrial practices have also been widely reported. Broad-spectrum, environmentally persistent pesticides, herbicides, and inorganic fertilizer applications have been linked with pollution and biodiversity loss [1]. Monoculture cropping systems and oversimplified farm ecosystems lack resilience, making them vulnerable to pests, diseases, and climate change [6]. Heavy machinery and repetitive soil disturbance exacerbate compaction, erosion, and the loss of topsoil, and release carbon dioxide (CO_2) into the atmosphere [1], [4]. Table 1 presents some of the leading practices used by industrial agriculture and their unintended consequences on the environment and wildlife [1]–[6].

Farmers, governments, and food value chains have already begun work to counteract the impact of industrial agriculture in Canada. Examples include the widespread adoption of reduced and no-till practices across the Prairies [5], along with increased government and food value chain funding to support farmers in adopting and maintaining sustainable practices [7]. Concerted efforts that support systems change throughout the agri-food sector are key to building more sustainable and resilient production systems across Canada.

To address some of the environmental challenges that Canada's agri-food system is facing, there has been a call to transform the agri-food system to one that is more sustainable and just. Numerous sustainable agriculture approaches have emerged that also focus on environmental and socioeconomic outcomes, including regenerative agriculture, organic agriculture, conservation agriculture, sustainable intensification, and agroecology [8]. Transitioning to

Table 1: Industrial agriculture practices and potential environmental impacts [1]–[6].

Industrial agriculture practices	Potential environmental impacts
Tillage	Soil erosion, soil compaction, carbon release
Synthetic fertilizers	GHG emissions, runoff, soil biodiversity
Chemical pesticides and herbicides	Pollution, runoff, biodiversity
Monoculture cropping systems	Resilience, soil health
Concentrated animal/confined feeding operations	Pollution, runoff, animal welfare
Wetland conversion to agriculture land	Loss of habitat, GHG emissions, resilience
Treed area conversion to agriculture land	Loss of habitat, GHG emissions, resilience

regenerative agriculture could support ecosystem resiliency and may address concerns such as climate change adaptation and mitigation [9], [10]. In addition, regenerative agriculture could support economic benefits, such as optimized resource management and sustainable livelihoods, while honouring Indigenous food systems that embrace an integrated approach to living sustainably off the land [11]. In the Canadian context, transitioning to regenerative agriculture could also support Indigenous food sovereignty, the revitalization of Indigenous foodways, and Indigenous knowledge sharing. Many of the principles of regenerative agriculture stem from Indigenous agricultural practices and foodways, and a national transition to regenerative agriculture could promote ethical settler–Indigenous relationships based on solidarity and responsibility [1], [12].

The absence of a clear definition and framework for regenerative agriculture in Canada creates confusion and leaves relevant parties questioning how to support or invest in these types of systems. For example, regenerative agriculture's broad scope raises questions around necessary minimum requirements or defining factors (e.g., on-farm outcomes such as soil health) and associated benefits. This confusion has led many corporate and government actors to prioritize regenerative practices with environmental outcomes without considering how policies and programs can also address sustainable livelihoods and societal well-being [9]. Consequently, the primary goal of this report was to provide clarity around the scope of principles, outcomes, and practices of regenerative agriculture to inform the development of transition plans, stimulate broader adoption [13] and knowledge transfer, and to advance the inclusion of regenerative outcomes in existing business models [14]. This report also explores the potential for developing a standard for regenerative agriculture in Canada, and reviews key considerations.

2. Methods

The research conducted for this report included a literature review and two focus groups. The literature review explored the breadth of international and Canadian principles, outcomes, practices, barriers, policies, and tools for measurement, reporting, and verification (MRV) in the regenerative agriculture space, ensuring any international articles met Canadian applicability criteria (e.g., region, production type, policy context). The review began with an initial scan of 45 grey literature programs and publications to identify key words. Based on these key words, a suitable list of references was obtained by running a search through specific databases (i.e., Web of Science, SCOPUS, Geobase, CAB Abstracts, CABI Reviews). Once this list of references was obtained, a systematic screening process was performed to select documents based on predefined inclusion and exclusion criteria. Documents published from 2003 onward were selected for review. Data on the impact of specific regenerative practices (see Appendix A) were sourced primarily from Canadian

studies, with some inclusions from the United States if the articles met applicability criteria for Canada. Additional inclusion criteria were determined by an analysis of production systems and climate conditions across Canada to identify contextually similar systems and locations in the United States. Other jurisdictions were not included when assessing the outcomes of regenerative practice adoption to ensure the results remained applicable to Canada.

The literature review was contextualized through two focus groups held between March and May 2024. The first focus group was held with a group of seven Canadian farmers and focused on identifying how farmers define regenerative agriculture, their opinions on standardization, and the barriers they face when engaging with the concept. This focus group provided valuable insight into the adoption process and outlined opportunities for better supporting farmers in regenerative agri-food systems transitions. The second focus group included 18 representatives from government, academia, farm groups, farmers, and other relevant groups, and focused on validation and asked participants if they agreed with the scope of principles identified through the literature review and the first focus group. After discussing the principles with the group, participants were engaged in a discussion on the key barriers to regenerative agriculture adoption, followed by a solutions-focused discussion on how to catalyze regenerative agriculture adoption and sustained use in Canada.

3. Results and Discussion

3.1 Definitions and Principles

3.1.1 Definitions

At the time of writing, regenerative agriculture remains ambiguously defined. There is no universally-accepted, clear definition in either the academic or grey (e.g., standards, government documents, association briefings, and other reports) literature [15], [16]. However, some definitions were more common, such as one of the earliest definitions of regenerative agriculture, developed in the 1980s by Robert Rodale, where the concept was described as a holistic approach to farm management where yield increases over time and topsoil deepens [17]. Other common aspects of this definition emphasize both environmental and social improvements and stipulate that production should have little to no impact on the environment beyond the farm or field boundaries [2], [15], [18], [19]. Another common definition in the literature was from Schreefel *et al.,* who conducted one of the first academic reviews on regenerative agriculture [20], and proposed that it is an approach that starts with soil conservation and evolves over time into the provision of many different regulating and supporting ecosystem services that enhance food production. Although this definition is limited to food production, other definitions consider fiber production, healthy food, and clean energy [15], [16]. Some academic definitions have similar interpretations of systems-level thinking and progression over time, such as Gremmen [3], who spoke to the systems-based nature of regenerative farming and its ability to encourage continual innovation for environmental, social, economic, and spiritual well-being. The literature also noted the value of integrating the knowledge of local landholders and Indigenous communities with established scientific knowledge, prioritizing sociocultural and relational values [1], [16]. As such, Jayasinghe *et al.* proposed that regenerative agriculture is a "transdisciplinary approach that integrates local and Indigenous knowledge of landscapes, as well as their management, with established scientific knowledge. It combines a range of adoptable principles with context-specific practices, focusing on soil conservation as the initial step to restore soil health, enhance ecosystem functions, and promote improved socioeconomic outcomes" [16].

Participants at the farmer focus group defined regenerative agriculture as conducting farming and ranching alongside nature and the four ecosystem processes (repair, rebuild, revitalize, and restore), starting with life in the soil and expanding to all life above the soil over time. This definition highlighted how regenerative agriculture starts with one objective and expands into an integrated management system over time, with some participants framing regenerative agriculture as a journey of incremental improvement over time. Other participants indicated that the core of any definition should highlight that regenerative agriculture aims to produce food in a



"Regenerative agriculture aims to produce food in a way that enhances terrestrial and natural processes."

way that enhances terrestrial and natural processes. Focus group participants also questioned whether regenerative agriculture was substantively different from sustainable agriculture. Some mentioned that the division between being regenerative or sustainable was likely detracting from progress on both fronts, and suggested that finding shared interests or unifying the two movements would catalyze action.

3.1.2 On-Farm Principles

It is important to note that principles differ from practices, in that principles offer higher-level generalizations that guide farm activities toward certain goals. The literature review found that the most common guiding principles for implementing and engaging with regenerative agriculture were:

1. **Minimizing soil disturbance:** Requires the absence of heavy tillage machinery, usually by reducing or eliminating tillage or direct seeding [2], [18]. This principle aims to enhance nutrient distribution and cycling in the soil, and is key to improving soil health, structure, biological activity, organic matter levels, and carbon sequestration [1], [4], [16]. Minimizing soil disturbance can also limit soil and water erosion, which can reduce costs and promote resilience during harsh weather conditions [4], [6].
2. **Keeping the soil covered year-round:** Entails using plants, crop residues, cover crops, or mulches that create a protective layer over the soil [2], [4], [18]. This principle has been linked to improving soil health, increasing soil carbon and organic matter [4], improving soil fertility, restoring biodiversity, and promoting water conservation [21], [22]. In addition, this principle is expected to improve ecosystem functions, such as reducing compaction, attracting beneficial insects, suppressing weeds, regulating soil temperature, and increasing water infiltration [2], [4].
3. **Keeping live plants and living roots in the soil:** Can be accomplished by either planting cover crops after harvest, under seeding cash crops, or using perennial crops that will maintain soil cover throughout the season [4]. This principle is linked to improving ecosystem functions, such as improving nutrient availability, reducing compaction, increasing soil carbon, suppressing weeds, regulating soil temperature, and increasing water infiltration [1], [4], [16].
4. **Enhancing biodiversity above and below ground:** Refers to the number and frequency of all forms of life above and below ground, including plants, insects, animals, fungi, and microorganisms [1], [2], [16], [40]. One common example of enhancing biodiversity is the use of diversified crop rotations, which has multiple benefits related to soil functioning, such as increased resistance and resilience to disturbances, improved soil fertility, reduced pesticide use, better water and nutrient use efficiency, and improved crop production outcomes [2], [4], [18], [20].

5. **Incorporating farm animals:** Entails combining livestock with cropping and agroforestry in the same landscape. This can increase soil carbon, improve soil health, and diversify income streams for adopting producers [4]. In addition, this principle entails raising farm animals in pasture, letting them move freely, and having them consume a natural grazing diet [2], [4]. Industrial livestock farming is known to contribute to methane emissions, but there is also evidence that grazing livestock is better from an environmental (i.e., reduces emissions and improves soil health) and animal welfare standpoint [2], [4]. Farmers have also noted that internal and external parasite problems can be reduced by adopting these types of practices [1].

These five principles were also largely agreed upon among focus group participants, both at the farmer session and at the broader sector session. These principles are commonly associated with soil health principles, which underscores regenerative agriculture's association with soil health. In an example of these principles in practice, the Soil and Climate Initiative's Farm Commitment and Verification Standard includes the following pillars of regenerative agriculture [24]:

- Minimize soil disturbance;
- Keep living roots in the ground year-round;
- Maintain year-round soil coverage;
- Maximize diversity above and below ground;
- Ensure appropriate integration of livestock; and
- Reduce synthetic inputs.

Table 2 provides some examples of Canadian companies and organizations that have adopted the five regenerative agriculture principles and practices discussed in this section.

Table 2: Companies and organizations incorporating regenerative agriculture principles and practices.

Principle	Program	Example Practices
Minimize soil disturbance	▪ Dairy Farmers of Canada [25] ▪ Regenerative Alberta Living Lab [26] ▪ McCain [27]	▪ Reduced tillage ▪ Zero tillage ▪ Perennial cropping
Keep the soil covered year-round	▪ Dairy Farmers of Canada [25] ▪ Government of Saskatchewan [28] ▪ Biological Carbon Canada [29]	▪ Cover crops ▪ Crop residue management
Keep live plants and living roots in the soil	▪ General Mills Canada [30] ▪ Regenerative Alberta Living Lab [26] ▪ Biological Carbon Canada [29]	▪ Perennial crops and grasslands ▪ Cover crops
Enhance biodiversity above and below ground	▪ Government of Saskatchewan [28] ▪ Regenerative Alberta Living Lab [26] ▪ McCain [27]	▪ Crop rotation ▪ Intercropping ▪ Multispecies cover crops ▪ Habitat for beneficial insects ▪ Agroforestry
Incorporate farm animals	▪ Dairy Farmers of Canada [25] ▪ General Mills Canada [30] ▪ McCain [27]	▪ Grazing ▪ Silvopasture



3.1.3 Other Production Principles

The research also identified other principles and concepts that have been associated with regenerative agriculture, both in Canada and internationally, some of which are becoming more common across the regenerative agriculture landscape. While the following emerging principles have not reached the same level of agreement as the five principles discussed in Section 3.1.2, they are important to consider when defining regenerative agriculture:

- **Efficient input use and reducing synthetic inputs:** Involves looking for natural solutions to pest and fertilizer issues [2], and using inputs as efficiently as possible when synthetic inputs are required. Regenerative agriculture often prioritizes animal manure over synthetic fertilizers and natural pest control over chemicals [16]. Limiting agrochemicals and pesticides benefits the production system and the environment by reducing the contamination of ground and surface waters, improving nutrient efficiency, reducing GHG emissions, and improving biodiversity and soil health [2].
- **Conserving and protecting water:** This is described in many different ways, with some relating to water holding capacity in soil [31] and others mentioning regenerative agriculture's capacity to support broader water outcomes, such as conservation and regulation [32], [33], or improving the water cycle [18]. Landers *et al.* reported that improving or conserving water resources was one of the top five reasons to adopt regenerative agriculture, denoting a high level of awareness and responsibility for this outcome among practitioners [18]. On the industry side, McCain lists optimized water use as the sixth indicator in its Regenerative Agriculture Framework, and provides examples like protecting waterways and decreasing surface or ground water pollution [27].
- **Understanding the farm context:** Involves identifying the needs of a farm within its regional and production system context. This principle recognizes that transitioning from conventional farming to regenerative agriculture involves addressing competing demands for environmental and economic outcomes in land use systems [16], and there is a need to maximize synergies and minimize trade-offs between ecosystem services on the farm and within the broader landscape [34].
- **Enhancing and restoring natural landscapes:** Refers to the preservation or creation of natural assets that can benefit the farm and the broader ecosystem. This principle addresses the fact that regenerative agricultural practices can assist in the regeneration of entire landscapes to help foster natural resources such as wetlands, treed areas, grasslands, and other wildlife corridors [40]. Benefits, which include landscape resilience and improved biodiversity, are shared by farmers and communities within the region. This type of landscape-level perspective integrates different

Table 3: Companies and organizations incorporating emerging regenerative agriculture principles and practices.

Emergent Principle	Program	Example Practices
Efficient input use and reduce synthetic inputs	▪ Regenerative Alberta Living Lab [26] ▪ McCain [27] ▪ Cargill [23]	▪ Organic matter addition ▪ Optimize synthetic or chemical inputs ▪ Legume use
Conserve and protect water	▪ McCain [27] ▪ Unilever [39]	▪ Cover crops ▪ Grassed waterways and setbacks ▪ Waterway fencing
Understand the farm context	▪ Dairy Farmers of Canada [25] ▪ Government of Saskatchewan [28] ▪ General Mills Canada [30]	▪ Evaluate needs of specific operation ▪ Regional differentiation
Enhance and restore natural landscapes	▪ Nestlé [40] ▪ McCain [27]	▪ Agroforestry ▪ Habitat restoration ▪ Pollinator strips ▪ Conservation buffers
Respect for human and non-human life and for the environment	▪ Regenerative Organic Certified [41] ▪ A Greener World [42]	▪ Ensure animal health and welfare ▪ Raising animals in pasture ▪ Letting animals move freely ▪ Natural diets

land management strategies for addressing multiple products from the land, including food, energy, wood, and ecosystem services. This integrated approach can advance new strategies for improving the profitability and environmental performance of the land [35]. This principle also emphasizes that farms sit within landscapes or catchments and are not isolated, meaning that management activities must respect environmental boundaries [36] and identify synergies that advance multiple ecosystem services across any given landscape [37].

