In Search of Net Positive Carbon Grain Farming in the Northern Great Plains:

Innovation in Policy and Practice.

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ABSTRACT

This thesis addresses the opportunities that exist for grain farms to help mitigate anthropogenic global warming. The thesis developed Rourke's General Farm Practice Change Theory, then uses that theory to develop a Net Positive Carbon Grain Farming Framework along with a Global Warming Mitigation Credit Framework. In-depth semi-structured interviews were conducted for sixteen cases involving participants from Manitoba, Saskatchewan, Alberta, North Dakota, and South Dakota. The research is a qualitative exploratory participatory narrative case study. The data was transcribed via UM Zoom and uploaded to NVivo where it was coded and queried for emerging themes. Data was also collected to calculate estimates of emissions, CO_2 sequestration, contribution margins, and production output. From this data I was able to determine a Net Positive carbon grain farming score as well as a Sustainable Farm Index rating.

During the interview, each participant was asked 10 questions on each of 12 Beneficial Management Practices, BMPs. A 1 to 5 scale was used to record their response and then fed into a tool developed for the study labelled as BERT /E. The BERT/E tool considers the following variables: beliefs (B), economics (E), regulatory (R), technology (T), and the farmer's physical and mental energy (E) to make a change. BERT/E scores are an indicator of the farmers BMP adoption score.

This study yielded both theoretical advancement as well as practical outcomes. The practical outcomes included identifying two participants whose farms are currently Net Positive. This included identifying the BMPs they used to become Net Positive and how their approach differed from the overall group. I was also able to assemble 50 recommendations that would improve the ability of the twelve BMPs to assist farmers in becoming Net Positive. Ultimately, the findings of this work demonstrate that grain farms can be instrumental in tackling anthropogenic global warming.

ACKNOWLEDGEMENTS

I began this journey to help tackle the existential threat that human use of fossil fuel-based products has caused. I have not done this for my benefit because at 69, it will not be me that suffers the consequences of unabated emission release from continued use of fossil fuel-based products. My motivation is our 9 grandkids and future descendants. Our generation lives in an unprecedented time of immense wealth, freedom, and consumption. Many people have learned to take this all for granted as if we are entitled to proceed with no thought of the consequences or need for alternatives. We are living beyond our planetary ecosystem limits.

Farmers, ranchers, and other land-based managers have the unique opportunity to help drawdown the excess CO_2 from the atmosphere and use it to build soil organic matter which results in more resilient food production. This thesis provides examples to encourage others to develop their own Net Positive carbon grain farms.

It is difficult to know where to begin in terms of acknowledgements. I will start by thanking my parents, Don, and Myrna Rourke (both deceased). They brought me into this world with a status I now consider to be privileged. We had a middle-income life, good access to food, shelter, health, and school and even some world travel. I was never told that I could not achieve something and they by example showed me that by planning and hard work many things could be achieved. My Dad was a carpenter, he gave me a love for building, from houses to businesses to people. My Mom was a life long learner with a RN, a BN, a master's in education, a master's in nursing and finally near the end of her career as Director of Nursing for the Women's Hospital in Winnipeg she completed her PhD in Nursing.

Both sets of Grandparent taught me a lot and gave me lots of love. My Grandpa Rourke taught me how to rebuild a Ford flat head V-8 engine. My Grandpa and Grandma Sparks enabled me to start farming, as did my Mom and Dad and their good friends Marge and George Moffat.

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My kids and grandkids, I love you all.

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Thanks to everyone who expressed an interest in reading the final thesis and wanting to put it into action. Lots of possibilities ahead to make a difference.

David

DEDICATION

To Diane my wife, my partner, and best friend for ever.

To my Kids and Grandkids

May you appreciate the smallness of this planet

and how each one of us needs to take care of her.

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List of Acronyms and Definitions and Abbreviations

It is suggested that a copy of the proceeding table be made to avoid the need to flip back and forth between further text and this table.

AE	AgroEcology
AAFC	Agriculture and Agri-Food Canada
ASC-OFCAF	Agriculture Climate Solutions- On Farm Climate Ag Fund
AGW	Anthropogenic Global Warming
AGWM	Anthropogenic Global Warming Mitigation
AI	Artificial Intelligence
ASAP	Available, Stable, Accessible, Perception for accepting Global Warming credits
BAU	Business As Usual
BECCS	Bio Energy with Carbon Capture and Storage
BERT/E	Beliefs, Economics, Regulation, and Technology divided by Energy of the farmer to make a change
BMPs	Beneficial Management Practices or Best Management Practices
BRM	Business Risk Management
CANZA	Canadian Association of Net Zero Agriculture
CDAP	Canadian Digital Adoption Program
CDP	Carbon Disclosure Project
CDR	Carbon Dioxide Removal
CEO	Chief Executive Officer
CFRA	Canadian Agriculture Resiliency Agency
C/N	Carbon/ Nitrogen ratio
CO_2	Carbon Dioxide
CoP	Conference of Parties (UNIPCC)
C of P	Community of Practice
CM	Contribution Margin
CRP	Conservation Reserve Program
DACCS	Direct Air Carbon Capture and Storage
DGST	Delayed Germination Seed Technology
EG&S	Environmental Goods and Services

ESG	Environment, Social and Governance - commitments and reporting
EMILI	Enterprise Machine Intelligent and Learning Initiative, Manitoba
EM	GHG Emissions
FCS	Farmers for Climate Solutions
FF	Fossil Fuel
GARS	Global Ag Risk Solutions, private crop insurance
GPD	Gross Domestic Product
GIFS	Global Institute for Food Security
GPS	Global Positioning System
GRoW	Growing Outcomes in Watersheds- Manitoba government conservation bond
GW	Global Warming
GHG	Greenhouse Gases
GWM	Global Warming Mitigation
GWMCR	Global Warming Mitigation credits
IMOS	Indigenous Micro Organism System
IPCC	UNIPCC, United Nations International Panel on Climate Change
IPI	Individual Productivity Index as it related to crop insurance
LCA	Life Cycle Analysis
LL	Living Labs
MAOM	Mineral Associated Organic Matter
MRV	Measure, Report and Verify
N	Nitrogen
NDC	National Determined Contribution
NFU	National Farmers Union
NGO	Non governmental organization
NIR	National Inventoery Report for GHG emissions
NP	Net Positive (Carbon Grain) Farm - a farm that virtually eliminates the use of fossil fuel-based fuel, fertilizer, and heat, plus sequesters carbon into the soil and minimizes GHG emissions. This can also be referred to as Zero Till Plus. Net

	Positive Carbon means the use of fossil fuels is minimized, and carbon sequestration and storage increased. This could also be called Net Negative, as it results in putting more carbon in the ground than is being used from inputs used to grow the crop. It is a drawdown or a net subtraction of atmospheric CO_2. I have chosen to use Net Positive because it has a better connotation.
NPN	Net Positive Network
NRCS	Natural Resource Conservation Service part of USDA, United States Department of Agriculture
NUE	Nitrogen Use Efficiency
NZ	Net Zero
PFRA	Prairie Farm Rehabilitation Agency
PiN	People in Nature framework
PiN-ASAP	People in Nature /Nature in People -Availability, Stability, Access, and Perception
POM	Particulate Organic Matter, less stable than MAOM
PSCB	Prairie Soil Carbon Balance
PWCP	Prairie Watershed Climate Program
REB	Research Ethics Board
RFCT	Rourke's Farm Change Theory
ROI	Return on Investment
SAS	Sustainable Agriculture Strategy Federal government
SBTi	Scientific Based Target initiative
SCAM	Scientific Certainty Argumentative Mantra
SCAP	Sustainable Canadian Agriculture Partnership—Federal Provincial funding program for agriculture
SCS	Soil Carbon Sequestration
SEC	US Securities and exchange Commission
SFI	Sustainable Farm Index
SOC	Soil Organic Carbon
SOCC	Soil Organic Carbon Change

SOM	Soil Organic Matter
SVO	Straight Vegetable Oil
ToC	Theory of Change
UNIPCC	United Nations Framework Convention on Climate Change
UNTEEB	United Nations- The Economics of Ecosystems and Biodiversity
VBN	Value Beliefs Norn theory
WRI	World Resources Institute
WUE	Water Use Efficiency
WWF	World Wildlife Fund
Zero Till Plus	This builds on the practice of Zero Till farming by adding regenerative principles and reduced GHG emissions. It can result in Net Positive Carbon Grain Farming.

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Figure 4.1 Major soil zones of the Canadian Prairies (Awada, Nagy, and Phillips 2021 used with permission)All files are provided under the Statistics Canada Open Licence (Statistics Canada Open Licence (statcan.gc.ca) and Open Government Licence - Canada | Open Government.

Figure 4.2. Vegetation-Soil zones in USA Great Plains (Sylvie 2014, used with permission). "PPT - The Great Plains PowerPoint Presentation, Free Download - ID:5657136." SlideServe. October 21, 2014. https://www.slideserve.com/sylvie/the-great-plains.

Table 5.2. Evolution of farming practices on the Gray farm from 1970 to 2020 (Gray 2021 used with permission) From: Gray, Richard <richard.gray@usask.ca>Date: Friday, October 20, 2023 at 7:24 PM To: drsrourke@gmail.com <drsrourke@gmail.com>Subject: slide

Chapter 1: Introduction

1.1. Rourke's Vision Statement

This project aims to empower Western Canadian farmers to tackle the threat of extinction from global warming (GW) using a (theoretical) framework to help guide systematic change. However, I also envision applied outcomes to be derived from this process. These outcomes are Beneficial Management Practices (BMPs) that balance food production with global warming mitigation (GWM) supportive policy recommendations, research priorities, and support networks. The network, while farmer led, will accommodate innovation and support from all stakeholders from the field to the fork. Through this process, agriculture will move from contributing to global warming to becoming a part of the solution. Although there is a preliminary understanding of what is required to mitigate global warming at the farm level, the challenge is to make this plausible. Through stakeholder participation, the discovery of innovation, refinement of BMPs, and articulation of current barriers and limitations, farm practices can be changed to produce the food needed by the world and provide the environmental goods and services (EG&S) required to correct negative externalities that have been allowed to accumulate since the industrial age.

The scientific basis of anthropogenic global warming (AGW) is well-documented. This is the new lens through which we must view our actions. The United Nations Intergovernmental Panel on Climate Change (UNIPCC) Special Report on 1.5°C (UNIPCC 2018) and the UNIPCC 6th Assessment (UNIPCC 2021) state that if we act to eliminate greenhouse gas (GHG) emissions by 2050 and work on removing excess GHGs from the atmosphere, we can avoid sustained warming of more than 1.5°C. The consequences of inaction pose an existential threat to humanity. Agriculture is a sector of the economy that has been a part of the problem, accounting for approximately 10% of global emissions. It has been suggested that when upstream and downstream activities are included, agriculture and food systems are responsible for 18.4% of the world's total GHG emissions (Ritchie and Roser 2020). Research has shown that agriculture can be used as a solution. Agriculture is ideally situated to replace fossil-fuel-based fuels and fertilizers with Green substitutes. Using Regenerative Ag principles, particularly Zero Till Plus, we can start rebuilding our soils by sequestering excess GHG from the atmosphere into soil organic carbon (SOC). Collectively, I label these activities Net Positive Carbon Grain Farming. My work concentrates on bringing emission-reducing technologies and carbon-sequestering BMPs to the Canadian Prairies.

1.2. Purpose and Objectives

The purpose of this research is to support the transformation of Western Canadian grain farms into Net Positive carbon grain farms.

The research question: What is needed for Western Canadian grain farms to help mitigate global warming and become Net Positive?

Research Objectives: This study has four research objectives:

Objective 1: To develop a practical theory, framework, and tools to complement this exploratory narrative research process (Chapter 7).

Objective 2: To determine whether any of the participants can be categorized as Net Positive farmers and how this relates to their Sustainability Farm Index (SFI) score (Chapter 5).

Objective 3: To determine if BERT/E (adoption rating) analysis helps to identify enablers, barriers, gaps, and innovation to assist farmers moving to Net Positive (Chapter 6).

Objective 4: To determine how innovative farmers rate the adoption of the twelve BMPs proposed to help mitigate AGW (Chapter 6).

1.3. Biogeographical Location of Research

The focus of this thesis will be restricted to geographical and climatic areas represented by the Canadian Prairies and the Northern Great Plains. This is a short season, moisture-deficit area which makes it significantly different to farm compared to long-season growing areas with surplus rainfall, as found in British Columbia and the Eastern provinces. I focused on grain farms. Two participants were located in Alberta, six were located in Saskatchewan, five were located in Manitoba, two lived in North Dakota, and one was located in South Dakota. The participants farmed in the major climatic zones of the Prairies and Great Plains: four farmed in the brown soil zone, two farmed in the dark brown zone, five farmed in the thin black zone, and four farmed in the moist black soil zone. None of the participants farmed grey wooded soils. Biogeographical soil zone maps of these regions are presented in Chapter 4.2.

The objective of this work is to influence the maximum number of acres possible in Western Canada. Most of the arable land in Western Canada is used for straight grain farming, which is where the largest opportunity exists for AGWM. Two of the twelve participating farms had cattle year-round, and two had seasonal custom grazing.

1.4. Overview of Methods

The research comprised sixteen case studies using in-depth semi-structured interviews. Twelve of the interviews were with farmers, and four were with research agronomists. The work detailed in this thesis was exploratory, participatory narrative research. All interviews were conducted using UM Zoom with an average length of approximately 2.5 hours. The interviews were recorded using the UM Zoom recording function and transcribed immediately using UM Zoom. Handwritten notes were also taken during the interviews, with additional notes taken when the interviews and transcripts were reviewed. The interview data was uploaded into NVivo, where it was coded and later queried to draw out themes around the BMPs, as well as identifying enablers and barriers.

A case history was prepared for each participant describing their practices, beliefs, and the general history of their farms. During the interviews, I used a tool, BERT/E, which was developed to help score the adoption rating for each BMP. This tool will be explained in greater detail in later chapters. The participants' BERT/E scores were subsequently used to develop insights into individual and group adoption rates.

A template was developed to gather data from participants on farm practices and their impact. This was later used to calculate farm emissions using the AAFC-Holos emission calculator(AAFC and Kröebel 2024). I also used this data to calculate the value for Net Positive Carbon Grain Farming status and the value for the Sustainable Farm Index.

1.5. Expected Outcomes

The expected outcomes of this thesis will contribute to our understanding of how and why farmers adopt new farming practices. These outcomes will be both theoretical and applied.

1.5.1. Theoretical Outcomes

Theoretical outcomes are achieved through my contribution to change theory. This is discussed at length in Chapter 7. Rourke's General Farm Practice Change Theory is a generalized change theory that is used as a theory of change when applied to the specific problem of tackling AGWM due to AGW. Rourke's General Farm Practice Change Theory consists of a Net Positive

Farm Framework and a GWMcredit- Availability, Stability, Access, and Perception (ASAP) Framework. It uses the BERT/E tool to assess the adoption potential of specific BMPs, and it uses farm data to calculate a Net Positive ranking as well as a SFI score.

1.5.2. Applied Outcomes

It is also expected that there will be applied outcomes in the form of refined BMPs, policy suggestions to enhance the adoption of AGWM BMPs, and a list of technology gaps/research needs that currently slow down or prevent the adoption of GWM BMPs. The project itself should enhance awareness of and movement toward Net Positive Carbon Grain Farming. Additionally, the research should build stakeholder support for a farmer-led Net Positive Network (NPN) to encourage the adoption of BMPs for Net Positive Carbon Grain Farming. This may also be enhanced through the development of and eventual support from a Net Positive Community of Practice (C of P).

My goal is to be a catalyst in helping stakeholders encourage, support, and enable Western Canadian grain farmers to become a significant part of the solution in the fight against AGW. We need to achieve the UNIPCC SR 1.5°C 2050 goals of no fossil-fuel-based products and optimum carbon dioxide removal (CDR) to sequester carbon and build soil organic matter (SOM).

There is a noticeable desire among some Western Canadian farmers to deny AGW. To a large extent, these farmers do not believe or have the tools to change, or they are comfortable with business as usual (BAU). Therefore, understanding qualitative issues will be key to future adoption.

Farmers also respond to visible evidence of success. This research identifies two Net Positive farmers. While it is not known whether their practices can be transferred to other farms, these farmers nevertheless stand as significant examples of innovation that helps to mitigate AGW by producing a Triple Win at the farm level. The sixteen stories presented in Chapter 4 and Appendices 4.5 and 4.6 provide valuable extension material that can help motivate other farmers.

1.6. Thesis Organization

The following is a brief synopsis of the remainder of this thesis. Chapter 1 introduces the work, the research objectives, and the thesis process map. Chapter 2 consists of a review of the academic literature and secondary documents. This review focuses on five topics: the international response to global warming; agriculture and Canadian/provincial climate policy; the role of agriculture in mitigating global warming; farmers' beliefs and energy to engage in global warming mitigation; and theoretical frameworks, change theories, and the theory of change. These areas of literature help define the multidisciplinary scope of expertise needed for this project and help to set boundaries and ensure there are both theoretical and applied outcomes. Next, Chapter 3 presents a synopsis of the narrative research methods used in the thesis, and Chapter 4 provides the case histories for each participant as well as summary tables. The findings and analysis of the SFI data and the calculation of the participants' Net Positive carbon balance scores are presented in Chapter 5, while the participants' BERT/E scores for the twelve BMPs are discussed in Chapter 6. Finally, Chapter 7 describes the development and application of Rourke's General Farm Practice Change Theory, a Net Positive Farm Framework, a GWM-credit Framework, and tools such as BERT/E, SFI, and Net Positive calculations. Chapter 7 includes the results of a short survey probing the participants' thoughts regarding the idea of a Net Positive farm network and a Net Positive community of practice. It also describes a typical Prairie grain farm in 2050 where the norm is Net Positive. It is Rourke Farms, and it is run by my granddaughter.

Thesis Process Map

Overview of the thesis process, based on Rourke's General Farm Practice Change Theory.

Review of Literature and Government Actions

Convert Change Theory to a Theory of Change: Anthropogenic Global Warming Mitigation on Great Plains Grain Farms

Set Objectives and Methods:

In-Depth Exploratory Narrative Case Study

Identify the Participants and Interview

Collect Data:

Production kcal/ha

Contribution Margin/ha

Emissions/ha (Holos Model)

Sequestration/ha (Multiple Estimates)

Document Stories:

Filter Through BERT/E Adoption Score Rating

BMPs for Net Positive Farming

Enablers

Barriers

Outcomes

Theory

Rourke's General Farm Practice Change Theory

NP Farm Framework

AGWMcredit Framework

Research Measurement Tools

BERT/E

Sustainable Farm Index

Net Positive Farm

Calculation

Applied

Critical BMPs for NP Farms

Enablers/Barriers

Potential for

NP Network

Chapter 2: Literature Review

2.1. Introduction: The Problem

Climate change has been classified as a "wicked problem" by numerous researchers (Riedy 2017; Sun and Yang 2016; Wohlgezogen et al. 2020). The concept of a "wicked problem" was first detailed by (Rittel and Webber 1973) in their work outlining the ten characteristics of such problems. As Briggs (2007) would later note, unlike "tame problems," wicked problems often do not have straightforward solutions. The question of whether climate change is a wicked problem depends on one's perspective on solving complex, multidisciplinary problems involving a wide range of actors—some of whom having significant interest in maintaining the status quo and lack a clear understanding of the scientific evidence and its implications. Nonetheless, there are many individuals who are committed to pursuing an interdisciplinary approach to taming this problem (wicked or not) and work to secure the necessary political or market support to act.

2.1.1. Scientific Evidence

Anthropogenic global warming (AGW) due to the release of greenhouse gases (GHGs) has been a subject of study since 1824, when Joseph Fourier hypothesized that something in the atmosphere must be trapping the heat from the sun. This hypothesis was later confirmed by Eunice Newton Foote in 1856, who discovered that high atmospheric CO_2 concentrations would cause the Earth to warm. In 1861, Foote's work was expanded by John Tyndall, who found that CO_2 could trap 1000 times as much heat as dry air (Thompson 2019), and a few decades later Svante Arrhenius (1896) estimated that the Earth would be 15°C cooler without the heat-trapping effects of GHGs. In 1896, Arrhenius and Chamberlain calculated that the continued production of GHGs from human activities would cause the global temperature rise (Enzler 2004). Nearly a century later (1988), James Hansen, one the world's leading climate scientists, urgently warned the US Senate that AGW is real. Hansen reiterated his warning in his sobering 2010 TED talk, stating,

> *Now, you know what I know that is moving me to sound this alarm. Clearly, I haven't gotten this message across. The science is clear. I need your help to communicate the gravity and urgency of this situation and its solutions more effectively. We owe it to our children and grandchildren* (Hansen 2012).

The Intergovernmental Panel on Climate Change (IPCC) has determined that the planet is warming at a pace that is faster than would be possible from natural forces alone. After analyzing and weighing the vast body of scientific research on the subject, the IPCC arrived at the conclusion that fossil-fuel usage is the main driver of the current increase in global temperatures, noting that there is high consensus among scientists as to the existence of AGW (UNIPCC 2021). Indeed, as of 2021 approximately 100 million barrels of oil equivalents are extracted and used throughout the world each day (Blas and Hurst 2021). According to the UNIPCC SR 1.5°C report, halting the use of fossil fuels by 2050 and removing excess CO_2 from the atmosphere will be necessary if we are to keep global temperatures from rising above 1.5°C: "Overall CDR deployment over the 21st century is substantial in most of the pathways, and deployment levels cover a wide range, on the order of 100–1000 Gt CO_2 in 1.5°C pathways with no or limited overshoot (730 [260–1030] $GtCO_2$ (UNIPCC 2018) Chapter 2 Section 2.3.4 page 96. This chapter explores the potential of using plants and agriculture as significant CDR solutions.

2.2. International Response to Global Warming

The global scientific community's concern about the health of the planet was first addressed at the Earth Summit held in Sweden in 1972 (Jackson 2005). After four decades of further research and efforts on the part of the international community, the Paris Accord, which established a legally-binding treaty on climate change with the aim of limiting global warming to below 2°C, and preferably not exceeding 1.5°C, was ratified by 196 countries and took effect on November 4, 2016 (UNFCCC 2015b). Under the Paris Accord, the optimal outcome would entail reducing GHG emissions by 45% by 2030 and achieving net zero emissions by 2050. This would result in atmospheric CO_2 levels of approximately 400 ppm by 2100 (Arias et al. 2021; UNIPCC AR6 Technical Summary 2021), down from the most recent measurement of 426.9 ppm obtained in May of 2024 (NOAA Observatory, Mauna Loa; Stein 2024).

Rattan Lal (2016a) notes that the Paris COP21 conference marked the first time that agriculture and carbon were included in the agenda of a COP meeting. As a widely recognized carbon sink, agriculture assumed a key role French Agricultural Minister Stephan LeFoll' s "4 per 1000" program, which aimed to increase the global soil organic carbon levels by 0.4% per year to a depth of 40 cm (LeFoll 2015). According to Lal (2016b), the world's cropped soil has the potential to sequester 0.8 to 1.2 t/ha of carbon for 50 to 75 years, amounting to approximately 88 Gt CO_2eq. This could cover approximately 1400 Mha of arable cropland. Lal (2016b) also notes that there is potential to sequester carbon on 3500 Mha of grazing land. Other studies also highlight the potential of agricultural land as a carbon sink (Smith 2012; Paustian et al. 2016; Zomer et al. 2017; Kon Kam King et al. 2018; Soussana et al. 2019).

The United Nations Intergovernmental Panel on Climate Change's (UNIPCC) sixth assessment report (summer 2021) cautions that continuing to use fossil fuels at current levels will cause global temperatures to rise by more than 1.5°C, emphasizing that damage from such warming is now highly probable and will be extremely damaging to ecosystems. Consequently, the report calls for an aggressive, rapid, and sustained reduction in GHG emissions to attain a net-zero emission state (UNIPCC 2021). The subsequent Conference of the Parties (COP26; Glasgow, October 31 to November 13, 2021) was anticipated to be a pivotal moment wherein nations would finally commit to taking the necessary steps to keeping AGW below 1.5°C. However, data presented at this meeting indicates that failure to act has put the world on course towards a 2.4°C increase in global temperatures (UNFCCC 2021).

2.2.1. International Initiatives

The global community has not acted at a pace commensurate with the imminent threat of climate collapse due to our widespread reliance on fossil fuels and the unchecked emission of their byproducts into the atmosphere. Despite efforts by leaders to promote change, the urgency of the situation remains unaddressed.

Table 2.1. An overview of significant global climate agreements and events

Year	Event	Place	Focus	Result
1949	UN Scientific Conference *1	Lake Success, NY, USA	Conservation and utilization.	Pre-global warming awareness.
1972	UN Scientific Conference First Earth Summit *1	Stockholm, Sweden	Preservation and enhancement of the human environment.	The resultant Declaration acknowledged the issue of climate change for the first time and established stations to monitor long-term trends in atmospheric constituents, including climate changes.

1979	UNEP—Earth Watch *1	General Assembly	Air pollutants.	"Convention on Long-Range Transboundary Air Pollution."
1985	UNEP *1	Vienna, Austria	Ozone protection.	"Vienna Convention for the Protection of the Ozone Layer."
1988	UNEP *1	General Assembly	First focus on anthropogenic global warming.	Intergovernmental Panel on Climate Change (IPCC) established.
1989	UNEP *1	Montreal, Canada	Protocol development.	"Malé Declaration on Global Warming and Sea Level Rise." "Helsinki Declaration on the Protection of the Ozone Layer." "Montreal Protocol on Substances that Deplete the Ozone Layer."
1992	United Nations Conference on Environment and Development. Rio Earth Summit *1	Rio De Janeiro, Brazil	Stabilize atmospheric concentrations of greenhouse gases to levels conducive to long-term sustainability.	"United Nations Framework Convention on Climate Change (UNFCCC)" was established. By the end of 1992, 158 countries had signed on.
1995	The first Conference of the Parties to the UNFCCC—CoP 1 *1	Berlin, Germany	Protocols and stronger commitments for developed. countries and those in transition.	
1997	UNFCCC—CoP 3 *1	Kyoto, Japan	Reduce overall emissions of carbon dioxide and	"Kyoto Protocol." Ratified by 160 counties but did not take effect until 2005.

			other greenhouse gases to at least 5% below 1990 levels by 2012.	
2009	UNFCCC—CoP 15 *2	Copenhagen, Denmark		“Copenhagen Accord,” which pledged $100 B/year for developing countries and a Green Climate Fund.
2015	UNFCCC—CoP21 *3	Paris, France	To meet commitments for serious change due to inadequate implementation of measures (most countries had failed to meet Kyoto targets).	“Paris Agreement.” Called for a maximum temperature increase of 2°C with a goal of 1.5°C. The Agreement establishes common binding procedural commitments for all countries but leaves it to each to decide its nonbinding nationally determined contribution (NDC). The Agreement also establishes an enhanced transparency framework to track countries’ actions and calls on countries to strengthen their NDCs ever five years. Every country must conduct and submit a national inventory report (NIR) on emissions to the UN each year. Article 6 of the Agreement also makes provisions for carbon pollution pricing and carbon credit accounting.

				"The Paris Agreement" was the first to identify agriculture as a solution to global warming. The "4 per 1000" soil carbon sequestration initiative was unveiled at this meeting.
2018	UNIPCC SR 1.5°C *4		We are falling behind on our commitments.	Chapter 4, Section 3.7.3 includes agriculture as having potential for carbon dioxide removal (CDR).
2021	UNFCCC—CoP 26 *5	Glasgow, Scotland	Stronger commitments and accountability to stay below 1.5°C.	"Glasgow Climate Pact" and the Accelerating to Net Zero coalition. NDC Synthesis Report gauging present levels of ambition. Phasing down of coal power and phasing out "inefficient" fossil fuel subsidies. "Enhanced Transparency Framework." Santiago Network, which connects vulnerable countries with providers of technical assistance, knowledge, and resources to address climate risks. "Global Methane Pledge," which aims to limit methane emissions by 30% of 2020 levels by 2030. Stop and reverse forest loss and land degradation by 2030. All new car and van sales to be zero-emission vehicles by 2040 globally and 2035 in leading markets.

				$8.5 B over 5 years to phase out coal in South Africa. Glasgow Financial Alliance for Net Zero. This Alliance consists of 450 firms across 45 countries that control $130 trillion in assets and requires member to set robust, science-based, near-term targets. Approval of Paris Article 6: "Rules for Carbon Credit Trading, Valuation, and Pricing." Section 6.8 further introduces non-market cooperation of finance, technology transfer, and capacity building, but does not involve or need trading of emission reductions.
2022	UNFCCC—CoP 27 *6	Sharm el-Sheikh, Egypt	Thirtieth anniversary of the adoption of UNFCCC. Better understanding of science, impact tracks, and solutions. Opportunity to show unity against the existential threat of global warming.	Virtual Climate Action Day Establishing a Regional Baseline for Circular Economy in Latin America and the Caribbean. Advancing Glasgow Pact—1 GT emission reduction from forests by 2025. Private sector finance for climate adaption as part of National Adaptation Plans (NAPs). UNEP's "Adaption Gap Report." World Adaption Science Programme (WASP) launched for global goal on adaption.

			Focus on education and youth.	Enhancing climate action through peatlands. “Emission Reduction Report 2022: Accelerating to Net Zero in New Energy Paradigms.” Accelerating youth skills and talent for green jobs. Pathways to sustainable building markets through LCA information. Youth Leadership to finance and accelerate global climate action solutions.
2023	UNIPCC AR6 *7		Status of the impact of current mitigation efforts and probable future scenarios.	“Unless deep and immediate emission reductions are made the remaining carbon budget for 1.5°C will be exceeded. The current track has a high probability is taking the Earth to scenarios well above 2C with major consequences for humanity.” We must achieve net zero on or before 2050. C.1 Urgency of Near-Term Integrated Climate Action “Climate change is a threat to human well-being and planetary health (very high confidence). “ “There is a rapidly closing window of opportunity to secure a liveable and sustainable future for all (very high confidence). The choices and actions implemented in this decade will have impacts now and

				for thousands of years (high confidence)."

Table Note: The information presented in Table 2.1 was obtained from a variety of sources, including the (Jackson 2007(*1); UNFCCC 2013*2); 2015(*3); 2021(*4); 2022(*5); UNIPCC 20189*6); UNIPCC AR6 2023(*7)

The global effort to mitigate climate change initiated at the Rio Earth Summit can be characterized as being well-intended but yielding disappointing outcomes. The most recent UNIPCC AR6 report highlights the urgency of this situation with the dire warning that humanity is running out of time to correct course. However, despite numerous initiatives and legally-binding commitments to reach the goals set for 2030 and net zero by 2050, global emissions have continued to increase, reaching 59 $GtCO_2$-eq in 2019 (2.8 times higher than the 1990 Kyoto benchmark of 21 $GtCO_2$-eq). These commitments are supported by annual emissions reports, which serve as the basis for measurable National Determined Contribution (NDC) targets. Although scientific research has been integral in measuring and reporting environmental changes, it has also been frustrated by a lack of action. The central barrier to action is the challenge of convincing the leaders of more than 190 countries to agree on a solution (or set of solutions) and then ensuring they follow through, particularly when such solutions may go beyond most individuals' capacity for action. To address this issue, institutions and companies that control their own infrastructure must take the lead in providing low-carbon alternatives. Unfortunately, as James Hansen and the UNIPCC AR6 emphasize, progress has been too slow in this respect.

The Overton Window theory presents a tool for analyzing shifts in public opinion (Overton 1990; Astor 2019). Political leaders rely on voter support; if they propose solutions that are perceived as excessively radical (either from a right- or left-wing perspective), they may lose their authority to govern and any progress they have made in global climate negotiations. Activists on either end of the spectrum can cause a window to open or shift, transforming that which was previously viewed as unattainable, illogical, or absurd, into common-sense propositions. For example, women's right to vote is a given across Western societies today, but it was once beyond the window of acceptability. The scientific consensus on AGW and the urgent need for action is becoming a common-sense issue. To be sure, it is eminently logical to want to neutralize the most severe existential threat to ever face humans. The United Nations has played a crucial role in bringing us to this point of awareness and potential solutions however we are reaching or surpassing the tipping point (Gladwell 2001).

2.2.2. Businesses Are Engaged and Starting to Drive Adoption

One of the more notable outcomes of the United Nations climate negotiations has been pledges by private sector entities to join the battle against global warming. As of June 25, 2023, a total of 5378 companies have signed on to the Scientific Based Target initiative (SBTi 2018, SBTi 2023), which aims to establish legally-binding commitments to achieve net zero emissions. The number of companies signed on to the SBTi had reached 7659 as of March 12, 2024, and surpassed 8400 as of June 18, 2024. It was 9969 on January 11, 2025. All companies registered with the SBTi are required to commit to being net zero by 2050. This initiative is a partnership between the Carbon Disclosure Project (CDP), the United Nations Global Compact, the World Resources Institute (WRI), and the Worldwide Fund for Nature (WWF), and its call to action is based on the business ambition for the 1.5°C campaign and the commitments made by the We Mean Business Coalition. The SBTi website outlines its three primary functions:

1. *To define and promote best practices in emissions reduction and net-zero targets in line with the latest climate science.*
2. *To provide technical assistance and expert resources to companies that set science-based targets aligned with the latest climate science.*
3. *To bring together a team of experts to provide independent assessment and validation of targets set by companies.*

As part of its function, the SBTi provides sector-specific guidance, including the Forest, Land, and Agriculture Guidance Protocol (SBTi-FLAG 2023), which covers agriculture. However, most farmers are unaware of the commitments made by SBTi members. These members, which include the largest buyers of agricultural commodities, are only themselves beginning to understand the implications of their pledges with respect to their Scope 3 emission suppliers (Kenyon 2024). For instance, one of the largest SBTi members in the food sector, General Mills (2022), has made a legally-binding pledge to be net zero by 2050, which encompasses Scope 1, 2, and 3 emissions. Scope 1 emissions are those that are directly controlled by General Mills within their production plants and the associated administrative and logistical operations. Scope 2 emissions are those resulting from the electricity that General Mills purchases or produces to power its operations. Here, electricity generated via hydro or other Green sources is much preferable to power generated via fossil fuels, such as coal or natural gas. Finally, Scope 3 emissions relate to the production and delivery of the oats used to manufacture cereals, such as Cheerios (one of General Mills' flagship products). If Scope 3 emissions exceed 40% of the total output, General Mills must collaborate with its suppliers to bring them in line with their net-zero target. It is worth noting that Scope 3 emissions typically account for 70% to 85% of total emissions for food companies.

While the SBTi is a praiseworthy endeavor that demonstrates corporate commitment to mitigating global warming, many member companies have failed to inform their suppliers of such initiatives. In addition, it is unclear how farmers can economically achieve net zero on a scalable basis. Thus, while society needs farmers to act swiftly, farmers must also act with caution, as some BMPs may not be suitable for all situations. Ultimately, farmers must act in ways that allow them to maintain or increase their food production and remain profitable as it is imperative to their survival. The most commonly proposed BMPs are similar to those advocated by the Canadian government, including Regenerative Ag, the incorporation of perennials, rotational grazing, the 4Rs of nitrogen fertilizer management, and perennializing annual cropping systems using cover crops to optimize plant growth from snow to snow. Cover crops are particularly important for increasing soil carbon sequestration (SCS) (Van Eerd et al. 2023; McClelland et al. 2021; Blanco-Canqui et al. 2015; Obour et al. 2021), but challenges persist in enabling the large-scale adoption of cover crops in the Prairies (Morrison 2021; Rourke 2022b).

Some strategies proposed by the SBTi for minimizing Scope 3 emissions have been deemed insufficient, such as removing suppliers who are unable to attain net-zero emissions independently. This policy suggestion is detailed in the Procurement Policy and Choices section of the SBTi's "Best Practices in Scope 3 Greenhouse Gas Management" (SBTi 2018, p. 29). Addressing AGW is now a responsibility that extends beyond international accords, between heads of state. Businesses are beginning to respond to the demands of their shareholders and consumers, recognizing the long-term consequences for their companies and communities if they fail to do so. Financial institutions, including the US Securities and Exchange Commission (SEC) and banks, now require companies to disclose information related to climate change, with the SEC predicting that the world's largest corporations will face costs totaling $1 trillion due to the impacts of AGW in the near future (Thornton 2022). Furthermore, it is anticipated that, by 2030, the fertilizer industry will be investing approximately $30 billion annually into the research and development of low-carbon products to mitigate global warming and meet the expectations of shareholders (Kenyon 2024). These efforts will significantly assist farmers in reducing their Scope 3 emissions.