- **Respect for human and non-human life and for the environment:** This principle can be operationalized through improvements in animal welfare, which entails raising animals in pasture, letting them move freely, giving them access to outdoor areas in nature, allowing them to consume their natural diet, and generally treating them humanely [2], [4], [38].

Many of these emerging principles speak to the desired outcomes of regenerative agriculture and move toward a more holistic approach to farm management. Table 3 provides some examples of companies and organizations that have incorporated some of these emerging principles and concepts into their regenerative agriculture programs.

3.1.4 Social Principles and Concepts

This report also identified a set of socially oriented principles and concepts of regenerative agriculture, which were more novel than the principles discussed in sections 3.1.1 and 3.1.2 and were primarily found in the international landscape. While the following socially oriented principles are less common in Canada, they are important for facilitating a fair and just transition in agri-food systems, and should be considered from a market access and alignment perspective:

- **Supporting farm livelihoods and food system resilience:** This was commonly identified as a desired outcome of regenerative agriculture, but it was less common to formalize the concept as a principle. In the Canadian context, the Regenerative Alberta Living Lab defines resilience in terms of climatic uncertainty, while McCain lists ensuring farm resilience as the first principle of their Regenerative Agriculture Framework [26], [27]. In the United States, Field to Market provides content related to farmer livelihoods and includes "ensuring the viability of farm production" in their regenerative agriculture definition [43]. At the global level, the Sustainable Agriculture Initiative Platform includes performance as one of the key principles and practices that informed its Global Framework for Regenerative Agriculture [44].
- **Community revitalization, health, and empowerment:** This principle was operationalized in several different ways across the regenerative agriculture landscape. In the United States, the Lexicon of Food includes "support human and social capital" in its regenerative agriculture principles and highlights practices such as greater community engagement, the provision of nutritious food to support healthy communities, and empowering the development of local food systems [45]. Similarly, in the United Kingdom, Unilever includes "enable local communities to protect and improve their environment and wellbeing" as the second principle of their regenerative agriculture program [39]. Other research emphasizes the importance of creating greater harmony among value chain parties and promoting ties between the land and its heritage, as well as the importance of empowering communities [46], [47].
- **Capacity building and knowledge transfer:** This involves the provision of learning opportunities, mentorship, or supporting the development of communities of practice. In the United States, the Lexicon of Food operationalizes this as part of their "support human and social capital" principle and provides education and training opportunities [45], and the Soil and Climate Initiative includes "continuous learning" as the sixth principle of their program, which is operationalized through a mentorship program where farmers who have achieved higher levels of certification are paired with newer farmers to share experiences and insights [24]. Both approaches support the development of communities of practice, a key recommendation in Obregon *et al.* [46], which are based on local social networks, where farmers can share best practices for regenerative agriculture with each other. It is ideal when they are organized by local farmers and supported by existing multiple-actor networks to stimulate diverse knowledge sharing and discussions on regenerative agriculture [46].
- **Advancing equality, safe work, and fair business practices:** As with many industries, this principle has also emerged in the regenerative agriculture landscape. Internationally, Danone and the Regenerative Organic Certified Framework both include principles and metrics regarding farm workers and farm work, and these are operationalized as positive on-farm working conditions, including working hours, health and safety, equal pay, and wages [41], [48]. In Canada, the British Columbia Government's report on Regenerative Agriculture and Agritech includes the health and welfare of farmers, ranchers, and farm workers in the scope of regenerative agriculture's objectives. [49]. Furthermore, the Regenerative Organic Certified Framework contains standards for product buyers, which mandate that they must negotiate transparently, engage in fair contracts and payments, and support capacity building (e.g., skill building opportunities for smaller producers) [41].

The inclusion of social principles was debated at both the farmer and the broader sector focus groups. While several participants appreciated the inclusive scope and agreed with the importance of these principles in regenerative agriculture, they also noted that social principles were not generally incorporated into regenerative agriculture definitions. Other participants indicated that social outcomes were out of scope, that they were too broad, and that including social outcomes meant regenerative agriculture was trying to be too many things to too many people. An important sentiment arising from the discussions was that while

Table 4: Companies and organizations incorporating social principles and practices into their regenerative agriculture programs.

Emergent Principle	Program	Example Practices
Supporting farm livelihoods and food system resilience	▪ Kering [50] ▪ Danone [51] ▪ Sustainable Agriculture Initiative Platform [44]	▪ Building productivity and profitability ▪ Creating resilient farming systems
Community revitalization, health, and empowerment	▪ Lexicon of Food [45] ▪ One Planet Business for Biodiversity [52] ▪ Unilever [39]	▪ Creating jobs in agriculture ▪ Localizing food systems ▪ Nutritious and safe food production
Capacity building and knowledge transfer	▪ Soil and Climate Initiative [24] ▪ Lexicon of Food [45] ▪ Regenerative Organic Certified [41]	▪ Mentorship ▪ Communities of practices ▪ Building farmer networks
Advancing equality, safe work, and fair business practices	▪ Regenerative Organic Certified [41] ▪ Danone [51] ▪ A Greener World [42]	▪ Safe work ▪ Fair wages ▪ Fair business practices ▪ Transparency in negotiation

some farmers might be interested in engaging with the social components of regenerative agriculture, they are not always in control of post-farm gate social outcomes. Flexibility and an understanding of capacity is key to ensure that social principles do not deter participation in regenerative agriculture for those who feel these outcomes are out of their control.

Table 4 provides some examples of companies and organizations that have incorporated some of these emerging social principles and concepts into their regenerative agriculture programs.

Regenerative agriculture's principles are not static, and Gualandris *et al.* have proposed three new principles: proportionality, reciprocity, and poly-rhythmicity [47]. These are intended to demonstrate the systemic paradigm shifts that are required to effectively transition to a regenerative agri-food system in Canada, and they help guide the development of social-ecological systems and supply chains that move beyond a minimal harm approach. Specifically [47]:

- Proportionality encourages supply chains to restore native species in specific locations and to ensure production and consumption activities are tolerable to social-ecological systems;
- Reciprocity proposes a new type of food system where interactions between supply chain members, local communities, and nature are designed to benefit multiple human and non-human actors in a community; and
- Poly-rhythmicity emphasizes the need to consider and characterize trends within social-ecological systems and integrate them into decision-making (e.g., management decisions around efficiency and relationship-building and maintenance with local communities).

Overall, these three principles emphasize the importance of restoring regional farming communities that share resources (e.g., production inputs, equipment, labour, livestock, and learnings) to facilitate the transition toward more regenerative and inclusive agriculture [47].

3.2 Common Practices in Regenerative Agriculture

Building on the principles outlined in Section 3.1, the research identified a list of more than 80 different agricultural practices that could be associated with the various principles of regenerative agriculture. Table 5 groups these practices into 12 categories. Input management, livestock and pasture management, and minimizing soil disturbance were the most common regenerative practices, followed by broader landscape-level restoration or management activities and pest management. Farmer focus group participants agreed that many of the practices they associated with regenerative agriculture were present in Table 5. The analysis in this report will focus on some of the more common practices, including reduced tillage, cover crops, crop rotations, grazing, efficient input use, manure use, and agroforestry.

3.2.1 Regional Implementation in Canada

The research found that many of the on-farm and soil health definitions and principles were consistent across different provincially-focused or production system-specific organizations in Canada. Although the principles of regenerative agriculture did not change significantly from province to province, the way each is implemented differed depending on the length of the growing season, the type of production system, and other factors such as soil type and climate. Table 6 presents high level implementation considerations for a common set of regenerative practices and highlights potential limitations on practice function or applicability in different regions or production systems in Canada.

Table 5: Common regenerative agriculture practices supporting regenerative principles.

Category	Practices	
Input management [17], [53]	▪ Organic matter addition ▪ Reduce synthetic or chemical inputs	▪ Green manure ▪ 4Rs of nutrient management (right source, right rate, right time, right place)
Livestock and pasture management [17], [54]	▪ Livestock integration ▪ Rotational grazing ▪ Animal health and welfare	▪ Silvopasture ▪ Forage production
Minimize soil disturbance [2], [16]	▪ Reduced tillage ▪ Direct seeding/drilling	▪ Zero tillage ▪ Perennial crops (less tilling)
Crop, plant, and grass diversification [1], [55], [56]	▪ Crop/plant diversity ▪ Relay cropping ▪ Intercropping	▪ Crop rotation ▪ Companion planting
Soil cover [14], [56]	▪ Soil cover ▪ Cover crops	▪ Stubble retention ▪ Vegetative cover
Tree incorporation [16], [17], [56]	▪ Tree intercropping ▪ Silvopasture ▪ Windbreaks	▪ Shelterbelts ▪ Hedgerows
Maintain living roots [1], [16]	▪ Perennial crops ▪ Perennial grasses	▪ Permanent cover

Category	Practices	
Systems-level management [17], [55]	▪ Holistic management ▪ Agroecosystems ▪ Ecological farming	▪ Permaculture ▪ Mimics nature
Beneficial landscape features [16], [17]	▪ Wildlife habitat ▪ Pollinator strips ▪ Ecosystem diversity	▪ Marginal land for beneficial insects ▪ Conservation buffers
Pest and disease management [17], [57]	▪ Agrophage-resistant crops ▪ Crop rotations	▪ Integrated pest management ▪ Natural pesticides
Water management [2], [17]	▪ Cover crops (infiltration) ▪ Water conservation	▪ Optimized water use ▪ Safeguard water cycles
Other [2], [14], [16]	▪ Earthworms ▪ Solar irrigation ▪ Sun drying ▪ Solar energy ▪ Biochar	▪ Crop breeding ▪ Limit non-renewable resource use ▪ Ethical practices ▪ Fair work and safe work

Table 6: Regional implementation of regenerative principles and relevant limitations. Prairies refers to Manitoba, Saskatchewan, and Alberta.

Regenerative Practice and Principles	Examples of Canadian Implementation	Examples of Practical and Regional Limitations
Cover Crops **Principles:** *Keep soil covered* *Keep living roots in the soil*	**Ontario:** Legume cover crops in corn–soy–wheat rotations [58]. **Prince Edward Island:** Fall rye or wheat after potatoes [59]. **British Columbia:** Multispecies cereal and legume cover crops in blueberry systems [60]. **Nova Scotia:** Grazed forage cover crops [61].	Cover crop use can be limited by growing season constraints, harvest timing, and weather conditions: ▪ In the Prairies, shorter growing seasons and weather variability contribute to skepticism around the use of cover crops [62]. ▪ Crops harvested later in the season (e.g., potatoes) limit the types of cover crop species that can be planted and established [59].
Reduced Tillage **Principles:** *Minimize soil disturbance* *Keep soil covered*	**Prairies:** Notable Canadian success story of the widespread adoption of reduced and no-till, especially in grain and oilseed operations [5].	Reduced till suitability depends on soil type, moisture, crop grown, and temperature [63]: ▪ Regions of Manitoba that experience excess moisture and cool soil temperatures or regions that have clay soils may not be conducive to reduced tillage [64]. ▪ Certain crops require tillage for harvest, making the adoption of no-till difficult in potato or sugar beet production systems [64].

Regenerative Practice and Principles	Examples of Canadian Implementation	Examples of Practical and Regional Limitations
Crop Diversity **Principle:** *Enhance biodiversity*	**Potatoes:** Rotated with forage and cereal crops [65]. **Corn:** Rotated with soy and wheat [51]. **Canola:** Rotated with cereals and pulses [66].	▪ Crop rotation is very common in Canada [67], but there are limitations related to economic considerations about reducing the prevalence of high value crops [68] or incompatibility with perennial systems:Crop rotation is often not applicable to orchards, vineyards, and other perennial or permanent systems, several of which are common in British Columbia, New Brunswick, and Nova Scotia.
Manure Use **Principles:** *Efficient input use* *Incorporate farm animals*	**Manitoba:** Corn, oat, or alfalfa systems with manure amendments [69]. **Alberta:** Canola, pea, and barley systems with manure amendments [70].	Manure use is currently estimated to have low adoption in Canada, but its adoption feasibility is estimated to be high [71]. Common limitations are related to manure access (e.g., transport, sufficient amount, nuisance) [72], salinization or leaching [73], or manure application regulations: ▪ Limited access to manure can occur in regions with low livestock density, such as regions dominated by grain and oilseed production (e.g., Peace River region in British Columbia, Great Lakes–St. Lawrence Lowlands in Quebec and Ontario, and urban and suburban regions) [74], [75], and the need to transport manure from far away can make the practice unprofitable [72]. ▪ Alberta has manure application rules governing set-back distances from water courses, time of application constraints, and soil testing requirements to avoid soil salinization or high soil nitrate levels [76].
Nutrient Management **Principles:** *Efficient input use*	**Ontario, Manitoba, and Saskatchewan:** Commitments to advance 4R practices across production systems, such as variable rate, nutrient management planning, enhanced efficiency fertilizer use, and split application [77].	Nutrient management practices are applicable to any system that applies nutrients, but impose practical limitations based on the type of nutrients used and equipment needs: ▪ Nutrient management practices involving synthetic inputs are not used in organic farming systems. ▪ Certain nutrient management practices, such as variable rate applications, are limited by the need for new equipment or substantial amounts of farm data to generate prescription maps [78].

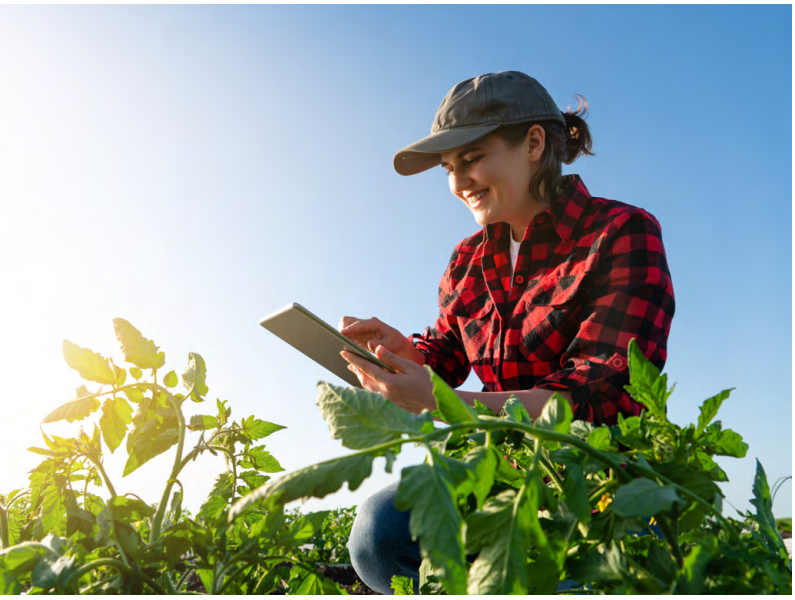
Regenerative Practice and Principles	Examples of Canadian Implementation	Examples of Practical and Regional Limitations
Livestock Grazing **Principles:** *Incorporate farm animals* *Enhance and restore natural landscapes*	**Nova Scotia:** Grazed forage cover crops [61]. **Ontario and Saskatchewan:** Grazing management improvements supported through the Resilient Agricultural Landscape Program [7], [79], [80], [81].	The implementation of a new grazing plan depends on the land area, intended stocking density, forage regrowth rates, pasture quality, and water availability [82]: ▪ Ontario's program requires a minimum of 10 acres and 4 paddocks dedicated to rotational grazing to qualify for funding [79], and Dairy Farmers of Canada recommends that grazing periods are spaced at least 30 days apart to facilitate sufficient regrowth of the forage [83]. These factors may limit some smaller scale farmers from participating. ▪ Water availability across paddocks can limit the feasibility of the practice and funding is often required to manage the upfront infrastructure costs, such as fencing and water sources [84].
Agroforestry **Principles:** *Incorporate farm animals* *Keep living roots in the soil* *Enhance biodiversity* *Enhance and restore natural landscapes*	**Manitoba and Alberta:** Significant use of shelterbelts and windbreaks [85]. **Ontario and Quebec:** Tree intercropping systems [86]. **British Columbia:** Silvopasture on lands used for forestry and pasture management [87].	The use of shelterbelts is widely applicable across Canada, but more integrated practices such as tree intercropping can be regionally limited: ▪ Tree intercropping is less applicable in the Prairies due to larger average farm sizes and the use of larger farm equipment, which are difficult to operate between tree rows [86].

3.3 Common Outcomes in Regenerative Agriculture

Given the integrated nature of regenerative agriculture, it can be difficult to determine where to start or which practices will contribute to a desired outcome. In addition, working within a natural system can lead to highly variable outcomes (see Appendix A). Each of the principles of regenerative agriculture may benefit a farm in different ways or to different degrees depending on the production system and location. Furthermore, regenerative agriculture requires combining multiple practices and principles to obtain desired outcomes, and understanding the costs and benefits of the entire system is important for the most accurate valuation of outcomes [88].

3.3.1 Minimizing Soil Disturbance, Keeping Soil Covered, and Enhancing Crop Biodiversity Outcomes

While many Canadian studies have evaluated the impact of practices that align with regenerative principles, they have not always used regenerative terminology to describe their efforts. For example, Mueller *et al.* [89] assessed the practices of using diversified crop rotations, interseeding with legume cover crops, and reducing tillage intensity, which align with the regenerative principles of enhancing crop biodiversity, keeping soils covered, and minimizing soil disturbance, respectively. Their results from Ontario found that continuous corn rotations produced the lowest yield over a four-year cycle, whereas diversifying the rotation to include soybeans increased



"A survey of farmers in Ontario found that the primary reasons for adopting management practices like no-till, cover crops, and crop rotations, were to improve soil health, reduce erosion or runoff, and improve yields."

the yield by about 9%, regardless of tillage method [89]. Their results also showed that yield could be increased by another 2% if additional diversification was adopted in the rotation (e.g., adding winter wheat under seeded with red clover) but this increase did not persist under no tillage. Furthermore, the study found that no-till corn–soy–wheat and under seeded clover systems reduced yield by 4% compared to the same system under regular tillage, and in general, that no-till systems had lower yields than conventionally tilled ones. However, no-till corn–soy–wheat and under seeded clover systems had 5% higher yields than continuous corn, indicating that adopting a suite of regenerative principles can be beneficial to productivity when compared to business as usual [89].

Despite the potential reductions in yield from adopting reduced or no tillage, there are several other reasons to consider minimizing soil disturbance in conjunction with other regenerative principles. A survey of farmers in Ontario found that the primary reasons for adopting management practices like no-till, cover crops, and crop rotations, were to improve soil health, reduce erosion or runoff, and improve yields [90].

Adopting the principles of minimizing soil disturbance, keeping soil covered, and maximizing biodiversity have also been shown to improve soil carbon sequestration. In the Prairies, reducing tillage was estimated to sequester an additional 0.43 to 0.71 tonnes of carbon per hectare per year [91], while in Ontario, soil carbon levels were estimated to be an average of 12% higher in no-till plots compared to conventionally tilled plots [92]. Furthermore, the Ontario study found that incorporating soil cover (in the form of red clover cover crops) into a corn–oats–barley rotation increased total carbon content by 11% compared to the same rotation without cover crops [92].

Not all studies reported positive outcomes from adopting some of these principles. For example, in terms of keeping soil covered with cover crops, the GHG emissions outcome can vary, and more research is likely needed. Some studies found that the use of cover crops increased soil organic matter and soil carbon [92], [93], [94] and reduced nitrous oxide emissions in Eastern Canada [94]. In contrast, Hung *et al.* [95] and Gao *et al.* [96] found that cover crops in Quebec and Ontario, respectively, either had very little effect on or increased nitrous oxide emissions. Similar variability in nitrous oxide emissions has been reported with reduced tillage practices [91].

In terms of enhancing crop biodiversity, positive impacts on yield or total net returns may not be consistent across all diversified rotations. As crop rotations extend and diversify, high value cash crops become less prominent in the rotation, which can reduce net returns from the system [68], and in some cases, may have little to no positive impact on cash crop yield [97]. Still, diversified rotations that include legumes can be beneficial from a nitrogen availability perspective [98], and the added production costs (e.g., seed and management) of integrating legumes or green manure crops into rotations can be offset by subsequent savings in input costs via reductions in fertilizer and weed control expenses [97].

3.3.2 Incorporating Farm Animals Outcomes

Ensuring efficient input use, reducing synthetic inputs, and incorporating farm animals are some of the regenerative principles demonstrated in a case study by Lynch *et al.* [99], which reports on a 75-cow dairy system in Nova Scotia that diversified their existing cropping and pasture systems with small grains and legumes, implemented a new managed grazing system, addressed nutrient management through animal feed intake, and adopted a systematic approach to soil testing. Within ten years, the farm reported significant increases in milk production, with no negative impact on milk attributes, such as protein and butterfat content [99]. In addition, the farm was able to eliminate synthetic fertilizer purchases by managing legumes in rotation and pasture more efficiently, and by relying more on dairy manure to provide the necessary nutrients, which saved the farm up to $10,000 annually and significantly reduced feed costs per unit of milk produced [99]. While the results of this case study were positive, there were several points of uncertainty during the early stages of the transition, which highlights the risk farmers could incur when trying to adopt a more regenerative approach. For example, after implementation of the grazing system, milk production decreased by 3 to 10% for a four-year period. Simultaneously, the farm had to increase its area by 19% because legume-based forage systems support fewer cattle than those fertilized with synthetic nitrogen fertilizer [99]. Transitional impacts like these underscore the need for new financing instruments or support programs that assist farmers through the period of increased risk.

Incorporating farm animals has been the focus of several other Canadian studies, some of which have reported positive impacts on forage yield and productivity, as well as more plant-available nutrients when animals grazed over crop or pasture lands. For example, Jungnitsch *et al.* [100] reported significant increases in forage yields (2–6 times higher) in Saskatchewan when cattle were grazed overwinter in pasture compared to the spread of feedlot manure on pasture. In contrast, Alemu *et al.* [101] found that forage yield increases were offset by a reduction in pasture quality (e.g., digestible nutrient content), which led to an 18% reduction in daily animal weight gain. In organic production systems in Manitoba, livestock grazing increased nitrogen supply by 25%, compared to ungrazed plots, for subsequent grain crops without negatively impacting yield levels or crop quality [102], [103].

From an environmental perspective, livestock and pasture management practices influence many aspects of soil, water, and biodiversity outcomes. Two dimensions of soil health—soil organic matter and soil carbon—can be improved by using perennial pasture plants, whose roots contain up to three times more carbon than annual grasses [104]. In addition, grazing practices can have a similar positive impact on soil carbon accumulation (in the range of 0.23 to 0.34 tonnes per hectare annually [101]) and the inclusion of livestock in landscapes can increase soil moisture and other organic matter levels [101], [104]. However, when the intensity of the grazing or the stocking rates are too high, these factors can increase soil compaction or facilitate soil erosion [104].

High-intensity grazing can also negatively influence certain water dynamics in the Prairies by increasing water runoff when vegetative cover is depleted and reducing water infiltration when compaction occurs [104]. To protect watershed quality, farmers can implement rotational grazing plans that incorporate exclusionary fencing and setbacks from watercourses. One study in Alberta found that implementing a rotational grazing plan that limited livestock access to the watercourse reduced nitrogen and phosphorous levels in the water and increased vegetation diversity along the shore [105].

3.4. Measuring Performance of Regenerative Agriculture Principles

There are many ways to operationalize the principles of regenerative agriculture, so any standardization effort must include a level of flexibility that respects contextual differences and varying farm management goals. Organizations such as McCain, Danone, Regenerative Organic Certified, and General Mills have provided a starting point for identifying key performance indicators, as they demonstrate that there is a range of different ways each regenerative agriculture principle can be implemented. Table 7 summarizes a few examples of how each principle is operationalized and evaluated in these programs.

Table 7: Examples of regenerative agriculture indicators.

Proponent	Indicator Description	Key Performance Indicators
Principle: Minimize soil disturbance		
McCain [27]	Each instance of intensive tillage is known as an "event" and events should be kept to a minimum across the rotation cycle.	**Potato crops:** ▪ **Engaged**: Reduce tillage by 1 event ▪ **Advanced**: Reduce tillage by 2 events ▪ **Leading**: Reduce tillage by 3 events **Rotation crops:** ▪ **Engaged**: Decrease tillage by 10% ▪ **Advanced**: Decrease tillage by 25% ▪ **Leading**: Decrease tillage by 50%
Danone [48]	Percentage of untilled cultivated land per year.	**Level 1:** 30–59% **Level 2:** 60–90% **Level 3:** >90%
Principle: Keep soil covered year-round		
McCain [27]	Fields on the farm are covered by living plants with an average normalized difference vegetation index (a measure of greenness) value of >0.25, and at least 30% of soil surface is covered by living crops or residue year-round.	**Engaged:** 90 days/year **Advanced:** 180 days/year **Leading:** 270 days/year
Regenerative Organic Certified [41]	Operations will aim to cover land with living vegetative cover year-round. Otherwise, crop residues or mulch is required when field preparation or planting is not underway.	**Bronze:** Maintains year-round vegetative cover on 25–50% of all cultivated land. **Silver:** Maintains year-round vegetative cover on 50–75% of all cultivated land. **Gold:** Maintains year-round vegetative cover on 75–100% of all cultivated land, and uses at least one nitrogen-fixing cover crop in each full crop rotation.
Principle: Keep live plants and living roots in the soil		
General Mills [38]	Fields have a living root in the ground.	**Level 1:** For at least 130 days **Level 2:** For at least 200 days **Level 3:** For at least 300 days
Regenified [106]	Days of the year active living roots from cash crops, cover crops, or pasture are present.	**Tiers 2–3:** 50–70% of the year **Tiers 4–5:** 70–90% of the year

Proponent	Indicator Description	Key Performance Indicators
Principle: Enhance Biodiversity Above and Below Ground		
General Mills [38]	Increase crop and plant diversity over a 3-year period.	**Level 1:** Fields include at least 3 different species of plants, including grasses and broadleaf plants. **Level 2:** Fields include at least 4 different species of plants from at least 3 of the following 4 categories: warm season grass, cool season grass, non-legume broadleaf, legume. **Level 3:** Fields include at least 5 different species of plants from all 4 categories listed in Level 2.
McCain [27]	Over prior 4 years, including the current season, crops of different species are grown to provide a range of growth cycles, plant architecture, and root types.	**Engaged:** 4 crop species, including grass. **Advanced:** 6 crop species from 3 different plant families, including a grass and a legume. **Leading:** 8 crop species from 4 different plant families, including a grass, a legume, and 2 perennial crops.
Principle: Incorporate Farm Animals		
General Mills [38]	Integration of planned livestock grazing into cropping systems.	Producer integrates livestock into cropping area and at least 30% of the crop residue and/or living vegetation remains in the field after grazing. Level 3 also requires a written Holistic, Prescribed, or Adaptive Grazing Plan.
Regenerative Organic Certified [41]	Rotational grazing is practiced in commercial livestock operations.	Required for all levels. Animals, excluding bison and pigs, are used in high concentrations for brief periods and pastures are divided into paddocks, with animals moved regularly.
Principle: Efficient Input Use and Reduce Synthetic Inputs		
McCain [27]	Crop protection products are selected to reduce environmental, human, and consumer impact, and measured by the Environmental Impact Quotient (EIQ) of the inputs applied.	**Engaged:** 800 EIQ/hectare or less. All inputs are applied based on decision support tools or expert advice from recognized crop advisor. GPS is used. **Advanced:** 500 EIQ/hectare or less. Must meet Engaged level, and 15% of crop nutrient needs are provided from organic sources (plant/manure). **Leading:** 200 EIQ/hectare or less. Must meet Engaged level, and 30% of crop nutrient needs are provided from organic sources (plant/manure).
General Mills [38]	Improve nutrient management practices by adopting 4R practices and using organic sources of nutrients.	**Level 1:** Nutrient application follows the 4R's of nutrient stewardship. **Level 2:** Meets baseline 4R and at least 25% of all nutrients applied (by weight) is made available to the plant via decomposition. **Level 3:** Meets baseline 4R and at least 75% of nutrients applied (by weight) is made available to the plant via decomposition.

Proponent	Indicator Description	Key Performance Indicators
Principle: Conserve and Protect Water		
Regenerative Organic Certified [41]	Operations do not directly discharge untreated wastewater generated on farm into natural waterways or soil, and do not divert wastewater to bypass treatment. Industrial wastewater goes through primary and secondary treatment (onsite or offsite).	Required for all levels. Facilities producing more than 50 cubic metres of wastewater per day shall have evidence of compliance to the prevailing authority.
Danone [48]	Percentage of farm water courses surrounded by buffer zones.	**Level 1:** 25–34% **Level 2:** 35–50% **Level 3:** >50%
Principle: Enhance and Restore Natural Landscapes		
Regenerative Organic Certified [41]	Operations engage in additional regenerative practices (beyond those required by the United States Department of Agriculture's National Organic Program) to improve overall ecosystem health and productivity of operations.	Practices may include: agroforestry; forage and biomass planting; grassed waterways; integrated crops and animals; mulching; perennial planting; pollinator habitats, insectary strips, or wildlife habitats; reduction of off-farm inputs and recycling of on-farm biomass; riparian restoration; silvopasture establishment; tree or shrub establishment; water conservation and wetland restoration; windbreak and shelterbelt establishment. **Bronze:** 3 of the practices are used. **Silver:** 4 of the practices are used. **Gold:** 5 or more of the practices are used.
McCain [27]	Enhanced farm and ecosystem biodiversity, including promotion of small natural habitats and natural landscape elements. Small natural habitats are near the edge of the field, and riparian buffer zones are present.	**Engaged:** 1% of non-cultivated land is dedicated to natural habitat. **Advanced:** 5% of non-cultivated land is dedicated to natural habitat. **Leading:** 8% of non-cultivated land is dedicated to natural habitat.
Principle: Respect for Human and Non-Human Life and for the Environment		
General Mills [38]	**Five Freedoms of Animal Welfare:** 1. Freedom from hunger and thirst. 2. Freedom from discomfort. 3. Freedom from pain, injury, or disease. 4. Freedom from fear and distress. 5. Freedom to express normal behaviours.	**Level 1:** Producer adheres to the Five Freedoms of Animal Welfare and animals have access to the outdoors for at least 100 days/year. **Level 2:** Meets Level 1, and animals have access to the outdoors for at least 180 days/year. **Level 3:** Meets Level 1, animals have access to the outdoors for at least 300 days/year, and operation is certified by one of the following: Global Animal Partnership, Animal Welfare Approved, Certified Humane, Beef Quality Assurance, or Pork Quality Assurance.

3.4.1 Quantification of Outcomes

Quantifying agri-environmental outcomes can be difficult, but there are several tools, models, and methods to support the measurement, reporting, and verification of farm-level activities. While they were not necessarily developed for regenerative agriculture, they can be used to assess outcomes in the soil, crop, water, biodiversity, and whole-farm sustainability context. Table 8 provides a summary of the tools, models, and measurement methods identified in this report, which present a starting point for identifying Canadian analogs or adaptation opportunities.

3.5 Practice Change in Regenerative Agriculture

This section presents a framework that describes the process of regenerative agriculture practice adoption at a high level. To align with focus group feedback, a key component of this framework was to visualize regenerative agriculture as a journey of continuous improvement. The structure of the framework in Figure 1 is based on adoption process frameworks developed by Pannell *et al.* [111] and de Oca Munguia *et al.* [112], and has been adapted to the context of regenerative agriculture. Using this format to discuss the research findings can inform standard development by demonstrating how end users interact with the system, and highlighting where incentives, policies, knowledge resources, and other supports would be most influential in supporting different stages of the adoption process (e.g., targeting knowledge resources to the pre-trial evaluation phase to support learning or targeting new financing opportunities to the trial evaluation phase). For the purposes of this report, *trialling* refers to the adoption state where a farmer tests out a new practice on their farm to evaluate if it is right for their farm context.