2.3. Agricultural and National/ Provincial Climate Policy

2.3.1. Canadian Climate Change Policy: Agriculture as a Solution Provider

The Canadian government has long been committed to addressing AGW, with this commitment intensifying after becoming a signatory to the Paris Accord in 2015. In 2016, the Canadian government introduced the Pan-Canadian Framework on Clean Growth and Climate Change (Government of Canada 2016). Notably, this framework addresses agricultural emissions, which are expected to account for approximately 10% of Canada's emissions until at least 2030 (i.e., they are not expected to increase significantly). The framework also acknowledges the crucial role Canadian agriculture plays in absorbing and storing atmospheric carbon, identifying a number of mechanisms for carbon sequestration, such as practices that increase soil organic carbon (SOC), including growing perennials, cover crops, and zero tillage. Additionally, the framework suggests maintaining and restoring wetlands and utilizing bioenergy crops and agricultural waste to produce bioenergy, while emphasizing the importance of continued research and development in sustainable intensification (Government of Canada 2016).

More recently, Agricultural Climate Solutions (ACS), a sub-section of the Natural Climate Solution Fund managed by Environment and Climate Change Canada, established a fund of $4 billion to be disbursed over a decade. Concurrently, the federal government launched a $185 million 10-year program to develop and implement agricultural practices that address climate change (Agriculture and Agri-Food Canada 2021). The ACS program is an integral component of Canada's Strengthened Climate Plan with the central goal of lowering greenhouse gas emissions by 40% to 45% below 2005 levels by 2030 and achieving net-zero emissions by 2050, as legally mandated by the Canadian Net-Zero Emissions Accountability Act (Canada Net Zero Act 2021). To this end, the ACS has implemented an initiative called Living Labs, which is designed to support farmers who are developing and implementing climate-smart solutions (Canada and AAFC 2021). The program's creator, Dr. Brian Gray, stated that Living Labs was specifically created to address the carbon sequestration goals established by the Paris Accord's "4 per 1000" initiative (i.e., 0.4% per year) (Gray 2022). However, the first phase of the Manitoba Eastern Prairies projects mainly focused on water management rather than carbon sequestration.

The November 2021 meeting of federal, provincial, and territorial agriculture ministers resulted in "The Guelph Statement," a joint statement emphasizing the significance of agriculture in addressing climate change. Specifically, this statement highlighted the agriculture sector's potential to decrease emissions, enhance carbon sequestration, revitalize the soil, promote biodiversity, and safeguard vulnerable ecosystems (Government of Canada 2021). To help achieve this potential, the federal government developed a carbon-offset processes—namely, the GHG Offset Credit System Regulation and the Enhanced Soil Organic Carbon Protocol—as outlined in Canada Gazette (2021). These initiatives marked a significant step forward, as financial compensation for carbon offsets may be necessary to encourage farmers to increase SOC.
While international CoP agreements establish general objectives and aspirations, it is up to individual countries to interpret and work toward these targets. To track and report emissions, countries submit NIRs, and each country must also present its NDCs to fulfill its commitments towards the 2030 and 2050 (i.e., net zero) objectives. As noted above, Canada has taken steps toward honoring its commitments by establishing legally-binding targets under the Canada Net Zero Emissions Accountability Act, which also includes an “evergreening clause” that allows for more ambitious targets (Canada ECCC 2022).

2.3.2. National and Local Goals: Targets, Policies, Plans, and Actions

Table 2.2. Major initiatives by the Government of Canada to address climate change.

Year	$	Initiative	Salient Features or Impact
1990		Kyoto Protocol: reduce 1990 emission levels by 5% by 2012.(UNFCCC 2013)	Canada signed in 1998 but withdrew in 2011 to avoid noncompliance penalties of $12 billion.
2015		Paris Agreement. (UNFCCC 2015)	Ratified by 197 countries and is the basis of all subsequent climate change initiatives. The USA withdrew in 2016 but re-signed in 2020. US companies, states, and cities continued to

			work toward their goals from 2016 to 2020, despite lack of federal leadership.
2016		Pan Canadian Framework on Climate Change-PCF.(Government of Canada 2016)	Canada's overriding philosophy on tackling AGW.
2020	$15B	Strengthening Climate Plan (SCP): A Healthy Environment and a Healthy Economy.(Williams and Shakil 2022)	The updated overall national plan.
2021		Canada Net Zero Emissions Accountability Act.(Canada 2021)	Legal obligation for Canada to reach Net Zero by 2050.
2022	$100B	Emission Reduction Plan (ERP) (Canada ECCC 2022). Reduce fertilizer emissions by 30% by 2030 (voluntary).(Western Producer editorial 2021; Canada AAFC 2022) Reduce GHG emissions to 60% of 2005 levels by 2030 (mandatory). Net Zero by 2050 (mandatory).	Funds over 100 climate initiatives. Climate change mitigation is an overriding principle for all government ministries and actions. Eventually all sectors will comply.
		Programs affecting Agriculture, the fifth-highest emitting sector in Canada.	
		Sustainable Agriculture Strategy (SAS). Sustainable Agriculture Advisory Committee (a twenty-one-member	This is the umbrella for all federal agriculture climate programs. Focuses on five priority issues: soil health, climate adoption

		public consultation).(Canada AAFC 2021)	and resilience, water, climate change mitigation, and biodiversity.
	$3.3B	Sustainable Canadian Ag Partnership (SCAP).(Canada AAFC 2022)	FPT agreement supports the use of environmental farm plans and provides 60% of funding for many provincially managed programs. Sets an emissions reduction target for agriculture of 3-5 MT of CO_{2eq} per year.
	$165M	Ag Clean Tech.	Adoption and research streams
	$330M	Ag Clean Tech 2.(NIR- Canada 2019; Canada AAFC 2018; Canada Gazette 2022)	Three priorities: Green energy and energy efficiency, precision agriculture, and bioeconomy.
	$200M	Agriculture Climate Solutions.	Part of the $4B Natural Climate Solutions Fund.
	$470M	Agriculture Climate Solutions 2. (Canada AAFC 2021)	Includes ACS-Living Labs program. ACS, On Farm Climate Ag Fund (OFCAF). AgriScience program.
	$250M	Resilient Agriculture Landscape program (RALP).	Centers on supporting ecological goods and services provided by the agriculture sector. Priorities are to maintain and restore grasslands and wetlands, as well as to improve grazing management and water.
	$100M	Additional funds for R&D and knowledge transfer.	Expand AAFC research efforts.

	$15M/P	AgriScience cluster and project grants.	Includes work on GHG emission reduction or carbon sequestration.
		Initiatives outside of agriculture, but that affect agriculture.	
	$1.4B $8B $1.1B $2.2B $790M $5.5B+	Nature Climate Solutions Fund, (NSCSF-ECCC).(Canada ECCC 2023; Canada ECCC 2022) Clean Tech and Climate Innovation (Canada AAFC 2018). Sustainable Finance (Canada Finance 2021). Sustainable Jobs, Skills, and Communities. Carbon pollution pricing: $170/Mt by 2030 (ECCC Canada 2018; Canada Gazette 2021). Clean Fuels Fund.	Focus on grasslands, wetlands, and forests; 24 $MTCO_2eq/y$ from 2030 to 2050. Invest in clean energy, transportation, concrete, hydrogen, electricity. Sustainable Finance Action Council. Greater private sector commitment. Create jobs and prosperity with switch to a low-carbon economy. Cost of polluting: GHG fuel charge and output-based pricing system (cap and trade). Clean fuel standard. Invest in biomass, hydrogen, biofuels, and renewables. Low-Carbon Economy Fund. Climate Action and Awareness Fund. Canada Infrastructure

		Clean Growth Economy (Umbrella).	Bank. Greening Government Strategy.
		Methane Reduction Strategy (Umbrella).	Global Methane Pledge. Emission Reduction Fund. Canada Emission Reduction Innovation Network. Food Waste Diversion Program. Clean Fuel Fund.
		Transport Canada Emission Reductions (Umbrella).	Investment in zero-emission vehicles, charging stations, retrofits for HD trucks, hydrogen fueling, electrify government fleets, public transit, batteries, renewable diesel, sustainable aviation fuel.
		Canada's Greenhouse Gas Offset Credit System (ECCC Canada 2020b).	Federal offset protocols limited to landfill methane and GHGs from refrigeration. Possibility to extend to agriculture for soil carbon sequestration.

Table 2.2 clearly demonstrates that the Canadian government is taking its commitments to addressing AGW very seriously, as evidenced by its allocation of $100 billion for over 100 individual climate action initiatives (Canada ECCC 2022a). Canada has also led or been an active participant in various UNFCCC initiatives to mitigate global warming. The Paris Agreement is a significant milestone in this regard, as it brings together numerous initiatives, such as International Climate Finance, the Powering Past Coal Alliance, Phasing out Inefficient

Fossil Fuel Subsidies, the Global CH_3 Pledge, the Climate and Clean Air Coalition, the Arctic Council Framework for Action on Enhanced Black Carbon and Methane Emissions, the Kigali Amendment to the Montreal Protocol, the Ocean Plastics Charter, the Deforestation and Sustainable Land Use Commitment, Circular Economy-UNCTAD (Conference on Trade and Development), the North American Leaders Summit, the Roadmap for Renewed US-Canada Partnership, and the High-Level Ministerial Dialogue on Climate Ambitions (Canada ECCC 2022a).

Table 2.3 documents countries' varying degrees of success in tackling AGW. Currently, China is the world leader in renewable energy (Zinglersen 2019) and is working toward achieving long-term environmental stability. In addition, the decline in emissions in Russia following the collapse of the USSR can be attributed to the closure of inefficient industries and a significant decrease in meat consumption due to affordability issues (Schiermeier 2019). President Putin has announced that Russia is working to achieve carbon neutrality by 2060, with the initial 30% reduction coming from carbon sequestration by forests and other ecosystems (Zagoruichyk 2022). However, considering the ongoing conflict in Ukraine, it is uncertain how relevant these climate targets are at present.

Table 2.3. World, Canadian, and Canadian Agriculture emission over time ($GtCO_2$/year).

Year	**World CO_2 ppm *1**	**World Gt *3**	**GDR Gt *4**	**UK Gt *4**	**USA Gt *4**	**China Gt *5**	**India Gt *6**	**Russia Gt *4**	**Canada Gt *2**	**Cnd Ag *7**	**W. Cdn Ag Gt *7**	**Canada LULUCF Gt crop Land * 7**
1880	291											
1990	354	22.76	1.24	.79	6.45	2.17	.56	2.16	.59	.041	.022	.001
2005	380	29.61	.98	.69	7.43	5.82	1.13	1.61	.74	.054		-.022
2012	394	35.01				9.54	1.90	1.67				
2015	401	35.56	.89	.50	6.68	9.86	2.14	1.59	.70	.052	.037	-.017
2019	411	37.08	.79	.48	5.57	10.77	2.45	1.70	.73	.054	.033	-.018
2020	414	35.26	.72	.40	5.98				.67	.055	.033	-.016
2021	418	37.12			5.01	11.47				.054		-.018

	144% of 1880 % of 1990	+163%	41%	49%	-22%	+527%	+413%	-21%	+113 %	+132%	+150%	>-18X

Table Notes: Statista*1 (2023), Canada*2 (2023a), UNFCCC*3 (2020), Sealevel *4(2022), Macrotrends China*5 (2023), Macrotrends India*6 (2023), Canada ECCC-NIR*7(2023).

Canada recorded a 13% increase in emissions from 1990 to 2019, a figure that falls far short of the targets set forth in the Kyoto Protocol and the commitments established by the Canada Net Zero Emissions Accountability Act. Although there has been a decrease in emission intensity for agricultural products (i.e., greater production with lower emissions/ unit of output), Canada still has a considerable way to go if it is to be net zero by 2050. Sadly, agriculture-related emissions in Canada have risen faster than the global national agricultural average of 32%, with Western Canadian agriculture experiencing an increase of 50%. In Manitoba, a low-industrialized province, agricultural emissions constitute 29% of the province's total emissions. Nonetheless, agricultural emissions still only account for 8% of Canada's total emissions (Manitoba 2022).

Leaders have convened with the aim of aligning immediate requirements with long-term sustainability. The progress made in these meetings is reflected in the decrease, and even reversal, of GHG emissions in several countries, including the United States. This is cause for optimism, as several other such initiatives are only just beginning.

2.3.3. Are Our Policies and BMPs Scalable?

According to data from 2020, Canada's NIR emissions have been increasing at an annual rate of 1% to 2%. In Western Canada, agricultural emissions rose by 2% to 3% between 1990 and 2015 (Canada ECCC-NIR 2023). To achieve net zero by 2050, which is 26 years away, it will be necessary to reduce emissions by 3% to 4% per year.

To this end, the Canadian and Manitoba governments have entered the FPT Sustainable Canadian Agricultural Partnership (Sustainable CAP), which is a 5-year, $221 million program aimed at promoting strategic agricultural initiatives in Manitoba (Top Crop Manager 2023). At present, the primary climate policy in Manitoba is the "Made-in-Manitoba Climate and Green Plan" published in 2017, which intended to position Manitoba as "Canada's cleanest, greenest, and most climate-resilient province" (Manitoba 2017). Although agriculture is a crucial element of this plan, the plan only includes a call for agricultural exemptions, with no mention of a carbon tax on farm fuels or targeted reductions in agricultural emissions. This approach represents a "business-as-usual" strategy, which is no longer deemed acceptable in today's world. Nevertheless, many farmers have expressed support for this policy.

Manitoba's Climate Change and Green Economy Action Plan from 2015 (Manitoba 2015) is largely consistent with the federal government and international community's current ambitions with respect to combating global warming. This plan points out that agricultural emissions comprise 31% of Manitoba's total emissions, thus necessitating the exploration of: methods for reducing emissions and enhancing resilience; supporting climate-friendly BMPs; improving soil health; promoting fertilizer emission reductions; encouraging the cultivation of perennial and pulse crops to increase carbon sequestration; reducing reliance on fossil-fuel-based nitrogen fertilizers; supporting research initiatives; promoting organic farming; improving rural internet access; expanding the production of bioproducts; and fostering diversity in farm structure and local food production.

Table 2.4 highlights initiatives that have a direct impact on grain farmers' capacity to decrease emissions and enhance carbon sequestration. This table does not encompass broader "sustainability" programs, such as the Manitoba Protein Advantage Strategy, which features four sustainability criteria: minimal environmental impact, well-being of individuals, cultural acceptability, and economic feasibility.

Table 2.4. Programs available in Manitoba to tackle AGW.

Government Initiatives and Programs in Manitoba	**$**	**Program Priorities**
Made-in-Manitoba Climate and Green Plan (2017). This plan needs to be overhauled and is superseded by the Federal Emission Reduction Plan.		Philosophy of tackling climate change but does not call for changes to the agriculture sector.
Conservation and Climate Trust. GROW Trust. Wetland Grow Trust.	$200M trust $10M/y	CR, B, F W, Soil Health (ZT, CC, IPM, P).
Manitoba Associations of Watersheds (MAW)		

Administrators of programs: GROW: Growing Outcomes in Watersheds. PWCP: Prairie Watershed Climate Program. OFCAF: On-Farm Climate Action Fund. LL: Living Lab Initiative with AAFC.	GROW PWCP $40M LL $7M	W, P, CC, B, SI, CR, F ,4R, ZT, IPM.
Natural Climate Solution Fund (Canada) (Umbrella) : -Agriculture Climate Solutions (ACS). (Umbrella for PWCP, LL, OFCAF). -Nature Smart Climate Solutions Fund. -Two Billion Trees Program.	$4.7B/10y $185M $1.4B $3.19B	 W, P, CC, B, CR, F, 4R, ZT, IPM CR, F F
Agriculture Clean Technology Programs: - Adoption stream. - Research and innovation stream.	$4.4M in MB	Tech.
Sustainable Canadian Agricultural Partnerships: - Cost-shared F/P programs. - Environmental farm plans. - Ag Action Manitoba Assurance Program. - Resilient Ag landscape programs (RALP). - Wetland and grassland restoration.	$3.3B/5y	W, P, CC, M, B, F, CR
Additional Research Funding Programs: -AgriScience clusters and projects (AAFC). -NSERC Sustainable Alliance Cluster/Project. -NSERC College ARD., MITACS, IRAP, SCAP		 ALL ALL
Manitoba Habitat Heritage Corporation (MHHC). GRoW trust (money to MAW for delivery). Regeneration Accelerator.	$10M/y $324K	W, CR, F P
Commodity groups (e.g., Canola Council of Canada, Manitoba Crop Alliance, Manitoba Pulse and Soybean Growers, Manitoba Forage and Grassland Association).	$22 M	SI

NGOs, DUC, NU, TNC, ALUS E.g., DUC winter wheat program/ perennial program; ALUS environmental goods and services.		CC, CR, ZT W, CR, F, P
Education—universities and colleges. E.g., ACC/Westin Foundation for soil health.	$1.7M/5y	ALL
Food processor initiatives. E.g., McCains/Simplot, General Mills.		W, P, CC, M, B, F, ZT, IPM

Table Notes: *Program priorities: W-water management; P-pasture management; CC-cover cropping and intercropping; M-manure management; B-biodiversity; SI-sustainable intensification; CR-conserve or restore grass and wetlands; F-forest, shelterbelts, and trees; 4R-fertilizer management; ZT-reduced tillage; IPM-reduced pesticides; O-organic; Tech-clean tech

2.3.4. Current Status

It has taken a long time for international agreements to recognize net zero by 2050 as a major priority. As a result, governments are now actively working to provide structure, measurement tools, rules, and requiring all sectors of society, including agriculture, to take steps to reduce their emissions. These measures reflect public opinion, which is now staunchly in support of low-emission alternatives.

Agriculture is one sector that can be particularly useful in reducing GHGs in the atmosphere, as carbon can be captured in the soil, thereby enabling a higher SOC equilibrium. However, soil can become carbon-saturated, which limits its effectiveness in mitigating AGW to between 10 and 100 years. To fully capitalize on agriculture's potential in combating climate change, it is crucial to discontinue the use of fossil-fuel-based products. Although healthier soil provides significant benefits, it is imperative to prioritize emissions reduction and carbon sequestration.

There are several methods that could improve carbon retention in farming and grazing lands, but only a few come with no cost to society. The costs associated with these methods come in the form of research aimed at developing more cost-effective solutions, such as delayed germination seed technology, more refined Zero Till practices, and expanded cover crop development. The higher cost of food due to higher-priced inputs (e.g., low-emission fertilizers), which may have no return for the farmer, is another cost to consider. This lack of mitigation contributes to more extreme weather events, including floods, droughts, winds, tornadoes, hurricanes, extreme temperatures, and hail, resulting in less food and higher prices. Furthermore, the lack of insurance due to the high number of claims related to extreme weather events can cause farmers to go bankrupt or become more cautious, resulting in less investment and production

To ensure ample reliable long-term food supplies, we must invest in mitigation measures. For their part, businesses are making pledges to reduce emissions and increase sequestration. This is significant and will facilitate change. The federal and provincial governments have also enacted policies to help all sectors in Canada, including agriculture, to do their part to mitigate global warming. The next step is to actually reduce emissions and sequester carbon dioxide.

2.3.5. Criticisms of Government Response to Global Warming

World leaders have convened on twenty-nine occasions with the express purpose of determining how to mitigate the detrimental consequences of AGW. According to one UNIPCC report, global GHG emissions increased from 32,000 MMT CO_2eq in 1990 to 56,000 MMT in 2015, a 175% increase (US EPA 2016). Canada's emissions have also risen significantly during this period, increasing by 120% from 600 MT CO2 eq in 1990 to 725 MT CO_2 eq in 2018 (Canada ECCC-NIR 2019) . Despite accounting for only 1.5% of the world's total GHG emissions, Canada's per capita emissions are among the highest globally, at 14.2 tons CO_2 eq/capita (Statista 2020), when factoring in land use, land-use change, and forestry (LULUCF), Canada's per capita emissions 25 tons CO_2 eq/capita (Statista 2020). In addition to their moral obligation to address AGW, countries that fail to reduce their emissions will eventually find themselves at a trade disadvantage, as other nations are increasingly demanding low-emission products. Ideally, the world, including Canada, will recognize agriculture as a potential sink for CDR and part of the solution to AGW. The next step is to implement practices that position agriculture as a leader in AGWM. Although several such programs have been recently announced, their impact to date has been negligible. The government has supported the development of green substitutes, such as Green NH_3 fertilizer and Green diesel alternatives like straight vegetable oils, biodiesel, and renewable diesel, and fuel companies are currently in the process of building new commercial renewable diesel plants (Tidewater Renewables 2023; Stephenson 2023; Djuric 2022).

2.3.6. Good Intentions Without Practical Solutions

Undoubtedly, the idealism inherent in government programs is one of their key limitations, as such programs are often developed based on recommendations from organizations such as Farms for Climate Solutions (FCS), the International Institute for Sustainable Development (IISD), and the

National Farm Union (NFU) (FCS 2021; NFU 2021; LaForge, Corkal, and Cosbey 2021); none of whom represent the majority of grain farmers operating in the Prairies. For example, while the use of cover crops is a widely accepted strategy for increasing SOC, it is seldom feasible to establish them affordably and effectively, particularly in semi-arid regions. In Western Canada, attempts by innovators and early adopters to incorporate cover crops on their grain farms has been unsustainable.

The government's promotion of cover crops as a BMP can result in negative consequences for Western Canadian farmers and further reduce interest in adopting cover crops in the future. The current BMP, which recommends seeding cover crops in the early spring or fall, has a high failure rate in Western Canada. Furthermore, expecting Western Canadian farmers to seed approximately 78 million acres for a second time each year is simply unrealistic in terms of time, labor, and machinery. While some farmers have had success with this method, it has not been proven to be effective on a larger scale. Instead of subsidizing farmers to use existing BMPs, which would cost approximately $3.1billion per year (78 M acres x $40/ acre) and have limited success in reducing greenhouse gas emissions, it would be beneficial to invest in research to develop more practical and dependable BMPs.

Discussions regarding the carbon offset market are currently underway. Although not accepted initially, Article 6 of the Paris Agreement (2015), which sets a global price on carbon pollution, was finally adopted five years later at COP 26 (2021) (Connolly 2021; UNFCCC 2015). According to William Nordhaus, Nobel Laureate in economics, carbon pricing is an effective and efficient way to reduce GHG emissions (Nordhaus 2019), as well-designed carbon-pricing policies motivate individuals and businesses to reduce their use of fossil fuels and, consequently, their emissions. Carbon offsets could also aid in financing research and initiatives that promote emissions reduction and carbon sequestration. Nevertheless, imposing a tax without practical and economical alternatives is irresponsible.

Agricultural carbon sequestration methods and programs have numerous names and variations, for example: Regenerative Ag, climate smart soils, "4 per 1000," common ground (International Union for Conservation of Nature), natural climate solutions (Nature United), agricultural climate solutions (AAFC), and carbon farming (Australia). Regardless of nomenclature, the core point is that global policy is required to support farmers in sequestering excess CO_2 to increase SOC.

2.4. Agriculture's Role in Mitigating Global Warming

2.4.1. Agriculture Recognized As a Solution

Plants utilize sunlight and photosynthesis to convert absorbed atmospheric carbon dioxide into photosynthates, carbon building blocks, and the energy they require to grow. The relationship between plants, solar energy, and carbon dioxide is the foundation of the carbon-oxygen cycle, which supports most living organisms, including humans. CDR can occur naturally through SCS, which was initially proposed as a solution to address global warming at the 2018 UN Intergovernmental Panel on Climate Change (UNIPCC) (see Special Report 1.5°C, Chapter 4.3.7.3). Chapter 3.6.3 of this report details five land-based CDR options: bioenergy with carbon capture and storage (BECCS); afforestation and reforestation; enhanced weathering; biochar; and SCS (UNIPCC 2018). Of these five CDR strategies, afforestation and SCS (soil carbon sequestration) are the most cost-effective and dependable, while offering the greatest co-benefits and least risks (UNIPCC 2018). The advantages of adding carbon to soil include increased soil moisture retention, improved soil structure, enhanced microbial habitat, greater water infiltration, reduced runoff and erosion potential, and higher crop yield potential.

2.4.2. Role of Agriculture in GWM and Emission Reductions

Agriculture is a distinct segment of the economy, providing sustenance, fiber, and biofuels to the world's 8 billion inhabitants; however, an alarming 33% off all agricultural production is ultimately wasted. The agricultural sector is responsible for approximately 10% of global emissions, but this figure can easily double when the emissions generated by nitrogen fertilizer production in the heavy industry sector and the transportation and processing of goods are accounted for. Nonetheless, food is not a luxury; it is fundamental human right and is essential for survival. Therefore, it is crucial to consider not only how to provide sustenance for individuals, but also how to minimize or eliminate negative externalities associated with food production and consumption. Agricultural participation in CDR is illustrated in Table 2.5.

Table 2.5. Carbon dioxide removal (CDR) options.

CDR option	Potential Gt CO_2/ Yr	Cost $/ CO_2	Required land. M ha/ Gt CO_2	Required water km^2/ Gt CO_2
BECCS*	0.5-5	100-200	31-58	60

Afforestation and reforestation	0.5-3.6	5-50	80	92
Biochar	0.3-2	30-120	16-100	0
Soil carbon sequestration	2.3- 5	-45 to100	0	0

Table Note: * BECCS is a bioenergy carbon capture and storage system. The data presented in Table 2.5 adapted from Cross Box 7 of Chapter 3 in the SR 1.5°C report by the UNIPCC (2018).

According to the UNIPCC SR 1.5°C, Chapter 4.3.7.3, there is robust evidence that SCS has co-benefits in agriculture, and that many measures associated with it are cost-effective, even in the absence of a supportive climate policy (Masson-Delmotte et al. 2018). The UNIPCC report also notes that the cost of SCS ranges between 45 and 100 USD/MT of CO_2 eq. Some SCS practices, such as Zero Till, have negative costs due to multiple co-benefits, such as increased crop productivity and soil resilience. The potential of SCS for 2050 was estimated to be between 0.5 and 11 $GtCO_2$ yr−1, but this range was latter narrowed to 2.3-5.3 $GtCO_2$ yr−1. This estimate assumed that studies producing figures above 5 $GtCO_2$ yr^{-1} were overly optimistic, and that estimates lower than 2 $GtCO_2$ yr^{-1} primarily focused on single practices (Fuss et al. 2018) in UNIPPC 2018. SCS also requires negligible amounts of water and energy (Smith 2016), positively impacts nutritional content and food security, and can be applied without changing current land use, making it more socially acceptable than CDR options with a high land footprint, such as BECCS, afforestation, and biochar. Smith (2016) points out that soil sinks can become saturated with carbon anywhere between 10 and 100 years, depending on the SCS option, soil type, and climate zone. At the Paris Accord, the French Minister of Agriculture proposed the “4 per 1000” program, which called upon nations to increase their SOC by 4 per 1000 or 0.4% per year (LeFoll 2015). Minasny et al.(2017) and other researchers (e.g.(Lal 2016a; Soussana et al. 2019) have demonstrated that this goal is achievable for much of the world's arable land, especially lands that have become depleted.

Section 3.7.3 of the UNIPCC report (2018) highlights the robust evidence indicating that agroforestry, the reforestation of degraded lands, and conservation agriculture management practices are effective, low-cost methods of reducing GHG emissions that do not require additional land or water. Notably, grassland and wetland conservation and restoration are not mentioned in the report, despite these methods’ potential for assisting in climate change mitigation. The costs of direct air carbon dioxide capture, and storage (DACCS) are estimated to range from $20 to $1000 per metric ton of CO_2 equivalent, but there is little agreement on the success of such methods (UNIPCC 2018) as outlined in Section 3.7.5 of Chapter 4.

Two primary methods exist for Western Canadian farms to alleviate the effects of global warming. One method is to decrease their use of fossil-fuel-based products, to maximize efficiency, thus minimizing emissions. This is the same objective being pursued by other sectors across Canada. The second approach is to capture atmospheric carbon. In this regard, agriculture presents a distinct opportunity. Zero Till crop production, which has been widely adopted as a profitable AGWM practice in the drier regions of the Prairies, uses less fuel and sequesters more carbon compared to other methods. However, due to Zero Till's ability to conserve soil moisture, farmers can attain higher yields by adding more fertilizer. Since 1990 increased fertilizer use has caused emissions in Western Canada to rise by 50% compared to the Canadian average of 13% (Canada NIR 2023a). Therefore, Western Canadian farms must undertake greater efforts to mitigate their GHG emissions.

At this point, a question emerges: how do farms increase SCS and reduce emissions while also remaining profitable and keeping up with global demand for their products? The main tools and programs available to assist Canadian and, specifically, Manitoban farmers in achieving these goals are listed in Table 2.6. These solutions are largely centered on climate-smart farming (no till, low-till cover crops, rotational grazing, and agroforestry) and natural climate solutions (cover crops, shelterbelts, agroforestry, rotational grazing, and improved manure management) (Canada ECCC 2022a). Various AGWM approaches has been discussed and promoted by many individuals and groups, including: **Carbon Farming,** (Jansson et al. 2021; Pretty et al. 2005; Swingland et al. 2002; Kragt et al. 2017; Macintosh 2013; Toensmeier 2016)**, Climate Smart Agriculture**-FAO& Agriculture and Food Security (Tumwesigye et al. 2019); **Climate Smart Soils** (Paustian et al. 2016); **A Down Payment for a Resilient Farm Future**, (Farmers for Climate Solutions 2020); **Imagine if…a vision of a near-zero-emission farm and food system for Canada** (NFU 2021,NFU 2019); **Recruiting Soils to Tackle Climate Change** (Soil Conservation Council of Canada 2020); **Common Ground: Restoring Land Health for Sustainable Agriculture,** International Union of Conservation of Nature (IUCN 2021, Larbodière 2020); **Natural Climate Solutions for Canada**-Nature United/TNC (Drever et al. 2021)**; BMPs for Reducing GHG Emissions in Prairie Agriculture-**(Viresco Solutions and Nature United 2022) **Natural Farming Systems** Thiessen-Martens et al. 2015; Entz 2024); **Regenerative Ag** (Brown 2018; LaCanne and Lundgren 2018; Toensmeier 2016; Newton et al. 2020); **Farming the Future, IISD**(LaForge et al. 2021).

Conspicuously absent from this list is the voices of innovative, forward-thinking, environmentally conscious medium-to-large Western Canadian grain farmers who are striving to use minimal inputs and practicing reduced tillage or Zero Tillage. These voices have also not been represented by most commodity or general farm organizations, especially if the group depends on check-off dollars to fund their operations. If these organizations are seen supporting climate solutions, many farmers have threatened to withdraw their check-off dollars to them. The National Farmers Union, NFU, a volunteer-member-driven general farm policy group is a notable exception and is proactive in its concern and support for developing climate solutions within agriculture.

2.4.3. New Understanding for Rapid Soil Organic Carbon Accumulation

The formation and accumulation of SOC can help illustrate why CDR can work in a physical sense. In his book, *Dirt to Soil* (2018), Gabe Brown explains how incorporating regenerative cropping practices improved the SOM on his farm from 1.7% to 5.7% over a 20-year period. Such increases in SOM should not be possible according to the long-held theory of stable humus from plant biomass conversion. New insights (e.g., Sokol et al. 2018) show that, while the contribution of shoot material to SOC is negligible, the photosynthate leaked out of the roots is three to thirteen times more effective in building SOM (vs. the entire root biomass), as the photosynthate directly feeds the soil food web. Lavallee et al.'s (2020) findings also support the microbial model, showing that microbial-derived SOC can be very stable, especially when associated with and protected by well-aggregated mineral soil particles, known as mineral-associated organic matter (MAOM). Similarly, Kallenbach et al. (2016), show that, in a laboratory setting, microbes in Petri dishes can form what was previously known as long-term stable SOC within a few hours. Given the appropriate environment and food, the plant/soil microbe relationship can develop stable SOC faster and at higher levels than previously thought. These findings help provide a scientific basis for what leading farmers such as Derek and Brandon have see in situ and measured by the Regenified 3rd party certification (Regenified 2024). These are two of the participant farmers.

2.4.4. Soil Carbon Sequestration Practices

In their comprehensive review article, Paustian et al. (2016) highlight ten soil-management practices for sequestering carbon dioxide in the soil that they deem crucial in the battle against AGW. According to their estimates, these practices have the potential to sequester as much as 8 gigatons of CO_2 equivalent per year, which is almost equal to the current global emissions from fossil fuels (~10 gigatons of CO_2 equivalent per year). The authors point out that soil is the largest terrestrial carbon pool, with 2400 to 2000 petagrams of carbon in the top two meters, which is three times the amount of atmospheric carbon (estimated to be around 830 petagrams). Furthermore, they report that the soil on arable land throughout the world has lost between 30% and 50% of its organic carbon, which represents a significant opportunity to restore this land and remove excess GHGs from the atmosphere. Numerous other researchers have also endorsed the use of improved crop and soil management practices to achieve this goal (Lal 2016; Lal and Bruce 1999; Smith 2012; Jansson et al. 2021; Toensmeier 2016).

In Australia, "carbon farming," is used to refer to the use of improved cropping practices to increase CDR through SOC accumulation (Lin et al. 2013; Macintosh 2013; Swingland et al. 2002). In Western Canada, scientists (e.g., (Campbell et al. 1997; Congreves et al. 2015) have demonstrated how the use of enhanced farming techniques can improve SOC accumulation. Notably, McConkey et al. (2020) found in the Prairie Soil Carbon Balance (PSCB) Project from 1996 to 2018, that SOC accumulation was positive on farms that had adopted Zero Till practices and stopped the practice of summerfallow. St. Luce et al. (2024) conducted further analysis of the PSCB samples from more focused continuous zero till farms, finding approximately double the carbon sequestration of the original study.

Table 2.6. lists important agricultural strategies and practices for developing BMPs for Net Positive carbon grain farms in Western Canada.

Table 2.6. On-farm mitigation and emission-reduction strategies—towards Net Positive.

Strategy	**Practices**	**Examples**
Regenerative Principle 1	Plants from snow to snow.	Cover crops, intercrops, perennials, trees.
Regenerative Principle 2	Increased diversity.	Crop rotations, cover crops, perennials, pollinator strips.
Regenerative Principle 3	Keeping the soil covered. Amor on the soil.	Crop residue and living covers. Eliminate fallow periods. Reduce erosion and loss of soil fertility.

Regenerative Principle 4	Minimizing soil microbe disturbance.	Implement Zero Till, strip-till, minimum-till. Avoid soil-microbe-damaging pesticides. Avoid natural senescence fallow.
Regenerative Principle 5	Integrate grazing cattle.	Use adaptive/mob grazing techniques to build SOC faster. Explore feed additives to reduce enteric emissions. Watch new research on GHG balance in pastures. Re-examine the CO_2/CH_3 cycle from cattle.
Agroecology	Use of crop rotation and competition to reduce need for synthetic pest control. Pollinator strips to encourage beneficial insects and birds.	Higher seed rates; narrow row spacing; genetic pest resistance in crops; greater use of diversity such as intercrops and cover crops; judicious use of pesticides/IPM/agroecology.
Sustainable intensification	4R fertilizer management. Judicious use of pesticides/IPM/agro ecology. Variable rate/ precision farming/sectional control. Field drainage: tile and surface. Big Data and AI.	Increasing input efficiency for greater yield and lower emissions / kg of output. Practices such as 4Rs can be dead ends for GWM. Focus on higher yielding crops. Better pest control for higher realized yields. Can result in higher input/ha but lower emissions/Kcal.

Green fertilizer alternatives	Green NH_3. Biological N.	Enables net-negative goals when combined with 4R fertilizer management (right place, type, rate, and time). Symbiotic: legume-based rotations. Asymbiotic: initiatives just starting to be commercialized. E.g., Envita, UtrishaN and encourage natural asymbiotic N fixers associated with mature Zero Till fields.
Green fuel alternatives	Alternative fuels. N_2O reductions. Reduced fuel use.	Renewable diesel. Straight vegetable oil. Biodiesel. Electric. H_2/NH_3 fuels. Tier 5 emission engines on farm. Four-legged self-propelled self-feeding harvesters with on-board value-added processors—cattle. Zero Till uses 20% to 25% less fuel.
Intensive feeding operations	Use feed additive to give up to 99% less CH_4. Switch cattle for lower emission pigs, chickens, or fish.	Enteric emissions. Discussion on methane modelling.
Biomimicry	Natural soil building.	Undisturbed soil has greater biological activity and can supply all its N requirements.

		Grazing ruminants speed up the accumulation of SOC.
Land use	Preservation or restoration of wetlands, grasslands, or forest	Lowers emissions.
Agroforestry/Silvo-pasture	Add fruit, nut, lumber, or trees for biochar.	On-farm biochar can add to SOC.
Organic farming	CSA vegetable. Smaller mixed farms fully integrated with livestock.	Organic farming can build SOC and have low emissions in the right situation. Requires a good source of manure and timely rainfall.
Manure management	Passive compost is supposed to have fewer emissions, but it has many limitations to scale. Anaerobic digesters—maybe. Pasture manure can have low emissions.	Many considerations.