Table 8: Potential tools for measuring common regenerative agriculture outcomes.

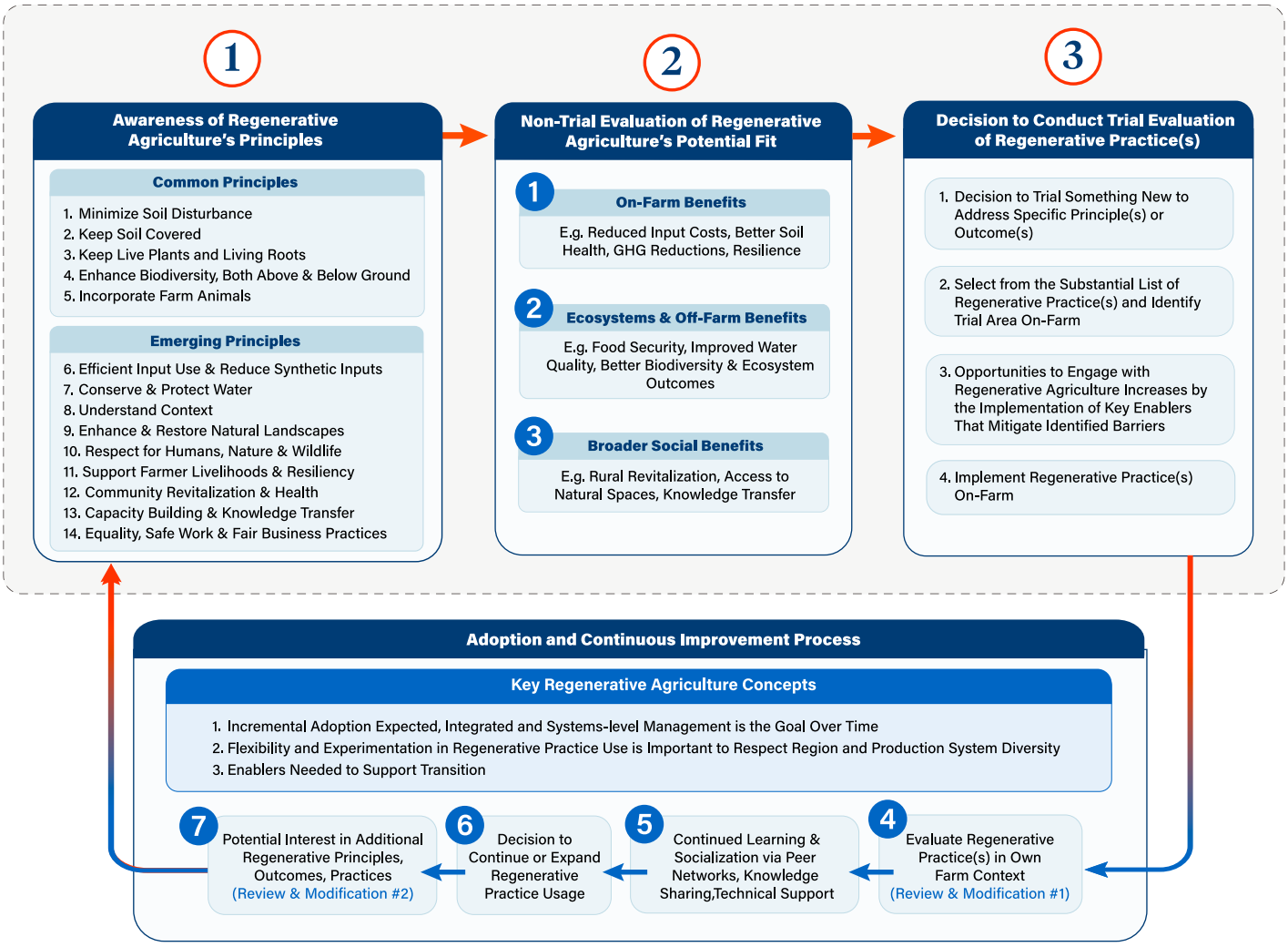
Outcome	Parameter	Measurement Tools/Models/Methods
Emissions/soil health	Carbon sequestration	DayCent, CropSyst, CQESTR, COMET-Farm [107]; RothC, visible near-infrared or mid-infrared spectrometry [17]
Emissions	Carbon dioxide, nitrous oxide, methane	DeNitrification-DeComposition (DNDC) [108]
Soil health	Soil moisture	Time domain reflectancy [17]
Soil health	Bulk density	Penetrologger equipment [17]
Soil health	Electrical conductivity	Soil sensors [17]
Soil health	Soil texture/profile	Gamma ray spectrometry [17]
Soil health	Soil erosion	Integrated Erosion Tool: Water Erosion Prediction Program and Wind Erosion Prediction Service [109]
Productivity/ biodiversity	Vegetation and growth	Visible near-infrared spectrometry, Normalized Difference Vegetation Index (NDVI) [17]
Practice verification	Cover crops, reduced tillage, crop rotation	OpTIS satellite data and ground truth data via surveying apps [108]
Biodiversity	Capacity to support diverse plants/animals	Habitat Potential Index [109]
Water quality	Risk of nutrient loss	Stewardship Tool for Environmental Performance [109]
Overall sustainability	Whole-farm quantification	Cool Farm Tool, Field to Market, COMET-Farm [110]; MOTIFS and SALCAsustain [16]

The first stage of the framework is awareness, which represents a farmer's exposure to the breadth of regenerative agriculture principles, which are listed in Box 1 of Figure 1. When awareness turns into an interest or curiosity in the potential outcomes of regenerative agriculture, farmers move into the non-trial evaluation phase, where data gathering and socialization become key in understanding whether regenerative agriculture is a good fit for the farmer's own context.

During the farmer focus group discussion on barriers, participants noted how their neighbours' perceptions impacted their decisions around regenerative agriculture and the value of information obtained from peer groups.

Farmers indicated that both knowledge resources and skill development opportunities for regenerative agriculture concepts were limited, and suggested a peer-to-peer approach would be their preferred method of learning more about the concepts. Some of the farmer focus group participants noted that they had engaged in additional reading to gather more information, while others referred to YouTube or other online sources to advance their understanding. Some also mentioned that they preferred learning opportunities that gave them a sense of autonomy, and these encouraged them to consider a small-scale trial as a first step. All of these avenues facilitate the non-trial evaluation phase, which is represented in Box 2 of Figure 1.

Figure 1: Regenerative agriculture principles framework. Adapted from [111] and [112].



Once farmers have gathered enough data, they may decide to conduct the first trial evaluation, as shown in Box 3 of Figure 1, and adopt a new or change an existing production practice, provided that relevant barriers have been mitigated through the implementation of the correct set of enablers. Farmer focus group participants noted that trials generally started small and expanded to larger plots over time if outcomes remained positive. Once the trial is in place, the continuous improvement process begins with the first review and modification phase (Box 4), during which the farmer reviews how the practice changes impact outcomes within their own context, and then makes the decision to continue using it, expand the scale of the trial, or dis-adopt (Box 6). For those choosing to fully adopt or expand the trial, there is a second component of the process, wherein a farmer who has bought into regenerative agriculture through a first trial may decide to revisit the guiding principles and integrate another production practice for evaluation (Box 7). If the decision is made to continue engaging in new regenerative practices, the cycle repeats; however, individuals may start at different stages in their second cycle (e.g., they may already be aware of the principles and fit, so they are now just looking for a new practice and skip right to Box 3).

3.6 Enabling a Regenerative Agriculture Transition in Canada

3.6.1. Barriers

Building a regenerative agri-food system in the Canadian context requires an examination of the key barriers that farmers and other practitioners face in promoting and adopting regenerative agriculture principles and practices, which include:

- **Operational and biophysical barriers:** Items that influence how the farm is managed and the regional limitations imposed by soil type, climate, or other factors [113];
- **Financial barriers:** Concerns around practice costs, accessing financing, or the appropriateness and administrative burden of existing incentive programs, including payment for ecosystem services and other compensation programs [14], [35], [107], [114];
- **Knowledge and support barriers:** Concerns around the lack of technical support, reduced research capacity, perceived complexity, limited skill development opportunities, and limited availability of knowledge resources or context-specific trial data [107];
- **Social and cultural barriers:** Concerns related to mental shifts, social acceptance, lack of support from agribusiness, norms, and threats to the status quo [35], [115]; and
- **Financial risk barriers:** Concerns around the transition period when implementing regenerative agriculture practices, which can be exacerbated by crop insurance and market conditions [14], [107].

These barriers are complex and evolving, and often occur simultaneously, resulting in a knot of intertwined challenges that need to be dealt with [113].

3.6.1.1 Operational and Biophysical Barriers

Regenerative agriculture practices tend to influence the way a farm is managed, and introduce new labour requirements, machinery, planting and harvesting schedules, and scales of production. These practices may be seen as incompatible with existing farm management structures and resources, as additional labour may be unavailable to farmers and new practices or systems may interfere with the use of existing machinery or require the purchase of new equipment. Some regenerative practices may also interfere with the planting and harvesting of commodity crops, requiring farmers to generate novel farm plans or shift cropping priorities. Because of these operational incompatibilities, regenerative practices may also be seen as difficult to scale at a commodity level and as requiring intensive management, especially in the Prairies. Operational shifts in production systems may be seen as an intimidating barrier for producers, requiring significant planning and change to their operations [113].

In addition to operational incompatibilities, biophysical factors may be another constraint for farmers adopting regenerative agriculture practices. Some practices may be inappropriate for specific soil types or less effective in different climates, highlighting the importance of regional adoption campaigns and additional research on regional outcomes of regenerative practices across Canada [113]. Agronomic concerns are also prevalent with regenerative agriculture, such as increased pests and weeds and interference with commodity crop



production. Farmers and practitioners will require supplementary information on how to manage these outcomes and implement regenerative solutions to them. Finally, as extreme weather events and shifts in weather patterns, particularly precipitation, become more frequent, producers may feel more risk averse to trialling new practices, especially when the outcomes may result in losses for transitional years [113].

3.6.1.2 Financial Barriers

In general, the financial barriers identified for this report stemmed from the need for more capital and financing or loan programs [107], [114]. Farmer participants mentioned financing programs as an attractive type of incentive for promoting regenerative agriculture, which is perceived as costly to implement. In some cases, participants suggested that loans were needed to manage these upfront costs.

Both the literature and the focus groups suggested that regenerative agriculture financial support programs in Canada and elsewhere are limited, and when they are available, they are considered burdensome for farmers to access [35]. Another commonly identified financial barrier was the transition period, which is associated with regenerative practices that may cause a reduction in yield or productivity in the short-term [14], [99] and practices that require the purchase of new equipment or changes in farm management that impact the profitability of production [113]. In the context of the framework (Figure 1), these limitations might be preventing farmers from getting to the trial evaluation stage due to unmanageable transition costs, and might also be hindering their ability to adopt multiple practices over time and enter the continuous improvement process.

3.6.1.3 Knowledge and Support Barriers

In addition to financial concerns, findings from the literature and focus groups indicated that farmers face technical challenges and knowledge barriers when adopting regenerative agriculture, which influences the awareness, non-trial evaluation and data gathering, and trial evaluation stages in the framework (Figure 1). These barriers are mainly driven by a lack of access to technical support and limited learning opportunities or resources for practice assessments, planning, and evaluation [107]. Limited accessible research on the agronomic and economic impacts of regenerative practices in the Canadian context, specifically in terms of soil health and return on investment, are also contributors to this issue [113].

The reduction in Canadian extension service capacity over the years has also been described as a barrier to the adoption of new, more sustainable management practices, which is likely exacerbated by the focus group feedback suggesting more peer groups are needed to more effectively share information and connect farmers [107], [116]. The lack of consensus around regenerative agriculture definitions and principles further exacerbates the situation, as it leaves farmers and other actors uncertain about the outcomes and practices associated with regenerative agriculture [18].

3.6.1.4 Social and Cultural Barriers

Socio-cultural barriers, such as social acceptance, culturally entrenched production practices, farm demographics, government and institutional distrust, and perceptions of agriculture in relation to natural systems were also found to hinder the transition to regenerative agriculture practices. These social and cultural issues may hinder awareness of regenerative principles and influence the context in which data about regenerative agriculture is interpreted by the farmer. They may also prevent the implementation of a trial or the sustained use of regenerative principles over time when farmers feel that cultural factors or social norms generate discomfort or isolation from their communities. Some farming practices may be culturally significant or entrenched within production systems, requiring broader cultural changes for producers to shift away from traditional production processes. Furthermore, some regenerative practices require more intensive management, which creates the perception of a lifestyle change or departure from traditional management approaches [113]. These perceptions highlight the need for a mental shift, both individually and at the community level, to facilitate a large-scale transition to regenerative agriculture [115]. For example, this could include a fundamental shift in mindset regarding the relationships between humans and the environment to ensure the relationship is rooted in reciprocity and a sharing, rather than sparing, perspective.

Focus group feedback confirmed that farmers may struggle with the adoption of regenerative agriculture principles and practices because they feel it will alienate them from peers, exacerbating concerns over the social acceptance of trialling new approaches. The aging farm population may also influence slow adoption rates of new farming practices, as some farmers may hesitate to invest in new management practices as they near retirement [113]. Distrust in government and agricultural service providers may also inhibit the adoption of regenerative practices, as some farmers feel disconnected from policymakers and advisors or feel that practices may be biased or tied to economic or political agendas [113].

3.6.1.5 Financial Risk Barriers

Financial risk was identified as a critical barrier that farmers face in transitioning to and trialling new regenerative agriculture principles [35], and it is exacerbated by limited crop insurance coverage for regenerative agriculture, market conditions, and societal expectations of farmers to usher in this transition and provide environmental and social benefits [107], [113]. When farmers decide to trial new regenerative practices, it can enhance their exposure to risk and they may be penalized by a reduction or elimination in crop insurance coverage, which makes experimenting with new regenerative practices less attractive. In terms of market conditions, because farmers are price takers, uncertain financial futures may limit the trialling and enactment of new practices, as capital resources may need to be conserved for less profitable seasons. Taken together, there is an expectation that farmers take on the majority of the transitionary risk associated with regenerative agriculture and accept market prices for their products, even though the scope of regenerative benefits provided extends far beyond the fields they manage.

3.6.2 Enabling Conditions

While barriers to regenerative agriculture are prevalent, there is no shortage of opportunities to break down barriers and promote a regenerative transition in Canada. The research identified several important enablers and transition levers, which include:

- Promoting the development of peer networks or communities of practice that create a sense of community, shift cultural norms around regenerative agriculture, and promote the dissemination of new farming perspectives;
- Enhancing the availability of extension services or knowledge resources to promote knowledge sharing, learning, and a sense of community [33], [117], [118], [119];
- Providing access to new financing programs, such as revolving loans or other financial incentives, that help manage transitional and adoption costs [14], [107], [118];

- Shifting to outcomes-based or payment for ecosystem service style programming, with an appropriate set of MRV tools in place, to recognize the full scope of benefits provided by regenerative agriculture [18], [34], [120];
- Creating strong value propositions that entice investment, such as capitalizing on existing demand pulls (e.g., interest in insets) or generating new mutually beneficial opportunities to invest in regenerative agriculture; and
- Working toward greater standardization or certification as a means of accessing capital, creating a demand driver, and communicating benefits to value chains and end users (i.e., consumers) [18], [31], [121].

Promoted simultaneously, these enablers could increase awareness in regenerative agriculture practices, trialling, and sustained adoption, and could promote engagement with a breadth of actors to design and drive forward new solutions.