Table Note: A conservative estimate of the potential to sequestered carbon dioxide in Western Canada is 1000 kgCO2/ ha/ year (from St. Luce et al.) x 31Mha of cropland = 31Mt/ year.

The items listed in Table 2.7 provide the basis of the BMPs that will be refined based on the discussions with the participants in the case studies.

2.4.5. Does Soil Carbon Sequestration Work?

Some researchers have been hesitant to endorse SCS as a viable strategy for carbon dioxide removal. For instance, Powlson et al.(2014) argue that, although long-term studies in Rothamsted, United Kingdom, confirm considerable SOC accumulation, such results are not scalable due to the limited availability of manure, the lack of widespread adoption of SOC accumulation practices, and the absence of regulatory incentives for such practices, among other factors. They caution that overemphasis on SOC accumulation could lead to reduced food production and, consequently, compromised global food security.

Similarly, Ranganathan et al. (2020), point out that, while building SOC can increase the functionality of the soil, the opportunity to sequester SOC is often overstated and can lead to false hope and wasted resources. They argue that emerging science has reduced or eliminated the expected carbon sequestration benefits from Zero Till and adaptive grazing, and that increasing the SOC would require the addition of large quantities of nitrogen, as the C:N ratio of stable SOM is approximately 12:1. By comparison, most crop residues and plant tissues have C:N ratios of 20:1 (legumes), 40:1, or 80:1 (mature grasses). Ranganathan et al. (2020) observe that this nitrogen would have to come from fossil-fuel-based fertilizers, thus increasing emissions and offsetting any gains from SOC accumulation. Elsewhere, (Stanley et al. 2018) study of a mob-grazed pasture revealed that SOC had increased by 3.79 Mg C/ha/yr over a 4-year period, without the addition of any nitrogen fertilizer. Rather, they show that free-living and symbiotic nitrogen-fixing microbes can naturally supply the nitrogen needed for healthy soils. This observation is further supported in diverse perennial pastures (Franzluebbers et al. 2001) or long-term no-till (Franzen et al. 2019). Indeed, nature has supplied the nitrogen required to build soils for millions of years, long before fossil-fuel-based nitrogen fertilizers were invented.

Another point of contention regarding CDR through SOC accumulation is the question of saturation and the maintenance of higher flux levels in the soil. Despite these concerns, the soil possesses ample capacity to receive and store carbon, and it will only require the use of a fraction (well below saturation levels) of this capacity if we can stop using fossil fuels (Lal 2016). Given the technical knowledge for enhancing SOC accumulation and the political recognition that agriculture can be a solution to AGW, where are Western Canadian farmers in this battle?

2.4.6. Assumptions

The following assumptions were made regarding the context in which practical changes must be implemented on Western Canadian grain farms to contribute to AGW mitigation.

1. Based on UNIPCC AR6, we do not have time to completely redesign the world, even if it is possible or needed. Emissions need to fall by 40% over 5 years, with no net emissions in 25 years (UNIPCC AR6 2022). We will change the world, but we can only work with what we have now. Smil (2023) suggests it will take 10% of the world's GDP to change from dependence on fossil-fuel-based energy to renewable energy every year until 2050, and he is not confident this will happen. However, as Seth Klein points out, at the peak of WWII, the UK spent 52% of its GDP (Gross Domestic Product), on defense (Klein 2020). Therefore, the question of funding is less about whether *we can* do it, and more about our *willingness* to do it.
2. While the focus of this dissertation is limited to Western Canada and the Northern Great Plains, I will contrast my arguments and findings with other contexts when necessary to illustrate why the proposed solutions need to be regional or even locally oriented. Western Canada comprises 129.543M of Canada's 153.7M acres of farmland. This land consists of 78.860 M acres of cropland, 10.808 M acres of pasture and hay land, and 36.865 M acres of wetlands, shelterbelts, woodlands, Christmas tree farms, unimproved land, and land dedicated to prevent plant situations (Government of Canada 2018).
3. Everything must be balanced. We must achieve net zero, meet the demand for our products, reward farmers, and provide affordable food.
4. We must use every tool in our toolbox to master the challenge; however, it is a long game in that today's perfect solution may become obsolete tomorrow if or when nature finds its weakness. There will be no single solution; there is room and need for many types and sizes of farms.
5. Although farmers can help mitigate AGW, they cannot afford to do so on their own. Farmers gravitate towards "easy" practices because they are more profitable. Zero Till is a practice used on 70% of the cropland in Saskatchewan. It reduces erosion, is cheaper, allows for bigger farms per operator, increases moisture availability, and enables higher yields (Lyseng 2010; May et al. 2020; KAP et al. 2022). Zero Till also sequesters excess CO_2 from the atmosphere, thereby mitigating AGW at no extra cost. This is key because most other AGWM solutions cost farmers money and time. All the practices promoted by

Nature United cost between \$10 and \$100/MT CO_2 (Viresco Solutions and Nature United 2022).

6. Ruminate agriculture may be an easy option for restoring or regenerating farmland (Teague et al. 2016; Byrnes et al. 2018; Franzluebbers 2005; Stanley et al. 2018; Gosnell et al. 2020),but it accounts for only 10 M acres of tame pasture and hay land in Western Canada. Cattle numbers have fallen due to a number of factors, including poor economics, declining per capita consumption, and a misunderstanding of the difference between biogenic and linear emissions (Werth 2020; Quinton 2019). Some funds are being devoted to encouraging better grazing techniques, which are similar but go by various names such as holistic, adaptive, rotational, or mob grazing, which has been employed by some cattlemen for years, often out of the necessity to earn the most income from their land or simply to survive BSE (bovine spongiform encephalopathy), and all the other calamities that have befallen their industry (Savory and Butterfield 1999). However, cows or bison will not have a significant impact on 78 million acres of cropland, and grain farmers are not going to start buying cows en masse based on current economics (Manitoba Government 2021).
7. Grain farming represents a major opportunity to reduce emissions and sequester CO_2 in Western Canada. We crop 78 million acres, which also functions as the largest intensively managed terrestrial carbon sink in Canada. Thus, while other farming systems should not be ignored, it will be critical to engage grain farms in the quest to mitigate global warming. While there are important lessons and tools to be gleaned from organic crop production, organic farming requires more land to feed the same number of people, especially when done at scale. Indeed, organic farming is better suited for small mixed farms and vegetable-market gardens close to cities. In addition, the tillage associated with organic farming can often lead to site-specific droughts, lower yields, and more soil erosion. Organic farming is more viable in humid zones where moisture is abundant. Furthermore, organic produce is significantly more expensive due to increased labor requirements and lower yields. Recent years of higher-than-normal food inflation have provided some insight into how the public would respond to a wholesale change to organic production. Although sustainable intensification and improved Zero Till are more pragmatic options for almost every grain farmer in Western Canada, organic production techniques must be heeded because they provide alternative production

methods that help to maintain a full toolbox. Agroecological answers come from the pre-high-input farming era (Bracken 1921) and from the current needs for organic farms to achieve innovative crop rotations with less reliance on fossil-fuel-based fertilizers and pesticides. Simple solutions to weed control used in non-organic farming are not sustainable, as weeds soon adapt and become resistant to the overused herbicide (Perotti et al. 2020; Beckie et al. 2019; Beckie et al.2020). Thus, organic farms can provide a source of more integrated alternatives.

8. Every region and farm will have to develop production systems that are pragmatic for their context. For instance, in Western Canada, there are significant and ever-changing differences in rainfall, potential evaporation, soil types, topographies, water use efficiency, and heat units. Marchildon et al. (2008) discusses these dynamic conditions in their review of the Western Canadian drought experience between 1914 and 1939, observing that,

   "*The 1988 and 2001–2002 droughts would likely have been much worse without the lessons learned from the earlier droughts and the institutional adaptations of the 1930s. In particular, permanent changes in land tenure plus improved land and water conservation practices, plus tillage practices, which minimize topsoil loss and maximize moisture retention have been major adaptation measures"* (p.392).

Ironically, they also praise the efforts of the Prairie Farm Rehabilitation Agency (PFRA) stating,

> *"Due to the exacerbating influence of climate change, more will be required of the PFRA and the federal government in the near future"* (p.410).

The Harper government disbanded the PFRA in 2009 (Gilson and Baker 2020), but the NFU is pushing the current government to establish a new and expanded PFRA in the form of the Canadian Farm Resilience Administration (CFRA) (NFU 2019). The Prairie Climate Center has warned of the stress that climate change will place on farmers in the Prairies, stating that, generally, the climate will be characterized by more moisture and much warmer temperatures. Unfortunately, this increased moisture will mainly occur during the winter and not in late summer when rain is badly needed for cash crops and to establish cover crops (Prairie Climate Center 2021). In addition to the short growing season, the main limiting factor for crop production in the Prairies is the moisture extremes: sometimes there is too much, sometimes there is not enough, and sometimes farmers get both in the same year.

One limitation often seen in Western Canada is the inability to establish cover crops consistently and economically. This poses a problem, as cover crops are needed to increase carbon sequestration rates. In other words, Western Canada is not a region where cover crop seeds can be broadcast on the soil surface and expected to grow, nor is there a long open fall after harvest in which cover crops can be established at scale. At present, there are likely 25 M acres of Western Canadian farmland where cover crops will be too risky, primarily in the brown soil zone. These are the areas where Zero Till will continue to shine, and carbon will still be sequestered through diverse crop rotations. Many organizations encouraging farmers to be more proactive in mitigating global warming are continuing to promote the planting of cover crops using methods and technologies better suited to other regions (e.g., Ontario). However, cover crop practices must be tailored to achieve a scalable increase in SCS on at least 50 M acres in Western Canada every year. The federal government is spending a substantial portion of its $470M ACS fund (See Table 2.2 for more detail) to promote and subsidize cover crop practices, which will end in frustration when the subsidy is completed, and the novelty wears off with no sustainable adoption.

In summary, the pragmatic and timely approach is to concentrate on the largest opportunity first, namely, the 78 million acres of Western Canadian cropland. As such, all tools that are technically, legally, and ethically available must be employed to this end.

2.4.7. Demands on Agriculture Today

In general, agriculture must do four things:

1. Help sequester excess CO_2 from the atmosphere. Paustian et al. (2016) suggests the theoretical value of SCS is approximately equal to the CO_{2eq} emitted annually from global use of fossil fuel-based products. The PSCB study in Saskatchewan has shown that 450 to 1000 kg CO_2/ha can be sequestered just using continuous cropping in combination with Zero Till (McConkey et al. 2020; St. Luce et al. 2024).
2. Stop using fossil-fuel-based products (especially fossil-fuel-based fuels and nitrogen).
3. Continue to feed as many people as possible, including producing food, feed, fiber, fuel and bioproducts. In the bigger picture, agriculture can also contribute to stabilizing the overall population, which has happened naturally when three criteria are in place: food security, women's education and rights, and urbanization. The populations of over twenty countries, including China and Japan, are expected to be cut in half by 2100 owing to low fertility rates (Bricker and Ibbitson 2019).

4. Ensure farmers can continue to function at a high level (i.e., informed, profitable, good crop insurance and safety nets, good tools, avoiding drudgery, a positive ROI (return on investment), avoiding the promotion of false and romantic myths of food production systems, and ensuring farmers have pride in what they do). Farmers require public support and appreciation.

2.4.8. Proposed Solutions

Many organizations are invested in mitigating global warming, including the UNFCCC, the 197 signatory nations to The Paris Accord, and the thousands of companies that have launched initiatives, via the SBTi, to help them become net zero by 2050. Collectively, these companies buy, process, and retail the bulk of the commodities used for food, which will have a significant impact on farmers. Scope 3 emissions are those associated with producing and delivering commodities to SBTi companies and often account for 70% to 85% of total missions. Therefore, these buyers cannot achieve net zero unless farmers also reduce their farms' carbon footprints. SBTi companies are encouraged by their shareholders, bankers, and customers to become net zero.

An example of an SBTi processor commitment to achieving net zero by 2050 is General Mills, which has adapted its production in recognition of the urgency to mitigate AGW. This recognition is reflected in its climate policy:

> *The imperative is clear: Business, together with governments, NGOs, and individuals, needs to act to reduce and reverse the negative human impact on climate change. Changes in climate not only affect global food security but also impact General Mills' raw material supply which, in turn, affects our ability to deliver quality, finished product to our consumers and ultimately, value to our shareholders. General Mills has assessed that over 90 percent of the GHG emissions associated with our value chain can be considered Scope 3 - occurring in entities not owned or controlled by the company. General Mills was the first company across any sector to set a science-based target initiative (SBTi) commitment in 2015. During 2020, we launched new goals to drive further progress, in alignment with the new SBTi 1.5°C criteria. General Mills will reduce absolute GHG emissions across our full value chain (Scopes 1, 2 and 3) by 30% by 2030 (compared to 2020). By 2050, we will achieve net zero GHG emissions across our full value chain.* (General Mills 2022, p. 1)

The policy statement goes on to state that General Mills strives to

"*Advance Regenerative Ag as a key lever to mitigate GHG emissions and minimize the impact farming has on the environment; to fund research, farmer training and coaching to expand adoption of practices like no-till and cover cropping that mimic nature to improve overall ecosystem health and function*" (General Mills 2022, p.2).

SBTi member companies will eventually come to understand, as General Mills has already realized, that carbon offsets alone are not sufficient to achieving net zero. These companies must put resources into real mitigation and emissions reduction to achieve legally binding customer- and shareholder-driven goals. I believe that all companies will eventually support the transition of their suppliers to net zero. General Mills has already invested money in cover crop research in Manitoba and is promoting Regenerative Ag in North Dakota, Manitoba, and Saskatchewan. Corteva has announced a program to fund net zero intercropping research (Corteva 2023). Research is needed to drive down costs, and inset credits, rather than offset credit, may be a useful vehicle for funding innovation and invention.

Based on the new understanding of soil as a potentially effective carbon sink, many governments, NGOs, companies, and researchers have begun promoting AGWM BMPs to farmers Many recommendations include key phrases, such as "conservation ag," "Regenerative Ag," or "climate smart," and promote reduced tillage or Zero Till plus cover crops and rotational or adaptive grazing. Many also promote the preservation and restoration of grasslands, wetlands, agroforestry, and tree planting.

To reduce emissions from nitrogen fertilizers, many recommendations include the 4Rs of nitrogen management, namely, right place, right time, right rate, and right source. Other recommendations attempt to set goals in terms of CO_{2eq} sequestered per year. For example, Nature United suggests that 37.4 Mt CO_2 eq/year, or 48% of their estimated potential from Natural Climate Solutions, could come from better management of agricultural soils (Drever et al. 2021). Another report focusing specifically on Western Canada included twenty-four distinct pathways for AGW mitigation through natural climate solutions (Viresco Solutions and Nature United 2022). This report detailed the expected costs in terms of $/Mt of CO_2 sequestered, which ranged from $10 to $100/MT.

In contrast, VandenBygaart (2016) highlighted the fragility of soil carbon storage, citing findings showing rapid declines in SOC after just one tillage operation following years of Zero Till soil carbon accumulation. Despite this potential fragility, researchers and farmers need to develop solutions to make Zero Till a permanent practice with as much continuity as possible. Expanding

Zero Till will be essential for addressing food security and land sustainability issues, regardless of the impact of AGW. Many farmers are enthusiastic about enhancing "soil health," but they are less inclined, or directly opposed, to addressing issues that they believe do not exist or cannot be caused by burning a small amount of diesel fuel (Davidson et al. 2019). Further, the lack of confidence that cover crops can improve "soil health" and Zero Till helps to manage weeds, soil moisture, or trafficability challenges, are some of the reasons farmers resort to tillage (Lessitar 2011).

There are many opportunities to expand the use of Zero Till. In 2016, Zero Till was practiced on 70% of Saskatchewan cropland, with 95% being either Zero Till or minimum till (Awada et al. 2021). In contrast, only 32% of agricultural land in Manitoba was Zero Till in 2021(Manitoba 2021). There is good reason to believe that successful cover cropping strategies and innovative technologies will enable the expansion of Zero Till to include wetter and heavier textured soils in the future.

Table 2.7. List of GWM practices proposed from various sources.

Practice	**Rourke's BMP for Net Positive or Zero Till Plus**	**Viresco Nature United 25 BMPs**	**Canada-Nature Smart Climate Solutions**	**Canada-Agricultural Climate Solutions**
Plants growing from snow to snow (perennializing). Cover crops.	xx	x		x
Minimal disturbance.	xx			
Keeping soil covered (armor).	xx			
Increased diversity. intercropping	xx	x		
Integrate livestock. rotational grazing.	x lower priority	x		x
Fossil-fuel-based product substitution.	xx fuel xx nitrogen			x
Sustainable intensification.	x	x		x

4Rs. Precision ag.				
Agroecology. IPM.	x			
Preservation and restoration. Grassland, Wetland, Trees.	x	x	x	
Managing and recycling phosphorus.	x			
Organic farming.	-	x		
Biochar.		x		

Table Notes: The solutions listed in Table 2.7 are taken from (Rourke 2022a), (Viresco Solutions and Nature United 2022), two programs from the federal government (Canada ECCC 2022; Canada ECCC 2023; AAFC Canada 2021). Rourke (2022a) is the only one of these sources to actively seek alternatives to fossil-fuel-based products.

Table 2.7 contrasts proposed GWM practices from 3 sources to those highlighted in the thesis.

Diesel fuel should be easy to substitute on farms. Diesel-powered equipment represents almost all the motive power requirements of a modern farm. The most straightforward method for replacing diesel is to use renewable diesel from oilseed crops grown on farms. It has the same specifications as normal diesel; no modifications are required. Other options that could be implemented with some modification include biodiesel or straight vegetable oils. Currently, cost, availability, and convenience are barriers to the adoption of these alternatives. Other more dramatic changes involve modifying existing engines to operate on H_2 or NH_3. Small tractors, trucks, pickups, and augers could be electrified eventually.

With regards to replacing nitrogen fertilizer, many agronomists suggest increasing the use of legumes, as they directly reduce the need for fossil-fuel-based nitrogen fertilizers. Franzen (2009) conducted over 100 nitrogen-response trials, finding that fields that have been Zero Tilled for at least 5 years required 50 lbs/acre less nitrogen for wheat crops compared to conventionally tilled fields. The Zero Till nitrogen alternative could reduce nitrogen use by 50% and significantly cut N_2O emissions, which tend to become proportionally higher as nitrogen rates increase (Millar et al.2014). Biologically-based products are another alternative to fossil-fuel-based nitrogen. For instance, Corteva, Bayer, and Syngenta are among the many companies selling early versions of asymbiotic nitrogen-fixing organisms, and Pivot Bio is working on products that will replace all the nitrogen required for optimum crop production (G2 Venture Partners 2021).Research conduct by third party institutions such as Franzen et al.(2017) have not seen positive results from using the early versions of these products. Another solution which has been pursed for many years is to transfer the ability to create a symbiotic N – fixing relationship found in legume to non legume plants. Ziemienowicz working at AAFC Lethbridge is making progress working with triticale (Ziemienowicz et al. 2015). Finally, companies including Yara, Fuel Positive, and AAMPOWER, are working on Green NH_3 and nitric acid nitrogen products to replace fossil-fuel-based nitrogen (FuelPositive 2021; Doyle 2020; YARA 2021).

Even with the above strategies, the 4Rs will remain important to ensuring that N_2O emissions are kept to a minimum. For instance, N_2O emissions can be very high the following spring if high rainfall occurs after green manure has been terminated (Westphal et al. 2018).

2.4.9. Section Summary

For over 26 years, world leaders have been promising to reduce emissions; however, emissions continue to increase. The Canadian NIR on emissions (Canada NIR 2021) indicates that agricultural emissions rose to 125% between 1990 and 2018 (from 47,000 to 59,000 kt CO_2eq). Worse yet, NIR data show that Western Canadian agricultural emissions have increased to 143% since 1990. If Canada had met its Kyoto Protocol targets, its emissions would be at least 5% below 1990 levels. Regardless of this failure, Canada has set a goal of being net zero carbon by 2050. However, to reach the targets set in UNIPCC SR 1.5°C, agriculture must be one of the major sectors wherein carbon can be sequestered effectively and relatively cheaply (Smith et al. 2013), it must be net negative (or, as I prefer, Net Positive) by 2050. Unfortunately, it appears that policies to date have been unsuccessful in reducing agriculture-related GHG emissions.

Documents such as UNIPCC SR 1.5°C outline the targets and available tools for keeping the Earth's climate from rising by more than 1.5°C. Despite the recent pledges made during COP26, it is estimated that the global temperature will rise by 2.4°C by the end of the century. Although Canada has taken a leadership role in some AGW mitigation efforts and adaptation strategies, our emissions continue to increase. Likewise, while Canadian and Western Canadian agriculture have recently been recognized as having high potential for net-negative emissions, emissions in this sector also continue to climb. The good news is that the Canadian government recently announced several initiatives to help transform agriculture to net-zero carbon (this author believes that agriculture should and can be net-negative carbon or as named in this study, Net Positive). These initiatives include the Agricultural Climate Solutions program, and the Carbon Offset program.

Smil (1994) offers a sobering reminder that no one can predict what the food system will look like more than two decades into the future, pointing out that our past predictions have failed to account for disruptors, or game-changing inventions or innovations. Although Smil's most recent work takes a pessimistic view of our battle with AGW (Smil 2023), I find the SBTi to be a reason for optimism, as its membership has grown from 3500 businesses in December 2022 to 8400 as of June 2024 to 9969 as of January 10, 2025 with all member companies making binding commitments to achieve net zero emissions by 2050 . This has garnered the attention of the corporate sector, which must now invest in innovation and invention to help farmers reach net zero Scope 3 emissions as cost-effectively as possible.

2.5. Farmers Beliefs and Energy to Engage in AGWM.

2.5.1. Belief Factors

Harari (2011) suggests that humans are different from other species because of our ability to observe, create, and share ideas using stories, which can unite (or divide) people in pursuit of (or resistance to) a given cause. This begs the question: what stories have farmers been listening to? On March 14, 2024, the Saskatchewan Association of Rural Municipalities voted 95% in favor to "*recognize that CO_2 is not a pollutant and have the Saskatchewan Party government remove the province from all national and international net zero agreements*" (Easton 2024, p.1). What beliefs and actions define farmers' decisions to implement AGWM practices on their grain farms? Beliefs are one of the five components that farmers rely on when making decisions regarding possible changes. Unfortunately, researchers have found that farmers across the world have limited beliefs in AGW or engagement in AGWM practices.(Arbuckle et al. 2015; Davidson et al. 2019; Van Wyngaarden et al. 2024; Sorvali et al. 2021; Haden et al. 2012; Niles 2014).

Table 2.8. List of factors that affect beliefs related to AGWM practices.

Main Factor	**Factors that favour beliefs to implement AGWM practices.**	**Factors that tend to favour beliefs to not implement AGWM practices.**

Worldview	Outward-looking worldview: Importance of succession.	Inward-looking worldview.
	Checks and balance and government oversight.	Free marketers.
Religion	Pope Francis Encyclical on Climate Change (Pope Francis 2015), Man made problem needs manmade solution	"God will look after us."
Stewardship	Responsibility / soil health. Improve the land.	"You can't tell me what I can do on my land."
Economic	More than money/love to farm. Passion to do the right thing.	Do not believe in AGW, so will not adopt AGWBMPs, regardless of incentive.
	Western Canadian grain farming works on profit—it must pay.	May participate in the name of soil health and profitability.
Farm Size	Large size can make it easy to afford technology and change. Small size may be more oriented toward environmental stewardship and Value-Belief-Norm Theory.	Large-size farmers may be more oriented towards Theory of Planned Behavior (adaption) vs. Value-Belief-Norm theory (mitigation) (Zhang et al. 2020; Stern 2000).
Permanency	Being the landowner.	Land renters/short tenure.
Science-based farming	Science-based farming, including AGW.	Denier of scientifically proven AGW.
	Trust the messenger/institution.	Conspiracist.

	Democratic, center-leaning Republicans.	Follow oil-company-supported AGW denial and uncertainty SCAM mantra (Freudenburg et al. 2008).
	Knowledge of climate change and understanding of uncertainty of science.	Internet researchers—algorithm susceptible.
	Techno-optimists (Gardezi and Arbuckle 2020a)	Believe this is good as it gets.
Perception of risk, potential harm, and solutions.	Experience: locally on their own farm.	Ignore extremes as normal.
	Appreciation of extremes around the world.	Ignore world news as "fake news."
Personal Ability to adopt AGWM practice	Believe practices are logistically and economically possible.	No need to solve a problem that does not exist or is natural.
	Ethical/moral obligation.	
	Mitigation is needed and have the personal energy to do it.	Burn-out (O'Shaughnessy et al. 2022).

Table Notes: the main factors influencing beliefs can lead farmers to implement AGWM practices on their farms. The list of factors has been derived through interactions with farmers from Manitoba, Saskatchewan, Alberta, North Dakota, and South Dakota, along with a review of a selection of research papers(Arbuckle et al. 2015; Gardezi and Arbuckle 2020; Arbuckle 2013; Arbuckle and Roesch-McNally 2015; Han et al. 2021; Heikkinen and Arbuckle 2015; Prokopy et al. 2015; Baumgart-Getz et al. 2012; Prokopy et al. 2019; Mase et al. 2017; Prokopy et al. 2017; Doll et al. 2018; Doll et al. 2017; Rogers et al 2012; Mazur et al. 2013; Gosnell et al.2019; Gosnell et al. 2020).

The studies that were reviewed in the construction of Table 2.8 focused on farmers from the mid-west states and Canadian Prairies. In many cases, the interviewed farmers were not interested in mitigating AGW but were very interested in improving soil health, building SOC, and reducing erosion. Profitability and incentives to reduce financial risk were key motivating factors. These results are consistent with studies conducted in other countries, which find that most farmers will implement AGWM practices if it results in improved farm and soil health and profitability.

Interestingly, in Norway, Farstad et al.(2022) found that, even among a group of farmers who were already implementing AGWM practices, there was little interest in climate mitigation unless such actions directly supported farm continuation (succession) and were subsidized (making it economical). Similarly, Mwongera et al. (2020) found that East African farms were more willing to implement AGWM practices that were compatible with food security and the livelihood needs of smallholder farmers. Elsewhere,(Niles 2014) a study of farmers in New Zealand and California revealed that willingness to implement GWM practices was dependent on the farmer's belief in AGW and its associated risks, and significantly influenced by the cost of change, their capacity to do so, and how effective the change will be in reducing emissions. Niles' (2014) data set consisted of forty-eight interviews and 652 completed surveys. In China, a study of 1538 farmers found that pro-environmental-intentioned (Value-Belief-Norm, VBN) farmers were more likely to embrace AGWM practices compared to those with a planned behavioral outlook. Theory of Planned Behavior oriented farmers were more likely to implement adaptation practices that garnered immediate personal rewards, but the authors did not indicate the distribution of mitigation-oriented and adaption-oriented farmers within the overall group (Zhang et al. 2020).

Farmers who have direct experience with losses caused by prolonged extreme weather are more likely to believe in AGW. For example, farmers in Saudi Arabia are concerned about increases in droughts, insects, crop diseases, and heat stress. However, despite acknowledging AGW, they have limited means to adopt adaptive practices due to poor government and financial support (Azeem et al. 2023).

2.5.2. Belief Groups

A distillation of belief-based attitudes is presented in Table 2.9.

Table 2.9. Grouping of farmers according to their beliefs in AGW.

Belief Group	Rourke 2023*	Midwest (Arbuckle, et al 2015)	Alberta (Davidson et al. 2019)
Belief in AGW & hope we can fix it.	10%	10%	10%

Belief in AGW but think it is too late—no sense to change.	10%		
Belief in AGW—think they are already sustainable—no change needed.	20%		
Belief in AGW—think there are no viable diesel and nitrogen alternatives.	20%		
Belief in GW, but do not think humans contribute much. It is mostly natural.	30%	58%	64%
Do not believe in GW only change to improve profitability.	5%	5%	2%
Can not decide if AGW is real or not.	5%	27%	19%

Table Note: * Informal author survey. There is a need for current Western Canadian data.

A combination of government incentives and market pressure may ultimately drive the adoption of AGWM practices. Many companies that have made SBTi net zero pledges are starting to search for climate-friendly suppliers or are working with existing suppliers to help them become net zero. An example of the former is the collaboration between John Deere and Cargill to establish the Cargill RegenConnect program (Lessitar 2023). Although many current AGWM BMPs lead to additional costs, it is unclear whether this will result in premium prices. For instance, a limited market for non-compliant supplies will likely result in price discounts (SBTi 2023). Furthermore, Cargill's sustainable canola program is a very small step, which raises concerns that little is required to be labelled as sustainable (Cargill 2023). Indeed, the criteria for acceptance into the program are remarkably low, and the program provides a small price premium for "sustainable" canola and the possibility of carbon credits for any sequestered or stored carbon.

The federal government is developing carbon credit protocols for regulated markets (Canada ECCC 2020a; 2020b; Canada Gazette 2021a; ECCC 2022). The voluntary market has been developing for some time and includes companies such as Indigo Ag, life science companies, grain companies, and many aspiring aggregators. However, the entire carbon credit initiative has come under question. While the carbon credit initiative could be used to pay farmers for unprofitable AGWM BMPs, many are concerned that it would simply allow bad practices to continue (National Farmers Union 2023). UNIPCC SR 1.5°C states that we must stop using fossil fuels and actively work to sequester carbon (UNIPCC 2018a). How can a farm sell carbon credits if it uses fossil fuel to make those credits? Indeed, in 2024, one would be hard pressed to find a single productive grain farm that does not use any diesel fuel or fossil-fuel-based nitrogen fertilizer.

While farmers will need financial and technical assistance in adopting some AGWM BMPs, this cannot be achieved by allowing the continued use of fossil fuels to make carbon credits. Nestle, the world's largest food company and a member of the SBTi, announced in July 2023 that,

> *"it would no longer be using carbon offset credits to reach its Net Zero targets, but would instead be making emission cuts within its operations and supply chains"* (Segal 2023),

as market research indicated that its consumers and shareholders were demanding real action to this end. This move speaks to the value of trust, which is emphasized by Arbuckle et al.(2015) in their discussion of the findings of one of their studies:

> *Results indicate that beliefs varied with trust, and beliefs in turn had a significant direct effect on perceived risks from climate change. Support for adaptation varied with perceived risks, while attitudes toward GHG reduction (mitigation) were associated predominantly with variation in beliefs.* (p. 205)

Hopefully, companies will not lose trust by greenwashing real problems and solutions to AGWM in the early stages of the SBTi program.

The Gun Smoke farm near Pierre, South Dakota, may be an example of belief overriding good sense and science. The Gun Smoke farm is situated next to Ted Turner's 141,000-acre Bad River Ranch, which employs regenerative grazing practices to foster SCS and improved soil health (Turner 2023). It is an example of sustainable land use. Several owners/investors have tried to run the 34,000-acre Gun Smoke farm as a conventionally tilled farm and, more recently, an organic farm. They believed that organic food production was better, more sustainable, more valuable and demanded in the market. However, the Gun Smoke farm is on fragile semi-arid land. Their efforts have had limited success due to severe soil erosion from wind and rain. The tillage required for organic crop production causes soil disturbance, loss of precious soil moisture and soil organic matter. Soil health has been continuously degraded since it was first being broken in the early 1970s (Charles 2021). As Gun Smoke farm shows, it takes more than belief to maintain and build the health of fragile soils in semi-arid regions, particularly if using tillage-based large-scale production.

Not far away, the Dakota Lakes Research Farm has been demonstrating the value of Zero Till for several decades. Diversified rotations, precision fertilizer placement, nitrogen alternatives, minimal use of herbicides, insecticides, and fungicides, and the careful integration of cattle have established it as an excellent example of a climate-friendly farm. Dakota Lakes is also working to become fossil-fuel-neutral with respect to its use of diesel and lubricating oils, and self-sufficient by generating its own electrical energy. These moves have allowed Dakota Lakes to feed the farmer and the people, while also rebuilding the soil (Ireland and Beck 2023).

Beliefs can be difficult to change (Arbuckle et al.2015; Van Wyngaarden et al. 2024), however it is known that when people are paid to believe (consciencely or unconsciously) they tend to believe. This next section illustrates that incentives can help override a belief. Belief is higher when it pays to believe.

Unfortunately, AGWM practices are not financially sustainable in many cases, which highlights the need for research into cheaper, faster, and more effective practices. Nature United has estimated a contribution/incentive to help farmers cover the cost of adopting various AGWM practices (Viresco Solutions and Nature United 2022; Viresco 2021). The US has implemented cover crop subsidy programs that pay $12 to $92/acre. In Maryland, the state with the highest payments, the principal goal in encouraging farmers to grow cover crops is to ensure that the runoff flowing into Chesapeake Bay contains as little nutrients and pesticides as possible (Kepler 2021). This helps to ensure that water is suitable for human consumption, as cover crops improve water infiltration and storage in addition to helping to sequester carbon. To illustrate the importance of such programs, a 1% increase in SOM will allow the soil to hold an additional 26,000 US gallons of water per acre.

In Canada, the ACS-OFCAF program (2023-202) grants farmers up to $35/acre with a cap of $75,000 for all programs over a 5-year period. If this money were put into the cover crops program and averaged over the 5 years, it would result in approximately 430 acres of cover crops per year per farm. For context, which would account for only 7% of the author's 6000-acre farm. On such farms, a fall-seeded cover crop can be expected to cost between $7 and $40/acre for seed and about $20/ acre for the seeding operation, with no guarantee of any tangible short-term benefit to the farm. As a result, this practice would have to be done indefinitely to achieve the full benefits for soil quality and to maximize the amount of sequestered carbon.

AGWM practices that are not financially self-sustaining need support, either through increased food prices or taxes. While NGOs tend to supply funds for education, extensions, demonstrations, and small pilot projects, SBTi-registered companies may also provide financial support for AGWM practices. It is understandable if farmers are cautious about change. As such, the government, SBTi companies, and NGOs must fully understand what they are asking farmers to do. For context, the expected average net profit for grain farms in SW Manitoba is $50/acre in 2024. Demands for change on the part of these organizations is, in practice, asking farmers to gamble with their entire net income. Table 2.10 lists factors that may cause an individual to support or resist change. Here, it is important to note that each situation may require a different approach, and that these situational factors will impact personal believes and energy to make a change.

Table 2.10. Factors affecting personal energy to make a change.

Factor or Situation	**Positive Example**	**Negative Example**	**Insight/Example**	**Reference**
Global location	Good crop insurance	No crop insurance	Canada has better insurance than Pakistan and a lower farm suicide rate.	(National Sustainable Agriculture Coalition 2023; Harvey et al. 2014; Hussain et al. 2022.
Farm type	Good economics	Marginal economics	All types can work, but it depends on management, the weather, and markets.	
Economic	Positive economics	Marginal economics	Depends on management and many external factors. A 300% increase in interest rates may make some farms insolvents.	Historically farm margins / acre have been declining. (NFU 2019)
Farm size	Economic and easy to run	All sizes of farms can work or fail	All can work, but larger is the trend and has been favored by farm equip/input companies and government programs	(Debra J Davidson et al 2019)

Gender	Good manager	Poor manager	Individual > gender. Inclusion of women generally increase the use of AGWM strategies.	(Yener et al. 2022)
Education	Successful farms looking for change.	Struggling farms cannot change	After a diploma, it is likely the individual's farm income is diminished with higher education.	(Stats. Can. Government of Canada 2019)
Age of farm: old	Stable multi-generational early adaptors	Stable multi-generational resistance to change	Some individuals will feel extra pressure and anxiety about being responsible for the family legacy.	
Age of farm: new	Nothing to lose	Everything to lose	These new farmers must be innovators to even have a chance.	
Age of farmer	Early adopter	Laggard	Farmers of any age can be innovators.	
Existing infrastructure	Old and in need of an update	New but obsolete	Farmers on the wrong side of this factor did not pay enough attention to trends.	(Smil 2023)

While it is possible to group or stereotype certain farms and farmers, no two farms or farmers are exactly alike. In addition, the circumstances on one's farm can derail the best of intentions. For example, Zero Till can conserve and store more water, but few farms can withstand the financial stress that results from multiple years of low rainfall, as has happened recently in Saskatchewan. Individuals or regions dealing with such immediate concerns are often not concerned with AGWM practices.

2.5.3. Lessons from Zero Till

The story of Zero Till from the 1970s to today is that of an adaption strategy. Adaptation, as described by Arbuckle et al (2015), is characterized by its observable nature and immediate tangible benefits. Most farms strive to adapt to the challenges they face, and the conversion of millions of acres to Zero Till stands as a testament to its significant tangible benefits. Recently, and more significantly within the context of this work, Zero Till has been acknowledged as a viable AGWM practice.

Arbuckle et al. (2015) define mitigation practices as practices that are characterized by uncertainty, delayed benefits, government involvement, and advantages for the common good rather than individual farms. While these features may deter some farmers, they highlight the importance of garnering public support for AGWM practices and their benefits for the broader community.

Zero Till was developed and adopted because of the following conditions:

1. Tillage-induced soil erosion was resulting in the loss of topsoil, SOM, and soil moisture. This erosion was an observable negative externality affecting the immediate and long-term sustainability of Western Canadian farms.
2. Zero Till is rooted in nature. Therefore, the question was not whether it would work, but how it could be made to work economically.
3. There were five key challenge areas (KAP et al.2022; Beck 1998, Beck 1994):
    i. Straw management.
    ii. Fertilizer placement.
    iii. Seeding equipment.
    iv. Crop rotations.
    v. Weed control.
4. The rewards for the successful adoption of Zero Till include (Awada et al. 2016; Gray et al. 1996; USDA-NRCS 2017; Lyseng 2010):
    i. Lower costs.
    ii. Less erosion.
    iii. More available soil moisture.
    iv. Less risk from drought and dry seed beds.
    v. When combined with expanded rotations and greater and more precise fertilizer use, significantly higher net profit.

vi. Zero Till is particularly advantageous in the drier parts of the Prairies.

5. Other than the initial research work and a few demonstrations—primarily of seeding equipment and many peer-to-peer exchanges through the Manitoba North Dakota Zero Tillage Farmers Association, Saskatchewan Soil Conservation Association, and Dakota Lakes Research—little public support in terms of incentive programs were required.
6. Zero Till reduced the farm risk to the public. Crop insurance liability decreased when farms went Zero Till and increased their SOC (Chutter and Hart 2022).
7. Food security has been enhanced due to continual improvements in soil health via carbon sequestration, which has in turn led to improved SOC. This is one of the first examples in which AGWM activities were cost negative. Indeed, there was no cost to the public, except for the emissions associated with the current Zero Till system. The next challenge is the evolution to Zero Till Plus (Rourke 2022a).
8. How does climate mitigation differ from the Zero Till adaptation experience? Briefly, Zero Till is self-supporting, while agricultural AGWM practices may not be, and farmers cannot adopt practices that do not reward the change.

2.5.4. Challenges with AGWM in Western Canada

There are eight key challenges to engaging farmers to mitigating AGW on Western Canadian farms:

1. Many mitigation practices add extra work and costs, while potentially not providing any timely rewards.
2. Many farmers do not believe in AGW. They believe that weather fluctuations are normal and caused by normal variations in Earth cycles, tilt, wobble, etc. Many have no idea that 100M barrels of oil are used globally every day—the energy equivalence of 10,000, Hiroshima nuclear bombs detonated each day (Romik 2023; Mechlin 2013).
3. Farmers cannot visually verify a change in GHG. Zero Till solves problems they can see. For example, farmers can observe soil erosion due to wind—a problem which Zero Till prevents.
4. Western Canada may benefit from AGW in the short term, as it will result in a longer growing season, warmer temperatures, and more moisture.
5. Pakistan and other hard-hit areas are a world away. While some people view problems in these distant places to be “not my problem,” others seem them as an opportunity to provide the people there with supplies.

6. If China and other large polluters do not take the lead and actively adopt measures to reduce their GHG output, what Western Canadian farmers do will make no difference.
7. There are concerns that the extra cost of tackling AGW will make products too expensive, resulting in lost market share.
8. Some farmers have no energy or desire to make changes and are doing well with business as usual. Most importantly, there are no economic and scalable AGWM BMPs that are not already being practiced, such as Zero Till.

2.5.5. Next Step: What Do the Innovators Think and Practice?

Given the discussion in this chapter, the question seems to be: how do we convince farmers to become part of the solution? One answer is to provide them with plausible, logistically pragmatic, and economical ways to contribute. Chapter 6 presents an analysis of on-farm AGWM BMPs using the BERT/E adoption analysis tool, with subsequent recommendations being made based on the results of these analyses.

Chapter 3: Research Methods

This chapter details the scope of the study and the methods that were used in conducting it. In addition, I consider and examine the known biases embedded within the study and my own worldviews and experiences.

3.1. Theoretical Frameworks, Theories, and the Theory of Change

3.1.1. Introduction

Farming practices have evolved from being based on the use of simple hand tools and manual labor to the use of 600 horsepower tractors with GPS autosteering and air seeders equipped with mapping software to enable the precise application of seeds and fertilizers. As with most human practices, farming continues to evolve. The central questions around the next stages in the evolution of farming relate to our ability to feed more people per hectare while using less energy, labor, and fossil-fuel-based products (especially motive fuel and nitrogen fertilizers), thus meeting our commitments to be net zero by 2050. Other questions relating to the future of farming include whether we can achieve the aforementioned goals while also leaving more area for habitat, beneficial insects, and wildlife, and whether it is possible to sequester carbon in the soil faster than we are currently able to do. Furthermore, what will it take to convince farmers to adopt AGWM practices, and how many know or acknowledge that current farming practices in Western Canada have played a significant role in GHG emissions rising to 143% of 1990 levels (Environment and Climate Change Canada 2021).

Arbuckle's (2013) analysis of annual surveys of mid-western US farmers shows that many farmers do not think GW is a real phenomenon or that, if it is, it is not anthropogenic. In my experience, I have found that most farmers are either unwilling or unable to implement AGWM at the present time or with the tools at hand. Nonetheless, most farmers are willing to update their farming practices to strengthen soil health and water conservation, as such measures will ultimately reduce costs, increase resilience, and improve yields (Davidson et al. 2019). AGWM BMPs should reduce emissions and increase the ability to sequester excess CO_2 from the atmosphere and store it in the soil as SOC. Collectively, such practices can be referred to as Zero Till Plus or Net Positive Carbon Grain Farming. In addition to reducing atmospheric CO_2, the SOC added as a result of CO_2 sequestration helps increase soil health, water storage, infiltration, and plant-available water. The use of Zero Till practices helps to minimize soil erosion and improve the function of the soil food web, resulting in an improved water cycle. Franzen et al. (2019) note that asymbiotic free-living nitrogen-fixing soil microbes become active when soils have been Zero Tilled for five or more years, thereby reducing fertilizer requirements. Zero Till practices have many advantages (Richard et al 1996; Lafond 1987; Stobbe 1979), including lower emissions due to the reduced need for machinery and fuel, as well as higher yields and profits in most areas of Western Canada. Zero Till Plus is the next evolution in Zero Till soil building practices in Western Canada, which will further aid in the struggle against AGW, regardless of whether or not farmers believe in it.

3.1.2. Understanding to Drive Change

There are many theoretical frameworks that can help understand and drive innovation in AGWM initiatives. One such framework is change theory. According to Reinholz and Andrews (2020) a theory of change (ToC) is intended to solve specific problems, while change theory comprises generalized theories that provide the theoretical basis for a specific theory of change. They go on to note that ToC consist of five main components: defining the project context; describing the desired outcome and expected preconditions/steps and rationales for each one; determining appropriate indicators for each step or preconditions for measuring progress; listing all possible interventions to ensure the outcome was achieved; and ensuring that all assumptions used in the project's development are explicitly known, thereby allowing them to be reviewed as required. May et al. (2018) described the UN TEEB Agri-Food Theory of Change as a planned intervention aimed at achieving a policy or project goal. However, since there is no single approach to tackling all specific policy or project ambitions, distinct theories of change for individual initiatives are required.

While the use of participatory cost-benefit analyses can help secure buy-in from stakeholders, farmers' decisions on such matters are influenced by a wide range of factors, including markets and property rights (May et al. 2018). As May et al. (2018) observe, it is more challenging to change one 's beliefs or culture than it is to change one’s actual practices, and this path dependency can lead to locked-in values, resulting in pushback and resistance to new ideas and practices. Further complicating efforts to change farmers’ behaviors is confusion resulting from information overload or deliberate misinformation, or confusion about who to trust. May et al. (2018) identify numerous sources that can be used to influence farmers’ attitudes and practices, including using entry points through researchers, the media, trendsetters, influential individuals, consumers, businesses, and other farmers, with the most effective source depending on the opportunity and situation. Unsurprisingly, however, May et al. (2018) report that payment for ecosystem services is an excellent incentive for getting farmers to adopt the best new management practices.

Many theories can complement ToC when examining how and why farmers make decisions, and what policies, extensions, and influencers can move them in a particular direction. Zhang et al.'s (2020) findings indicate that the value-belief-norm theory is better at predicting positive action toward AGWM, while the theory of planned behavior better explains self-interest actions, such as adapting to the climate changes they are confronted with daily on their farms. Similarly, Haden et al.'s (2012) study of farmers in California's central valley shows that construal level theory can be effective in getting farmers with psychologically distant perceptions of AGW (i.e., they have not noticed any direct or immediate impacts) to adopt AGWM actions, while those with more concerns about the local impacts of AGW are more likely to focus on adaptation strategies and actions. Conversely, theory of planned behavior is often used to understand the drivers of employee actions, but it may also be useful for providing insight into farmers' motivation. According to Dan Pink, money is the main motivator in this theory (SmartHR 2017), which is consistent with the most basic theory in business, namely, if there is no money, there is no business.

Farms, large or small, are business enterprises: some feed themselves, others feed thousands. Generally, the more time or money a farm has, the more it can consider efforts to ensure its long-term sustainability as a business. In their study of farmers in New Zealand, Niles's (2014), application of the theory of planned behavior revealed that only perceived capacity and self-efficacy were predictors for both intended and actual adoption of AGWM practices. They describe the theory of planned behavior as a

> "*psychological theory that suggests behavioral intentions are driven by beliefs and attitudes towards the behavior, subjective norms and perceived behavioral control.*

However, their findings did not indicate that the farmers' beliefs about AGW led to the adoption of mitigation practices, nor did the repeated highlighting of facts related to AGW.

Elsewhere, DeMeyer et al.(2020) findings show that, in real life, the relationship between beliefs and behaviour can go in opposite directions, and that adoption can be increased by shifting the narrative from issue-based negative fearful stories to action-based positive stories. As such, the authors proposed developing a library of science- and technology-based positive action-based stories that storytellers could relay to their intended audience.

3.1.3. Farm Practice Change Theory

The Farm Practice Change Theory, which was developed specifically for this work, is a general change theory that can be applied to any change anticipated for a farm. In the context of this study, the anticipated change/opportunity is the addition of AGWM to the core task of raising crops for the market, either in the form of food, feed, fiber, or fuel. This theory contains two additional sub-frameworks, the Net Positive Farm Framework and the Global Warming Mitigation credit framework, which are intended to help visualize the path forward. These frameworks are based on factors that I and other farmers consider either conscientiously or unconscientiously before changing farm practices. Generally, farmers are more likely to be interested in new practices/changes that make their work easier, reduce costs, increase revenue, increase profits, or some combination thereof. Most commercial-scale grain farmers respond to the price × yield – cost = profit equation. From this framework, a vision and mission with specific objectives and goals can be formulated. Once these are established in an evergreen format (continual improvement), BMPs can be proposed to drive the desired change. To this end, I developed a tool, which I call BERT/E, which considers a farmer's Beliefs, Economics, Regulatory, Technology, and Energy with respect to change. BERT/E helps farmers evaluate whether adopting, rejecting, or refining a given BMP is necessary to enabling the desired change. The BERT tool described below is the original version, which was adapted into the BERT/E tool to be used in this work. I consider BERT to be an intuitive model based on my life time of making many decisions and dealing with change. The second E was a result of a discussion with my accountant, John Guthrie who pointed out that a high score with BERT still does not mean adoption will occur. The farmer has to have the mental and physical Energy to act. Each component can be supported in the literature. The BERT/E model is a quick way for farmers to express their thoughts about a new practice. Adoption theory either based on Rogers (1962) "diffusion of innovation" which focuses on an individual's decision to adopt a practice or technology or the more contemporary interdependence view of Leeuwis and Aarts (2021) are both complimentary to BERT/E . The decisions that a farmers makes when using BERT/E are individualistic but are always made within the context of the larger society and how the farmer participates in that context.

B—Beliefs

Of the four BERT components, beliefs can be the hardest to change. Indeed, Arbuckle (2013) argues that humans are hardwired to stay in their belief groups and to actively look for information that supports their beliefs. This observation is supported by over 20 years' worth of survey data clearly indicating that farmers in Iowa are reluctant to adopt new practices in order to combat AGW (Arbuckle et al. 2015a). For instance, as recently as 2013, an overwhelming number of Iowa farmers either believed global warming did not exist or that, if it did, it was not caused by humans Arbuckle et al. 2015a). Similarly, Davidson et al (2019) findings reveal deep skepticism by farmers in Alberta, Canada, regarding the potential for farming to play a key role in AGWM strategies. Ultimately, beliefs are strong drivers of action (or inaction) because they stimulate passion, which in turn motivates people to act.

E—Economics

Innovation will play a key role in tackling global warming, as farmers require economical AGWM strategies in order to maintain a positive balance sheet. A report from McKinsey & Company suggests that successful agricultural transformation is linked to improved household incomes (Boettiger et al. 2017). This is echoed in the findings of Davidson et al.'s (2019) survey of 301 larger Alberta farmers, which show that economic factors (vs. consideration for GHGs) are four times more likely to motivate farmers to adopt mitigation practices. These economic factors include reduced costs, increased efficiency, and increased revenue. Davidson et al. (2019) also note that some farmers had adopted AGWM practices despite not believing in AGW, a move that was primarily motivated by the opportunity to increase profits or improve their soils, water, or habitats. Notably, these pragmatic factors were more predictive than the various models and theories tested, including the expectancy model, the theory of planned behaviour, and the value-belief-norm theory. Research focusing on the United States, primarily Iowa, seldom mentions economics as a variable affecting farmers' adoption of conservation practices or AGWM practices (Prokopy et al. 2019). Nonetheless, Arbuckle (2013) points out that different mitigation approaches could incur different costs and benefits for farmers, while Meier et al. (2017) suggest that the promotion of abatement practices in the grain industry should focus on strategies that are also profitable. However, very few papers consider profit as a motivator of AGWM initiatives on farms, which is surprising given that the adoption of AGWM practices on farms must be profitable, either through the market (i.e., food, feed, and fibre, or fuel) or via AGWM credits and on-farm EG&S payments. Another option is to lower costs by introducing green input substitutes that do not have a Green Premium (Gates 2021). Such products would be less costly than fossil-fuel-based products and could include Green electricity, Green NH_3, Green biofuels, and Green H_2. A carbon tax would influence this balance by making non-Green alternatives more expensive.

R—Regulation

Government or industry regulation influences how farmers respond to new problems and the need to change. For an in-depth discussion of international and Canadian agreements and policies, please refer to Chapter 2. For now, it is sufficient to re-state that the world is now paying attention to AGW and what can be done to avoid the worst-case scenarios.

The Canadian government is aiming to reduce fertilizer-based emissions to 40% to 45% of 2005 levels by 2030 (Environment and Climate Change Canada 2022). Proponents of the status quo argue that such targets are impossible to achieve and will result in billions of dollars of lost income (Dawson 2021) . As such, funding is badly needed for research into alternative solutions that can render fossil-fuel-based nitrogen fertilizers obsolete. To this end, researchers are currently working on the development of asymbiotic biological nitrogen-fixing microbes (Pivot Bio 2022; KulaBio 2022; Azotic 2021; Corteva 2022b; Sound Agriculture 2022; Joyn Bio 2022; BioConsortia 2020; NewLeaf Symbiotics 2022) and affordable on-farm Green NH_3 production (FuelPositive 2021; Starfire Energy 2022; Reise 2020; MacLane 2021). Notably, YARA, Nutrien, and Koch are working on large-scale Green NH_3, while Nitricity, a start-up out of Stanford University, is working to refine the process of making on-farm Green nitric acid fertilizer (Nitricity 2021).

Another regulation currently being developed is a framework for carbon offsets (Canada ECCC 2020b). One of the world's rules for carbon offsets is not to allow compensation for practices that are new for some but ongoing for others. The best example of this type of practice would be treating all Zero Till farmers in Western Canada the same, as even those who have employed this practice for 30 or 40 years are still nowhere near reaching soil carbon saturation. Thus, good policies and regulations are needed to move everyone in the same direction to reach the 2050 goal.

T—Technology

Farmers cannot be asked to change unless there is something to adopt that puts their farms in a better position. Various types of technology will make a difference, some with immediate environmental and financial returns and others that only accumulate the desired effects sometime in the future. Farmers cannot be blamed for being reluctant to jump into a full suite of AGWM practices when, as Arbuckle points out, mitigation practices have uncertain outcomes, have a lag time, are government-led, benefits tend to accrue partially or wholly to the commons, and can be a net cost (Gardezi and Arbuckle 2020). For example, current BMPs for cover crops are logistically challenging on a large scale in Western Canada. When cover crops either are not established or are late in establishment, many of their potential advantages are lost. Lack of technology is to blame, not farmers.

E—Energy

This second E is used as a denominator and refers to the physical and mental energy a farmer is willing or able to expend to make a change. This second E came as a later addition to the BERT/E assessment tool. If a farmer is overwhelmed by just trying to put food on the table and keep the bills paid, they will not have the ability or desire to take on more debt, more work or exploration, and training. On the other hand, farmers with no stress and who are doing excellent financially may not have any desire to risk that position with mitigation practices for the good of the world.

To help measure progress in incorporating AGWM-BMPs on the farm, I developed two indices: the Sustainable Farm Index, which assesses the balance between the farm's profitability, output, and GHG emissions (I label this the "Triple Win" strategy); and an index measuring the farm's position with respect to being Net Positive, which I define based on emissions minus sequestration. The theories, frameworks, and rating tools introduced in this chapter are discussed in further detail in Chapter 7.

3.2. Philosophical Worldview

Creswell and Creswell (2017) define a philosophical worldview as a basic set of beliefs that helps guide one's actions and note four common subcategories: post-positivism, which is used primarily in experimental quantitative science; constructivism, which is typically used in qualitative research to understand how people construct meaning in the world; transformativism, which motivates researchers to highlight the voices of marginalized populations to affect political and social change to counter oppression; and pragmatism, which entails "dealing with things sensibly and realistically based on practical rather than theoretical considerations" (Oxford Languages 2022). Creswell and Creswell (2017) note that pragmatists are not committed to any one system of philosophy and will use whatever methods and research designs are required to thoroughly investigate the research question. Given the objectives outlined in Chapter 1, I will assume a pragmatic worldview in this research. I believe that farmers only change their operations in response to the need for short-term cash flows tempered by their ability to invest in long-term improvements, pragmatic entrepreneurial solutions are required.

My personal worldview is anchored in my acknowledgement of my good fortune of having been born in Canada, which is one of the few countries in the world with an effective pluralistic social capitalist democracy. Canadian society is orderly, and citizens have ready access to good public schools, adequate infrastructure for effective commerce, and low-cost per capita universal healthcare. Canadians also enjoy an expansive list of freedoms and rights, which have been critical in allowing me to live a good life. However, rights are accompanied by responsibilities, including obeying the laws of the land and, more recently, accepting and receiving a science-based and tested vaccine to help slow down diseases such as Covid 19. In addition to this lens, I also view the world through the lenses of history and science, which, I believe, improves my ability to make objective decisions, especially regarding the existential threat posed by AGW to our planet and, more specifically, to our descendants' quality of life.

Is it possible to transform 78 million acres of Western Canadian grain farm from being a key contributor to global GHG emissions to being a part of the solution in an effective and timely manner? The solution to this quandary may be for more farmers to adopt a science -based pragmatic entrepreneurial worldview.

3.3. Background, Role, and Positionality

I completed my BSc. in plant science in 1978 and my MSc, which focused on Zero Till management practices, in 1981. I have been conducting applied agronomic research since 1976, first as a summer student, then as a graduate student, then as a University of Manitoba Plant Science research associate working on winter wheat production, and, finally, as an entrepreneur when I formed my independent contract research company, Ag-Quest, in 1983. Ag-Quest was founded in Minto, Manitoba, and has grown to include five research farms across Western Canada employing twenty-nine research crews as of 2024. I served as CEO until my retirement in 2016, at which point my oldest daughter, Dana Maxwell, took over the company's operations. Most of my current applied agronomic research is for the direct benefit of our 6000-acre grain farm. While most of my contract research at Ag-Quest was for private clients, I have also done some notable work for the public sector, including winter wheat agronomy research for the University of Manitoba (1980 to 1983), developing the *Guide to Intensive Wheat Management and Risk Management in Wheat Production* for the Canadian Grains Council (1984 to 1989), and I founded and operated the Conservation Tillage Productivity Center for the Manitoba North Dakota Zero Tillage Farmers Association (1990 to 1994). I have also been privileged to sit on several boards, including the Manitoba North Dakota Zero Tillage Farmers Association, the Manitoba Wheat and Barley Growers

Association, Cereals Canada, the Canadian Agri-Food Policy Institute, and the Environment Committees of the Keystone Agricultural Producers and the National Farmers Union.

With my wife, and later with the help of my children, I started grain farming in 1980 when I was presented with the opportunity to rent 300 acres of land. Over the last 42 years, we have turned that modest start into 6000 acres of owned land. For the first 35 years, our farm was primarily managed as a Zero Till farm; however, in 2016, the decision was made to be more self-sufficient and reduce our GHG emission footprint. Initially, we attempted to achieve this goal by implementing organic farming practices, but by 2021 we were forced to conclude that, while profitable, large-scale organic grain production in our semi-arid region was not sustainable from a soil health perspective. Our goal is to invest in farming systems that allow farmers to make a decent living, supply safe and nutritious products to consumers, and contribute to healing the planet. Indeed, in line with UNIPCC SR 1.5°C, farmers must become part of the solution to AGW by working to eliminate fossil-fuel-related emissions by 2050 and to find more effective methods of sequestering excess CO_2 from the atmosphere in the soil. The latter goal is critical to our ability to feed the world's growing population, irrespective of AGW. Due to soil degradation from agriculture, better practices must be adopted to rebuild the soil's productive capacity. This is a global problem. Fortunately, rebuilding our soils can also help mitigate excess GHGs and AGW.

I believe the present is one of the best times to be alive on this planet, but, unfortunately, we have not accounted for the cost of our historically lavish lives. Human ingenuity has brought about AGW, and it will ultimately be what solves this problem. Thus, we must use all legal and moral options at our disposal to ensure that our descendants are able live as well as we have, albeit with different standards of consumption. I have taken four personal actions to help in the fight against AGW: I attended a Climate Reality Leaders training hosted by Al Gore in 2019; in 2021, I authored a book, *A Road to Fossil Free Farming: An Example and A Challenge*; I am continuously working to make my farm a model for tackling global warming, especially through the ultimate goal of achieving a Net Positive system; and, finally, I have embarked on a PhD to further my ability to achieve net zero. Hopefully, this thesis work will allow me to identify Net Positive carbon grain farms and form an understanding of which BMPs they rely on most.

Since this is a participatory project, and since I consider myself a participant, it is critical that I be as transparent as possible about my biases. I come from a position of privilege, but that does not mean that my parents were wealthy or that I got everything I wanted growing up. However, my dad often told me that I could have anything I want if I worked hard and smart enough and could pay for it myself. My privilege comes from not being told that I could not have or do something. This meant having family support to help me along the way. It was easy to get jobs, attend university, and find a good partner. Diane and I will have been married 48 years on June 26, 2024. It was not easy to start farming, but it was possible. It was not easy to raise a family, run a farm, and research business, but it was possible. And we did it. As a result, I can see where I have privilege compared to others who have had opportunities taken away, who do not have family support or encouragement, and who struggle to find hope from their current lives. No one gave me a big pot of money, but no one stood in my way, and many people helped me, and Diane build our successful marriage, family, and businesses.

It is easy to say that others should wake up and see the future as I do, but many find it a challenge to survive from one day to the next. Tackling global warming should not be difficult, but so many, including many powerful people, seem to fail to see the truth and opportunity to build a good life on Earth, our sacred home. I hope this research will provide examples of farms that are successfully rebuilding their soils, seeking to provide a good life for their families, helping to fill the demand for agricultural products, and doing it in a way to help heal the planet. Imagine what we could do together if we were all privileged and had a desire to heal the Earth?

3.4. Accounting for Bias: Bounded and Selective

This thesis consists of exploratory, participatory, and qualitative narrative research. In selecting a sample, I applied bounded selection criteria: all participants had to believe in AGW and have a desire to find solutions through improved Western Canadian farming practices. The case study participants were primarily chosen from among farmers who are innovators in AGWM practices and researchers actively experimenting with practical solutions for on-farm AGWM. The survey group participants consisted of the same farmers and research agronomists who participated in the one-on-one interviews, with the surveys giving them an opportunity to provide input into the findings and recommendations regarding the adoption of Net Positive farming. Gender, race, religion, ethnicity, sexual orientation, and other discriminatory traits were not factors in sample selection, but organic farms and farms with cattle were largely avoided intentionally, as I wanted to focus primarily on grain farmers in Western Canada and the Northern Great Plains.

3.5. Research Approach

This study was conducted using a four-step research approach. The first step consisted of a review of the academic literature and secondary documents relating to Net Positive grain farming BMPs. The second step entailed qualitative exploratory narrative research case studies with sixteen participants. The objective of these case studies was to document the participants' innovations, their feedback regarding the BMPs identified in the literature/document review, and the barriers and enablers to their transition to Net Positive.

Before continuing, two brief notes regarding the case studies are necessary. First, the participants' adoption of BMPs was assessed using a custom-designed tool, referred to as BERT/E (Beliefs, Economics, Regulatory, Technology, and Energy), which captured their physical and mental aptitude and willingness to make a change. A score of 1 to 5 was assigned for each of the B, E, R, and T components, with 5 being the highest adoption score. Thus, the highest score a participant could receive was 625 (5 x 5 x 5 x 5 = 625). An inverse score was used for the energy component, with 1 being the best score. Thus, a score of 625 remained the maximum adoption score (625/1 = 625).

Second, a case-study-based approach was selected because, when well-done, this approach should enable a better understanding of the subject, yield reasonable and defendable findings, be relatable to other research on the topic, and produce plausible change actions or further research directions (Tight 2017). Furthermore, in-depth, interview-based case studies that employ a narrative approach frequently generate findings that combine the participant's and researcher's life perspectives (Clandinin and Connelly 2020), which can bridge the dichotomies that arise in polarized agricultural development discussions ((Mockshell and Birner 2020).

The third step of the research involved collecting raw data from the farms and inputting them into the Holos emissions calculator (AAFC and Kröebel 2024). These data were also used to obtain the participants' Net Positive emission score and Sustainable Farm Index (SFI) scores. The findings obtained in this step were used to assess which BMPs each participant could adopt to transition their farm to Net Positive. Finally, the fourth step comprised the development of academic and applied outcomes. A goal of this research was to produce a farm practice change theory and practical outcomes, including practical BMPs, the identification of research and policy gaps and opportunities, wider community trust and support for Net Positive farmers, and stronger linkage for carbon offset and inset programs to Net Positive farms. Notably, I was able to facilitate a large grant to Assiniboine College in Brandon, Manitoba from the Weston Foundation for Soil Health, which enabled the development of a Net Positive Carbon Grain Network and may help in establishing a Net Positive Community of Practice.

3.6. Description of the Study Area

The study area primarily consisted of farms in the Canadian Prairies but also included agronomists and farmers working in the US Northern Great Plains, specifically, North and South Dakota. These regions were selected for two key reasons. First, they are sub-humid to semi-arid areas with short growing seasons. In addition, farmers in these regions face challenges in establishing and reaping the benefits of cover crops, which are recommended critical factors for enhanced carbon sequestration. Thus, greater innovation is required to learn how to use cover crops in this area. Second, I have conducted agronomic research and farmed in this area since 1976, so I am very familiar with the challenges facing farmers in this region. I expect that any of the innovations uncovered as a result of this study will be transferrable to similar regions around the world, especially in the US Northern Great Plains, the Russian steppes, and the Northern Chinese plains and beyond. This assumption is supported by a recent correspondence with a farmer from Kentucky, who also reports having problems with the logistics and cost of establishing cover crops, despite having a longer and wetter growing environment.

3.7. Measurement of Net Positive: Emission Calculators

As of 2015, there were forty-four environmental calculators available for agriculture contexts (Peter et al 2017). Fortunately, the resource platform, (AgLEDx 2024), provides tools to help users discern between the various conversion calculators, GHG calculators, MRV tools, and scenario planners. Two of the more notable calculators are Holos, which is an emissions calculator developed by Agriculture and Agri-Food Canada (AAFC and Kröebel 2024), and Cool Farm Tools, which is an emissions calculator that was developed through a collaboration between approximately ninety organizations worldwide (The Cool Farm 2024). In this work, GHG emissions were primarily calculated using the Canadian-developed Holos calculator, with the results being cross-checked using the calculator from Cool Farm Tools. Holos helps supply the information needed to complete the National Inventory Report (NIR), which is an obligation that many countries, including Canada, must fulfill to satisfy their National Determined Contributions to the UNIPCC (Canada 2023).

The Holos, SOM change, and contribution margin data collected from the participants were subject to the following limitations.

1. The collected data may not be reflective of the most recent crop. In some cases, because of drought or factors such as historically high grain prices, the participants were encouraged to provide an average expectation.
2. The data collected included a range for contribution margin, crop yield, inputs applied, trips over the field, and average distance travelled to haul grain from the field to storage. I also asked each participant, based on the best available historical data, to estimate the change in SOM caused by their change in practice. For many, this change began when they started to practice Zero Till, while for others it was due to their adoption of a combination of Zero Till and regenerative practices. One participant asked to include an estimate of sequestration within the wildlands of their farm consisting of wetlands, treed areas, and grasslands. This information was then used with literature-based estimates of the net carbon sequestration from these undisturbed wildlands (Badiou 2016). These findings may be important for future carbon-based incentives.
3. The data does not include any information on the emission efficiency of farm engines (i.e., whether the engines are pre-emission, TIER 1, 2, 3, 4, or 5 emissions equipped, or whether the emission equipment had been removed due to dependability issues).
4. While grain farms were originally intended to be the focus of this study, two of the participants had integrated cattle onto their farms (cow/calf and yearlings) and another two either allowed or were open to custom grazing opportunities to monetize cover crops and grassland on their farm. Based on the current UNIPCC-approved emission model, the inclusion of cattle dramatically increased farm emissions. Thus, the twelve farms will be considered as grain farms, and examples of the effect of cattle on farm emissions will be shown separately.
5. The data provided a good indication of the relative emissions from the participating farms.
6. Due to the wide range of soil zones, moisture availability, soil types, and yield potential, it is impossible to directly compare SFI scores between farms. However, the results indicate that there are large differences.
7. Each participant is a leader in their own context, striving to improve their farm both financially and environmentally. While all the participants are working to improve soil

health, none were solely dedicated to sequestering carbon to mitigate AGW. AGWM was simply a co-benefit.

8. Each farmer has unique goals and farming methods, and each farm is financially successful.
9. I considered it a privilege to be able to learn about the participants' unique approaches and innovations, and to eventually extend this information to help other farmers, research scientists, policymakers, and consumers in their quest for the "Triple Win."

Appendix 3.6.1 describes the data entry and decisions that were made while using Holos. Matt Wiens (MSc) was hired as a research assistant to help input and run the data through Holos.

3.8. Development of 12 BMPs

Twelve BMPs for Zero Till or Net Positive Carbon Grain Farming were developed using a combination of existing literature, document reviews, and discussions with knowledgeable informants. The participants were asked to provide feedback on twelve management areas selected from a mix of UNIPCC SR1.5°C's acknowledgement of agriculture as a solution provider and their recommendation to eliminate fossil-fuel-based products. Additionally, the selection of BMPs was also informed by Canadian federal and provincial programs as outlined in Tables 2.4 and 2.7, such as the Sustainable Agriculture Strategy, the Fertilizer Emission Reduction Act, Living Labs, the Pan-Canadian Framework on Clean Growth and Climate Change, the 2030 Emission Reduction Plan, the On Farm Climate Action Fund, and Sustainable Canadian Agricultural Partnership. Furthermore, agriculture-based AGWM solutions proposed by a variety of sources were also considered. These sources included, Carbon Farming, Carbon Smart Yale360, Climate Smart Agriculture (FAO), Climate Smart Soils (Keith Paustian, Pete Smith and others, Farmers for Climate Solutions, the National Farmers Union (What if), Recruiting Soils to tackle Climate Change (Soil Conservation Council of Canada), Ecological Farming Systems, Natural Systems Farming (Entz and Thiessen-Martens), Nature-Based Solutions for Climate (IUCN), Natural Climate Solutions (Nature United and TNC – USA), Regenerative Ag (Gabe Brown-Understanding AG), A Soil Owner's Manual (Jon Stika), Holistic Management (Allen Savory), Forest, Land, and Agriculture-FLAG (SBTi), and various company initiatives (Bayer, Corteva, Syngenta, RBC, General Mills, Nestle, McCain Foods).

The twelve BMPs and their connection to Regenerative Ag are summarized below. The primary objective of Regenerative Ag is to halt soil degradation and to promote natural systems that help restore it to a healthy pre-settlement state. These management areas are commonly referred to as beneficial management practices (BMPs), or best management practices, depending on the context. In his book, *Dirt to Soil: One Family's Journey into Regenerative Ag* (2018), Gabe Brown credits Stika (2016), as well as Jay Fuhrer and Ray Archuleta, both long-time USDA-NRCS researchers, for being the first to outline the first five principles of Regenerative Ag. Gabe has made these principles famous. The five regenerative principles form the foundation for five of the twelve BMPs explored in this thesis.

3.8.1. Lack of Disturbance

As its name implies, this principle entails minimizing disruptions to the soil food web (Ingham and Slaughter 2000) from practices such as tillage, use of harsh pesticides, excessive fertilizer application, or natural crop senescence without subsequently growing plants to support soil microbes. Participants who focused exclusively on the use of Zero Tillage typically had higher adoption score compared to those who attempted to consider all disturbances.

3.8.2. Plants Growing from Snow to Snow

This principle is based on the idea that living roots release root exudates, which directly contribute to increased SOC (Lavallee et al. 2020; Prescott et al. 2021; Sokol et al. 2018; Kallenbach et al. 2016; Kallenbach et al. 2019). The easiest way to achieve this goal is to grow perennial crops. However, perennials tend to be ideal when there is the desire, skill, management, infrastructure, and economics to have cattle on the farm. For grain farmers, options for ensuring plant growth from snow to snow include postharvest cover crops, full-season cover crops, and biennial or perennial companion crops wherein the companion is grown for a subsequent year's seed crop or baled for the hay market. Additional options include the use of winter annuals for grain crops in the subsequent year or for green seeding and termination the next spring. Volunteer from annual spring crop plants grown in the fall can be used for brown seeding the next spring.

3.8.3. Growing a Diverse Mix of Plant Species

This principle of Regenerative Ag encourages farmers to mimic nature by avoiding monocultures. Several studies (Cong et al. 2015; Congreves et al. 2015; Chahal et al. 2020; Van Eerd et al. 2023) have demonstrated that greater plant diversity can promote synergistic interactions between species and soil microbes. Maximum diversity can be achieved by harvesting all plants together, which can be carried out via direct grazing or cutting and baling the mixture (Stika 2016). While it can be challenging to implement diversity on grain farms, it can be achieved by rotating a diverse range of monoculture crops. This approach is particularly suitable in locations where moisture is limited. Another option is to grow intercrops, which can include two or more cash crops or a companion crop.

3.8.4. Keeping Armor on the Soil

Maintaining soil armor is the fourth principle of Regenerative Ag, which emphasizes creating a favorable environment for soil microbes and provides a "roof" that protects the soil from direct sunlight and raindrop impact. Research suggests that a soil temperature of approximately 30°C is ideal for optimal functioning (Balser et al.2002). The use of armor can protect the soil from extreme temperatures and moisture loss, which can help maintain the soil structure and promote healthy microbial activity.

3.8.5. Alternative Nitrogen

Nitrogen is a crucial macronutrient for plants. While the fossil-fuel-based Haber-Bosch method of synthetic nitrogen production is estimated to have fed about half of the current global population (Erisman et al. 2008), the total elimination of fossil-fuel-based nitrogen is unfeasible in the absence of suitable alternatives or population reduction plans. Current available alternatives to fossil-fuel-based nitrogen fertilizers include:

- the use of legumes,
- long-term Zero Tillage with asymbiotic free-living nitrogen fixation and enhanced nutrient cycling,
- bugs in a jug biology, perhaps with gene-editing technology,
- Green-based NH_3,
- the use of the 4Rs to increase efficiency and reduce emissions, and
- exploiting improved soil biology and rhizophagy as a natural nutrient supply.