3.6.2.1 Peer-Based Networks and Communities of Practice

Peer networks, mentoring, and communities of practice are key approaches to addressing socio-cultural, knowledge, and skills barriers in regenerative agriculture transitions. Peer networks were identified as the preferred approach for farmer knowledge sharing during the focus groups. These networks are attractive because they allow for collaborative trialling, knowledge and data sharing, mentorship, storytelling, and social or technical support, which overall contribute to increased awareness, interest, and confidence in trialling [20], [107], [113], [117]. Strengthening these social networks can also reduce feelings of isolation or make the process of trialling new practices feel less overwhelming [33].

Regional or production-specific peer networks are preferred because they connect farmers with similar localities or operational interests [119], but these networks should also be expanded to promote socialization between different groups. Recognizing that peer networks and mentorship are critical to expanding awareness and knowledge of regenerative practices, communities of practice should include actors from government, research communities, farmer organizations, non-profits, and corporations to promote collective action, resource sharing, and synergies between actors. Some peer networks and communities of practice have been supported by organizations such as ALUS and the Ontario Soil Network, and are operationalized by connecting producers and other actors with common goals in order to catalyze action and knowledge sharing [122]. However, the establishment of additional and diverse networks and communities should remain a priority across Canada. Identifying the best practices for establishing, coordinating, and maintaining peer networks or communities of practice remains a potential area for further research.

3.6.2.2 Knowledge Resources, Skill Development, and Technical Support

Knowledge sharing, skills training, research, and access to extension services are also core enablers for a regenerative agriculture transition, as these interventions provide farmers and other actors with the information, support, and skills needed to conduct non-trial evaluations, trial practices, and to develop regenerative farming systems over time. As mentioned in Section 3.6.2.1, knowledge sharing, though peer-to-peer, communities of practice, or accessible research initiatives, is one method for spreading awareness and providing information about applications and best practices [33].

Other opportunities for formal training on regenerative agriculture could include support for the trialling and evaluation of regenerative principles by providing farmers with the skills needed to plan and monitor practice adoption [117]. Demonstration farms were also mentioned in the focus groups as an opportunity to engage established regenerative farmers in showcases that expose conventional producers to different methods of production. Demonstration farms also provide experiential learning opportunities, create space for storytelling, and create pathways for regenerative practice advice that is independent of agricultural marketing and products or government goals [113].

Knowledge and skill development can also be achieved by improving the availability of extension services [123], [124]. In this regard, government could revitalize extension services through new investments or leverage existing funding envelopes to expand demonstration project opportunities [18]. For example, the Living Laboratories Initiative was highlighted as a successful example of multi-party, farmer-led demonstration sites that promote learning about different methods of production. The Living Laboratories approach represents an important opportunity to further research in key areas, such as evaluating the agronomic and economic outcomes of regenerative agriculture practices in various Canadian contexts to reduce uncertainty in the adoption process. Concerns surrounding the profitability of regenerative practices could be addressed through region- and practice-specific cost benefit analyses that account for emerging markets and valuations of the ecosystem services associated with regenerative practices. Access to this type of knowledge and research may also drive the engagement of corporate actors and financial institutions, helping them build a business case to develop value chain initiatives, market levers, and flexible financing mechanisms that usher in regenerative agriculture transitions.

3.6.2.3 Financing Tools and Addressing Unintended Consequences

Innovative financing opportunities are critical to help farmers overcome the financial barriers they face when trialling regenerative agriculture practices, and to compensate them for the ecosystem services and broader co-benefits they provide through regenerative farming. Several novel financing programs have been proposed globally, and many are applicable to Canada, such as revolving low interest loans [18], price premiums for transitioning or transitioned farmers [13], [118], de-risking finances from foundations or governments, and green bonds. All these tools create monetary channels for farmers and could support trialling, adoption, and sustained engagement with regenerative principles over time.

This report also identified crop insurance policies as a potential barrier. Focus group participants suggested that crop insurance coverage was sometimes unavailable when using regenerative practices, as they were not compatible with crop insurance requirements. To mitigate this barrier, focus group participants suggested that existing business risk management programs should be re-evaluated to provide producers with the flexibility to experiment without compromising their eligibility. Some studies have suggested that crop insurance for regenerative practices should be made available to insure land that is in transition to regenerative agriculture and de-risk the process [113]. Overall, business risk management programs should ensure that regenerative farmers have at least equal access to coverage, especially given the substantial public benefits they provide through adopting the principles.

3.6.2.4 Outcomes-Based Programming and Associated MRV Processes

Outcome-based programs, ecosystem service credits, and payments for ecosystem service programs, are another opportunity for delivering innovative incentives that could catalyze transitions [18], [34], [35], [120]. These programs would generate new streams of income for regenerative producers in Canada at varying scales, allowing for flexibility in participation across different regions and production systems [34], [35]. Both the literature and the focus groups proposed the development of MRV processes as an enabler for a systems-wide regenerative agriculture transition, because MRV processes and accounting systems that can quantify carbon emissions, carbon sequestration, water retention and filtration, food nutrients, and the host of other regenerative benefits will enable monetization and create new revenue streams for adopting producers. MRV systems that quantify the beneficial outcomes from regenerative agriculture could promote access to financing [53], drive interest from corporations to invest in regenerative agriculture programming, and enable market levers such as price premiums and premium contracts [34], [110].



"Important enabling actors in regenerative agri-food systems include academia and research networks, corporations, government, non-governmental organizations, producer groups, extension services, financial institutions, and underserved and Indigenous groups."

MRV processes and associated verification tools for regenerative outcomes could also catalyze farmer engagement, as these tools can help them develop a clear business case for adoption and provide decision support tools to identify effective practices for trialling [32]. To catalyze the widespread use of MRV systems, cost-effective, streamlined, and comprehensive tools and monitoring systems must be developed in a way that is accessible to farmers [113]. Easing monitoring requirements or streamlining data collection and reporting could help overcome the administrative challenges that farmers face with some of these programs, but the issue of designing MRV metrics that preserve flexibility and reduce data burdens in agriculture remains difficult, especially with the current broad concept of regenerative agriculture. Engaging with producers to develop accepted definitions and outcomes of MRV systems could support farmer enrolment and promotion [113].

3.6.3 Engaging all Parties in the Regenerative Agriculture Transition

To support the enablers, engagement and action will be required from all parties in Canada's agri-food value chain. Activating these important changemakers requires a better understanding of the role they can play in the transition, the barriers they face, and the interventions they require to develop meaningful, systems-engaged conditions to support awareness, non-trial and trial evaluation, and the sustained adoption of regenerative agriculture principles. Important enabling actors in regenerative agri-food systems include academia and research networks, corporations, government, non-governmental organizations, producer groups, extension services, financial institutions, and underserved and Indigenous groups. These different parties could play roles within the framework and catalyze farmer engagement by:

1. Providing knowledge, research, and skills development opportunities that help practitioners learn about regenerative agriculture and trial new practices;
2. Providing financing and other market or de-risking measures to support the trialling and evaluation of production practices; and
3. Establishing communication channels and partnerships to support equitable, reciprocal relationships and continued learning and peer support.

The roles of each party and the potential barriers to promoting a regenerative agriculture transition in Canada are summarized in Table 9.

Table 9: Roles for food system parties in regenerative agriculture transitions in Canada.

Relevant Party	Role	Barriers	Enablers
Academia and Research Networks	Lead multidisciplinary research; disseminate knowledge; promote awareness; co-create and consult; develop MRV	Impacts are context-specific; limited funding; few pilot projects for non-trial evaluation [125], [126]	Access to neutral funds; national-level research mandates; partnership building for awareness and trialling [17], [125], [126]
Non-Governmental Organizations and Farm Groups	Conduct and socialize research for trial and non-trial evaluations; convening; develop and implement programs; represent producer interests	Limited funding; focus on context-specific interventions; unclear terminology and goals [13], [127]	Flexible funding; framework co-creation and coalition building; diverse communication channels; hybrid models of governance [9], [13], [20]
Government	Develop policies and programs; set targets and required standards; deploy funding for awareness trialling and evaluation	Piecemeal policies; limited research; prohibitive governance models; patchwork of standards [13], [125], [126]	Research and network building; mandate and standard development; hybrid governance models [125], [126]
Industry	Develop market levers and programs; apply standards; set and progress toward ambitious goals and targets	Uni-dimensional investments; limited business case and accounting for regenerative agriculture outcomes [9], [126], [128]	Clear framework and policy landscape; comprehensive research on outcomes; demand from supply chain; outcome-based programs [16], [126]
Extension Services	Support adoption, trial, and evaluation of practices; disseminate knowledge and skills	Reduced funding; limited access to new training; unknown capacity to support regenerative agriculture [128]	Training and skills development; network building; engagement in programs and standards [16], [125]
Financial Institutions	Fund research and adoption; innovate financing mechanisms	Unclear business case and policy direction; limited incentives to develop revolving financing mechanisms [13], [126]	Framework application; inclusion in strategic partnerships; support social financing [121], [126]
Underserved and Indigenous Groups	Promote solidarity, reciprocity, and social justice; increase inclusion and representation; preserve and revitalize foodways; support land rights and access	Lean funding; limited voice and governance; persistence of violent legacy of settler colonialism; limited research and knowledge transfer of Indigenous foodways [1], [12], [128]	Co-creation; re-evaluation of colonial policies; Indigenous governance; integration of Indigenous knowledge [1], [12], [118]

Like farmers, food system parties may also face financial, knowledge, and social or perception-based barriers when trying to mobilize a regenerative agri-food system in Canada. Identifying these barriers within the context of the roles of interested parties promotes the development of comprehensive enabling conditions and recommendations, generating systems-wide capacity to transition to regenerative agri-food production. For example, industry, government, and financial institutions would benefit from the development of strategic partnerships and comprehensive standards for regenerative agriculture, which would facilitate their ability to support farmers in regenerative transitions [16], [126], [128]. Other parties, such as academia and research networks, non-governmental organizations, and producer groups, see value in flexible, unbiased financing to support research endeavours, program development, demonstration sites, and training opportunities that deliver context-specific, high-quality knowledge resources to the sector [16], [17], [126], [129]. These levers are critical to ensuring that farmers and other actors have the information, skills, and capacity to learn about regenerative agriculture and trial new practices. Exploring the roles, barriers, and enabling conditions for all actors to support a transition to a regenerative agri-food system in Canada presents an opportunity for further research to ensure that standards, policies, and programs promote practitioner-wide action toward regenerative systems.

3.7 Standards, Protocols, and Certifications

Participants from both of the focus groups suggested that regenerative agriculture standards could:

- Help advance clarity around what regenerative agriculture is;
- Act as the foundation for initiatives that communicate the value of regenerative agriculture to end users or consumers (e.g., via certifications);
- Act as a mechanism for accessing capital or investment and creating confidence by minimizing greenwashing through clear data collection and evaluation guidance; and
- Prevent another entity from defining and imposing their definition of regenerative agriculture on Canadian farmers and value chains.

Standard-setting bodies have a large role to play in advancing the awareness of regenerative agriculture principles throughout the agri-food value chain. By codifying common and emerging principles into a continuous improvement cycle, standardization could help provide clarity around the most appropriate definition of regenerative agriculture in Canada. This would send a clear message to the sector regarding how regenerative agriculture should be implemented and ensure that Canadian farmers have a regionally and contextually relevant standard for their systems. It would also help industry programs on regenerative agriculture align to a standard and could help investors identify high-quality initiatives to invest in. Overall, increasing awareness and clarity around regenerative agriculture through standardization could unlock new funding opportunities that enable more farmers to trial regenerative agriculture for the first time or enable early adopters to expand into new regenerative practices.

Standardization also has a role in the review and modification phase of the framework, as a standard would identify what needs to be measured and how to do so in a way that does not overburden farmers, while also generating confidence in the validity of the outcomes for investors. With sustainability increasingly becoming the cost of market access, being more concrete about how to assess regenerative outcomes will enable farmers and value chains to tell their sustainability story, avoid greenwashing, and potentially capture more market share.

Table 10 provides a non-exhaustive review of existing standards that should be considered when developing a Canadian standard for regenerative agriculture. While none of the global standard-setting bodies have developed a formal standard for regenerative agriculture, several are developing related standards in the sustainable agriculture [130], agroecosystem [131], and soil health spaces [132]. Other initiatives, such as the Canadian General Standards Board's organic production systems standards (CAN/CGSB-32.310 and

CAN/CGSB-32.311) [133], [134], and the internationally-developed Tool for Agroecology Performance Evaluation (TAPE) [135] should also be considered in the design of a standard for a systems-based approach like regenerative agriculture. Given the ongoing debate around terminology, analyzing these standards provides an opportunity to foster alignment and create connection points with other standards. Of note is CSA W218, which sets out the specifications for natural asset inventories, and could be applicable on the principle of enhancing and restoring natural landscapes [136]. Many of the ecosystem services provided by regenerative practices could be evaluated using the guidance laid out in CSA W218. Furthermore, Annex A, as well as the associated MRV standards for ecosystem service valuation, could be useful for assessing outcomes and communicating the value of regenerative agriculture practices to investors, governments, and others on the international stage [136].

Table 10: Existing standardization and certification efforts relevant to regenerative agriculture.

Organization	Scope and Example Practices	Applicability to Regenerative Agriculture	Limitations
Canadian General Standards Board	CAN/CGSB-32.310 and CAN/CGSB-32.311 lay out principles, management standards, and permitted substances in organic production [133], [134]. Includes permitted substances for food production, tillage, manure management, irrigation, livestock diets, and animal welfare.	Made in Canada, applicable to the development of holistic management standards for agricultural production systems, and provides guidance for several practices that would also be considered regenerative.	Not specific to regenerative agriculture and operates under different principles.
Canadian Standards Association	CSA W218 outlines specifications for developing a natural asset inventory [136]. Includes minimum requirements for natural asset inventories, data gathering and processing, inventory structure, and documentation.	Made in Canada, applicable to principles like enhance and restore natural landscapes, ecosystem service specifications and MRV standards are aligned with desired outcomes of regenerative agriculture, and could serve as a starting point for adaptation to the agricultural context.	Limited relevance to farm management practices and how they should be implemented or evaluated to align with regenerative agriculture principles.
Regenerative Organic Alliance	*Regenerative Organic Certified®* program promotes holistic regenerative and organic management of agricultural lands [41]. Includes vegetative cover, crop rotations, grazing, tree planting, water conservation, reducing synthetic inputs, and animal welfare.	Provides indicators and performance measures customized to the regenerative agriculture context, provides an example of how to operationalize continuous improvement, and is scoped broadly to include economic, environmental, and social principles.	Not specific to the Canadian context, includes organic requirements that are not common in regenerative agriculture (e.g., use of GMOs).

Organization	Scope and Example Practices	Applicability to Regenerative Agriculture	Limitations
A Greener World	*Certified Regenerative* program promotes regenerative management of soil, water, air, and biodiversity [42]. Includes crop diversity and rotation, reducing synthetic input use, animal welfare, and improving ecosystems and habitats.	Provides indicators and performance measures customized to the regenerative agriculture context, provides an example of how to operationalize continuous improvement, and is scoped broadly to include economic, environmental, and social principles.	Not specific to the Canadian context.
European Committee for Standardization	CWA 17898 lays out methodology for assessing soil health and the impact of agricultural processes on soil health indicators [131]. Includes mechanical processes, input use, water, and emissions.	Presents a standardized method for assessing soil quality and relevant impacts from agricultural production.	Limited to soil quality outcomes so it does not assess the full scope of regenerative outcomes and is not specific to the Canadian context.
ANSI and American Society of Agricultural and Biological Engineers	ANSI/ASABE S629 evaluates the sustainability of agricultural production systems around the world [130]. Includes crop and livestock practices.	Broadly scoped, evaluates social and environmental dimensions of sustainability, captures performance indicators and continuous improvement processes, and acknowledges potential for context changes influencing implementation and MRV processes.	Broad scope is not specific to regenerative agriculture context, and is not specific to the Canadian context.
ISO	ISO 23992 lays out a framework for assessing soil properties related to land use and soil management practices [132]. Includes soil management practices and soil carbon accumulation.	Can be used to assess the sustainability of agriculture and its focus on soil quality signals significant overlap with regenerative agriculture principles.	Limited to soil quality outcomes so it does not assess the full scope of regenerative outcomes, and is not specific to the Canadian context.