3.8.6. Alternative Energy

The United Nations has emphasized the need to stop using fossil-fuel-based products, which are a major contributor to global warming. Currently, there are a number of fossil-fuel alternatives for on-farm power, including electrification using renewable sources such as wind, water, solar power, nuclear, Green H_2, and Green NH_3, and biofuels such as biogas, biomass, SVO, biodiesel, or renewable diesel. While electrification is a good option for small, restricted-duty cycle equipment such as pickup trucks, ATVs, and yard tractors, renewable diesel is better suited for larger continuous-duty on-farm units. Notably, since renewable diesel is refined using the same process as regular diesel, there is no need for any changes in the equipment. According to my calculations, it would take 0.75% to 1% of the farmland (net of the oil seed meal) on a typical Zero Till Western Canadian farm to supply all of its motive power needs (see Appendix 6.6.1 for calculations). However, this equation does not factor in the transportation of grain from the farm.

3.8.7. Agroecological Solutions

Key agroecological practices that can help reduce or eliminate the need for synthetic inputs include crop rotation, crop variety selection, enhanced crop competition, planting orientation, sanitation, trap crops, sacrifice crops, pollination habitat, and precision crop practices, such as fertilizer placement. These practices favor competitive crops, with minimal losses from weeds, pests, and lodging without the aid of farm chemicals. Some participants associated agroecology with organic farming, not realizing the number of agroecological practices that they take for granted. Agroecology consists of six levels (Gliessman 2016, p. 187):

LEVEL 5: Rebuilding a global food system that is sustainable and equitable.
LEVEL 4: Re-establishing connections between growers and consumers, and developing alternative food networks.
LEVEL 3: Redesigning the whole agroecosystem.
LEVEL 2: Substituting alternative practices and inputs.
LEVEL 1: Increasing the efficiency of industrial inputs.
LEVEL 0: No agroecological integration.

Further insight into the potential of agroecological practices can be found in Gliessman (2018), Hill (1998), Altieri and Nicholls (2017), and Snapp et al. (2021).

3.8.8. Sustainable Intensification

The participants held varying opinions regarding the term, “sustainable Intensification,”' with Richard preferring alternative names like, “sustainable optimization.” Nonetheless, they identified tools such as GPS, auto steer, and precision spraying as being useful for increasing efficiency and reducing waste in the use of fossil fuel products and/or their alternatives.

3.8.9. Conservation and Restoration of Wildland

This management practice is often divisive; whereas many farmers see the advantages of having well-defined, open, square fields, others, along with most environmentalists, recognize the importance of natural habitats and avoiding the release of GHGs from breaking up and draining wildland. Draining water onto downstream neighbors or collectively flooding downstream towns and cities is also not a desirable outcome. The discussion around conversion of wildlands discussed by the participants included bans, financial incentives, restoration, enforcement, the availability of large equipment for conversion, and investment by owners wanting to "improve" marginal lands in the hopes of realizing financial gains.

3.8.10. Phosphorus Recycling

Phosphorus is an essential nutrient for plant growth. While its use has minimal impact on global warming, its availability is a sustainability issue. Each year, farmers apply millions of tons of phosphorus to their fields to foster the growth of crops, which are then shipped to cities worldwide in the form of farm products. Phosphorus use poses other problems as well; for example, leakage contributes to the pollution of rivers, lakes, and oceans. In addition, phosphorus is a finite resource that cannot be retrieved once it is diluted in water bodies. The participants were asked about phosphorus recycling, particularly whether they had tried using struvite, which is phosphorus recycled from cities, or phosphorus recycled from animal manure. Notably, some participants had found ways of exploiting soil biology and plant diversity to harness the phosphorus that is present in most soils but was largely unavailable for plant growth.

3.8.11. Integration of Grazing Animals on Cropland

This is the fifth principle of Regenerative Ag. Appropriate management of cattle can improve soil health. The group discussed the advantages and disadvantages of incorporating cattle into grain farms.

3.8.12. Organic Farming

The final BMP discussed with the participants was organic farming. There are many proponents of the role organic farming can have to help mitigate global warming (Rodale Institute 2014; Lynch et al. 2011). There was interest in this practice due to a recent decrease in non-organic grain prices, but the interest was mainly based on having organic with no tillage. Zero Till organic has not proven to be feasible in the Prairies. Indeed, one participant who had run a successful long-term organic grain farm and one research agronomist who has focused on organic farming for 15 years reported having little success with continuous Zero Till organic grain production.

3.8.13. Other BMPs

Participants were also asked if there were any other BMPs they used or could think of that could be used to help mitigate AGW on their farms. Nature United in particular have a list of twenty-four BMPs (Viresco Solutions and Nature United 2022; Drever et al. 2021).

3.9. Case Study Methods

3.9.1. Ethics Board Approval

A submission was made to the Ethics Review Board through the Research Administration System and approved under Project number HE2022-0218**.** Appendices approved by the REB for use in this project are found in appendix 3.9.1.

3.9.2. Research Objectives

The research was to employ in-depth semi-structured exploratory interviews to document the participants' journeys toward AGWM and to use their insights and experiences to assess whether and how the twelve innovative AGWM BMPs could be applied on Western Canadian grain farms. The interviews also identified enablers, barriers, and potential solutions that the participants had encountered in their efforts to implement Net Positive Carbon Grain Farming. This study had four key objectives:

Objective 1: To develop a practical theory, framework, and tools to complement this exploratory narrative research process (Chapter 7).

Objective 2: To determine whether any of the participants qualify as Net Positive farmers, and how this is reflected in their Sustainability Farm Index score (Chapter 5).

Objective 3: To determine how innovative farmers rate the utility of the twelve BMPs for mitigating global warming (Chapter 6).

Objective 4: To determine whether BERT/E (adoption rating) analysis is effective at identifying enablers, barriers, gaps, and innovations vis-à-vis the transition to Net Positive (Chapter 6).

Finally, the participants were asked to complete a short survey gauging their thoughts on the next steps for Net Positive Carbon Grain Farming (Chapter 7).

3.9.3. Selection Criteria

The sample contained twelve farmers from the Northern Great Plains, mainly Western Canada, who had employed an innovative, balanced, and productive approach to transforming their grain farms to Net Positive, with the ultimate aim of meeting the 2050 UNIPCC SR1.5°C goals. Although cattle ranches and feedlots were excluded, two farmers in the sample group operated mixed grain-cattle farms. The sample was rounded out with the inclusion of four research agronomists. The majority of arable land in Western Canada is used for straight grain farming, which is likely to remain the dominant model based on current and future economics. This region is generally sub-humid to semi-arid, which means that farmers here face challenges not found in more humid regions, such as British Columbia, Eastern Canada, the Midwest, and Eastern USA. The selected region is made up of a black soil zone/tall grass prairie (most humid), a dark brown soil zone (intermediate rainfall), and a brown soil zone/short grass prairie (most arid). Farms with plans for family succession were given preference for inclusion, with participating farms ranging between 2200 and 30,000 cropped acres. Note that, while the size of each farm was recorded, it was not used as a preliminary selection criterion. Grain farms in Western Canada range from a few hundred acres to 100,000 acres, with averages of 1135, 1668, and 1168 acres in Manitoba, Saskatchewan, and Alberta, respectively (Stats Canada 2011). Finally, preference was given to farms that adhered to practices and philosophies consistent with being Net Positive.

3.9.4. Participant Recruitment

The interviews were semi-structured, open-ended, and in-depth, and lasted an average of 2.5 hours (range: 1.5 to 4.25 hours). The interviewees were hand selected and were contacted via one of two methods. The first method was through articles *in The Manitoba Cooperator* (“Net-Positive Farm Research Taps into Farmer Knowledge,” Nov 2, 2023) and *The Western Producer* (“Farmer Pursues PhD with Sustainability Research,” Nov. 2, 2023). Both articles, which were written by Robert Arnason, reporting on this research and provided volunteers or peer referrals as a way of getting in touch regarding inclusion as a case study.

The second contact method comprised word-of-mouth recommendations and public announcements or stories involving potential candidates. Here, I either phoned or emailed knowledgeable informants soliciting ideas of possible interviewees. These knowledgeable informants consisted of individuals, often applied agronomic research or extension personnel, with an interest in this work area. Once a list of potential participants had been compiled, I sent each one an introduction letter and followed up with them if they expressed an interest in participating. Potential candidates were pre-screened to assess their knowledge of and commitment to Net Positive farm practices and provided with a handout outlining the purpose of the research. The handout provided information relating to their role in the research, how the data would be used, their willingness to participate in the study as outlined, the need for consent, and their ability to withdraw, review, and approve the description of their farm and practices. It was made clear that participants would not remain anonymous, as I wanted to showcase leaders who were willing to share their knowledge and experiences. Interviews were scheduled for the off-season and were conducted one-on-one with the farmers (i.e., other family members were not present). Data acquisition was halted after sixteen interviews (twelve with farmers, four with research agronomists), as satisfactory data saturation was achieved at this point. Remuneration for participants was neither offered nor requested. The first interview was conducted on November 25, 2023, and the final interview was held on December 20, 2023.

3.9.5. Informed Consent

After the sixteen participants had been selected, the purpose, process, expectations, roles, rights, and responsibilities relating to the study were explained to them both verbally and in writing. They were also asked to complete the ethics-committee-approved consent form, which emphasized that they had the right to review the portion of the research pertaining to them or withdraw at any time. None of the participants wanted to be anonymous. A copy of the consent form can be found in Appendix 3.9.5.

3.9.6. Preparation for In-Depth Semi-Structured Interviews

Each interviewee was given a copy of the BMPs and brief descriptions of what each one entailed. They were asked questions regarding the suitability of each BMP and their experiences with them, as well as ways they could be improved or if other practices had proven to be more effective. Limitations, barriers, and enabling factors were also discussed, and the BERT/E framework was applied to determine their adoption rating score.

3.9.7. Open-Ended, In-Depth Interviews

Each interview lasted between 1.5 and 4.25 hours, with an average interview time of 2.5 hours. The semi-structured interviews focused on the twelve BMPs, particularly with respect to the need to generate farm income, serve the market, and mitigate AGW. The use of semi-structured, in-depth interviews is a powerful way to gather data and, when done well, can provide the researcher with access to the participants' thoughts, reflections, motives, experiences, understanding, interpretation, and perception of the topic under consideration (Morris 2018). Although some researchers feel that one interview with a participant is not enough (Taylor and Bogdan 1984), the time and cost of extended interviews can be a limiting consideration (Earthy and Cronin 2016). For this study, I targeted a single two-hour interview with the sixteen participants. Originally, the sample was to contain ten participants, but it was later expanded to sixteen to provide a wider range of perspectives than would have been possible using the same time allocation with fewer participants. It should also be noted that there was additional communication between myself and the participant via follow-up questions after the formal interview. These communications were sometimes initiated by me and, at other times, were in the form of questions from the participants. The preliminary interview guide can be found in Appendix 3.9.7. The interview guide consisted of seven sections: Opening; Demographics and Background; BMP Review; Background on Your Journey with Net Positive Farming; Thoughts on Feed the Farm, Feed the Demand, and Heal the Planet; Thoughts on Climate Distress; and Closing. The BMP Review was the major section of the guide, with twelve BMPs and ten questions each.

Participants were asked the following questions for each BMP:

a. As an idea (100 = best idea ever, 0 = worst idea ever).
b. As a practice on your farm (100 = full adoption, 0 = no adoption).
c. Belief in BMP (5 = strongly believe, 1 = very weak belief in). Please describe.
d. Economics of BMP (5 = very economical, 1 = very uneconomical). What is the profitability of this practice for you currently?
e. Regulations affecting adoption, both from government and food companies (5 = strong regulations, 1 = weak regulations). Describe.
f. Technology: ready to go, scalable (5 = strongest 1 = weakest). Describe.
g. Energy: mental and physical energy to adopt the new practice (5 = very low energy, 1 = very high energy). Please rate and describe.
h. Enablers: What things enable the adoption of this practice?
i. Barriers: What are the barriers to the adoption of this practice?
j. GWM Credit Required $+/-: How much do you think this practice would pay or cost to implement per acre per year?

The twelve BMPs are listed in Section 3.8.

All interviews were conducted using UM Zoom. Each interview was also recorded and transcribed by UM Zoom. In addition, I took notes manually during each interview and while reviewing the recordings; in some cases, recordings were reviewed up to three times. The summaries of participant "stories," as found in Chapter 4, are my interpretation of the recording and my notes. More in-depth participant stories are found in Appendix 4. Each participant was given a copy of their story to review, and their feedback regarding the accuracy of my interpretation is provided at the end of each story as published in Appendices 4.5 and 4.6.

3.9.8. Data Management, Transcription, Coding, and Analysis

The transcribed data were coded using NVivo 14. The data were coded to the ten answers times the twelve BMPs, with special attention to enablers and barriers. I used fifty-three enablers and seventy-one barrier codes. I also mined the transcriptions for quotes that could be used to highlight trends and outliers in the data. Some discussions contained multiple codes—most often with respect to the first BMP, as many participants were eager to introduce a host of related topics into the discussion. The use of NVivo queries allowed these discussions to be categorized for easy retrieval. Examples of these codes can be found in Appendices 3.9.7.2 to 3.9.7.5 while Appendix 3.9.7.6 illustrates the use of the "Query" function in NVivo.

The interview data were transcribed using the UM Zoom transcription software, (Morgan 2019) suggested using computer-assisted qualitative data analysis software CAQDAS. Nvivo14, a CAQDAS, was used to code and index the data. Rustan Dow was hired to assist with this portion of the project. In addition to teaching me how to use NVivo, Rustan helped obtain the signed consent forms, schedule, and sit in on the interviews as quality control, double-check to make sure the interviews were properly recorded, and refine the interview process. Rustan has a master's degree in library sciences from the University of Toronto and had used an earlier version of NVivo for his Masters.

Morgan (2019), identifies four common approaches for analyzing coded data. The first is the summary-based analysis, which is the simplest way to capture the essence of a discussion. This approach is used for the stories in Chapter 4. He further notes that group x question grids can be developed from these summary-based results. The BERT/E framework was used in this context. Morgan (2019) further contends that, along with summary-based analysis, the other three approaches—content analysis, thematic analysis, and grounded theory—can be used in both case studies and focus groups. This project's participatory, semi-structured approach, along with its review of the developed BMPs using semi-structured data recording sheets and coded transcriptions, allows for high compatibility with a preliminary "content" analysis followed by a summary-based analysis.

3.9.9. Synthesis Draft

The farm descriptions and BMP analysis results were synthesized to obtain a consensus on both Net Positive practices and the various other practices and ideas that came up during the interviews. Potential barriers, limitations, and enabling factors were described to help illuminate the next steps. In total, fifty recommendations were compiled as a result of the interviews.

3.9.10 Feedback Loops

Each interviewee received a draft of the synthesized data to ensure the accuracy of the descriptions and conclusions. Revisions were made in response to any feedback obtained, and written permission was obtained to publish the findings of this study. Additional permission will be obtained for the inclusion of these findings in papers, books, and subsequent extension information.

3.10. Exit Survey

Originally, I intended to use an eDelphi focus group method as a second step, as focus groups can be an efficient way to engage a larger cross-section of stakeholders (Morgan 2019). Similarly, the findings of Goodarzi et al. (2018), review of forty-one Delphi-based studies from the *Journal of Agriculture Education* and two from the *Journal of Agricultural Science and Technology* confirm that the Delphi method can be a powerful tool for obtaining answers to important questions. However, rather than working with a larger group of “field-to-fork” stakeholders, I chose to administer a short survey to obtain feedback directly from the sixteen participants.

3.10.1. Selection Criteria, Recruitment, and Consent

The survey was completed by the sixteen case study participants, as this ensured the survey respondents were knowledgeable about the study, including the aspects relating to their individual stories, BERT/E × BMP scores, Net Positive ratings, Sustainable Farm Index Scores, and recommendations for addressing gaps and improvements that could help BMPs work better. Consent was obtained via a continued contact clause in the original consent form approving continued contact to help complete the study.

3.10.2. Preparation for the Survey

A report detailing the synthesized results of the case studies was distributed to the participants, with data being collected primarily via email. The survey probed the participants' thoughts regarding topics falling under two main questions relating to the next steps in the quest for Net Positive grain farming. The survey questions are listed in Appendix 3.10.2

3.10.3. Final Synthesis

The overall data were summarized to describe the review of the BMPs and provide policy and research recommendations to facilitate their refinement and further adoption, including technology gaps, possible solutions, and possibilities for community support for an agriculture-based solution to help mitigate global warming. The BERT/E tool was used to assess adoption potential (the BERT/E adoption scores are explained in greater detail in Chapter 6), and the participants' Sustainable Farm Index and Net Positive Carbon Grain Farming scores were also calculated (see Chapter 5 for further details).

3.10.4. Research Validity and Reliability

It is essential for research to be seen as trustworthy. This means that results and data are accepted as valid (accurate, reliable, consistent, and reproduceable) (Creswell and Creswell 2017). The validity of the findings presented herein was enhanced by employing the following practices:

1. I located innovations from numerous sources and acknowledged my bias.
2. Participants verified the accuracy of their story and the accompanying synopsis.
3. Thick, detailed descriptions were used to convey the findings with reference to specific participant transcriptions.
4. Considerable time was devoted to learning about the participants, both prior to and during the interviews, with follow-up discussions as needed.
5. Peer debriefing was employed to enhance the accuracy of my accounts, including tapes, transcriptions, and discussions with my research assistant.
6. My research assistant and I coded the transcripts independently and compared their outcomes. Due to consistency in the coding outcomes, I continued with a master code book.

The reliability of this research was enhanced by:

1. Documenting the steps and procedures.
2. Maintaining data and checking transcriptions for mistakes.

3.10.5. Security of Data, Confidentiality, and Informed Consent

Security of data, confidentiality, and informed consent were all addressed in accordance with the policies and practices outlined by the Ethics Board and summarized in the consent document (Appendix 3.9.5).

3.11. Collection of Raw Data for Holos and SFI

Participants were asked to complete a raw data entry form. The information on these forms was subsequently inputted into Holos, the AAFC emission and sequestration model, and the formula used to calculate their Net Positive Carbon Grain Farming scores. A summary of how Holos was used in this study is provided in Appendix 3.11.1. Matthew Wiens (MSc) was hired to help input the data into the Holos model. The raw data were also used to calculate the participants' Sustainable Farm Index scores, which were based on contribution margin, $/ha, farm output based on kcal/ha, and emissions in kg CO_2eq/ha. An example data form can be found in Appendix 3.11.2. The participants were not asked to enter their farm data directly into Holos. Examples of three Holos reports are provided in Appendix 3.11.3.

Chapter 4: Participant Stories

This chapter presents the participants' stories and summarizes key contextual information for each case. Beyond forming the foundation of this dissertation, the use of case studies provides future readers with examples of farmers doing the seemingly impossible, which will hopefully inspire them to strive to make Western Canadian agriculture a part of global warming mitigation.

Section 4.5 contains a short summary of highlights from each participant, and Appendix 4.5 and 4.6 contains the full versions of the participants' stories and their individual BERT/E adoption scores.

4.1. Introduction to Participant Narratives

In his book, *Sapiens: A Brief History of Humankind* (2011), Harari argues that "Homo sapiens conquered the world thanks above all to its unique language" (p19) and their ability to create a story. However, he goes on to lament that,

> *we are more powerful than ever before but have little idea what to do with all that power. We are accountable to no one. We are consequently wreaking havoc with our fellow animals and on the surrounding ecosystems, seeking little more than our own comfort and amusement, yet never finding satisfaction. Is there anything more dangerous than dissatisfied, irresponsible gods who don't know what they want?* (Harari 2011, p 416)

According to Hassan, narrative research is a "qualitative research methodology that involves examining and interpreting stories and narratives people tell in order to gain insight into the meanings, experiences, and perspectives that underline them" (Hassan 2024). Thus, the aim of the present qualitative research is to listen to, record, and assemble the participants' stories into a narrative. To this end, I have selected farmers who are striving to develop stewardship practices that enable sustainable progress via net-positive carbon grain farming, while remaining financially viable.

The farmers selected for this work all consciously or unconsciously follow a simple rule: if there is no money, there is no business; if there is no business, there is also no improvement. This maxim is underpinned by the following equation: profit = (yield × price) – costs. This equation can be interpreted in myriad ways. For example, in subsistence farming, the objective is to supply a diverse, secure, and sustainable food supply for your family or tribe; here, profit is the sustainable secure food supply. In contrast, modern agriculture uses dollars as a tradeable, measurable currency. There are many trade-offs associated with this simple equation: some farmers may pursue the highest yield, others may pursue the highest economic yield, others may focus on minimizing inputs to maximize profits, while some may pursue organic farming, which uses no synthetic inputs. Lower yields and higher costs are compensated for by a customer base that is willing to pay extra for that food. Regardless of the approach, it is necessary for farmers to balance what they want and can do with what the consumer/customer wants and will pay for.

Some farmers see the above as a “treadmill to nowhere” for their farms, often working harder for less return (NFU 2019). In response, some have attempted to improve profits by spending less; this approach results in lower yields, but higher profits. Other farmers have recognized the close relationship between GHG emissions and fossil fuel-based farm inputs, and that reducing these inputs positively impacts their carbon footprint—even to the point of making their farms Net Positive.

The farmers in this study interpret the profit = (yield × price) – costs formula in many ways. In addition to their various approaches to yield, price, and costs, some of the participants have also chosen to redefine “profits.” To some participants, profits do not strictly relate to money; rather, they also relate to stewardship, soil health, the ecosystem, ensuring diversity, reducing GHG emissions, and, above all, having time for their family. As long as there is enough income to support their chosen lifestyle, there is latitude to tackle the negative externalities. This chapter presents the stories of 16 innovative farmers and researchers in their pursuit of achieving Net-Positive operations.

4.2. Finding Innovative Participants

This work focuses on farmers who are striving for a Net Positive future. According to the BDC, Business Development Canada innovation is an idea which creates value. It can be incremental, expansive, or disruptive. (https://www.bdc.ca/en/articles-tools/business-strategy-planning/inno). Net Positive is largely the idea of minimizing GHG emissions by eliminating the use of fossil-fuel-based products and sequestering CO_2 from the atmosphere to go beyond net zero and be net negative, or, as I prefer, Net Positive. The sample for this study mainly consists of grain farmers in sub-humid and semi-arid regions, including the Northern Great Plains and Canadian Prairies. While the participants would have ideally shared a strong belief in AGW, in practice they held a range of convictions regarding this subject. Nonetheless, all participants were deeply concerned with finding ways to remain profitable, while also improving soil quality so future generations could also profit. For many, AGWM was a co-benefit.

Table 4.1. Summary of participants and first contact.

Farm	Soil Zone	Location	Context of Engagement
Josh	Brown	Claresholm, AB	Recommended as an innovative regenerative, multi-generational diverse enterprise farm.
Derek	Brown	Minton, SK	I have visited Derek's regen farm and know it to be a contender for net positive status.
Kelly	Brown	Max, ND	I met Kelly and DeAnna during a tour of Brandon's farm. From our conversation, their farm system seemed unique and a good candidate for inclusion.
Cliff	Dark Brown	Hardisty, AB	Cliff contacted me after seeing a story discussing this research in *The Western Producer*.
Brandon	Thin Black	North of Minot, ND	Brandon has one of the best non-cattle regen farms, which I visited in the fall of 2023.
Darren	Thin Black	Deloraine, MB	Darren is part of a Regenerative Ag initiative sponsored by General Mills.
Kristjan	Thin Black	Moosomin, SK	Kristjan et al. have a large grain farm and are involved in the CANZA Net Zero initiative.
Ian	Thin Black	Oxbow, SK	Ian is one of the best and most thoughtful organic grain farmers in the prairies.
Dorian	Black	Minto, MB	Dorian is my "farmer" daughter. She is pragmatic and always looking for ways to create the triple WIN.

Mike	Moist Black	Melfort, SK	Mike is a member of the General Mills regen ag group who has interest in measuring SOCC.
Dan	Moist Black	Starbuck, MB	I met Dan through a webinar, where he shared his experiences with zero till and green seed in the Red River Valley.
Rick	Moist Black	Gross Isle, MB	Rick is a progressive high-tech strip-till farmer in the Red River Valley who is associated with a digital ag project, EMILI.
Research Agronomists	**Soil Zone**	**Location**	**Context of Engagement**
Sam	Brown	Pierre, SD	Sam is the new manager of the 33-year-old farmer-owned applied zero till research farm in South Dakota.
Richard	Dark Brown	Saskatoon, SK	Richard possesses expertise in land reclamation and GHG emissions.
Bill	Thin Black	Indian Head, SK	Bill is an applied research agronomist who has worked on a wide range of zero till cropping projects.
Joanne	Moist Black	Winnipeg, MB	Joanne has considerable experience with natural system farming, P, and livestock integration.

Note: CANZA stands for the Canadian Alliance of Net Zero Agriculture, and EMILI stands for the Enterprise Machine Intelligence and Learning Initiative.

Table 4.1 tabulates the list of participants, soil zones, location as well as context of engagement.

4.3. Summary of the Participant Context

The sample consisted of twelve farmers and four research agronomists. These case histories were invaluable for exploring the participants' diverse histories, contexts, and innovative practices employed in the pursuit of Net Positive farming. Table 4.2 provides a summary of the participants' characteristics, allowing for a comparison of their differences and similarities. In addition, Table 4.2

provides a sneak peak of their respective SFI ratings, which will be discussed in more detail in Chapter 5.

Table 4.2 is organized according to soil zones, with the driest zone, brown-short grass prairie, at the top and the wettest, moist black-tall grass prairie, at the bottom. In general, available moisture, inputs used, and yields increased alongside the shift from brown to black soil zones. Notably, profitability did not always adhere to this trend. Regarding equipment, the disc drill was the preferred tool among the participants, although some in Western Canada preferred precision banding hoe drills. Significantly, not everyone was totally convinced that the climate is changing or, if it is, that these changes are anthropogenic. Furthermore, while everyone believed in improving soil health, profitability was the top priority for most respondents. Nonetheless, a few participants said they were playing the long game and would forego short-term profits for better soil quality and long-term stability and profit. All participants believed that change is necessary and/or inevitable. Each of the farmers ran successful farms, and each had their own way of dealing with climate change. All were willing to share their experiences and knowledge, as they understood that the problems ahead associated with climate change will require a collective effort.

T**able 4.2**. Key descriptors of participants.

Farm	**Soil Zone**	**Major Farm Feature**	**Input Level**	**Cattle**	**Belief AGW**	**Consider Change**	**SFI-par Score**
Josh	Brown	Regenerative ZT Disc Drill	Medium	Always	High	High	1.4
Derek	Brown	Regenerative ZT Disc Drill	Very Low	Custom	High	High	5.8
Kelly	Brown	ZT & IMOS Disc Drill	Ultra Low	Never	High	High	14.3
Cliff	Dark Brown	ZT - Full Season Cover Crop- Disc Drill	Medium	Always	High	High	1.8
Brandon	Thin Black	Regenerative ZT Disc Drill	Low	Seldom	High	High	2.4

Darren	Thin Black	Regenerative ZT Disc Drill	High	Seldom	M-H	High	1.3
Kristjan	Thin Black	Zero Till Hoe Drill	Very High	Fall	Low	High	1.3
Ian	Thin Black	Organic Tillage based	Ultra Low	Never	High	High	3.2
Dorian	Black	ZT Plus Disc + Hoe Drill	Medium	Never	High	High	1.9
Mike	Moist Black	Regenerative ZT Disc + Hoe Drill	Medium	Maybe	M-H	High	1.9
Dan	Moist Black	Flex-ZT Disc Drill	Highest	Not Likely	High	High	1.5
Rick	Moist Black	Flex-ZT, Strip Till, Disc Drill	Very High	Never	Low	High	1.8
Research Agronomist	**Soil Zone**	**Major Farm Features**	**Input Level**	**Cattle on Farm**	**Belief AGW**	**Consider Change**	**SFI-par Score**
Sam	Brown	Diversified ZT Disc Drill	Medium	Always	High	High	NA
Richard	Dark Brown	Mostly ZT	Variable	No	High	High	NA
Bill	Thin Black	Zero Till- Hoe Drill	Variable	Never	High	High	NA
Joanne	Moist Black	CT/Organic/ and ZT	Variable	Maybe	High	High	NA

Table Notes: Regen ZT= Regenerative Zero Till, ZT & IMOS+ Zero Till and Indigenous Micro Organism System, ZT - 25%full CC- Disc D+ Zero Till with 25% of arable acres seeded to a full season cover crop and seeded with a disc drill, ZT Plus+ Zero Till Plus Regenerative- Net Positive practices, Flex-ZT= Zero Till when possible, Diversified Zero Till= Zero Till with a diverse crop rotation and integrated cattle grazing, CT/Organic/ and ZT= Conventional tillage, organic production and Zero Till.

A

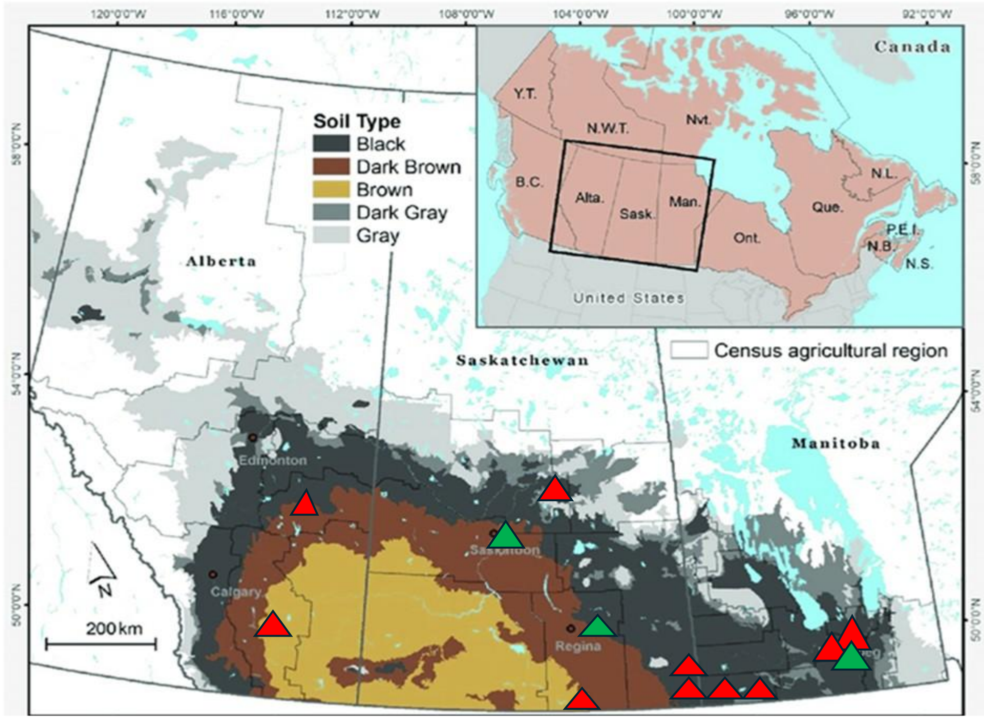

Figure 4.1. Major soil zones of the Canadian Prairies (Awada, Nagy, and Phillips 2021, used with permission).

B

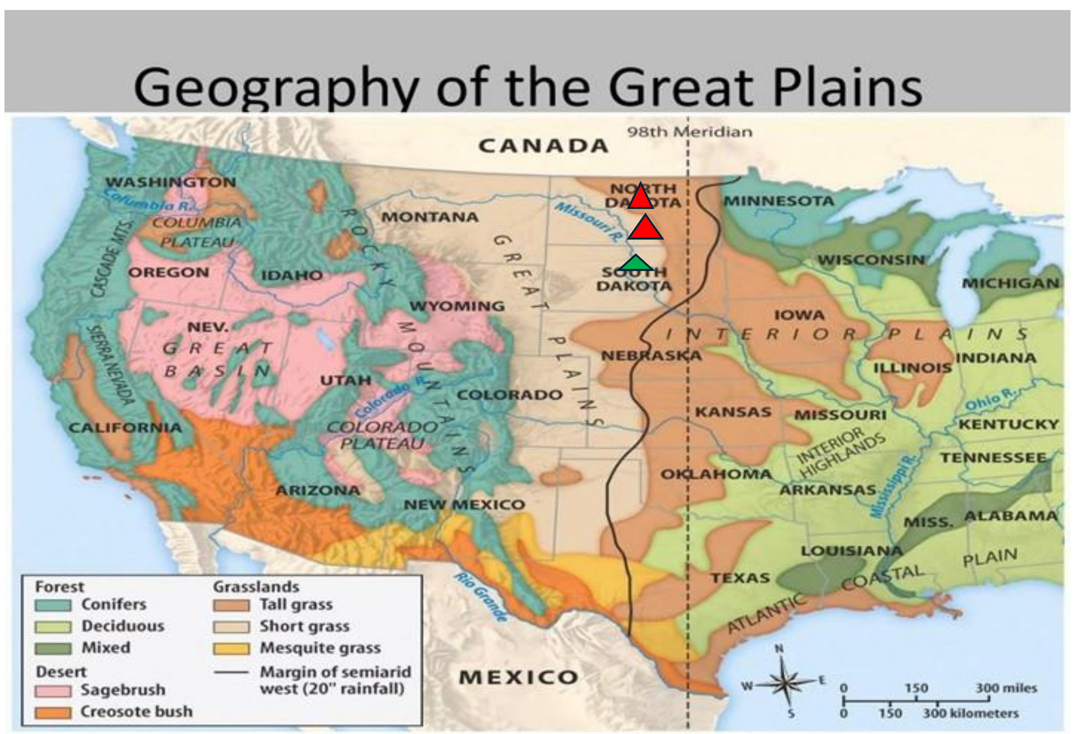

Figure 4.2. Vegetation zones in USA Great Plains (Sylvie 2014, used with permission).The short grass prairie zone roughly equates with the brown soil zone in Canada and the tall grass prairie would be similar to the black soil zone in Canada.

Figures 4.1 and 4.2 mark the approximate location of the various participants. Red triangles indicate the farm participants, and the green triangle signify the research agronomists.

4.4 The Story of Each Participant's Journey

Each participant and their farm are unique: they represent a wide range of soil types and zones, and, as such, they grow different crops based on their circumstances. However, they also share similarities. For example, each is an entrepreneur who must keep their business solvent and vibrant. The stories presented below provide a snapshot of their lives; however, as innovators they are unlikely to sit still for long, as they are continually searching for better ways to tackle the demands placed on their farms.

The stories presented in this chapter are the foundation for the data and understanding gleamed in this thesis. Indeed, after examining the participants' SFI scores (net emissions, profitability, and ability to produce), how these scores relate to their farms' Net Positive status (Chapter 5), and how they influence their BMPs as measured by BERT/E (Chapter 6), we can revisit their stories to further understand the complexities of their contexts and how they have woven a path to mitigating global warming.

Unlike Harari's characterization of homo sapiens as, "*irresponsible gods who don't know what they want,"* (Harari 2011, p. 2) these participants acknowledge the barriers to be overcome and are making progress towards a better world.

Narrative research can yield reams of testimony, transcription, and, ultimately, text. To solidify each farm in my mind, and to gain an appreciation of the diversity, context, challenges, and opportunities afforded to them, detailed summary descriptions were prepared and published in Appendices 4.5 and 4.6, along with their individual BERT/E adoption scores for the twelve proposed BMPs for mitigating AGW. I strongly recommend reading the full stories, as they enable a deeper appreciation of the participants' farms and practices.

The case descriptions are summarized in Tables 4.1 and 4.2, along with a few lines highlighting the most distinguishing features of each participant's farm.

4.5. Highlights of Participant Stories

4.5.1. Josh's Story: Lamb Farm

Josh farms 10,000 acres in the brown soil zone at Claresholm, Alberta with his parents, uncle, siblings, and cousins. They have dry land, irrigated land, and native pastures. They grow monoculture crops including spring and winter wheat, barley, oats, canola, and flax, as well as intercrops pea/mustard and flax/chickpeas. They have a 650-head cow herd.

The major practices (AGWM BMP) they use on the farm include:

1. Low-disturbance Zero Till to maximize moisture management and minimize soil erosion.
2. Continuous cropping with a medium level of cropping inputs to match their semi-arid dry land and their more productive irrigated cropland.
3. They have increased the use of legumes in their rotation, often as an intercrop component.
4. They add cover crops when moisture and time allow.

Their highest-rated AGWM BMP was lack of disturbance followed by keeping armor on the soil. These practices were accomplished primarily by using continuous cropping with low disturbance Zero Till.

4.5.2. Derek's Story

Derek and his wife, Tannis, along with their family and staff, farm about 11,000 acres in the brown soil zone at Minton, Saskatchewan, near the USA border. They work with relatives and neighbors to include cattle grazing on the farm. They also operate a value-added food-grade grain cleaning plant and a flour mill.