3.7.1 Gaps and Challenges in Standardization

3.7.1.1 Sectoral Concerns Around Standard Development

To advance the discussion around standards in regenerative agriculture, both focus groups were asked to provide their thoughts on the opportunities and challenges associated with standardization efforts. In general, participants at both focus groups indicated that any standard would need to allow for flexibility, incorporate the principles of continuous improvement, and minimize administrative requirements. The farmer focus group was more hesitant about the idea of standards, noting that prescriptive standards would limit autonomy, so to be successful a standard would allow farmers to make decisions about what is best for their farms in each production cycle (e.g., when growing season conditions hinder cover crop planting, farmers should not be penalized). While all accredited standards are voluntary upon publication, some farmers expressed concerns about the administrative burden that would come with participating in a standard or a standard-based certification program. These concerns were sometimes tempered by an acknowledgement that standards could be beneficial in bulk commodity settings and would help articulate the range of environmental benefits that farmers provide to society. Overall, it was suggested that any standard development effort should include substantial consultation with farmers.

The sector-wide focus group was supportive of standard development, and framed standards as a positive lever for change in the sector. However, this focus group expressed concerns around the inclusion and measurement of social outcomes. Some participants noted that metric development for some of the social outcomes would be very challenging and might require working with experts, such as environmental sociologists. Concerns about metrics and measurement extended to the full range of outcomes associated with regenerative agriculture, with several participants suggesting that a standard should be rigorous, representing more than just a "feel good" mark. Developing rigorous metrics and MRV standards for each principle or outcome was expected to be a significant undertaking for a standards development body.

3.7.1.2 Lack of Defined Terminology and Scope

The lack of a standardized definition or defined principles for regenerative agriculture has consistently been noted as a barrier to farm-level adoption, accessing capital, creating a demand driver, and communicating the benefits of practice change to value chains, governments, and end users (i.e., consumers) [18], [31], [113], [121]. Moreover, the term regenerative agriculture remains polarizing to some parties because it implies that something must be degraded in order to regenerate, which can portray farmers in a negative way. There is also an ongoing debate around the overlap between regenerative agriculture and other forms of sustainable agriculture, such as initiatives to improve soil health or agroecology [9]. Focus group participants indicated that soil health was a substantial component of regenerative agriculture, with some suggesting that regenerative agriculture is simply that—an initiative for building soil health. There was some agreement around including core soil health principles in regenerative agriculture, but some focus group participants and some of the literature understand the term in a more holistic way that includes economic and social considerations [24], [39]. Several programs and some of the literature have included social and economic principles alongside soil health principles, and this may blur the line between regenerative agriculture and agroecology, which is a similar form of farming that focuses on working with nature [9]. Several of the more socially oriented principles are more common on the international stage, and given the export-driven nature of Canada's agriculture sector, these should be considered during standards development to maximize market access.

Participants in the focus groups raised concerns about the inclusion of social principles in regenerative agriculture due to its potential to exclude or overburden participants. Many of the soil health and other on-farm regenerative principles (e.g., conserving water, fair and safe work) discussed in this report are within a farmer's locus of control, but requiring post-farm gate social outcomes (e.g., community revitalization, knowledge transfer) would be inappropriate. Accordingly, the emergent social principles discussed in this report should be facilitated by governments, value chain actors, and other organizations as part of their regenerative agriculture initiatives, given that capacity building, technical support, and access to networks of peers would be possible to facilitate within the boundaries of their programs. This might be operationalized as two different standards for regenerative agriculture, where the first is targeted toward farm-level principles and the second addresses social outcomes and program delivery agents.

Despite the ongoing debate around terminology and scope, both the literature and the focus group participants emphasized that an excess of competing sustainable agriculture efforts is hindering progress by confusing consumers and investors [18]. Instead of looking for opportunities to fully differentiate regenerative agriculture from other initiatives, standardization could look for synergies, alignment opportunities, and consider the development of bridges or connection points to similar standards, terminologies, or programs that allow producers to more easily switch between related terminologies. Although numerous sustainable agriculture initiatives (e.g., regenerative agriculture, organic agriculture, conservation agriculture, sustainable intensification, and agroecology) have emerged, each with its own history and with different supporters and drivers over time, they share many objectives and often propose similar, if not the same, set of practices [8].



Finding alignment and creating connections to other terminologies will be key at both the domestic and international levels, given Canada's role as a global exporter of high-quality agricultural products, which will need to be eligible under similar sustainability schemes to maximize market access. Overall, focus groups participants felt that harmonizing across similar terminologies would drive more concerted action toward the shared desire for a more sustainable and resilient agri-food chain.

3.7.1.3 Lack of Defined Metrics

Even with appropriate terminology and a clear scope, standardization efforts could encounter challenges when reconciling how each program implements and measures the outcomes of each principle (e.g., variability in how one keeps soil covered and how to ensure rigour across different implementations of the same principle). While there is value in having different operationalizations of each principle because it recognizes the heterogeneity across Canada's different production systems, it also creates complexity when trying to create one unified standard that facilitates "apples-to-apples" comparisons. Differences in interpretation also emerge from the choice between an outcomes-based or practice-based approach to program verification, and both options have implications for the type of MRV processes needed [32].

One challenge involves respecting that each production system may implement regenerative principles in different ways (e.g., cover crops are less attractive in the Prairies, different crop rotations are suited to different regions, and reduced tillage is more difficult to adopt in potato systems) [62], [64]. This means that there are opportunities to focus on standardization at the principle level, while leaving production system and region-specific interpretations to program delivery agents. From an MRV perspective, focus group participants emphasized that it would be a significant undertaking to develop standards for each regenerative practice or outcome. Within this structure, standards development bodies have an important role to play by bringing rigour to regenerative agriculture programs, setting out the necessary minimum requirements (e.g., the starting point to be considered regenerative and the process for becoming more engaged over time), and ensuring the standard limits greenwashing and ineffective program delivery that does not support farmer autonomy.

Another challenge involves developing MRV standards that recognize both practice-based and outcomes-based metrics, and how to standardize MRV processes across both types of metrics. McCain's Regenerative Agriculture Framework is one example of the application of both practice-based and outcomes-based metrics [27]. Within this program, increases in soil organic matter and pesticide toxicity are evaluated using outcomes-based metrics, and the rest of the principles are evaluated according to the way a practice is implemented (e.g., reducing

tillage events by a certain number to minimize soil disturbance and planting a minimum number of crops in rotation to enhance biodiversity) [27]. The program also has different levels and rewards that encourage farmers to expand and enhance practices over time to generate greater environmental outcomes [27]. In this example, MRV standards for verifying both annual practice implementation (e.g., self-reporting, satellite monitoring, or random compliance checks) and regenerative outcomes would be required (e.g., soil carbon baselining, monitoring requirements, and verification processes). MRV standards for practice verification and monitoring are likely simpler to operationalize, and MRV standards for soil health outcomes and nutrient or input application outcomes would serve as a good starting point for the standardization of regenerative agriculture. While practice verification standards may be easier to develop, the focus group participants and the literature indicated that regenerative outcomes are the real value-add of adopting these production practices and demonstrating quantifiable outcomes concretely showcases the value of regenerative agriculture to investors, governments, and the sector at large [53].

Focus group participants also suggested that a regenerative agriculture standard should consider how it aligns with GHG emissions reporting requirements (e.g., for carbon credits or value chain emission reductions efforts, such as scope 3 emissions targets) and whether it would support a verified product certification initiative. In these cases, the standard development body would need to consider additional standardizing efforts for GHG reduction programs, such as ISO 14040, *Environmental management — Life cycle assessment — Principles and framework,* and ISO 14067, *Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification* [31]. It was also suggested that proponents of a regenerative agriculture standard would be able to learn a great deal from the organic space and avoid facing the same challenges (e.g., high certification costs and significant administrative burden on producers to participate).

3.7.1.4 Lack of a Continuous Improvement Approach

The focus groups indicated that farmers perceive regenerative agriculture as a journey of continuous improvement over time, and that the flexibility to try new things or implement principles in different ways is vital. These sentiments have implications for the development of MRV standards and emphasize the need for two key pieces:

1. A staged or continuous improvement cycle; and
2. A definition of threshold or starting point for the transition to regenerative agriculture.

Throughout the development of a standard and associated MRV processes, assessment of the trade-off between flexibility in implementation and MRV complexity would need to be included, particularly when they influence the administrative burden and certification cost for participants [137]. Generally, as flexibility increases, so does MRV complexity, because enabling more individualized and context-specific programming requires detailed and flexible metric development.

An MRV standard that supports continuous improvement is attractive because it promotes positive change over time, allows for all individuals to participate regardless of their starting point, and provides the necessary flexibility to manage the farm according to one's priorities. Continuous improvement approaches could be framed as progressively more stringent practice and outcome requirements, or through expanding the area under regenerative management over time.

Requiring a suite of practices to be adopted all at once can be difficult for implementing farmers; this can be mitigated by requiring only a percentage of land area to transition at a time, and expanding the required acreage over time. This type of area-based approach aligns with the typical incremental adoption approach mentioned in the focus groups, wherein farmers tend to trial new practices on small fields first, then expand

practices into new fields in the following season if the trial meets their needs and expectations. However, this report did not find agreement on this among farmers, as some suggested an area-based approach to classifying farms as regenerative and others suggested that a minimum of two to three principles should be addressed to be considered regenerative. Others have suggested that a simplified approach would be best, where farms are classified as regenerative as long as more ecosystem services and co-benefits are present following practice change.

In McCain's Regenerative Agriculture Framework, the starting point is an onboarding phase that introduces the farmer to the concepts without too many new requirements [27]. To be considered an "onboarded" farmer, participants have to take a regenerative agriculture training course, conduct an initial soil health assessment, and target one indicator or parameter. When the farmer is ready to move to the "engaged" level, they must have no more than 90 bare soil days (e.g., implement soil armour practices) and must engage in activities that address at least five of the seven indicators outlined by McCain [27]. This model of progression is attractive, as it respects the early engagement and learning phase and promotes improvement in stages while providing farmers with the flexibility to address the goals most relevant to them.

3.7.1.5 Impressions and Understanding of Standards Development Process

While the focus groups and literature recognized beneficial aspects of standards, there was hesitancy around how standardization would be developed, whose voices would be involved, and how subsequent engagement would be approached. There was a clear desire for a bottom-up and participatory approach to standardization, and farmers emphasized the need for on-the-ground perspectives. Others felt that a standards development exercise could present an important learning and engagement opportunity for the sector, and emphasized the potential to generate substantial buy-in by engaging the sector in the process.

3.7.1.6 Engaging Indigenous Communities

Defining and advancing regenerative agriculture presents a direct connection to Indigenous and pre-industrialized practices, so it is vital to understand how different regenerative definitions and principles align with Indigenous knowledge and perspectives. Only a handful of definitions and principles were identified for this report, which could underrepresent the unique knowledge, values, and practices of Indigenous peoples from across Canada. To better understand the intersection and inspiration of Indigenous-led agriculture and the emerging principles of regenerative agriculture in Canada, establishing meaningful partnerships with Indigenous communities and leadership would be a crucial next step. Underserved and Indigenous groups could be critical partners in Canada's regenerative agriculture transition, but they face unique barriers. Although regenerative practices have been linked to Indigenous knowledge, this knowledge has not been included in programs [1]. There is an opportunity for standardization and certification programs to address these issues and increase the participation of Indigenous and underserved groups in local food systems [138].

Persisting socio-cultural challenges may also reduce knowledge sharing and opportunities for intergenerational connections, driving the loss of culture and knowledge [139]. Compared to other farmer groups, Indigenous and underserved peoples have limited access to agricultural lands, generational landholding power, capital, and influence within the Canadian agri-food system, driving unequal access to food production and reduced input into policies and programs that could shape farming [1], [114], [139].

Continued consultation to further understand the barriers faced by underserved and Indigenous groups and the co-creation of enabling conditions at local, regional, and national scales is required to ensure their voices and their knowledge are included in the transition to regenerative agriculture. Further engagement with Indigenous and underserved groups to co-create dynamic governance models, increase equity in agricultural systems, and support food sovereignty and self-determination is essential to a regenerative agriculture transition [1], [114], [138].



"To respect the diversity in management practices and production systems, regenerative agriculture is best identified through a set of principles that help guide its implementation and objectives."

4. Conclusion and Recommendations

The primary goal of this report was to provide clarity around principles, outcomes, and practices associated with regenerative agriculture, so action can be taken to develop transition agendas that stimulate broader adoption, diversify farmer revenue streams, and promote knowledge transfer. To respect the diversity in management practices and production systems, regenerative agriculture is best identified through a set of principles that help guide its implementation and objectives. This report found agreement on five key principles of regenerative agriculture in the Canadian context:

1. Minimize soil disturbance;

2. Keep soil covered year-round;

3. Keep live plants and living roots in the soil;

4. Enhance biodiversity above and below ground;

5. Incorporate farm animals.

This report also identified the following emerging principles of regenerative agriculture, which have yet to reach the same level of agreement, although some are included in several prominent regenerative agriculture programs:

- Efficient input use and reduce synthetic inputs;
- Conserve and protect water;
- Understand the farm context;
- Enhance and restore natural landscapes; and
- Respect for human and non-human life and for the environment.

In addition to production practices, this report revealed an ongoing debate around the inclusion of the following socially oriented principles within regenerative agriculture:

- Community revitalization and health;
- Building capacity and knowledge transfer;
- Advancing equality, safe work, and fair business practices; and
- Supporting farm livelihoods and food system resilience.

These principles were nascent in the Canadian context, and more common in the international landscape. However, supporting farm livelihoods and food system resilience was mentioned more frequently in both domestic and international regenerative agriculture programs.

This report found that some parties believe the broader set of principles are more akin to agroecology, and focusing on soil health principles alone would catalyze regenerative agriculture action without diluting the term or creating an undue burden on producers. Conversely, others believe that social components

are an important part of regenerative agriculture and recognize their value in a food system transition. Because of their presence internationally, these socially oriented principles are important to consider from an alignment perspective, given the export-driven nature of Canada's agriculture sector and the need to navigate competing international sustainable agriculture terminologies, standards, certifications, and frameworks.

While additional engagement, research, and a broader diversity of voices will be required to initiate a comprehensive transition to regenerative agri-food systems in Canada, this report has identified the following recommendations for industry, Indigenous leaders, and governments seeking to advance a regenerative agri-food system in Canada:

1. **Invest in knowledge sharing networks to ease transitions:** Establish diverse and regional peer farming networks that share resources and foster community building, storytelling, skill development, and the integration of Indigenous knowledge.
2. **Expand access to education and resources:** Increase access to regenerative agriculture extension services, and develop demonstration projects or other practical knowledge resources to build confidence in outcomes and promote experiential learning.
3. **Explore innovative funding mechanisms:** Mitigate financial risks and revise existing risk management programs to remove barriers in transitioning to regenerative practices.
4. **Implement outcome-based programs:** Develop programs, with appropriate and streamlined MRV processes, that compensate farmers for the ecosystem services they generate when using regenerative practices. The ability to clearly communicate the benefits of adopting regenerative principles will make a stronger case for supporting regenerative agriculture.
5. **Advance standards that are flexible and inclusive:** Continue advancing agreement around regenerative principles and practices through extensive consultations with farmers, Indigenous communities, and value chains to develop a standard that reflects their realities. Specifically, a standardization effort should:
   a. Allow for flexibility in the starting point or threshold for becoming regenerative;
   b. Acknowledge regional or production system differences in implementation;
   c. Allow for trialling new practices; and
   d. Encourage continuous improvement over time.