The major practices (AGWM BMP) they use on the farm include:

1. Low-disturbance Zero Till for maximizing moisture management and minimizing soil erosion. They use a disc drill.
2. Continuous cropping with negligible to very minimal cropping input.
3. They have increased the use of legumes in their rotation, often as an intercrop component.
4. They add cover crops when moisture and time allow. Cover cropping has decreased due to drought conditions in the past several years.
5. They have been using microbial inoculants and stimulants at seeding.
6. They use a stripper header where possible to help maximize water use efficiency.

Their highest-rated AGWM BMP was lack of disturbance followed by keeping armor on the soil. They are engaged in BMPs for alternative nitrogen and phosphorus, high diversity, agroecological solutions, and using as much sustainable intensification as they can. They have one of the first Green-on-Brown precision sprayers in Saskatchewan. The three main BMPs they were not actively pursuing were snow to snow crops, alternative fuels, and organic farming. They are one of the two Net Positive farms identified in this research.

4.5.3. Kelly's Story

Kelly and his wife, DeAnna, farm 2800 acres in the brown soil zone south of Minot, North Dakota, on hilly erosion-prone soils. Kelly is proud that he has left 600 acres of his farm as native wildland. Due to ongoing droughts, they have simplified their rotation to only include tall cereal crops that can be stripper harvested to maximise moisture retention. They are one of the two Net Positive farms identified in this study.

The major practices used on Kelly's farm include,

1. Low-disturbance Zero Till with a disc drill.
2. Primarily growing tall cereal crops to help manage moisture and maintain armor on the soil.
3. Adding a biological seed inoculant using their own IMOS (Indigenous Micro Organism System). After years of development, testing and using on their own farm, Kelly and Deanna now make this technology available to the public. The IMOS system is a seed inoculant that is prepared from productive "indigenous "nature microbes from untouched areas on your own farm. Kits are sold with training videos to demonstrate how to procure the initial microbes, how to multiply them, and how to treat the seed. Brewers and food for the microbes are also supplied.
4. They have not added synthetic nitrogen, manure, insecticides, or fungicides for up to 10 years on some fields and for 6 years on all fields.

Their highest adopted AGWM BMPs were lack of soil disturbance, keeping armor on the soil, conserving wildlands, using agroecological alternatives, and using alternatives to synthetic nitrogen.

4.5.4. Cliff's Story

Cliff along with his family, including his son and son-in-law, and hired hands farm about 7500 acres of cropland plus perennial forages for pasture. They used to run 1600 cows but have scaled back to 400. Their farm is near Hardisty, Alberta, in the dark brown soil zone. They grow wheat, oats, flax, peas, and canola, as well as some intercrops. This is the only farm to invest in soil health to enable full-season cover crops on 25% of their land. These acres are only lightly grazed. Their highest adopted AGWM BMPs were lack of soil disturbance, keeping armor on the soil, and using agroecological alternatives.

4.5.5. Brandon's Story

Brandon, his wife and kids, and a team of hired hands farm 5200 acres north of Minot, North Dakota, in the thin black soil zone. They practice regenerative Zero Till crop production and are regenified certified. Brandon relies on a low-disturbance Zero Till disc drill and planter to establish his crops. Whenever there is a wet year that triggers prevented plant acres, Brandon likes to establish full-season cover crops on those acres. He feels this approach provides a large boost in the pursuit of improved soil health. They grow a diverse range of crops, including spring and winter wheat, barley, corn, flax, yellow peas, sunflowers and a bit of durum and yellow mustard. He is experimenting with intercropping. Brandon uses a Johnson-Su seed inoculant to help improve the biological activity in his soil.

Brandon's highest rated AGWM BMPs were armor on the soil, lack of disturbance, keeping plants growing from snow to snow, having a diverse mix of crops, using legumes to replace synthetic nitrogen, using agroecological solutions to replace synthetic pesticides, and using sustainable intensification technology when it provides a good return.

4.5.6. Darren's Story

Darren and his wife and young children farm 3300 acres in the thin black soil zone at Deloraine, Manitoba. His dad also continues to help in the busy seasons. They practice regenerative Zero Till crop production. They use a low-disturbance Zero Till disc drill and a stripper header to maximize snow trap and manage available moisture. Darren grows a diverse range of crops, including spring wheat, fall rye, oats, canola, and yellow peas, and he occasionally includes flax, soybeans, perennial ryegrass, and hairy vetch. He has experimented with intercropping and cover crops, but he has decreased the number of acres devoted to this practice over the last few years due to lack of rainfall. He has tried to reduce his use of synthetic nitrogen and phosphorus but has found that going too fast in the reduction can be harmful to his bottom line.

Darren's highest rated AGWM BMPs were lack of disturbance, followed by armor on the soil. He uses legumes to replace some synthetic nitrogen, agroecological solutions to replace some synthetic pesticides, and sustainable intensification technology when it provides a good return.

4.5.7. Kristjan's Story

Kristjan has a large and expanding farm in the thin black soil zone. His farm was 30,000 acres at the time of our interview, and he added an additional 10,000 acres to it in 2024. Kristjan has several partners and roughly one employee for every 2000 to 2500 acres, and he also cooperates with his brother and father to supply some grazing opportunities. Although Kristjan's farm is one of the higher input farms in the study, he cites the study commissioned by the Centre for Global Food Security,(Bamber, Turner, and Pelletier 2022) which indicates that Saskatchewan farms have lower GHG emissions compared to exporting competitors, such as Europe, Australia, and the USA. Consequently, Kristjan uses higher rates of nitrogen and is not actively looking for alternative sources of nitrogen fertilizer. Kristjan uses precision banding hoe drills, which trade off disturbance for the ability to have one pass seed and fertilizing capacity. Kristjan finds hoe drills cheaper to run and more reliable than disc drills. He has a simple rotation based on wheat and canola, with inclusion of barley and peas from time to time. He does not sow cover crops. Kristjan is a refined version of the successful farms in much of the Prairies.

Kristjan's highest adopted AGWM BMPs were lack of soil disturbance, keeping armor on the soil, using as much sustainable intensification technology, and using recycled phosphorus—the only farm amongst the participants to primarily use this alternative fertilizer.

4.5.8. Ian's Story

Ian farms with his son, and with help from his brother and hired hands as needed. They farm in the thin black soil zone near Oxbow, Saskatchewan, and are the only organic farmers in the sample. They have 6185 acres, of which 5052 acres are cultivated. Of those acres, about 40% are used to grow green manure crops, which provide weed control and nitrogen. Ian does not have hay or pasture cattle. The remaining 1033 acres are left as wildlands. Ian's best cash crops are spring wheat, hemp, oats, and flax. He is not able to grow peas or lentils due to a buildup of root disease in his fields.

Ian's highest rated BMP was organic farming, with reliance on agroecology and alternative nitrogen. He also tries to include as much diversity as possible, as this helps to support natural beneficial insects and minimize plant diseases.

4.5.9. Dorian's Story: Rourke Farms

Dorian and her husband, John, farm 4000 acres at Minto, Manitoba, with her dad and hired hands as required. Dorian uses Zero Till crop production via three drills: a low-disturbance disc drill, a precision banding hoe drill, and a "just-in-case" drill, which can shallow cultivate and seed at the same time. This third drill is left over from their attempt at organic farming, but they hold onto it, as they know herbicide resistance is developing quickly and may put Zero Till in jeopardy. Thus, a minimum tillage alternative is necessary. Their farm can suffer from both drought and excess moisture. Each of these drills have their niche, but, if forced to choose, the precision drill is the mostly widely adopted option in the area. Dorian grows a diverse range of crops, including spring wheat, winter wheat, fall rye, barley, canola, soybeans, dry edible beans, and yellow peas, and she occasionally includes flax, sunflowers, oats, corn, perennial ryegrass, and hairy vetch. They have experimented with intercropping and cover crops; currently, cover crops tend to be the volunteers from the previous crop. The farm was Zero Tilled for over 35 years, prior to a 5-year stint with organic. It is currently transitioning back to a regenerative Zero Till farm, but it takes time to rebuild the microbial health of the soil. Dorian has used several biological seed inoculants to try to accelerate the transition.

Dorian's highest rated AGWM BMPs were lack of disturbance and armor on the soil. She uses legumes to replace some synthetic nitrogen, agroecological solutions to replace some synthetic pesticides, and sustainable intensification technology when it can provide a good return.

4.5.10. Michael's Story

Micheal and his young family, along with his parents, uncle, and hired hands (as needed), farm in the moist black soil zone near Melfort, Saskatchewan. Their soils are very fertile, with SOM at 7-8%. Their main drill is a precision banding hoe drill, but they also have a smaller disc drill for seeding forages and areas that are too small for the large drill. They farm about 3000 acres and run several side business: one involving carbon sequestration, one focusing on grain marketing, and another providing crop consulting services. They grow oats, wheat, barley, and canola, along with intercrops of canola/peas and peas/oats. They have recently added a diverse perennial forage phase into the annual cropping plan and are experimenting with fababeans. Michael does not have cattle, and he has not been able to find anyone to graze his forage crops. Thus, they are currently putting their forage crops up as hay.

Michael's highest rated AGWM BMP is armor on the soil, but he also uses legumes to replace some synthetic nitrogen. As a result, he uses about 20% less synthetic nitrogen than normally recommended for high yields. He uses agroecological solutions to replace some synthetic pesticides and sustainable intensification technology when it provides a good return.

4.5.11. Dan's Story

Dan farms the heavy gumbo soils of the Red River Valley with his dad in the moist black soil zone near Starbuck, Manitoba. Dan's ambition is to keep improving the soil. He uses a disc drill and Zero Tills as much as he can. Employing Zero Till on this soil can be a challenge, particularly in wet years. Dan farms about 3000 acres, and he also has a crop consulting/scouting business. About half of his land is devoted to cereals, including winter wheat, spring wheat, fall rye, oats, corn, and millet, while the other half is used to grow broadleaf crops including canola, soybeans, peas, and hairy vetch.

Dan's highest rated AGWM BMPs were armor on the soil and lack of disturbance. He looks for agroecological solutions rather than pesticides, and he is keen to embrace sustainable intensification tools. He is always trying to increase his nitrogen use efficiency, but, other than the addition of legumes, he has not found a good alternative for synthetic nitrogen fertilizers.

4.5.12. Rick's Story

Rick farms in the moist black soil zone of the Red River Valley. Apart from his sons, who help with the financial aspects of the business, Rick runs his farm and seed business with the help of a team of outside talent. He has two farms: the original at Gross Isle (6000 acres), and a new second farm NE of Gypsumville, Manitoba (6000 acres). Rick is a successful seed grower and retailer, and he also hosts EMILI, which is the Enterprise Machine Intelligence and Learning Initiative of Manitoba. Emili is in a group of innovative SMART farms. They are known as SMART due to their highly connected, digital-first approach to managing crops and livestock. Rick is an early adopter of precision farming and works tirelessly to improve his soil health and nitrogen-use efficiency. He Zero Tills where he can and is looking at strip tillage as way to optimize disturbance on his sticky clay soils. Continuous Zero Till is not practiced in the Red River Valley, as fall tillage allows for more flexibility on most farms in this area. Rick grows spring wheat, winter wheat, oats, barley, corn, peas, canola, and soybeans.

Rick's highest rated AGWM BMPs were armor on the soil, sustainable intensification, use of increased plant diversity, lack of soil disturbance and growing plants from snow to snow.

4.6 Research Agronomists

4.6.1. Sam's Story

Sam is the newly appointed manager of the Dakota Lakes Research Farm, which has been a steadfast innovator and promoter of no till (the USA version of Zero Till) farm practices for over 33 years. Dakota Lakes was started by Dr. Dwanye Beck, who is still active on the farm but is officially retired. The farm is located in the shortgrass prairie, brown soil zone SE of Pierre, South Dakota. The original purpose of the farm was to explore ways to increase moisture-use efficiency, both with irrigation and on dry land. Minimal disturbance no till is their method of cropping using either a disc drill for small grains or a one-pass no-till planter for corn. A major emphasis over the years has been optimizing crop rotations with warm/cool season broadleaf and grass crops. Recently Sam has been investigating the integration of cattle to improve soil health, as well as to recycle phosphorus before it leaves the farm.

Sam's highest rated AGWM BMPs were phosphorus management (Sam is also working on his PhD, which focuses on this practice), conservation of wildlands, and agroecological solutions. No till, as expressed in armor on the soil and lack of disturbance, is a given and has never been a research priority. The fact is tillage creates drought in this semi-arid environment. Sam is also continually looking for ways to increase diversity but is wary of using too much moisture trying to grow plants from snow to snow.

4.6.2. Richard's Story

Richard is an Associate Professor at the University of Saskatchewan and the Ministry of Agriculture Strategic Research Program Chair in Soil Biological Processes. Richard reflected that, in his first year at the U of S (1997), the sky was filled with dust from winds blowing over the tilled fields. As Zero Till has developed and become increasingly adopted, he no longer sees that kind of wind erosion of the soil.

Richard's highest rated AGWM BMPs were diversity, sustainable intensification (getting more out of the acres we currently farm), followed by lack of disturbance and armor on the soil. He was wary about the effort to find alternatives to synthetic nitrogen, but he was hopeful that research will yield new products and practices. Partial solutions can be found in 4R fertilizer management.

4.6.3. William's (Bill) Story

Bill has been a research scientist at Indian Head, Saskatchewan, since 1997. He says his program is a mile wide and an inch thick, but 99% of his research is based on Zero Till. The research station is in the thin black soil zone. Bill says if it can grow in Saskatchewan, he will have had it in his research. He has worked with all the cereal crops, oilseeds, and pulse crops, as well as spices, hemp, forages as well as some fruit crops.

Bill's highest rated AGWM BMPs were armor on the soil and lack of disturbance, followed by phosphorus management. Diversity was important to a degree, but Bill felt that too much diversity was unnecessary or even harmful. Plants growing from snow to snow were a concern for him in that the cash crops often needed all the available moisture. The other eight BMPs were of little interest to him.

4.6.4. Joanne's Story

Joanne is an Assistant Professor in Soil Chemistry and Fertility at the University of Manitoba. Her PhD focused on recycled phosphorus, and her previous research examined all things organic/natural systems, including small animal integration. Her work has encompassed a good range of soils and farms across Manitoba and SE Saskatchewan.

Joanne's highest rated AGWM BMPs were phosphorus management, organic farming, and diversity (three-way tie). Agroecology placed second, with plants from snow to snow, armor on the soil, and alternative nitrogen tied for third.

Chapter 5: The Triple Win, Sustainable Farm Index, and Net Positive Carbon Grain Farms

5.1. Introduction

In this chapter, I identify three components that must be balanced to ensure Northern Great Plains Grain farmers can help mitigate global warming, and I explain how the data obtained from the participants is used to determine their Sustainable Farm Index (SFI) score, which is a numerical expression of the Triple Win. The three datasets I used to achieve these objectives are presented in Table 5.1.

Table 5.1. Components of the Sustainable Farm Index and Triple Win.

SFI Component	**Triple Win component**
Contribution Margin $/ha	Support the Farmer
Crop Output kcal/ha	Feed the Cities/Meet the Demand
Emission Reduction and Sequestration kg CO_2/ ha	Heal the Planet

In addition, I describe the importance of each component and highlight the major factors that affect their value to society. To assist in this task, I use side bars (subsections) to illustrate some of the nuances, controversies, or opportunities related to each component. Net emissions data is employed to identify Net Positive farmers, which constitutes a significant finding of this thesis and serves as its central theme. These farmers' journeys to Net Positive farming is described in greater detail in Chapter 6. This chapter concludes by detailing the SFI's potential role in informing farmers of Triple Win opportunities available to their farms, and society's responsibility to ensure farmers have the necessary tools and resources to do their jobs. Finally, I emphasize the importance of society making decisions that ensure balance among the components of the Triple Win and SFI.

5.2. The Triple Win

The First Win: "Support the Farmers." It is critical to ensure that farmers are financially rewarded for the investment, labor, management, and risk required to run their farms successfully. Farmers receive income from many sources, including the traditional markets via the sale of food, feed, and fiber; the recent expanding market for biofuels and bioproducts; the emerging market for environmental goods and services, and occasionally government payments for crop insurance or

Agri-Stability payments. Private crop Insurance is also available for some farms e.g., GARS (Global AG Risk Solutions). Crop Insurance is vital to protecting farmers when calamity strikes (e.g., prices falling below the cost of production or crops failing). For some time, select farmers have received payments for environmental goods and services through programs and organizations such as the USDA Conservation Reserve Program (CRP), and the Alternative Land Use Service (ALUS) (Canada). Other sources of financial compensation for environmental goods and services include carbon credit offsets, inset trading. Crop Insurance, which is vital to protecting farmers when calamity strikes (e.g., prices falling below the cost of production or crops failing). Like anyone else, farmers want to feel appreciated, supported, and trusted. Significantly, acknowledging AGW and committing to being part of the solution are becoming increasingly important in building trust with the general public.

The Second Win: "Feed the Cities." This win, at least as articulated herein, can sometimes be controversial. In a perfect world, countries and cities would be able to feed themselves. There are a number of ways to ensure greater food self-sufficiency and food security, including eliminating food waste, reducing the use of corn to make ethanol, and converting vegetable oil into biofuels or grains into animal feed. Redistributing crop nutrients from countries in the Global North to those in the South would go great lengths to ensuring a more equitable regional food supply (MacLaren et al. 2022).

However, at present, only eight of the world's 196 countries are net exporters of food. The current global stock-to-use ratio is approximately 30% for wheat, 23% for coarse grains, and 31% for soybeans (Gervais 2023), which means that, at any time, the world has 110 (wheat), 84 (coarse grains), and 113 (soybeans) days of supply relative to demand. Significantly, these figures for wheat dipped to 16% not too long ago. Of the 30% wheat stock, half is stored in China for use in China, leaving the rest of the world with 15%, or 52 days of surplus. Furthermore, only half of the remaining stocks are available for trade, which works out to about 26 days of surplus (Glauber 2023). The potential threats of extreme weather and political turmoil make trade essential for minimizing the risk of famine. If this were a perfect world, the rest of the world would not need the surplus from Canada, the USA, and others, but, as of today, farmers in these countries remain critical to "feeding the cities." It is difficult to comprehend how much food it takes to feed megacities, such as Tokyo, which is home to 37 million people.

Side Bar 1: Feeding the Cities

As an example, Japan depends on imports for many food items. In 2021, Japan domestically produced 98% percent of rice consumed, but only 30% of its fruit, 76% of its vegetables, and 16% of its stock farm products. Further, Japan only produced 21% of soybeans consumed, 15% of wheat, and 11% of beef (Yoshikawa 2022). These statistics illustrate that some countries' have considerable dependence on food imports in addition to their domestic production. The way we think about farmers producing "food" has also changed, as they can now produce feedstocks for bioproducts, carbon credits, and environmental goods and services, in addition to food, feed, and fiber.

In the Japanese 2020 Basic Plan for Food, Agriculture and Rural Areas,(USDA 2020) the Ministry of Agriculture, Forestry, and Fisheries (MAFF) set goals to pull the country's self-sufficiency rate up to 45 percent on a calorie basis and 75 percent on a production value basis by 2030. In 2018, the calorie-based food self-sufficiency rating for Canada was 266%, 2.66 times what is needed domestically.

The Third Win: "Healing the Planet." The evolution of agricultural practices has allowed over 8 billion people to exist on Earth. However, today, agriculture is a key contributor to AGW. A primary objective of this study is to identify innovative farmer(s) who have found ways to cut their GHG emissions and become a part of the solution to AGW. At this point, it is worthwhile to consider how the agriculture industry has evolved not only to produce more food, but also to become a contributor to "healing the planet."

The world has relied on fossil fuels to leverage mankind's ingenuity and labor to levels considered impossible just a few decades ago. During the 1940s and the 1950s, famine was extensive. However, Norman Borlaug's Nobel-prize-winning work with wheat breeding to prevent stem rust and his development of high yielding semi-dwarf stature varieties helped usher in "The Green Revolution" and provided invaluable tools in the battle against famine (Vietmeyer 2004). Nonetheless, William Vogt, an ecological biologist and the Prophet in *The Wizard and The Prophet* Mann (2018), considered Borlaug's technology to be unsustainable. Vogt suggested that, although the use of better crop varieties and more fertilizer agriculture could feed more people, more people on Earth would lead to bigger collapses later. Borlaug's work was but the first step; we must now develop it further.

Despite the very serious challenges confronting us as a species, there is good news. In particular, human fertility rates are declining as women gain food security and become urbanized and more educated (Bricker and Ibbitson 2019). Undoubtedly, fewer people on Earth would reduce pressure on our ecosystems. Along with lower fertility rates, farm practices are evolving. When settlers converted the Western Canadian Prairies from grasslands to croplands, the tools available primarily consisted of plows, discs, cultivators, and rotation with summer fallow. However, when the droughts of the 1930s hit, crops failed, and the soil blew. In his book, *Men Against the Desert,* J. H. Gray(1967) explains that the effort to prevent the Pallister Triangle from becoming another human-made desert motivated the development of new tools and practices, such as lister seeders, noble bade cultivators, semi-deep furrow drills, strip cropping, and grassland restoration. The 1970s saw the introduction of Zero Till to mitigate erosion and replace summer fallow, using modern tools, including: glyphosate, straw, and chaff spreaders, Zero Till drill, and diverse crop rotations utilizing drought-tolerance legumes, such as peas, lentils, and chickpeas.

Table 5.2 shows the results of changes made by Richard Gray (agricultural economist, University of Saskatchewan) over the last 50 years on his family farm at Indian Head, Saskatchewan (Gray 2021). As can be seen, the changes implemented over this time period have resulted in a larger farm with a per-acre grain output 2.3 times the production of the farm in 1970. In addition, the significant reduction in the number of tractor hours led to less fuel used per hectare and, thus, lower fossil-fuel-based emissions. Notably, all of these gains were achieved without an increase in labor, while simultaneously expanding the diversity of crops and wildlife. Furthermore, the adoption of Zero Till practices has reduced soil erosion, which is a negative externality in cropping systems, and increased soil organic carbon (SOC) due to greater carbon sequestration. However, Gray acknowledges that they have significantly increased their use of nitrogen, and that the emissions from fossil-fuel-based nitrogen are a major negative externality that must still be addressed. Although not shown, pesticide use will also have increased. Typically, pesticides are less than 3% of the emission from wheat production in Western Canada whereas emissions associated with N fertilizer are approximately 65 to 85% for wheat (Wiens 2018). Nonetheless, the example of Gray's farm demonstrates their farm have become more efficient and productive.

Table 5.2. Evolution of farming practices on the Gray farm from 1970 to 2020 (Gray 2021, used with permission)

UNIVERSITY OF SASKATCHEWAN

Our family farm– Example Sustainable Intensification

Year	1970	2020
Land Area - acres	1040	3900 acres
Cropped Area Cropped	900	3600
Labour – Full Time Eq.	1.5	1.5
Yield per seeded acre	.9 tonnes	1.4 tonnes
Yield per cropped acre	.6 tonnes	1.4 tonnes
Total production (tonnes)	540	5000
Number of crops	Wheat/Barley	Wheat/Canola/peas/lentils
Tillage Summerfallow	45%	0%
Machinery-Tractor Hours	800 hours	200 hours
Soil Organic Matter	declining	increasing
Nitrogen per acre	Very little	.035 t/ acre
Wildlife Species		Moose, bear, beaver

Many farmers are doing a better job of protecting the soil, but a question remains, how well are we protecting our ecosystems? Emissions from the Canadian agriculture sector reached 49 Mt CO_2 eq in 2011 and grew to 55 Mt CO_2 eq in 2020 due to high-input crop production (Canada ECCC-NIR 2023). In 2021, emissions decreased to 54 Mt CO_2 due to a severe drought that led to a decrease in crop inputs on the Prairies. The 1990 levels, which provided the basis for the Kyoto Accord, were 41Mt CO_2eq. The Kyoto goal was a 5% reduction by 2012; instead, we recorded a 37% increase in 2021.

According to the National Inventory Report (NIR), 1991-2021, nitrogen is the primary driver of farm emissions (Canada ECCC 2022), and there is much work left to be done before farmers in Western Canada reach Net Positive carbon status. While it is true that Western Canadian farmers are producing products the world needs, it is critical that they continue to think about how they can slow the increase in atmospheric GHG levels and global temperatures. The UNIPCC calls for farmers, ranchers, and land managers to sequester carbon in the soil to increase SOC and wean us off fossil-fuel-based products, of which nitrogen and diesel fuels account for the majority in agricultural production systems. Fortunately, the practices required to improve soil health are the same as those required to sequester atmospheric CO_2.

To help move to the next level of sustainability, I will explore how the Triple Win can be expressed as a formula.

5.3. Sustainable Farm Index: A Look at the Components

The Triple Win calculation can also be called the Sustainability Farm Index (SFI). The SFI comprises three main values:

- Farm contribution margin ($/ha). Also called the "farming margin," this value is a measure of the farm's profitability before accounting for the cost of land, buildings, and financing. These additional costs are not included, as they are dependent on one's luck in terms of when one is born and to whom.
- Production output (kcal/ha). This value represents the overall farm production. Here, kg of product grown is converted to kcal to account for the differences in the energy densities of various crops. For instance, wheat is approximately 3500 kcal/kg, whereas canola is 5300 kcal/kg.
- Emissions (kg CO_2eq/ ha). Emissions are calculated by inputting the data supplied by the participants into the AAFC-Holos emissions calculator to obtain a snapshot of each farm's GHG emissions. The AAFC-Holos calculator is often used to run various scenarios on the same farm to reduce emissions. Net emissions can then be determined by subtracting the carbon sequestered in the soil from the farm's total emissions. Net emissions were calculated using a variety of soil organic carbon change (SOCC) estimates, including:
    - The built-in Holos SOCC calculator, which is based on cropping systems changes starting as far back as 1985.
    - SOCC, as measured by the Prairie Soil Carbon Balance Project (PSCB) (McConkey et al. 2020).
    - Participants' estimation of SOCC from soil tests taken over time.
    - A meta-analysis of SOCC converting from tilled to Zero Till (West and Post 2002)
    - The Global Institute for Food Security study (Bamber et al.2022)

The SOCC was excluded from the SFI calculations due to the latter's emphasis on reducing emissions. Farmers have the opportunity to sequester carbon, but SOCC is difficult to measure, especially in the short term. It is affected by many factors, including the initial SOM, tillage, crop rotation, fertility, biomass, rooting systems, soil and ambient temperatures, sampling, presence of fresh roots, method of analysis, bulk density changes and moisture availability. Emissions are simpler to estimate and are largely influenced by the amount of fossil-fuel-based products used on the farm, primarily nitrogen fertilizer and diesel fuel. Many groups are working to improve SOCC measurements. It is challenging, especially in the short term.

5.3.1. Emissions: The Denominator of SFI

This section introduces and considers various calculations for emissions, SOCC, and net emissions.

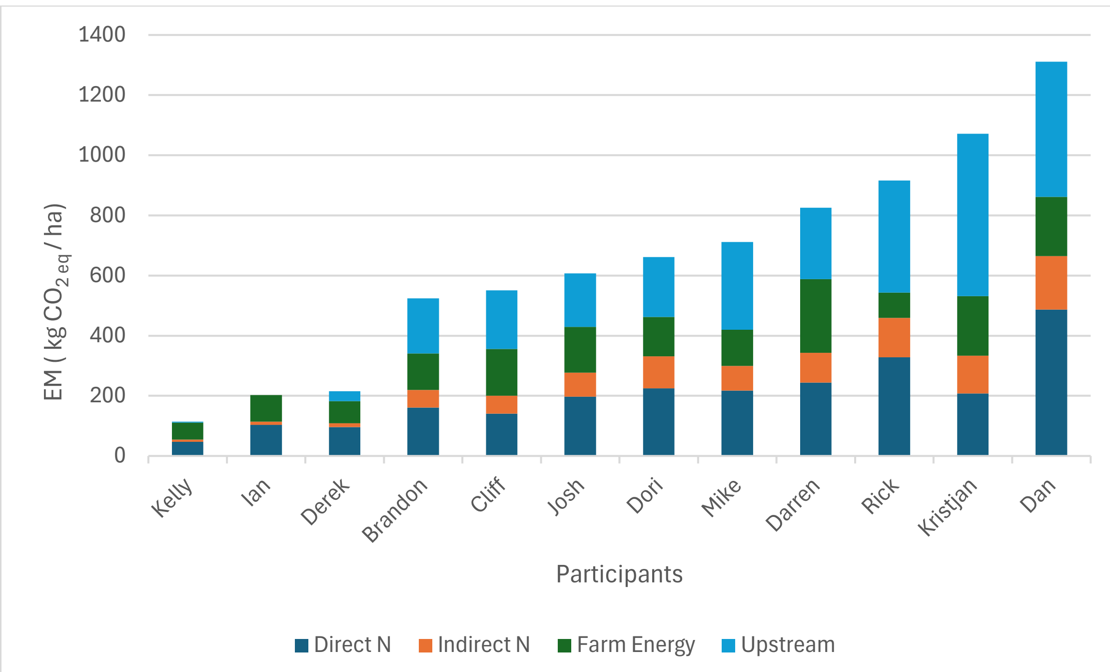

Figure 5.1. Farm green house gas emissions (EM) (kg CO_{2eq}/ha) as calculated using the AAFC Holos calculator.

The figure shows the major sources of grain farm GHG emissions; other emissions sources (not shown), such as pesticides, seed, and machinery, account for less than 3-5% of the total.

Grain farms produce four main types of emissions: direct N_2O emissions, which consist of the N_2O released from applied nitrogen or crop residues (for example a sweet clover plow down followed by a large rain); indirect emissions, which are produced by nitrogen that leaves the fields via leaching, runoff, or volatilization; farm energy emissions, which are primarily generated from burning diesel fuel, natural gas, and gasoline in farm equipment; and, finally, upstream emissions, which are created by the production and delivery of farm inputs, such as fertilizer, seed, pesticides, and machinery. These emissions comprise the data used for the net emissions calculation and the Sustainable Farm Index calculation.

The participants' farms differed vastly in their emissions. Dan used the highest amount of fossil-fuel-based products, with emission of about 1300 kg CO_2eq/ha, while Kelly's emissions were the lowest at 108 kg CO_2eq/ha—a twelve-fold difference. The three participants with the lowest fossil-fuel-based product use and emissions were Kelly, Derek, and Ian.

Side Bar 2: Per ha or Per kcal. What is the difference?

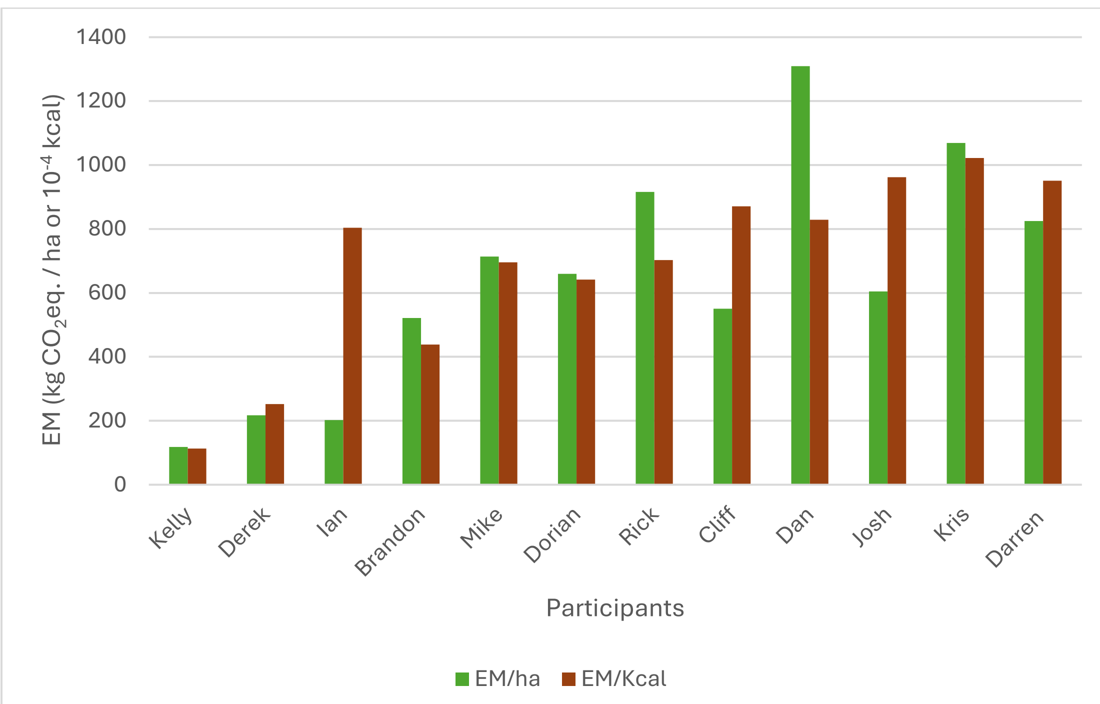

Figure 5.2. Farm greenhouse gas emissions (EM) per hectare compared with the emissions/kcal x 10^4 of production output.

This calculated using Holos based on the participant data. EM/ha = Holos calculated emissions/ha, EM/kcal = Holos calculated emissions/ 10^4kcal of farm output.

As shown in Figure 5.2, farms with a high kcal output tend to have lower emissions/kcal. That is, crops with a higher kcal/ha, either due to high yields (e.g., corn) or high energy density (e.g., canola), typically have lower emissions/kcal. This is known as a dilution effect. Dan is a good example of this principle, as his emissions/ha are higher than his emissions/kcal. This result is largely due to his location in the high-yielding Red River Valley, and his decision to grow corn, canola, and, to a lesser degree, soybeans. Soybeans have less oil content than canola, but more than wheat. Oilseed crops have higher kcal/kg. Rick's output was similar to Dan's, while Ian's organic farm had the highest emissions/kcal relative to his emissions/ha.

Conversely, Derek and Kelly had the lowest emissions/ha and emissions/kcal, while Kristjan had some of the highest. However, Kristjan believes that, compared to the rest of the world, Western Canada's production emissions are low, an opinion which is supported by a study commissioned by the Global Institute for Food Security (GIFS) (Bamber et al. 2022). Kristjan thinks that Western Canadian farmers should continue to strive to produce the largest crops with as little emissions/kg as possible, as this is better than scaling back production and giving high-emissions countries the opportunity to supply the market with their high-emissions products. While this is a practical approach (and likely the most profitable at present), it is not compatible with achieving net zero by 2050 or Net Positive grain farming. Kristjan's approach hits two components of the SFI—it supports the farmer and feeds the demand—but it is less aligned with healing the planet.

Some organizations, such as the GIFS (Global Institute for Food Security) and Fertilizer Canada express emissions in terms of unit of output rather than per hectare. For instance, using unit of output will make farms that produce more output/hectare look proportionately better compared to lower-output producers. However, changing the unit of measurement is ultimately a distraction, as it does not change the volume of emissions.

In their recent carbon footprint study, GIFS (Bamber et al. 2022) calculated carbon footprints in CO_2eq/kg (not /ha nor /kcal). In this study, the net emissions calculated for the average Saskatchewan farm were 0.372, 0.214, and 0.04 kg CO_{2eq}/kg for canola, wheat, and pea yields of 2118 kg/ha, 2986 kg/ha, and 2235 kg/ha, respectively. These figures can be converted using ((2118 × .372 + 2986 × .214 + 2235 × 0.04)/3 = 505 Kg CO_{2eq}/ha), which is consistent with lower-nitrogen-using participant farms that include legumes in their rotations. Using the GIFS approach, Josh, Cliff, Dorian, and Brandon's farms would all be considered Net Positive, while farms that use a lot of nitrogen (i.e., Dan, Kristjan, and Rick) would have higher average emissions compared to the GIFS averages. The GIFS report concludes that Saskatchewan's crop emissions are only 50% of the global values for canola, 39% for wheat, and 13% for peas. The GIFS study results suggest that the farms and the results obtained in this thesis are representative of a wide cross section of farmers, and they indicate that the participants' emissions are below the Saskatchewan averages (Kristjan's emissions would be higher than the GIFS average, but this is mostly due to the lack of legumes in his current rotation).

While lower emissions/kg of output can be a desirable goal we still need to reduce total emissions.

Side Bar 3: Cattle on a Grain Farm?

Figure 5.3 shows the impacts of having cattle on one's farm. The illustrated results align with the scientific consensus that beef production is a negative in terms of emissions.