On these issues, and many others, concerted engagement efforts with a diverse range of actors will be required. It is clear that each party in the agri-food system has a role in advancing regenerative agriculture principles, and this report attempts to take the first step in building agreement around the scope and key action items needed in the Canadian context. While much work remains, there is significant promise for advancing a regenerative agri-food system in Canada through a variety of collaborative and multidisciplinary interventions that benefit farmers, value chains, and broader society.

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Appendix A. Regenerative Agriculture Practices and Outcomes in Canada

A.1 Reduced Tillage (Minimize Soil Disturbance, Keep Soil Covered)

Reduced tillage was the first regenerative category evaluated, and it refers to a set of practices that reduce or eliminate tillage practices that are commonly used in conventional agriculture. Traditional tillage methods are known to disturb the soil structure, and can leave soil vulnerable to surface runoff, soil erosion, and loss of organic matter, fertility, and biodiversity. Intensive tillage can also disrupt water cycles and the soil's ability to sequester GHGs, and reduce the abundance of plant nutrients. To better understand these potential outcomes, this section examines literature that studied the relationship between practices in the reduced tillage category and regenerative agriculture outcomes.

A.1.1. Economic Outcomes

Reduced tillage was often associated with reduced costs, but in terms of profitability, there were an equal number of studies proposing positive and negative economic outcomes. Some studies reported negative economic outcomes associated with no-till, and these were long-term in nature (e.g., 10 years or more) [89], [140], [141], [142], [143], [144], [145], [146]. Most of the negative outcomes that limited profitability were attributed to reduced yield. However, studies did not always assess changes in resilience from soil health improvements or reduced farm costs during production, meaning they are not necessarily representative of profitability across the entire system.

A.1.2. Environmental Outcomes

The literature generally agreed that reduced tillage leads to better soil health, and linked no-till or reduced tillage practices to an increase in biomass in the soil, an increase in biodiversity, as well as general improvements in soil health [147], [148]. Mueller *et al.* [89] also correlated reduced soil disturbance with less subsoil compaction in Ontario. Two studies by Sheng *et al.* [149], [150] found that reducing or eliminating tillage allowed for fungi networks and bacterial communities to thrive in Eastern Canada, and Halde *et al.* [142] observed an increased richness of beneficial weed species in no till plots in the Canadian Great Plains.

Reduced till has also been adopted to reduce water and wind erosion in Quebec and Atlantic Canada [151], [152], and is associated with less rainfall-generated runoff in the Atlantic region and the Prairies [152], [153] and better nutrient retention in the Prairies [153]. However, the same studies found that no-till increased the amount of soluble inorganic phosphorus in the soil, which can result in larger phosphorus losses through runoff. In general, reduced tillage helps nutrients stay in the soil where they can be useful to crops.

Additionally, some studies have shown that reduced tillage can contribute to higher soil organic matter concentrations or have a positive effect on the soil's ability to sequester carbon in the Prairies and Ontario (e.g., an average increase of 12% for no-till plots when compared with tilled plots in a 20-year experiment in Ontario) [91], [92]. Soil disturbances directly speed up the release of CO_2 and other GHGs, meaning that a practice like reduced tillage, which reduces

soil disturbance, can help soil retain CO_2 and other GHGs, preventing them from entering the atmosphere [91]. In short, reducing or eliminating soil disturbances allows soil organic matter to decompose at slower rates, increases biomass, improves soil health, and helps climate change by sequestering GHGs.

As previously mentioned, reduced tillage increases nutrients like phosphorus and nitrogen in the soil, which can also increase runoff. Viana *et al.* [154] found that when runoff leaches into freshwater via streams and lakes in northeastern Canada, it can lead to the eutrophication (e.g., excessive amount of nutrients in the water) of algae and aquatic plants, some of which can be harmful to human health. Individuals engaging in recreational activities involving bodies of water, as well as people relying on the natural resources provided by bodies of water, would be more susceptible to these risks.

A.2. Cover Crops (Keep Soil Covered, Keep Living Roots in the Soil)

Cover crops are another common regenerative practice that are typically planted between harvests or during crop growth to maintain ground cover and living roots in the soil. Different cover crop species contribute to different desired outcomes, with legume cover crops contributing to nitrogen fixation and cereal cover crops being used to enhance soil organic matter. This report found that cover cropping was linked to different regenerative outcomes, including increased soil health and crop health, decreased input usage, enhanced water management, and yield benefits. No social outcomes were found in the literature.

A.2.1 Economic Outcomes

The economic outcomes associated with cover cropping were generally positive. Blackshaw [155], in Western Canada, and Chahal and Van Eerd [156], Chahal *et al.* [147], and O'Reilley *et al.* [157], in Ontario, all found that cover crops can increase yields and crop productivity. O'Reilley *et al.* also found that even with higher production costs, the adoption of cover crops led to higher profit margins [157]. However, not all results were positive. Blackshaw *et al.* [158] found that fall-planted pea reduced winter wheat yield by 23 to 37%, but fall-planted alfalfa increased the yield of succeeding canola crops in the Canadian Prairies. While most studies in Canada described positive economic outcomes from cover crops, there were some instances where cover crops might reduce yields or increase the cost of production.

Crop health in the form of weed management was another common outcome for cover crops. Many studies found that the planting of cover crops suppressed weeds, resulting in reduced weed biomass and reduced weed management [93], [102], [141], [155], [158]. Again, O'Reilley *et al.* did not find a consistently positive effect of cover crops on weed management, and instead suggested that cover crops had a neutral impact on weed growth [157]. Neilsen *et al.* found that cover crops in BC reduced pest populations, in addition to reducing weed growth, by promoting beneficial insects and predatory mites, promoting biodiversity, crop health, and growth overall [93].

A.2.2. Environmental Outcomes

The environmental benefits of cover cropping practices were discussed in the literature and many of the results were positive. Several Canadian studies generally agreed that cover crops were beneficial for soil health and biomass and for water management and quality [92], [97], [144], [147], [156]. Studies also discussed the ability of cover crops to increase soil nitrogen and soil nitrogen availability [93], [102], [156], [158], [159], [160], [161]. Erosion control was another commonly identified environmental benefit in some Canadian studies [93], [153], [155], [162].

Better water management and quality were discussed in terms of reducing nitrogen and phosphorus leaching and runoff [160], [161], [163], but one study in the Prairies showed that cover crops can increase nutrient concentrations, especially nitrate, in the following year's spring snowmelt [153]. Separate from runoff and leaching, Mooleki *et al.*

found that early seeded cover crops in Saskatchewan can enhance soil water retention, resulting in lower irrigation requirements and enhanced soil resilience to extreme weather events such as drought [159].

In terms of carbon and GHG outcomes, results were mixed, and more research is likely required. Some studies found that the use of cover crops increased soil organic matter and soil carbon [92], [93], [94] and reduced nitrous oxide emissions in Eastern Canada [94], but Hung *et al.* found that cover crops had little to no effect on nitrous oxide emissions in Quebec [95].

A.3. Crop Diversification (Enhance Biodiversity)

Crop diversification refers to a set of regenerative agriculture activities that increase the diversity of plant species in the field or pasture, and includes the practices of rotating crops, reducing fallow, and intercropping (when two or more crops are grown simultaneously). Karaca and Ince [2] found that diversification of crops can improve soil health, provide resistance to diseases, and improve the physical and chemical properties of soil. Depending on the desired outcome, farmers could adopt different approaches that target issues with weeds, diseases, insects, pests, soil erosion, degraded soil fertility, and market risk management.

A.3.1. Economic Outcomes

Some studies examined the economic viability of diversifying crop rotations. In general, diverse crop rotations have the potential to increase profitability through increased crop yields or reduced input costs, but it is important to select the right diversified rotation to maximize the economic benefits. A common example in Ontario is diversifying away from continuous corn toward a corn–soy–wheat rotation [94]. Extending the rotation with these crops can generate a nitrogen credit, meaning that farmers can save money on nitrogen fertilizers by reducing their application rates to account for the natural nitrogen being added to the soil by the crops [94]. Nitrogen credits for corn–soy–wheat systems can range from 10 to 50 kg per hectare over four years, and when including a clover cover crop, the system can increase net returns by about $100 per hectare compared to continuous corn [94]. Other studies on similar rotations in Ontario (e.g., corn–cereal–soy, with and without a cover crop) have reported long-term average yield increases between 8 and 20% [144], [146], [147], [164].

Further, Walburger *et al.* found an increase in net returns in the Prairies following the adoption of a legume–wheat rotation because of the legume crop's ability to fix nitrogen, which in turn reduced the input costs [165]. Li *et al.* also determined that introducing perennial legumes and grasses in rotations in Alberta enhanced nitrogen availability, which resulted in a faster soil organic matter turnover rate and increased yield [98]. Finally, Khakbazan *et al.* found that the inclusion of pulses in rotations in the Prairies had a positive economic impact on the productivity of subsequent non-pulse crops, and reduced nitrogen costs by 37% [166].

More generally, Congreves *et al.* [148] in Ontario, and Larney *et al.* [97] in Alberta found that diversification of crop rotations positively influenced several soil health indicators, which were subsequently associated with both yield increases and better resiliency. A similar study in Saskatchewan from Maillard *et al.* also correlated crop diversification with increased soil organic carbon and linked this outcome to crop productivity [167].

Positive impacts on yield or total net returns may not be consistent across all diversified rotations. As crop rotations extend and diversify, high value cash crops become less prominent in the rotation, which can reduce net returns from the system [68] and may have little to no positive impact on cash crop yield [97]. Still, diversified rotations including legumes can be beneficial from a nitrogen availability perspective [98], and in some cases, the added production costs (e.g., seed and management) of integrating legumes or green manure crops into rotations can be offset by subsequent savings in input costs, via reductions in fertilizer and weed control expenses [97].

A.3.2. Environmental Outcomes

When looking at water management, monocultures that employ high fertilizer requirement crops could lead to nutrients leaching into streams, rivers, and lakes, thereby causing eutrophication, but diversification of crop rotations with legumes, like those mentioned in Section A.3.1, could help to counter this due to their lower nitrogen requirements. Karimi *et al.* also found that implementing a crop rotation could help manage the accumulation of phosphorus in the soil and the associated risk of phosphorus loss in surface runoff in Manitoba [168].

Diversifying crop rotations also has positive impacts on climate change because it can increase carbon capture. Across the board, studies agreed that diversifying crop rotations and forgoing fallow increased soil's ability to sequester carbon, and multiple studies observed increased soil organic carbon stocks when integrating small grain cereals, perennial crops, pulse crops, or even canola into rotations [98], [147], [167], [169], [170], [171]. In one example, the switch from fallow to continuous cropping in Saskatchewan improved soil organic carbon by 0.2 tonnes per hectare [98], while moving from continuous cropping to a two-year rotation in Ontario improved soil organic carbon by 6% [147]. Ultimately, moving from a two-year rotation to a five- or six-year rotation enhanced soil organic carbon levels by between 20 and 49% over time in Alberta [169]. In terms of other GHG emissions, Asgedom and Kebreab showed that reduced fertilizer use in legume-based cropping systems results in lower GHG emissions in the Prairies when compared with monocultures [91].

Finally, Khakbazan *et al.* suggested that more risk averse producers may prefer more diverse rotations, as it mitigates the risk of crop failures [166]. The study also suggested that the diversification of crop rotations can be linked to improved resiliency across the system.

A.4. Manure and Compost Management (Efficient Input Use and Reduce Synthetic Inputs, Incorporate Farm Animals)

Manure and compost management encompass a set of regenerative practices that encourage the use of natural fertilizers to enhance crop and grassland growth or management. This report examined outcomes on practices, including different applications of animal manure (injection vs. broadcast, spring vs. fall, application amounts), incorporation of green manure and other compost, use of mulch and woodchips as side dress or amid crops, and incorporation of stubble and crop residue. The literature review showed that these practices result in several regenerative outcomes, such as enhanced soil health and fertility, reuse and recycling of natural inputs, climate change and GHG mitigation, and better water quality.

A.4.1. Economic Outcomes

Many Canadian studies discussed positive economic benefits from manure or compost use, such as increases in yield and decreased costs from the avoided purchase of chemical fertilizers [99], [172], [173], [174], [175], [176]. The addition of manure, compost, and crop stubble to fields in combination with other fertilizers was shown to increase yields [172], [173], [174], [175], and some studies found that these natural sources could eliminate the need for additional inputs altogether [99], [176]. Zheljazkov *et al.* found that compost additions yielded the same amount of forage in Nova Scotia as chemical fertilizers [177], reinforcing that in some cases, organic inputs can replace chemical fertilizers without a loss in production.

Other studies found that the addition of compost and manure alone reduced yields or generated higher costs than alternative inputs [165], [172], [178]. For example, Walburger *et al.* found that Prairie wheat rotations with manure treatments were not as profitable as those with chemical fertilizer treatments [165], and Watson *et al.* found that the application of compost and bark chip mulch cost $3,000 more in their British Columbia plots compared with

chemical inputs [178]. While some examples of economic outcomes are available, additional studies and cost benefit analyses are required to draw more concrete conclusions about this form of input management in cropping systems across Canada.

A.4.2 Environmental Outcomes

Most of the studies reviewed for this section described positive environmental outcomes from manure and compost management practices, including enhanced soil health and quality in the Atlantic region, Alberta, and the Prairies [98], [104], [179]; increased beneficial bacteria and fungi in Alberta and British Columbia [98], [180]; increased water retention and reduced leaching in Alberta and Saskatchewan [174], [181], [182]; higher soil organic matter and carbon stocks in the Prairies, British Columbia, and Quebec [104], [145], [180]; reduced GHG emissions in Ontario [183], [184], [185]; improvements in crop health in British Columbia and Ontario [93], [178], [186]; and enhanced soil fertility in Alberta, the Prairies, and Atlantic Canada [165], [174], [177]. The environmental benefits associated with manure and compost, specifically those that showed reductions in GHG emissions, were typically coupled with management practices such as better nutrient placement and application timing [173], [184].

Several studies also discussed the potential negative environmental impacts resulting from manure and compost management, specifically on water quality in Manitoba and Quebec [168], [187]; emissions across Canada [188]; and nutrient management in Alberta and Atlantic Canada [175], [177]. Two studies suggested that the application of manure could increase phosphorus surface runoff in Manitoba and Quebec, particularly if the manure is not incorporated into the soil [168], [187]. Roman-Perez *et al.* [175] concluded that organic matter alone could not meet the nutrient requirements for some crops in Alberta, which required synthetic fertilizer amendments to maintain productivity. Other studies reported neutral environmental outcomes from manure and compost management practices, such as similar soil fertility levels in the Prairies [100], comparable emissions in Quebec [95], and leaching of nutrients dependent on combinations of management practices in Ontario [189].

While organic amendments are usually preferred for environmental reasons, some studies in Ontario suggested that manure application could increase the level of human contaminants and diseases in watercourses. For example, Samarajeewa *et al.* [189] and Muhammed *et al.* [190] found that *E. coli* and *Salmonella* levels in watersheds sometimes increased when manure was applied to croplands. Specifically, Muhammed *et al.* found that chicken manure application increased *E. coli* levels [190]. Positively, Samarajeewa *et al.* suggested that *E. coli* and *Salmonella* levels from manure application can be abated through amending tillage practices to protect water quality [189].

A.5. Input Management (Efficient Input Use)

Separate from manure and compost management, input management refers to practices associated with synthetic and chemical inputs, such as chemical fertilizers, herbicides, fungicides, and pesticides. Practices associated with input management can include application rates, timing, and placement, and the different varieties and combinations of inputs used to enhance crop production. This report examined input management practices that could provide regenerative outcomes, such as increased yields, reduced application of chemical inputs, decreased emissions, and healthier water systems.

A.5.1 Economic Outcomes

The economic outcomes of input management found in the literature were all positive, discussing cost savings and increased profitability as a result of applying appropriate amounts of inputs and better input placement. Pittman [191] and Zentner *et al.* [192] found that the right rate and variable application of fertilizers increased the profitability of operations in the Prairies. Similarly, Khakbazan *et al.* suggested that the highest net returns could be achieved

with more efficient and marginally lower applications of fertilizers in the Prairies, and found higher applications of nitrogen and phosphorus resulted in minimal economic gains [193]. In terms of nutrient placement, Karamanos *et al.* concluded that the in-row application of phosphorus fertilizer, rather than mid-row or side dress, resulted in higher yields in Alberta [194].

A.5.2 Environmental Outcomes

Input management practices had a variety of environmental outcomes related to water quality, soil and crop health, emissions reductions, and carbon capture. Lychuk *et al.* [181] and Yang *et al.* [152] found that a reduction in nitrogen and phosphorus inputs could reduce leaching and sediment loss in Saskatchewan and Atlantic Canada, while Olson *et al.* [182] reported similar results in Alberta, asserting that areas with any nitrogen application are at greater risk for leaching and compromising water quality. Thus, a reduction in inputs could provide benefits for water quality in similar regions.

Another positive environmental outcome of input management was a reduction in nitrous oxide emissions. Lychuk *et al.* [181] and Asgedom and Kebreab [91] found that reduced and right rate applications of inputs were the most effective input management strategies to decrease emissions in the Prairies. However, Weber *et al.* showed that emissions outcomes in Alberta can vary significantly depending on soil type [195].

Soil health is another environmental outcome discussed in the literature, but the reported results were mostly neutral. Li *et al.* [143] found that organic farming led to a more neutral soil pH level, but also found that the system could not meet all aspects of good soil quality. The impact of reduced inputs on fungal and microbial communities were unclear, with one Canadian study reporting no significant changes [196] and another suggesting that fungal colonization decreased [149]. The impacts of input management on crop health were also inconclusive, with studies suggesting that reduced phosphorus application can both increase and decrease crop roots and crop root density [143], [149].

Finally, some studies found that input management practices could have negative outcomes on soil organic matter and carbon capture, largely stemming from reductions in nitrogen [197], [198]. Bell *et al.* found that organic crop management in Manitoba could reduce soil organic carbon without additional carbon inputs, such as compost [197], and Yanni *et al.* found that crop plots in Alberta with less nitrogen fertilizer lost soil organic carbon [198]. In short, the environmental outcomes of input management practices vary, with clear benefits for water quality and emissions reductions (depending on soil type), unclear benefits for soil and crop health, and potentially negative benefits for carbon capture and soil organic matter.

A.6. Livestock and Pasture Management (Incorporate Farm Animals, Enhance Biodiversity, Enhance Natural Landscapes)

The livestock and pasture management category explores another key theme of regenerative agriculture, livestock integration, and refers to a broad range of regenerative agriculture activities that support animal productivity, health, and sustainable forage, grassland, or pasture management. Several Canadian studies linked the integration of livestock and sustainable pasture management to common outcomes sought by regenerative agriculture through practices such as rotational grazing, diversifying pasture plantings, winter or bale grazing, and restricting watercourse access.

A.6.1. Economic Outcomes

Some of the more commonly reported economic outcomes included a positive impact on forage yield and productivity, as well as more plant-available nutrients when animals grazed over crop or pasture lands. Some Canadian studies reported a trend of increased plant-available nitrogen in response to animal grazing, which either maintained subsequent yield levels or increased them. For example, Jungnitsch *et al.* [100] reported significant increases in forage yields (e.g., 2 to 6 times higher) in Saskatchewan when cattle were grazed overwinter in pasture compared with the spread of feedlot manure on pasture. In contrast, another rotational grazing study in Saskatchewan found that forage yield increases were offset by a reduction in pasture quality (e.g., digestible nutrient content), which led to an 18% reduction in daily animal weight gain [101]. In organic production systems in Manitoba, livestock grazing increased nitrogen supply by 25%, compared to ungrazed plots, for subsequent grain crops without negatively impacting yield levels or crop quality [102], [103].

Another economic benefit of livestock and pasture management is the positive impact on yield and resilience that comes from diversifying pasture or forage plantings and using native species where possible. Serajchi *et al.* found that planting pastures with a mixture of forage species tended to exhibit greater yield levels when compared to monoculture, and demonstrated how mixtures that contain native forage species with high protein concentrations (e.g., western wheatgrass in Saskatchewan) and legumes made the pastures highly suitable for grazing and resilient to weather stresses [199].

A.6.2. Environmental Outcomes

From an environmental perspective, livestock and pasture management practices influence many aspects of soil, water, and biodiversity outcomes. Two dimensions of soil health, soil organic matter and soil carbon, can be improved by using perennial pasture plants, whose roots contain up to three times more carbon than annual grasses [104]. In addition, grazing practices can have a similar positive impact on soil carbon accumulation (in the range of 0.23 to 0.34 tonnes per hectare annually [101]) and the inclusion of livestock in landscapes can increase soil moisture and other organic matter levels [101], [104]. However, when the intensity of the grazing or the stocking rates are too high, these factors can increase soil compaction or facilitate soil erosion [104].

High-intensity grazing can also negatively influence certain water dynamics in the Prairies by increasing water runoff when vegetative cover is depleted and reducing water infiltration when compaction occurs [104]. To protect watershed quality, regenerative farmers can implement rotational grazing plans that incorporate exclusionary fencing and setbacks from watercourses. One study in Alberta found that implementing a rotational grazing plan that limited livestock access to the watercourse reduced nitrogen and phosphorous levels, and increased vegetation diversity along the watercourse [105]. While vegetation diversity is positively impacted by restricting watercourse access, other studies in Alberta have found no impact on benthic species diversity within the watercourses [200].

Outside of watercourse biodiversity, rotational grazing and appropriately managing the grazing intensity or stocking rates of pasture can support vegetative diversity and facilitate positive outcomes for certain bird or arthropod species [104], [105], [201], [202]. Pogue *et al.* reported that Prairie bird nesting sites were generally not destroyed during cattle grazing, and even reported that certain species had higher nest survival rates in more heavily grazed areas [104]. In conjunction with this, certain arthropod species were found to be more abundant in grazed pastures and arthropod species diversity also increased within these pastures [104]. Other studies in Saskatchewan have found that rotating or differing grazing intensities can benefit different bird species, suggesting that a range of grazing intensities could help support biodiversity outcomes in the Prairies. For example, species such as the chestnut-collared longspur and the western meadowlark can tolerate or increase in abundance under more intense grazing conditions, but species such as vesper or Savannah sparrows are expected to decrease in abundance above certain intensity levels [201], [202].

A.6.3. Social Outcomes

While studies on the social outcomes of livestock and pasture management were much less prevalent in the literature, a few proposed social benefits in the Canadian context. For example, Olson *et al.* found that using rotational grazing plans and fencing to restrict water course access reduced the amount of *E.coli* bacteria in the watercourse [105], which is beneficial from both a water quality and human health perspective. From an air quality and odour perspective, winter grazing has been proposed in the Prairies as an alternative to feedlot production systems in order to reduce odour concentrations [104].

In certain provinces, such as Alberta, beef production has become a significant part of the province's cultural heritage and has led to the creation of prominent agritourism events, such as the Calgary Stampede [104]. Pogue *et al.* analyzed the growth of the agritourism sector in the Prairies in 2018 and noted that farms with scenic landscapes, diverse or different species, or that generally engage visitors in other farm tourism activities can attract visitors and new revenue streams [104]. From a livestock and pasture management perspective, a regenerative farmer's commitment to maintaining biodiverse and healthy rangelands can draw in eco-tourists, such as hikers and wildlife enthusiasts, providing both aesthetic value and nature-based experiences [104].

A.7. Tree and Shrub Integration (Enhance Biodiversity, Keep Living Roots in the Soil, Incorporate Farm Animals, Enhance Natural Landscapes)

The tree and shrub integration category explores the regenerative outcomes associated with agroforestry practices, and refers to a broad range of activities to bring trees and shrubs into agricultural landscapes in order to increase the provision of on-farm ecosystem services. This report examined the link between the integration of trees and shrubs to common outcomes sought by regenerative agriculture and practices such as tree intercropping, windbreaks, shelterbelts, hedgerows, and vegetative filter strips.

A.7.1. Economic Outcomes

Integrating trees and shrubs into agricultural landscapes can result in mixed economic outcomes for farmers who adopt these types of systems, meaning that maximizing profitability requires careful planning. According to studies in Quebec, tree planting is harder to justify on-farm because it can reduce yield levels in the areas closest to the tree line; increase risk by reducing the number of acres eligible for crop insurance; make farm management difficult or inconvenient by introducing equipment limitations or requiring different production equipment; and lack private benefits to provide the farmer with a return on investment [203], [204], [205].

The losses in yield in tree intercropping systems are generally greatest in the areas closest to the tree line (i.e., 0–2 metre range) due to shading and weed pressures, but studies in Quebec showed that yields can increase or equalize further away from the tree line [203], [204]. One of the studies proposed that more modern tree-based intercropping systems, meaning those with lower tree densities and tailored to annual crop production needs, can actually produce comparable yields to traditional non-treed systems, even when factoring in the yield loss in the area immediately next to the tree line [204]. Other studies in Quebec have highlighted productive benefits, such as the establishment of windbreaks, which can increase yield by 3.5 to 20%, and the potential for certain tree species (e.g., hybrid poplars) to add nitrogen back to the soil through leaf biomass, reducing subsequent fertilizer needs for crops [205], [206].

To maximize the profitability of tree intercropping, farmers will need access to new revenue opportunities that make their investments in tree planting worthwhile. Two studies in Quebec have proposed that tree integration can create

two new opportunities: the sale of timber products and broader ecosystem service market participation [205], [206]. Specifically, Rivest *et al.* [206] noted that hybrid poplar trees could function well in tree-based intercropping systems in Quebec, as they can grow faster under intercropped conditions, where nitrogen is applied, and generate high value timber products. Alternatively, the sale of carbon credits in Canada, and potentially other ecosystem services credits as those markets develop, offers another financial incentive that can increase a farmer's return on investment [205].

A.7.2. Environmental Outcomes

Tree planting is often mentioned as a mechanism for carbon capture and water quality protection, which are key objectives of regenerative agriculture. Several studies in the Prairies and Quebec have reported that agroforestry systems are a better carbon sink than their non-treed counterparts [104], [203], [205]. For example, considering above and below ground biomass, as well as expected carbon releases from leaching and soil respiration, Alam *et al.* reported that tree-based intercropping systems in Quebec can sequester 2.26 tonnes of carbon per hectare per year [205]. However, carbon capture potential can differ significantly between tree intercrop systems, high-density shelterbelts, and other shrub-related practices.

From a water quality perspective, adopting agroforestry systems can significantly reduce the environmental impact of runoff and leaching to ensure agricultural watersheds remain healthy and unpolluted. A reduction in the nitrogen potency of runoff was achieved in Quebec by using tree species in intercropping systems that quickly absorb excess nitrogen from the soil (e.g., hybrid poplars) [206], and a 38% reduction in phosphorous potency in runoff was achieved in Ontario by placing tree, shrub, or grass strips alongside watercourses to filter out agrochemicals before they enter the water supply [163].

Other water-related benefits, such as a reduction in leaching, are attributed to the fact that trees have a much deeper root system than annual crops, which means they can collect leftover nutrients that have been leached below the cash crop's roots. Studies in Quebec found that nitrate leaching can be reduced by 28 to 55% in tree-based intercropping systems compared with traditional cropping systems [203], [205]. Agroforestry systems can also increase water availability for soil and crops because practices such as shelterbelt establishment trap snow during the winter months in the Prairies, helping to reduce moisture loss over winter and ensure that snowmelt becomes available moisture for the next crop [104].

Trees can also act as a filter that eliminates airborne contaminants and unpleasant odours. Shelterbelts can be a valuable investment in areas near or surrounding beef feedlots, as they can absorb odour-causing particles and purify the surrounding air [104]. This can benefit the local community by managing the odour and may even positively contribute to human health outcomes from a respiratory perspective [104]. One study in Quebec estimated that a single tree has the power to reduce up to 1.67 kg of pollutants per year in urban settings [205].

Similar to livestock and pasture management (see Section A.6), the incorporation of trees and shrubs can be attractive from an ecotourism perspective. Trees are known for providing aesthetic value to landscapes as well as wildlife habitat [104], [205], meaning that careful integration of trees into agricultural landscapes could appeal to the growing ecotourism industry or attract wildlife enthusiasts when treed areas can be designed to provide habitat for keystone, threatened, or endangered species.

A.8. Perennial Crops and Forages (Minimize Soil Disturbance, Keep Living Roots in the Soil)

Maintaining living roots in the soil was determined to be a key theme of regenerative agriculture, and maintaining these living roots can be achieved through the adoption of perennial crops and forages. This report examined literature that linked the integration of perennial crops and forages to specific regenerative agriculture outcomes in Canada, including practices such as perennial plantings and diversifying rotations with perennial crops.

A.8.1. Economic Outcomes

As mentioned in Section A.3, extending and diversifying crop rotations (e.g., to include perennials) requires a context-specific lens to ensure the most effective system is implemented. While not specific to perennial systems, Zentner *et al.* found that when cash crops are displaced in the rotation in favour of green manure phases in Saskatchewan, a reduction in net returns from the system as a whole can occur [68]. In addition, yield response can vary by context and system. In the context of diversifying rotations, a study in Ontario reported a 25% increase in corn yield in response to a long-term diversified rotation with perennials such as alfalfa [147]. However, in the context of comparing perennial grain crops (e.g., perennial rye) against their annual counterparts, a study in Alberta reported a 33% reduction in perennial rye grain yield [207].

Perennials are potentially more advantageous for farmers who manage livestock or engage in livestock grazing. As mentioned in Section A.6, selecting diversified and native forage species mixes can positively impact productivity and resilience [104]. In addition, perennials generally require less fertilizer inputs and can be grown on marginal or lower quality land for the purposes of grazing or animal feed [104]. These qualities make perennials well-suited to these systems.

A.8.2. Environmental Outcomes

Soil health and the accumulation of soil carbon are the most prominent environmental benefits associated with the adoption of perennial crops and forages. Benefits to soil health are wide ranging. For example, perennial roots provide increased soil structure, quality, and water infiltration, and reduce soil erosion [98], [104]. Perennial biomass provides increased soil organic matter inputs and increased beneficial microbial activity [98], [147], [207], and a reduction or elimination of tillage keeps soil undisturbed [147], [207]. In terms of soil carbon, a long-term study in Ontario indicated that diversified rotations that include perennial crops, such as alfalfa, can increase soil organic carbon levels by between 5 and 11% [147]. A similar study on long-term rotations using alfalfa as a perennial crop in Alberta reported significant gains in organic carbon (i.e., 21–49% increase), when compared with the soil organic carbon levels of a two-year rotation [98].

While maintaining living roots is generally regarded as a positive management practice for soil health and soil carbon, the results can be mixed for other GHGs. Abalos *et al.* found that perennial grass and legume systems in Ontario emitted four times less nitrous oxide than annual cropping systems compared to annual corn monoculture [183]. However, this benefit was significantly smaller when considering yield-scaled emissions (e.g., emissions expressed per unit of crop yield), closer to a 5% reduction in nitrous oxide emissions [183]. Conversely, longer term studies in Alberta using similar perennial grass and legume systems have found that cumulative nitrogen losses were nearly six times greater when compared to annual grain systems [91]. These results highlight the need to carefully manage perennial cropping systems and suggest that nutrient management practices should be considered in tandem to mitigate these losses.

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