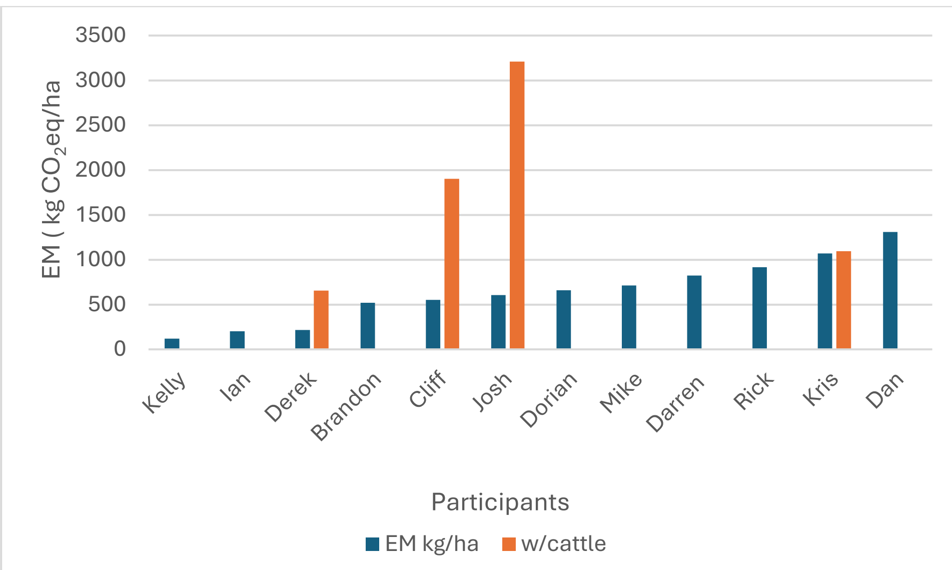

Figure 5.3. Effect of the addition of cattle on Holos calculated emissions (kg CO_2eq/ha).

EM kg/ha = Holos calculated emissions expressed as kg CO_2eq/ha. W/cattle = Holos calculated emissions when cattle are included on the various participant farms.

Josh and his family run about 650 cows and keep their yearlings for backgrounding. Despite their grain farm being 7000 acres, the addition of cattle according to the current Holos model raises their emissions from approximately 600 kg CO_2eq/ha to approximately 3200kg CO_2eq/ha—a five-fold increase. I largely tried to avoid including cattle in this project because the science of cattle emissions may not be as clear as expected. Most scientists agree that cattle increase emissions, but there are some who contend that methane created by a cow should not be treated the same way as methane from an oil well, as the former is part of the biogenic carbon cycle whereas the latter is not (Werth 2020). The cyclical model (vs. a linear release model) captures the way in which a well-managed grass-fed beef operation can positively affect SOC in pastures, thereby changing the emissions outlook from negative to positive.

Cliff is similar to Josh. He used to have a herd of 1600 cows and yearlings but has since reduced it to 400 due to the challenging economics of cattle farming. At the time of our interview, Cliff said he is trying to utilize their pastureland for cows while maintaining cropland for crops. Among the other participants, Derek has entered into long-term custom grazing arrangements, while Kristjan allows his brother's cattle to graze on stubble and volunteer growth on his cropland, as well as along the fence lines and in the natural areas. Overall, the emissions calculated via Holos were small compared to the overall size of Kristjan's and Derek's farm. The addition of cattle only increased Kristjan's emissions by 2% (1070 kg CO_{2eq}/ha grain only vs 1094kgCO_{2eq}/ha with cattle).

The world has approximately 3.4 billion hectares of grazing land but only 1.1 billion hectares of cropland. As farmers, we will have to ensure that we manage ruminants in a manner that improves carbon sequestration and enables the production of nutritious food with minimal emissions. However, as such considerations fall outside the scope of this thesis, they will not be considered further in this work.

Side Bar 4: Value of Old Trees and Water

Accounting for carbon sequestration on unfarmed acres may also be an important part of calculating net emissions on many farms. Of the participants in this study, Ian was particularly interested in the potential for carbon sequestration on his 459 hectares of wild lands.

Table 5.3. Effect of net carbon sequestration from wildlands on net farm emissions on Ian's farm.

Type of Wildland	Wildland Area (ha)	SOCC (t CO_2eq./ha)	Net Sequestration (t CO_2eq.)	Grainland Area (ha)	Total Wildland Net Sequestration/ Grainland Area
Wetland	34	2.5	85		
Seasonal Wetlands	196	2.5	490		
Trees	148	6.24	923		

Grassland/ Old Yards	81	2.1	169		
Total	459		1,667	2044	816 kg CO_2/ha*

Table Note: Wildland carbon advantage averaged over cropland.

Table 5.3 shows the area of wetlands, trees, and grasslands along with the estimated net carbon sequestration for each zone. Ian says he chose to protect the wildlands on his farm because they provide diverse habitats for soil biology, insects, birds, and many mammals, including gophers, deer, and moose. In addition, predators such as badgers, coyotes, and foxes also frequent these areas. Ian is not currently receiving any payment to preserve his wildlands. These uncultivated lands also capture and filter water (thereby keeping the water table charged), help prevent erosion from wind and water and accumulate and store carbon. In this work, carbon sequestration was estimated based on a Ducks Unlimited Canada study (Badiou 2016). However, since net carbon sequestration data varied widely between studies, values in the mid-range were chosen for the present analysis. The potential amount of sequestration for Ian's farm was calculated to be 1,667 t CO_2eq. It is important to note that such calculations are not intended to provide an exact value for a highly variable natural system; rather, they are intended to demonstrate that these wild lands have value, though how much remains an open question. Furthermore, it remains unclear whether society will recognize the value of natural sequestration and compensate farmers for conservation and carbon sequestration and/or diversity, either through higher taxes or food prices. If so, will carbon be valued at $5/t, $50/t, or $100/t? For example, 1667 t at $100/t works out to $166,700, a sum that would definitely give farmers pause when deciding whether to drain and clear wildlands on their property. However, the government may also find it cheaper to ban conversion and pay for enforcement.

Wildlands are valuable in offsetting emissions; 816 kg CO_2/ha of CO_2 sequestration would allow Ian to become Net Positive with room to spare. But how much wildland would be required to offset emissions from other farms? As food companies look to become net zero within their own operations (Scope 1 and 2 emissions) and their supply chains (Scope 3 emissions), wildlands will be a critical carbon sink worth examining. Treed lands appear to provide the largest benefit at roughly 6000 kg CO_2eq/ha; conversely, wetlands sequester up to 9900 kg CO_2eq/ha but emit CH_4 at 7200 kg CO_2eq/ha for a net gain of 2500 kg CO_2eq/ha. It will be up to society to determine how these areas are valued.

Side Bar 5: The Power and Problem of Fossil Fuel

Diesel fuel and nitrogen fertilizers are two of the largest sources of farm emissions.

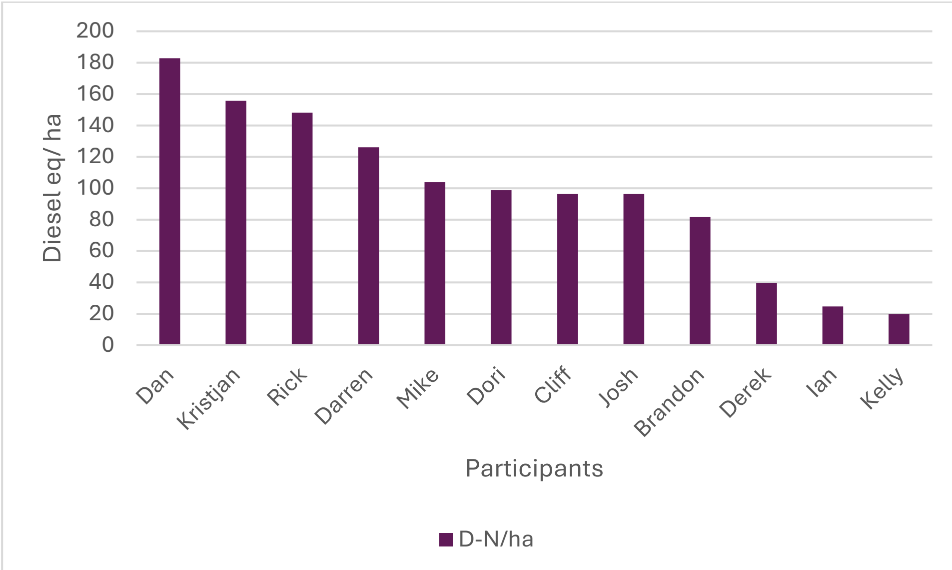

Figure 5.4. Farm energy input from nitrogen and diesel fuel (diesel fuel equivalents/ha) on the participant 's farms.

This data only captures on-farm fuel use for grain production and does not account for fuel used to deliver the grain to elevator points.

The data in Figure 5.4 are expressed as diesel equivalent in liters/ha. As can be seen, Dan used the most fossil-fuel-based products at 183 l/ha, while Kelly used the fewest at 20 l/ha, a nearly ten-fold difference. The calculations used to determine the values in Figure 5.4 were based on one kg of nitrogen requiring an equivalent energy of 1 liter of diesel fuel for the basic Haber-Bosch manufacturing process ($diesel_{eq}$/hectare = liters of diesel/ha + kg/ ha of N x 1 liter of diesel eq/kg of N) (Noelker and Ruether 2011). The 1-liter diesel fuel eq/kg of N value is about one half the current industry average of 2 liters/kg of N produced. The smaller number does not account for storage, transportation, and application; however it has been suggested as a target for small on-farm NH_3 plants using electric-powered hydrolysis (FuelPositive 2022). If the higher number is used, Dan's diesel eq would rise from 183 l/ha to 326 l diesel eq/ha. Kelly would stay at 20 l diesel eq/ha. Nitrogen and diesel fuel inputs can also be converted to kcal/ha at a rate of 8700 kcal/liter of diesel fuel. We will see later how this is related to grain production (Figure 5.13).

5.3.2. Net Emissions : Emissions Minus Carbon Sequestration

This section presents the first of several calculations of net emissions. While the Holos emissions calculations were constant for each farm, the SOCC, which represents the carbon sequestered in the soil, was dependent on the source of the data. Several sources were used to show the range of estimates.

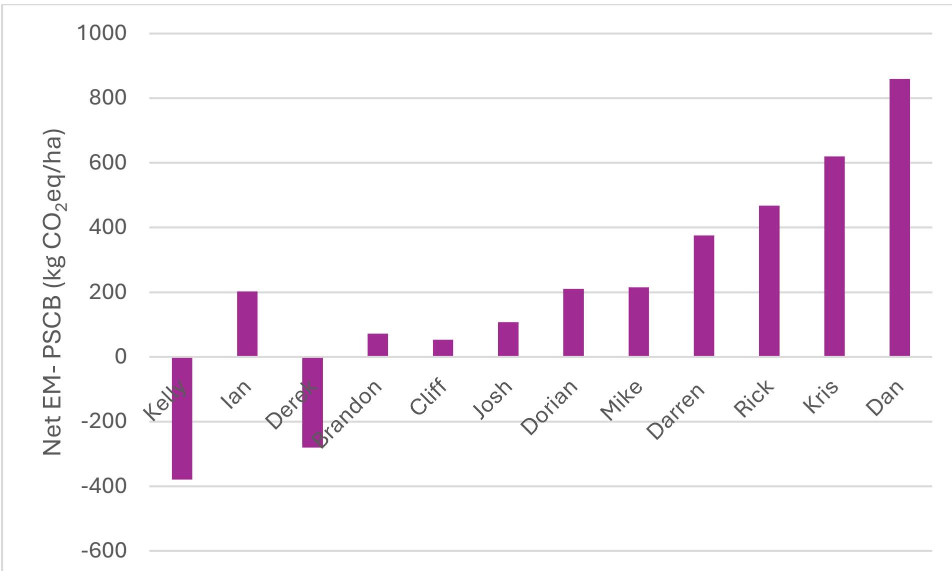

Figure 5.5. Net farm greenhouse emissions (EM-soil organic carbon change [SOCC] when SOCC from PSCB is used (kg CO_2eq/ha).

In this calculation, the SOCC value was derived from a 21-year prairie soil carbon balance (PSCB) study (McConkey et al. 2020). An average SOCC-PSCB of 449 kg CO_2/ha was calculated for farms in the more humid black and dark brown soil zones, and an average SOCC-PSCB of 498 kg CO_2/ha was obtained for the more arid brown soil zones. The values used above are derived from derived from Table 7 of the PSCB report. The mathematics used to convert Mg C/ha values in the table to kg CO_2/ha.is described next. The 1996 to 2018 period was chosen from the data, it was twenty-one crops between samplings. The data from sampling depth 0 - 39 cm. was used. The semi-arid locations had an SOCC of 2.85 Mg/ha. This figure was then multiplied by 1000 to obtain the kg/ha and then divided by 21 crops to equal 135.7 kg SOC/ha/year. This value was then multiplied by 3.67 (mol wt. CO_2, 44g/mol, /Mot wt. C, 12 g/mol) to obtain a final value of 498 kg CO_2/ha stored in the soil. A value of 449kg CO_2/ha was obtained for the sub-humid regions using similar calculations.

A notable exception to the carbon sequestration credit and the resultant carbon emission calculation for participants is that Ian did not receive a credit. This is due to the fact he did not note an increase in SOM over 38 years (see Figure 5.9) even though he utilizes alfalfa to help maintain available N and SOM. This may be explained due to his need to till the soil to kill weeds and mineralize stored nitrogen as an organic farmer. Given these practices, his self-reporting of SOM change, and since a PSCB credit is associated with a predominant change to Zero Till, fertilizer use and continuous cropping the decision was made to not subtract 449 kg CO_2eg/ha from Ian's emissions calculation. This decision is also supported by research at the long term Glenlea trial where similar practices to Ian's are utilized and whose results do not report much of an increase in SOM (Bell et al. 2012). Of course, if the PSCB value of 449 kg CO_2eg/ha was subtracted from Ian's emission he would be Net Positive, at a value of -249 kgCO_2eq/ha.

Kelly and Derek qualify as Net Positive according to these calculations. This is a major milestone, as it identifies a potential gateway to achieving the 2050 goal of net zero and Net Positive Carbon Grain Farming in Western Canada and the Northern Great Plains.

In a subsequent analysis of a smaller subset (n=20) of the original PSCB data, St. Luce et al. (2024) found that soils exposed to continuous cropping and direct seeding for twenty-one crops doubled their CO_2 storage to 1027 kg CO_2/ha/year. Here, the authors used a sampling depth of 0-30 cm, compared to the earlier report, which used a sampling depth of 0-39 cm and included fields where the use of direct seeding and continuous cropping was less consistent (n=43). This second analysis focused on semi-arid sites only. The PSCB project methods show that bulk density differences were used in the calculation of the SOC at each site. A more precise discussion of methods for SOC determinations can be found in Ellert and Bettany (1995) and McBratney and Minasny (2020).

Side Bar 6: SOCC-Participant Data

Figure 5.6 shows the results of the net emissions calculations using the participants' SOCC estimates.

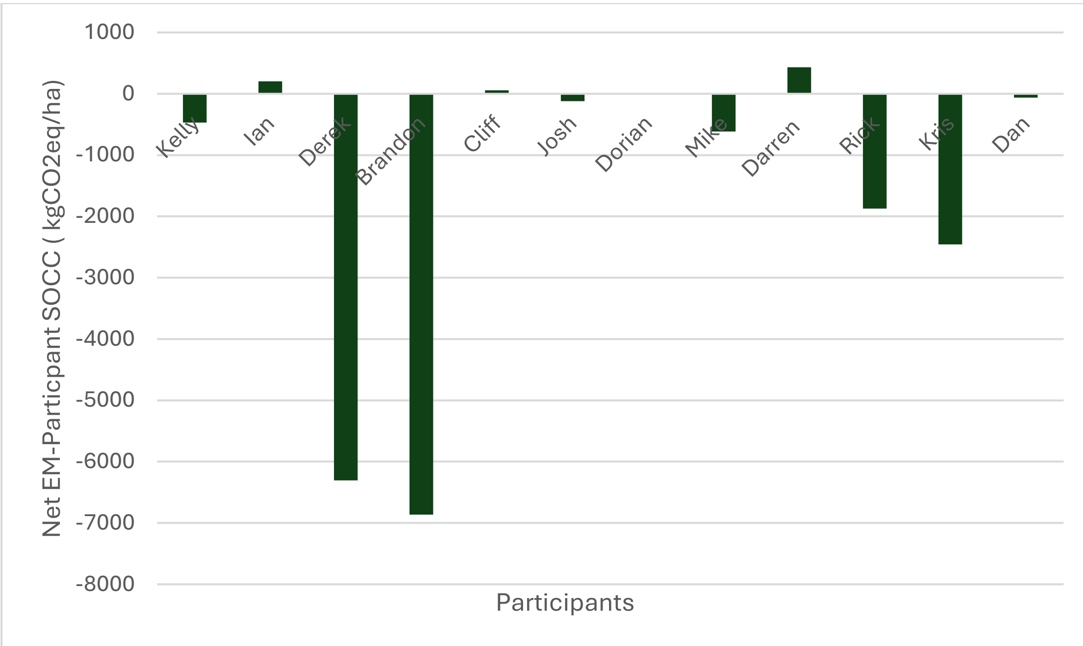

Figure 5.6. Net farm greenhouse gas emissions (kg CO_2/ha) using participant estimates of soil organic carbon change (SOCC).

Both Derek and Brandon have had extensive soil testing performed by a third party, the Regenified Organization. The Regenified Organization's 6-34 Verification standard can be found on Regenified .com. Since base levels were not established 20 years ago, it is likely that intensive across the fence line comparisons were used. There was no attempt to verify the SOCC estimated given by the participants. One of the goals on Kristjan's farm is to use the CANZA, (Canadian Alliance for Net Zero Agriculture), group to help develop tools to make SOCC estimated faster, cheaper, and more actuate, which has long been a goal of many organizations.

Net emissions are expressed in kg CO_2/ha and were calculated using Holos minus the participants' self-reported SOCC data. If the high SOCC change estimates are taken at face value, Brandon, Dorian, Mike, Rick, Kristjan, Kelley, and Derek's farms could be considered Net Positive, with most of the remaining eight participants also being close to the Net Positive threshold. The participants' SOCC levels were largely determined based on the results of commercial soil tests designed to assess nutrient content, although these tests also included SOM. In addition, these tests generally made no allowances for bulk density change over time, and the time frames used for SOCC varied between farms. Therefore, I used the available data to calculate the rate of change on an annual basis.

Roland Kröebel (AAFC-Lethbridge; 2024) suggests that it is very difficult to be Net Positive while using any significant amount of nitrogen. He says that the release of only a small amount of N_2O due to the use of nitrogen requires a multiplication factor of approximately 300 to calculate CO_2eq emissions. Kröebel says the global rule of thumb is that the application of 100 kg of nitrogen per hectare releases 1.5% or 1.5 kg/ha of N_2O, which, when multiplied by 300, works out to 450 CO_2eq/ha. Manitoba Agriculture suggests that, in Western Canada, the conversion of fertilizer nitrogen to N_2O may be just over 1% (Wiens 2018). Therefore, Western Canadian emissions from nitrogen may be lower than the global average.

The use of the 4Rs could further reduce emissions potential, thus resulting in more Net Positive farms. The use of the 4Rs is estimated to reduce emissions from nitrogen fertilizer use by at least 30% without any negative impact on yields (Tenuta et al. 2023; Thilakarathna et al. 2020). Kristjan, Rick, Dan, Mike, Darren, and Dorian use variable-rate fertilizer application to optimize the rate per zone and obtain better value for their nitrogen expenditure. Research is still being conducted to ensure that farmers are applying the right rate per zone (Glenn et al. 2021). Some participants used treated urea to reduce emissions; however, paying premiums for enhanced efficiency nitrogen products can be a tough decision for farmer, as these fertilizers cost more but do not always produce a positive ROI, return on investment (Tenuta et al. 2023).

I did not include grain drying emissions from the calculations. Grain drying and specifically drying of corn was only done on the two Red River Vally farms. Brandon who also grows corn has found more natural ways to handle excess moisture in harvested corn. Thus, there are non fossil fuel based drying options available. See Side Bar 11 for more details.

Due to the inability to accurately verify the participants' self-reported SOCC data, caution must be used when considering their Net Positive ratings without more knowledge about their soils, their practices, and their soil testing methods. One caution in trying to measure SOC is the confounding problem of fresh root mass in the sample. One must be very careful to exclude fresh or undecayed roots from the sample for a true reading of SOC.

Side Bar 7: SOCC-Holos

Figure 5.7 shows each participant's net emissions when SOCC is calculated using Holos.

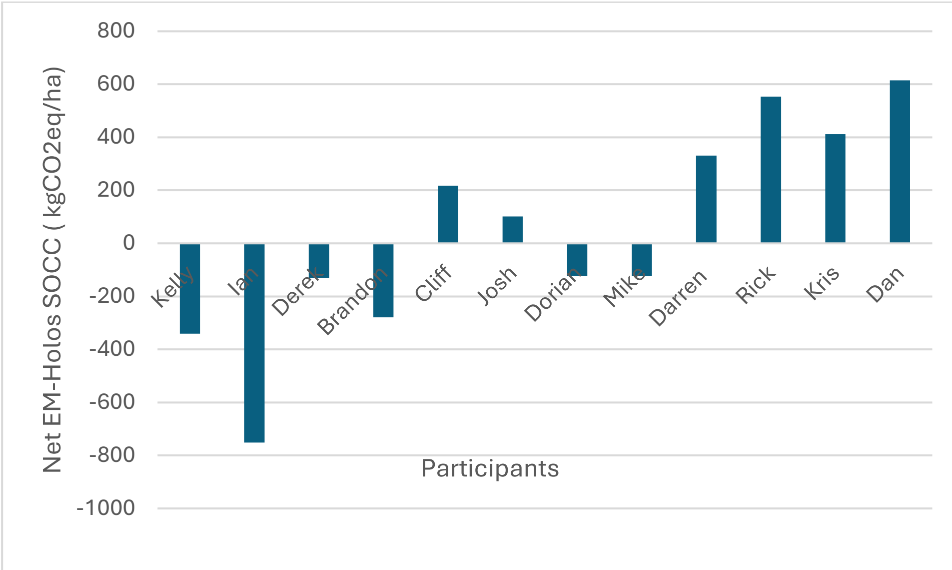

Figure 5.7. Net farm greenhouse gas emissions (kg CO_2eq/ha) calculated using Holos estimated SOCC for each of the twelve participating farms.

Figure 5.7 shows a third accounting of the net emissions based on the Holos-calculated emissions minus the Holos-calculated SOCC values. A description of how Holos was used to estimate SOCC is given in Appendix 3.8. The net emission results are intermediate compared to the previous calculations with one exception: Ian's organic farm was highly Net Positive. While Ian allocates up to 40% of his land to alfalfa and green manure crops (a positive factor for carbon sequestration) and uses much less tillage than many organic farms, he still uses tillage, which is a negative factor in building SOC. Ian also said that he does not think his SOC has changed at all during his 38 years of organic farming. Maintaining SOC without any appreciable addition of manure over that length of time would be considered by many to be a major feat in organic farming in a dry land situation. If Holos is correct, six of the farms in my sample are Net Positive. However, as stated above, Kröebel would likely doubt whether Brandon, Dorian, or Mike's farms could be Net Positive because they use moderate rates of nitrogen fertilizers, which triggers N_2O and higher CO_2eq/ha emissions.

A soil health update of the Glenlea long-term organic study at the University of Manitoba was presented at the 2019 Summit on Canadian Soil Health (Entz 2019). The reported findings indicated that a non-manured organic cropping system including perennials, similar to Ian's farm, could realize an increase in SOC of 200-400 kg C/ha over 10 years. Converting these figures to kg CO_2eq/ha/year would yield 73-146 kg CO_2eq/ha/year. These findings do not appear to support the Holos numbers used in the Holos net emissions figure. The Holos estimate of SOCC for Ian's farm was approximately 900 kg CO_2eq/ha. The discussion of wildlands in Side Bar 4 indicated that Ian's farm (Table 5.4) could potentially provide 819 kg CO_2/ha of extra carbon sequestration, which would qualify him as Net Positive (if wildland sequestration is included). Without the inclusion of wildlands, his farm would likely not be Net Positive.

Side Bar 8: Cross-Checking for Net Emissions

The data obtained from Kelly and Kristjan were entered into a second emissions calculator to cross-check the Holos emissions results. For this task, I selected the Cool Farm Tools (CFT) emissions calculator, as it is globally accepted and supported (The Cool Farm 2024). However, it uses more defaults than Holos due to not requiring specific land locations. It is quick and easy to use. Since Holos is specific to Canada, I needed to pick two surrogate sites with similar soil types and soil zones in Canada to be the basis for using the two North Dakota sites included in the thesis. Kelly's farm is in the North Dakota short grass prairie (brown soil zone). Derek's brown soil zone site was used as the surrogate site for Kelly. Brandon's farm (used elsewhere in the thesis) is on North Dakota tall grass prairie (black soil zone). Darren's thin black soil zone site was used the surrogate. The two calculators were used to compare the net emissions for Kristjan and Kelly's farms, with the results being shown in Table 5.4.

Table 5.4. Comparison of the Holos and Cool Farm Tools emissions calculators.

Farm	**Net Emissions**	**Net Emissions**	**Net Emissions**	**Net Emissions**
Model	Cool Farm Tools	Holos-Holos	Holos-PSCB	Holos-Participant Estimate
	kg CO_2/ ha	kg CO_2/ ha	kg CO_2/ ha	kg CO_2/ ha
Kris	1090	600	1100	-2300
Kelly	-148	-390	400	400

The negative numbers in the table represent Net Positive results. Although there is variance in the results, they are of the same magnitude, barring a few exceptions. Perhaps the most notable of these exceptions is the net emissions results obtained using Kristjan's self-reported SOCC estimate. Furthermore, whereas the CFT calculator seems to underestimate Kelly's Net Positive value, the Holos calculator appears to greatly overestimate Kristjan's Net Positive value when using his self-reported SOCC values. The results obtained using the Holos calculator alongside the PSCB project's SOCC and emissions values aligned best with those obtained using the CFT calculator.

Side Bar 9: SOM vs SOC

Throughout this work, I discuss soil organic matter (SOM) and soil organic carbon (SOC), which are both key elements related to carbon sequestration. SOM is approximately 58% carbon and can be measured via standard soil tests. The conversion number can vary with soil type, soil depth and type of organic matter and be as low as 40% (Pulske, Murphy, and Sheppard 2025) For the purposes of this thesis SOM x .58 = SOC.

There is much controversy surrounding SOC and SOCC, including the possible rate of increase that could be achieved and how well the SOC will stay in the soil, especially as the climate warms. Figure 5.10 shows the initial SOM estimates provided by each participant, which were based on standard soil testing conducted at various time points.

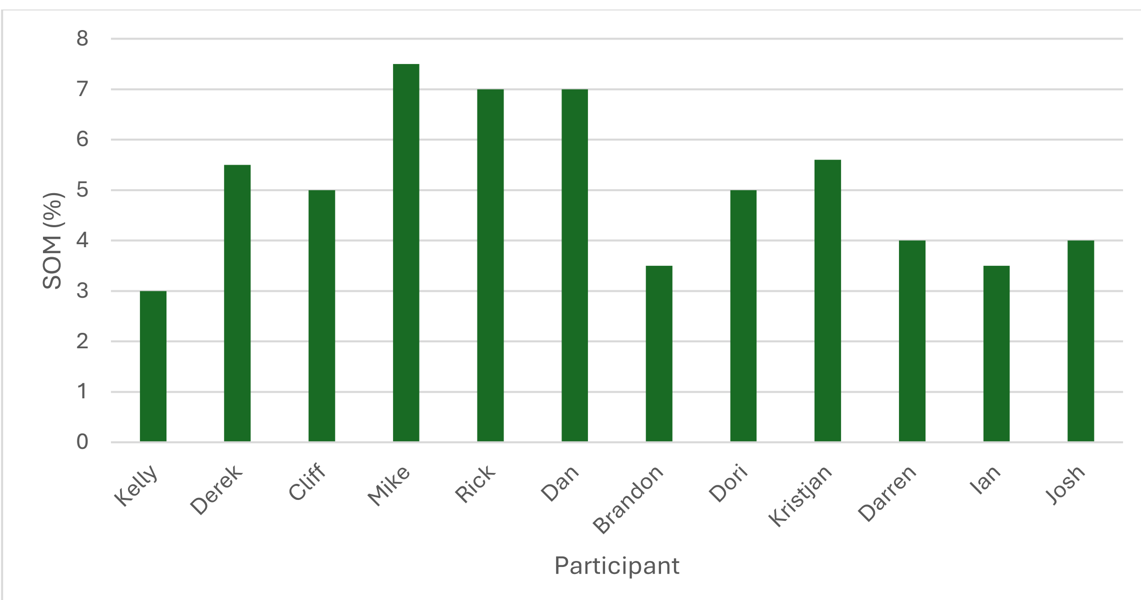

Figure 5.8. Current estimated soil organic matter (SOM%) levels for each participant farm.

As shown in Figure 5.8, farmers in the wettest areas (i.e., black, or moist black soil zones) of the Prairies reported the highest SOM levels (Mike, Rick, and Dan), while farms in the driest areas (i.e., brown soil zone) reported the lower SOM (Kelly, Josh).

The participants were also asked to estimate, to the best of their ability, how the adoption of new practices had impacted the SOM on their farms. Some (Mike, Derek, and Brandon) measured change over a period of 2 to10 years, while others (Kelly, Dan, Josh, Dorian, Cliff, and Darren) used data acquired over a10-to-20-year period.

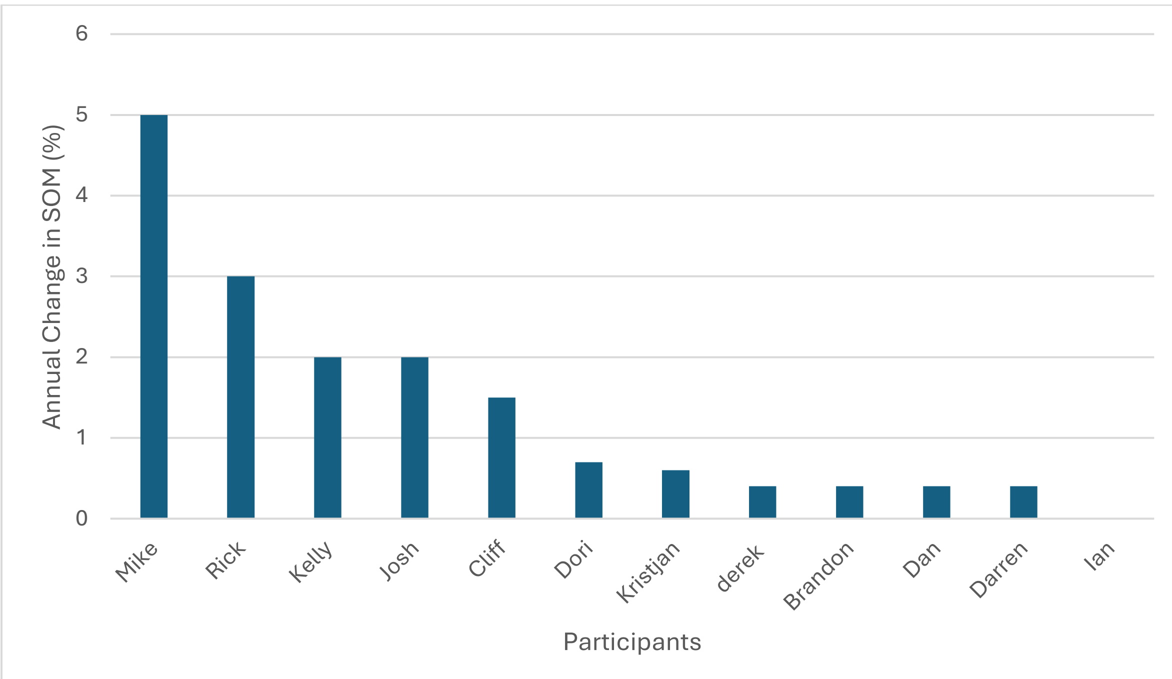

Figure 5.9. Annual % change in SOM on participant farms (see Side Bar 6 for more details on participant SOM/ SOC/SOCC estimates).

Figure 5.9 illustrates the participants' estimates of changes in SOM over time. As can be seen, the changes in the participants' SOM ranged from 0% (Ian) to 5% (Mike) per year. For reference, an SOM-improvement goal of 0.4%, or 4 per 1000, was established in the Paris Accord. Notably, there was little correlation between the initial SOM content and SOMC on the participants' farms. Mike estimates that 2 years of growing hayed alfalfa resulted in an increase of 5% per year. Derek and Brandon are Regenified certified, which is a process that includes intensive soil sampling. They both reported large increases in SOM content—about 4% per year, which is ten times the goal proposed in the Paris accord. This is likely a result of their use of cover crops and intercrops to complement the use of stripper headers and low-disturbance Zero Till. This figure is higher than the results reported in West and Post's meta-analysis, which suggests an increase of 2070 Kg CO_2/ ha per year (West and Post 2002). In a study of SOCC in Western Canada, VandenBygaart et al. (2003) found a sequestration rate of 1000 kg CO_2/ha, while St. Luce et al.'s (2024) detailed analysis of the PSCB data revealed that brown soil zone sites that had employed continuous cropping with zero till over the 21 years of the study increased their carbon sequestration capacity to 0.28 Mg C/ha/year (n=20) compared with 0.12 Mg C/ha/year (n=43) in the original analysis. Converting these finding to kg/CO_2/ha/year would yield a value of 1027 kgCO_2 /ha, similar to the findings reported by VandenBygaart et al. (2003). St. Luce et al. (2024) suggest that this value equated to a 0.4% increase/year, the target of the 4/1000 program unveiled during the Paris COP.

For a comparison, Derek's poorer soil would have an average of 2% SOM, or 1.16% SOC, when he started his transformation. Soil with 1.16% SOC would contain 25,984 kg C/ha 0–15 cm. To elaborate, 25,984 kg C/ha x .04 increase per year = 1038 kg C/ha/year, and 1038 kg C/ha x 3.67(conversion factor from C to CO_2) = 3408 kg CO_2/ ha of sequestered carbon/year. Along with these sizable increases, Brandon, and Derek both observed dramatic improvements in soil aggregation, water infiltration, soil biology levels, and yields. Derek said he has noticed a large difference between the land he has been managing with Regenerative Ag principles since 2009 and the land he recently purchased in 2022. This difference was especially noticeable during the drought of 2023, as the older land was much more resilient. The SOM increases for other farms were modest but very respectable compared to the Paris target, ranging from 0.4% (Kelly) to 0.2% (Darren).

Kristjan is working with the Canadian Alliance for Net Zero Agriculture (CANZA 2024) group to find better methods of measuring SOM. Kristjan believes the discovery of such methods will be critical in the move towards Net Zero. He is part of the CANZA-MRV (Measure, Record, and Verify) program.

Side Bar 10: Does SOM Equal Food?

Figure 5.10 shows that crop management can make a huge difference in grain output compared to the current SOM on the participating farms.

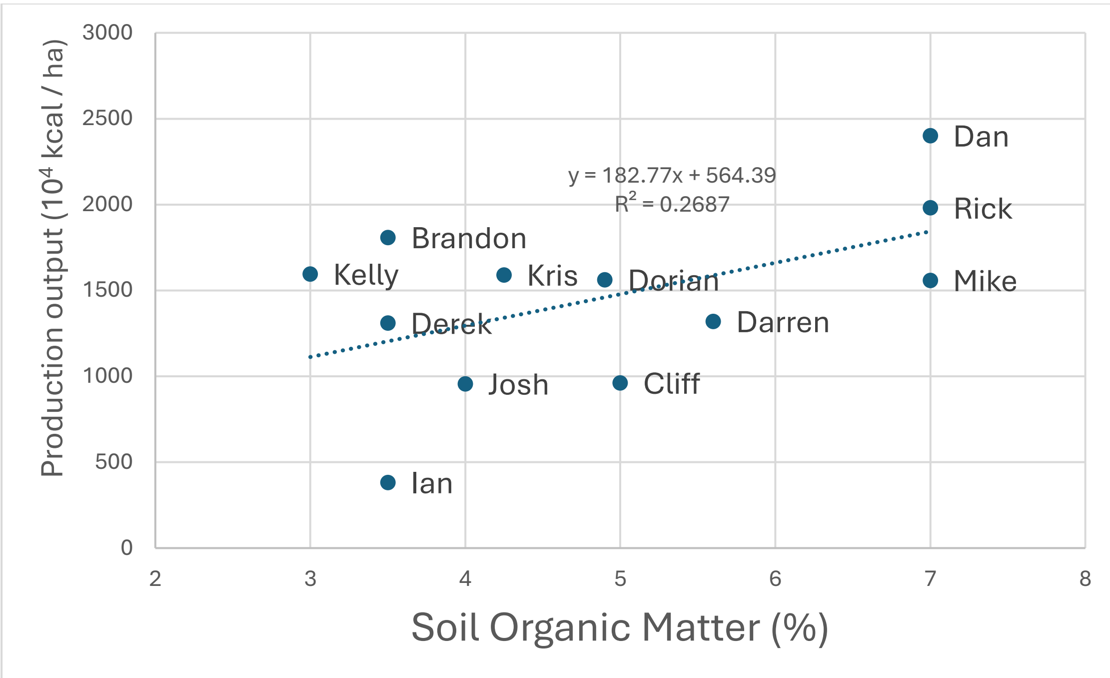

Figure 5.10. Relationship of soil organic matter (%) compared to production output (10^4kcal/ha) for participant farms.

The farms chosen for this study are very different from one another, and there are many factors influencing their individual grain output. The correlation between SOM and production output at R^2 =.2687 is weak but Figure 5.10 shows the variation well. For example, Rick, Dan, and Brandon grow corn, resulting in a higher kcal/ha (higher kg/ha x kcal/kg) compared to many other farms; however, their kcal/ha output was only loosely correlated to their SOM. These farmers were above the trend line. Cliff keeps 25% of his land in full-season cover, which contributes to lower overall yield and kcal/ha, especially as it relates to his SOM. Ian is an organic farmer who allocates 40% of his cultivated land to green manure crops. Ian's farm had low kcal/ha despite having good SOM for his soil zone and soil type. The farms of interest may be those that over yield relative to their SOM, causing the kcal output to be higher than the SOM level. Brandon and Kelly's farms are the two most notable in this respect, with Derek a close third. These farms are Zero Till and low-input but have high output relative to their SOM. Kristjan and Dan also have high output relative to their SOM, but they use high rates of fertilizer.

A farm's SOM levels are typically more the result of natural accumulation than the accumulated impact of farming (e.g., the black soil zone tends to have higher SOM levels than the brown soil zone, irrespective of practices). Generally, the higher the SOM, the greater the available soil water and the greater the yield potential. However, in the case of the participants' farms, yield is determined by more than SOM alone. Nonetheless, in an equal, side-by-side comparison, farms with higher SOM will be more productive (Chutter and Hart 2022; LaCanne and Lundgren 2018).

Unfortunately, due to the nature of this study, one can only speculate as to why certain farms can over-yield their SOM while others under-yield it. Given the management focus of each over-yielding farm, it may be hypothesized that active soil biology is a key difference. On these farms, active soil biology is fostered by an approach that emphasizes minimal soil disturbance, the use of soil armor, and the addition of soil biological inoculants along with small amounts of additives to stimulate soil biology. Growing a diverse selection of plants from snow to snow may also have been a positive factor with Brandon and Derek, but much less so with Kelly. Thus, while SOM is critical to the health of a farm, it is not the only factor, as farm management practices can also have a significant impact.

5.3.3. Contribution Margin: Support the Farmers

The contribution margin is the second component of the Triple Win and SFI.

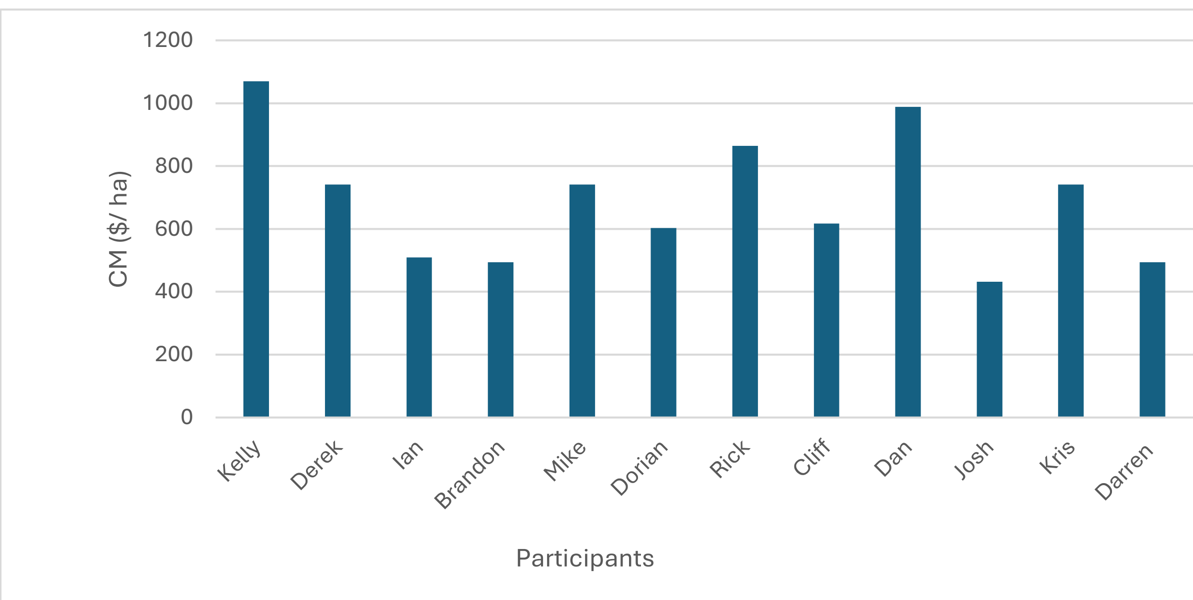

Figure 5.11. Contribution margin ($/ha) generated by various participants.

According to the accounting firm, MNP, a farm's contribution margin is one of the best metrics for determining its operating efficiency. As illustrated in Figure 5.11, all the participating farms are profitable based on their contribution margins. Of the twelve farmers, Kelly had the highest contribution margin, largely due to his low input costs and, consequently, relatively low financial risk. Kelly said that, when he was a high-input Zero Till farmer, he was constantly trying to expand his farm and working very hard, but he did not own any of the land he was farming. After converting to "conservation" farming Kelly downsized his farm from 7500 acres of rented land to 2800 acres of mostly owned land (he owned 80% of it at the time of our interview) and has a much more relaxed and less stressful lifestyle. The farms with the largest contribution margins (i.e., those above $600/ha) can be divided into two groups: high-nitrogen-use farms (Mike, Rick, Dan, and Kristjan), which tend to be high-input and high-output, and farms that use little-to-no nitrogen and instead focus on soil health and biology (Kelly and Derek). Anecdotally, Regenerative Ag practices appear to be a substitute for fossil-fuel-based nitrogen fertilizer, focusing instead on natural biological nitrogen fixation. However, Brandon and Darren both cautioned that it is important not to reduce fertilizer rates too quickly. They found that, if soils had not built up a higher level of biology before lowering fertilizer rates, crop yields would be reduced to unprofitable levels. They suggested there is a fine balance between building soil health with fertilizer and being able to reduce fertilizer dependence in favour of more biological yield enhancement. Kelly echoed this concern, observing that it is important to build SOM with fertiliser before cutting its usage. He further suggested reducing the use of N fertilizer by 20% per year over a 5-year period until a zero rate can be achieved. Kelly was also adamant that his IMOS system was critical in enhancing the soil's ability to supply N. Significantly, while Kelly noted that his yields could be up to 20% lower compared to his high-input neighbours in really good years, he felt that they were equal to, if not a bit higher, in more stressful years. Regardless, Kelly's reasonable yields and low input costs enabled him to enjoy high contribution margins. Cropping systems which use excessive fertilizer will supress beneficial soil biology (Fan et al. 2019; Altomare and Tringovska 2011; Singh 2018) and will raise cost without always increasing contribution margins.

Like all business owners, farmers must make sure they are financially healthy. However, data from the National Farmers Union (NFU) indicates that net margins have been shrinking since the 1940s. The 2024 net income projection by the FCC (Gervais 2023) and the government cost of production (Manitoba Government 2024) also showing continuously tightening margins. Despite these trends, margins were high in 2023, as most Manitoba farmers enjoyed extraordinary yields and good prices. Some farmers attribute higher yields to global warming, as higher CO_2 levels increase photosynthesis, water use efficiency, and grain yields. The shading due to western wildfires may also have had a short-term positive impact on crop growth. While it is difficult to tell successful farmers they are doing it wrong, it remains a fact that, in the long run, global warming benefits no one. In the best-case scenario, and if rains continue, crop yields in the prairies may be higher compared to the rest of the world, which would make farming very profitable. But, even if this best-case scenario comes to pass, it will be within the context of three likely long-term outcomes: there will be less and less people to buy our grains; powerful people may forcibly second the short-term advantage that the warmer environment affords northern farmers; and finally, crops may eventually fail due to inhospitably high temperatures. Thus, it is in everyone's best interest to pursue AGWM practices.

5.3.4. Product Output: Feed the Cities (or Meeting the Demand for our Products)

The third and final component used to calculate the SFI is food output, which is obtained by multiplying the grain produced in kg/ha by a factor to convert it to kcal/ha. Here, the words, "output" or "production," function as umbrella terms that include food and other products such as feed, fiber, fuel, and bioproducts. Commerce dictates the demand and profitability of each cropping opportunity.

Brandon, Rick, and Dan's farms were the only three with kcal/ha values over 1500, likely because they were the only ones growing corn, which has a much higher yield/ha, and a slightly higher kcal/kg compared to wheat. While canola has a lower yield than wheat, it has 1.58 times the energy/kg, which would also contribute to a higher kcal/ha.

As clearly shown in Figure 5.12, the only organic farm in this study (Ian) had substantially lower food output. Organic production is important for people who experience adverse physiological reactions to the chemicals used in nonorganic farming, or those who are willing to pay a premium for the "safest" choice of food. Ian's organic farm has a good contribution margin ($/ha) and one of the lowest emissions/ha. Individuals place value on the assumption of "quality" associated with organic products and are therefore willing to pay a premium for such products, which has allowed Ian to remain quite profitable during tough times.

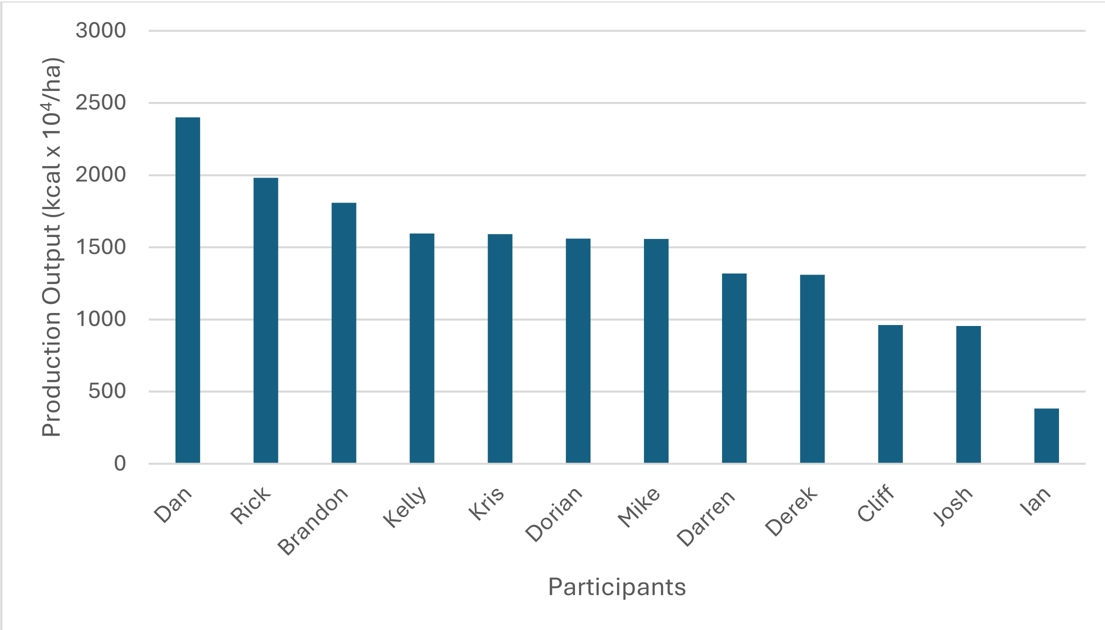

Figure 5.12. Contribution margin generated by various Participants.

Each farm's kcal/ha were calculated using the formula, kcal/ha = SUM (Crop1 kg/ha × ha/crop1 × Crop1 kcal/kg) + Crop2 + Crop ^{N})/total ha, with kcal/kg being derived from Feedipedia, an animal feed resources information system developed by INRA CIRAD and the FAO (Heuzé et al. 2024).

Ian's food output was substantially lower than his peers, primarily because he grows his own nitrogen using green manure crops. Yield loss due to weed competition can also be a factor. However, organic farmers are less vulnerable to changes in input costs and do not have to worry about pesticide resistance, further safeguarding their contribution margin.

Like Ian, Kelly also has low vulnerability to changes in input costs changes, resulting in the fourth highest kcal/ha. Kelly's farm is located in the dry brown soil zone, and, at the time of our interview, he was exclusively growing cereal crops, which are neutral in terms of energy density. It would be interesting to see how Kelly's style of farming would perform in more productive, higher rainfall soil zone. Dan's high-input farm outpaced the other participants in terms of food production; one of his main goals is to produce affordable food and feed as many people as possible. Unfortunately, Dan's current strategy is not compatible with reaching Net Zero or Net Positive.

Side Bar 11: Grain Drying

Dan and Rick produce more kcal/ha, but they also use more fossil-fuel-based products. Furthermore, grain drying was not included in the calculations. This is a significant omission, as emissions associated with corn drying can be substantial and account for the fourth-highest cost of growing corn in Manitoba (Manitoba Government 2024). To address these limitations, Brandon uses lower-yielding corn hybrids that grow in fewer days, leaving more time for natural drying in the field instead of using a grain drier. Conversely, Rick recently installed a new high-efficiency natural-gas-fired grain drier to dry his corn. Triple Green Products sells a biomass-based grain drier that could serve as an example of a more carbon-neutral alternative (https://triplegreenproducts.com/grain-drying/). Thus, there a number of choices that farms have to reduce what can otherwise be a high GHG producing activity.

For context, consider the following example calculation of GHG emissions from corn drying. Assume 140 bu/acre with corn initially at 25% moisture content to be dried to 15% moisture content. For this scenario, approximately .02 US gallons of propane/bu/point of moisture will be required to dry the corn. There are 62.8 kg CO_2 emissions/1M BTU and 91,500 BTU/US gallon of propane. Thus, drying an average 140 bu/acre (3.6t/ha) crop of corn would produce 162 kg CO_2/acre (400 kg CO_2/ha) of GHG emissions. This output would be near the maximum value, as corn is harvested below 25% moisture content in many years or left in the field until spring for further field drying. Another option for some farms is to sell wet corn directly to nearby cattle feedlots, which eliminates drying costs and further GHG emissions.

Side Bar 12: Making a Little Go a Long Way

Figure 5.13 illustrates the relationship between the participants' use of fossil fuel-based energy and their production of crop output energy.

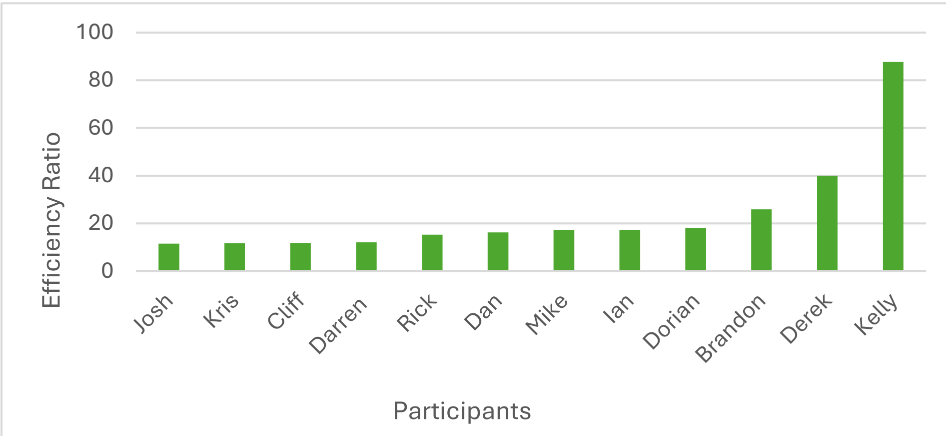

Figure 5.13. Relationship between crop energy output (10^4 kcal of crop output/ha) and fossil-fuel-based energy input (kcal of diesel eq/ha) converted to an efficiency ratio.

As shown in Figure 5.14, there was considerable variation among the participants regarding their ability to convert diesel and nitrogen energy (expressed as kcal of $diesel_{eq}$/ha to food energy output/ha, ranging from 10 to 1 and 90 to 1 kcal of energy input). Kelly uses no fossil-fuel-based nitrogen and very little diesel while maintaining an extremely high kcal output for the fossil-fuel-based products he used. If Kelly had access to renewable diesel, he would achieve an extraordinary level of kcal output for the small amount of fossil-fuel-based products he uses on the farm, which mainly consist of herbicides, seeds, and machinery inputs.

Hoeppner conducted a more thorough review of input/output energy efficiencies that included all fossil-fuel-based inputs (Hoeppner et al. 2006). The results revealed that fuel and fertilizer accounted for 75% of all energy consumption on Hoeppner's conventional farm, while seed energy, machinery, and pesticides accounted for 11%, 4%, and 10%, respectively. Nitrogen was the most elastic energy input with 34980 MJ/ha on the conventional farm and 0 MJ/ha (no fossil-fuel-based N) on the organic farm. Unfortunately, reducing nitrogen input resulted in much lower energy output. Hoeppner's results showed that the conventional farm had output energy (crops) of 465,841 MJ/ha while the organic farm had output energy of 252,054MJ/ha. It is worth noting that Hoeppner did not use green manure on either farm and grew peas twice as often as recommended, thus jeopardizing future use of peas. Ian's yields are much lower than those predicted in Hoeppner's study, and he says he can no longer incorporate peas into his rotation due to a build-up of root diseases from overuse in earlier years. Furthermore, Ian allots 40% of his land for green manure crops. A comparison of the kcal outputs of Ian and Kristjan's farms (Figure 5.13), which are on similar soils and in the same soil zone, reveals that the kcal/ha output of Ian's organic farm is about 25% that of Kristjan's and much lower than one would predict from the Hoeppner study. Interestingly, Kelly and Derek have developed hybrid systems that use little or no nitrogen and just enough herbicides to avoid tillage. Their systems allow for better soil health and more active biological activity.

In general, higher inputs yield higher outputs. As such, farmers try to optimize their inputs based on the potential yield of their area. Unfortunately, higher inputs also result in higher emissions, which may be difficult to justify when food companies are looking to develop net zero supply chains. Meanwhile, the public may say it wants food companies and producers to lower their emissions but, as COVID and food inflation have demonstrated, people do not like the higher prices or potential food shortages that can result from ill-advised efforts to this end. However, rather than immediately saying Net Positive cannot be achieved, the farming industry needs to innovate and invent solutions that remove any yield gaps.

In this thesis, Brandon, Derek, and Kelly's farms stood as the exceptions to the more input, more output rule, as they have actively worked to develop practices that allow them to produce more with less fossil fuel-based inputs. The example of these three participants demonstrates that it is possible for farmers to use fossil fuel products much more efficiently.

5.4. Sustainable Farm Index

The SFI is a numerical expression of the Triple Win that brings together the three key components of: financial health, crop output, and emissions. I have developed a numerically-balanced metric, SFI/ha, to demonstrate how a number can be assigned to the Triple Win, and I use side bars to discuss the various ways of calculating the SFI value, including how to weight or change the individual components to maintain balance between supporting the farmers, feeding the cities, and healing the planet.

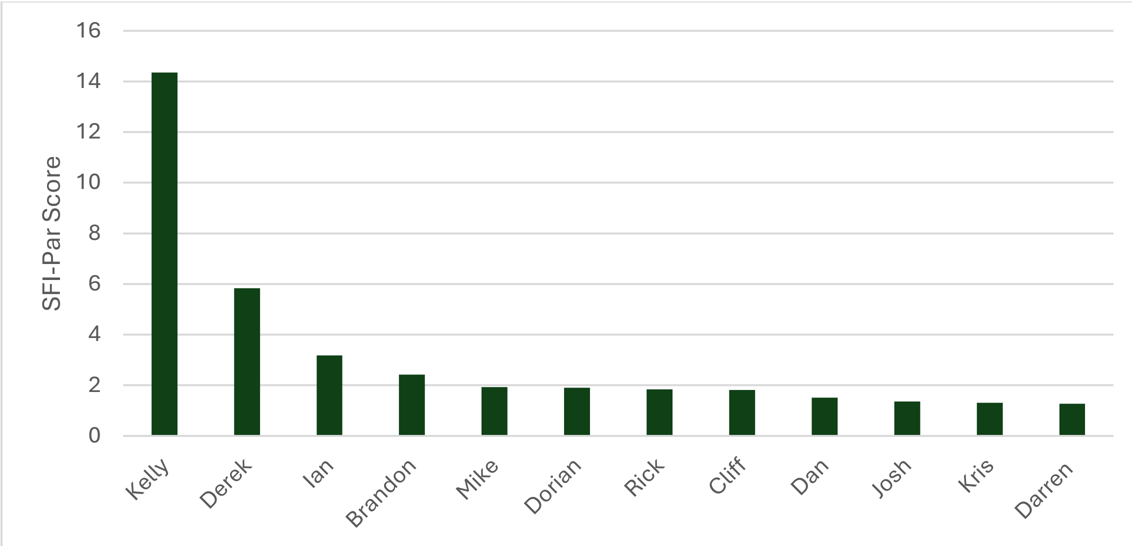

Figure 5.14. Sustainable Farm Index: SFI-par/ha.

Each participant's SFI-par score was calculated using a standardized numerical balance in which each component is weighted relatively equally (i.e., each component is weighted at par). The general equation is SFI equals the contribution margin/ha plus the product output/ha divided by the emissions/ha. The formula was further modified to equalize the value of each factor. Equalization or par) was based on the average data from all farm participants. Thus, SFI-par/ha = (CM$/ha + 10^4kcal/ (2.1x 10,000)/ ha)/EM x 2.15/ ha) x 2. The formula is oriented to a numerical range based on the contribution margin average value of all farm participants. The average values for the twelve farms were: contribution margin, $691/Ha; crop output, 1452 kcal10^4/ha; and emissions, 642kg CO_2eq/ha. A multiplication factor of two was added to the entire formula to provide a better scale.

Among the participants, Kelly and Derek had the highest SFI scores. Although they did not have the highest crop output (kcal/ha) (they are in the brown soil zone, so this is not surprising), they used little or no nitrogen fertilizer and, thus, had among the lowest emissions. Furthermore, Kelly and Derek also had excellent contribution margins—again, partly due to their low input use—and they had made major strides in improving the health of their soil. Besides using little-to-no nitrogen, Kelly does not use insecticides or fungicides, and he only uses about 60% as much herbicide as normal farms. Derek has gone a step further than Kelly and purchased of a See and Spray sprayer. Derek says that this sprayer was able to reduce his herbicide use by as much as 91.5% when spraying Canada Thistle in the fall. Collectively, these participants are better able to use water where it falls due to improved SOM, improved soil aggregation, and water infiltration rates, resulting in improved water use efficiency (WUE) and grain yields.

The majority of the participants had SFI scores between 1 and 2. Brandon's score was just over 2, Ian's was approximately 3, Derek's was 6, and Kelly's was 14. Significantly, the three farms that used little or no fossil-fuel-based nitrogen fertilizer had the three highest SFI scores.

5.5. Chapter Summary: The Triple Win, Net Positive, and SFI

The findings presented in this chapter address **Research Objective 2: To determine if there are Net Positive farmers in the participant group and how that relates to their Sustainability Farm Index Score.**

Farmers have always produced products for the market. Today, they are also being asked to reduce and eliminate negative externalities to help reduce GHGs in the atmosphere. The SFI provides a single number describing a farmer's progress towards the Triple Win and a second number was calculated for scoring Net Positive. The findings reveal that Kelly and Derek's farms have high SFI scores and are Net Positive with respect to net emissions.

The work in this chapter also makes it clear that there are more opportunities and challenges ahead, including:

1. Further improvement of all farms.
    - Even the best Net Positive carbon grain farms in this study still use diesel fuel. Regeneratively-grown renewable diesel would further reduce emissions and improve net emissions. This would also increase farmers' SFI scores.
    - We have only begun to use all possible BMPs to sequester carbon at a higher rate (see Chapter 6 for more detail). However, water availability is a limitation to crop production that cannot be ignored in Western Canada. Drought and lack of rain have caused even the most steadfast Net Positive innovators to take a step back from practices such as the use of cover crops.
    - Kelly has the highest SFI score, but he says he does not have the maximum potential yield—something he is proud of, because he says past efforts to do so have ended up costing him. However, from a global point of view, how much yield gap is acceptable, and how can it be closed without breaking more land?

- Derek has a very high SFI score and is also Net Positive. Derek says there is no negative yield gap between him and his neighbors, especially once his soil has been regenerated. Derek grows a wider variety of crops than Kelly, but they both have an above-average contribution margin per hectare.
- Derek's Net Positive farm was the most scientifically managed and had the highest SFI score. In large part, this result was due to the comparatively greater number of sources of fertility on his farm. Furthermore, Derek's high scores can also be attributed to the following practices: he incorporates legumes into his rotation, often as an intercrop; he adds ammonium sulfate (22 kg N/ha) to his cereals; he uses low rates of guano (bird dropping high in P); he applies minimal compost to portions of his land; he allows fall grazing on some of his land; he grows cover crops if there is sufficient moisture (less so lately); and he feeds his biology at seeding, either with or without additional biological inoculum. In addition, while Derek says there is less of a need to continue inoculation on his old land, he most definitely inoculates his newly acquired land. However, from a chemical balance calculation (e.g., N input to N needed), he still would fall short. Derek believes his yields are equal to or better compared to those enabled via traditional crop management, primarily because his soil is healthier and now has a higher SOC.
- Conversely, Kelly only uses his IMOS seed inoculant and careful management to improve his soil biology. For 10 years, he has heard warnings that his yields would plummet, but he has yet to see these effects since switching completely to his current form of crop and soil management 6 years ago. Kelly says his crop yields can be equal to those of his high-input neighbors, but they can also be 20% lower. He is less worried about yields than he is about profit, which he is very happy with.

2. The two farms that were the most Net Positive and had the highest SFI scores were both situated in the brown soil zone. We must be able to adapt and adopt their practices in other regions of Western Canada, which should be relatively easy in areas with more moisture. In this quest, finding viable alternatives to fossil-fuel-based nitrogen will be a key to success.
3. As discussed in Chapter 3, SBTi-registered companies are actively looking for Net Zero Scope 3 supply chains. Can farmers with a Net Positive network and investments from SBTi-registered companies create Net Positive supply chains? Payment for carbon insets could allow farms to be more aggressive in pursuing Net Positive through improved soil health. Likewise, with the right financial incentives, the use of full-season cover crops could be a

practice for jump starting soil health improvement. The development of viable alternatives to fossil-fuel-based nitrogen and diesel fuels will also be critically important to achieving Net Positive.

4. The results presented in this chapter show that innovative Net Positive carbon grain farms in Western Canada and the Northern Great Plains can help our society live within our planetary boundaries and accomplish the Triple Win. However, further work is required to develop a better understanding of the underlying science of these systems, as well as their longevity and whether further improvements are possible.
5. All twelve farms in this study make a significant contribution to the welfare of both Canada and the world. Regardless of their Net Positive status or SFI score, all farms in this study have important attributes, whether that is maximizing food output or filling a crucial market demand for a sector of the population with special needs. We are stewards of the land we farm and the air we breathe, and we all do our best within our financial constraints. We do our best given the technical options and knowledge available to us. With an open mind, we can keep evolving and discovering new ways of tackling the negative externalities of grain farming, namely, GHG emissions, global warming, and the loss of biodiversity and habitat.

In the next chapter, I introduce and discuss the BMPs that will be required to achieve Net Positive Carbon Grain Farming.

Chapter 6: Participant Review of Global Warming Mitigation BMPs

6.1. Role of Global Warming Mitigation BMPs in Achieving Net Positive

This chapter examines the twelve beneficial management practices (BMPs) for anthropogenic global warming mitigation (AGWM) that were reviewed by the farmers and research agronomists who participated in this study. In addition, factors encouraging or hindering the adoption and implementation of these practices, as well as policy and research gaps that must be addressed to help farmers reduce their carbon emissions and enhance their carbon sequestration are also identified. The research in this thesis employed qualitative methods, including in-depth interviews and farm data collection, to understand the practices of twelve innovative farmers and four research agronomists located in Western Canada and the Northern Great Plains. The collected data were then used to calculate the participants' total emissions, net emissions, SFIs, and NP ratings. These results were presented in Chapter 5. The interviews were conducted using the custom-designed BERT/E tool, which was developed using a Net Positive farm framework and farm practice change theory, for the purpose of rating the utility of BMPs for AGWM. The individual BERT/E scores can be found in Appendix 4.5 along with the full participant stories.

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Figure 6.1 illustrates the flow of information using BERT/E to assess change adoption.

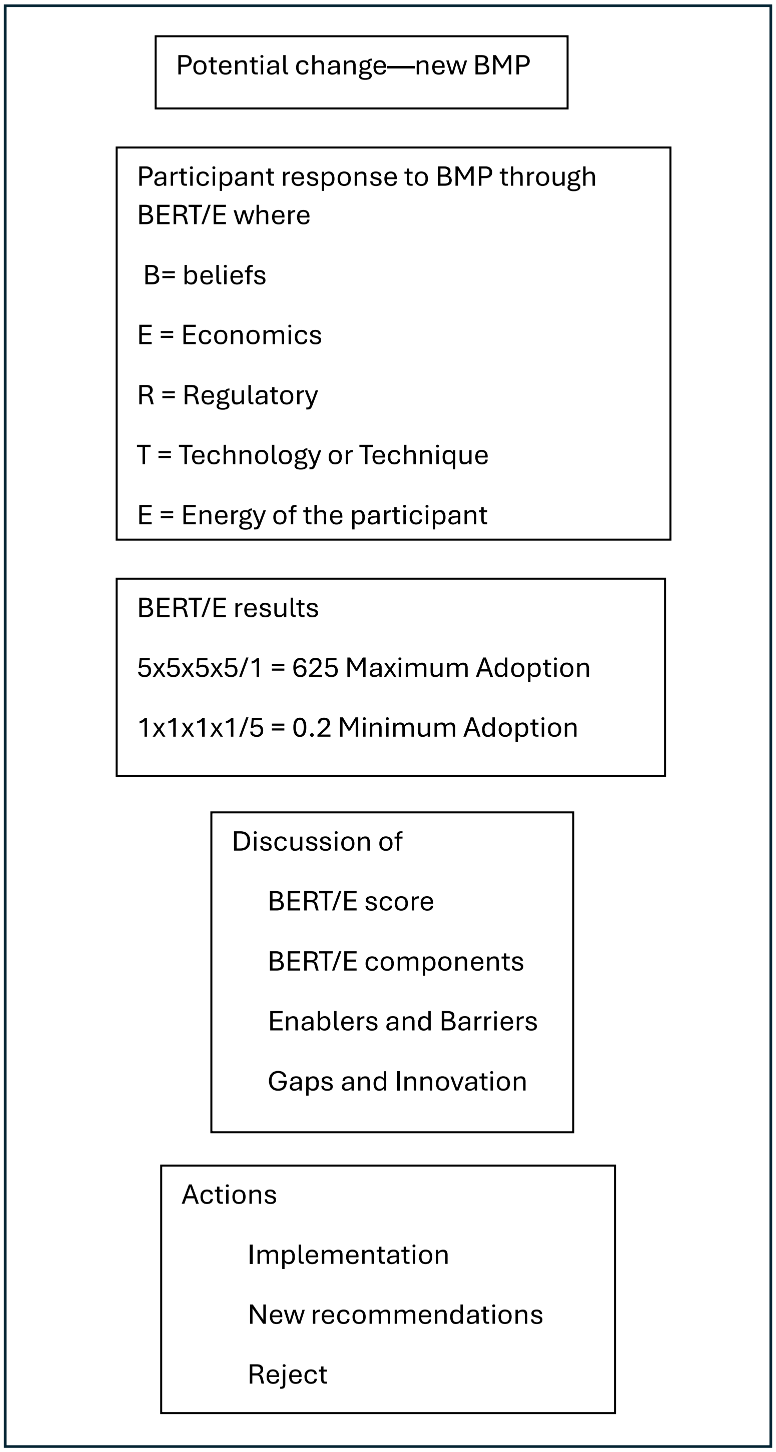

Figure 6.1. Information flow using BERT/E.

While a significant amount of data is examined in this chapter, each participant's overall BERT/E score and individual component scores can be found at the end of their story in the appendices for Chapter 4. In this chapter, I analyze the composite BERT/E scores to develop adoption trends, and I highlight how the various B, E, R, T, and E components can impact the adoption of the twelve BMPs (Table 6.4). Furthermore, a comparison between the average BERT/E scores across the sample and the scores of the top two Net Positive farmers is also conducted (Table 6.5).

This chapter addresses the final two objectives of this thesis:

Objective 3: To determine whether adoption rating (BERT/E) analysis helps to identify enablers, barriers, gaps, and innovation to assist in adopting Net Positive BMPs.

Objective 4: To determine how innovative farmers rate the utility of the twelve proposed BMPs for AGWM

6.2. List of the Twelve BMPs

The twelve BMPs (plus "other") examined in this study are listed below. Please see Chapter 3.8 for detailed descriptions.

1. Minimal disturbance to the soil food web.
2. Living roots from snow to snow.
3. Plant diversity.
4. Armor on the soil.
5. The use of Green nitrogen alternatives in place of fossil-fuel-based fertilizers.
6. The use of substitutes for diesel fuel.
7. The use of agroecology.
8. The use of sustainable intensification, such as the 4Rs, to increase efficiency.
9. Conserving and restoring wildland, including agroforestry, and preserving natural sites.
10. Enhanced phosphorus management.
11. Integrating grazers.
12. Adopting organic farming practices.
13. Other GMW-BMPs that could be used in Western Canada.

6.2.1. Key Descriptors of Participants

Research participants key characteristics of their farm have been preciously described in Table 4.2.

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6.2.2. Interview Questions

The interview guide comprised seven segments: introduction, demographics, background, beneficial management practices, Net Positive farming journey, climate stress, and conclusion. The beneficial management practices section consisted of twelve practices with ten questions per practice. These questions were as follows.

1. *Rate the practices as an idea on a scale of 0 to 100 (0 = worst idea ever, 100 = best idea ever).*
2. *Rate the adoption of the practice on your farm (0=no adoption, 100 = full adoption).*
3. *Rate your belief in the practice on a scale of 1 to 5 (1 = weakest belief, 5 = strongest belief). Describe.*
4. *Rate the economics of the practice (1 = very weak economically, 5 = very strong economically). What is the profitability of this practice for you currently?*
5. *How have regulations from government and food companies affected your adoption of this practice (1 = very little impact, 5 = very high impact)? Describe.*
6. *Is there readily available and scalable technology to help implement this practice (1 = very little, 5 = very available)? Describe.*
7. *Rate your mental and physical energy to adopt this practice (1 = very low, 5 = very high). Describe.*
8. *What factors enable the adoption of this practice?*
9. *What are the barriers to the adoption of this practice?*
10. *GWM credit required $+/-. How much do you think this practice would pay or cost per acre per year?*

Questions one and two were scored as percentages, with a maximum of 100%, while questions three to seven were scored on a scale of one to five for BERT/E adoption, with five being the highest. The second E was inverted for calculation purposes, with one being the maximum score. Thus, the maximum BERT/E adoption rating score was 625 (i.e., $5 \times 5 \times 5 \times 5/1 = 625$). Questions eight through ten were intended to stimulate open-ended discussion regarding the participants' rationales behind their BERT/E responses. These questions sought to identify enablers, barriers, and solutions for increasing their BERT/E adoption scores. Analyzing the responses to this suite of questions provided much-needed insight into why farmers—and, specifically, this group of innovative highly-committed individuals—do not have BERT/E adoption scores of 625 in each management area. In retrospect the "as an idea" question was essentially the same as the B in BERT/E, while the "as practiced" question followed the same pattern as the total value of BERT/E, but with less ability to tease out the factors affecting adoption. In the following sections, I examine the participants' responses to the twelve BMPs in relation to the BERT/E tool.

6.3. Lack of Disturbance and Armor on the Soil: Data Analysis and Findings

6.3.1. Participant Responses

Based on the overall BERT/E scores, the top two BMPs were armor on the soil and lack of disturbance. These BMPs are connected by the common practice of not tilling the soil, which is often referred to as Zero Till or no till in the USA. Darren (black soil zone) and Josh (brown soil zone) expressed disdain for tillage, as it can cause soil to dry out, reduce soil aggregation, and lower water retention. Although Darren and Josh's farms are in different climate zones, water conservation is a key factor in their success. Fortunately, Western Canadian farmers have been leaders in developing Zero Till methods that enable increased moisture retention, reduced evaporation, and increased yields. Josh's grandfather observed that their recent yields had been remarkable despite the drought conditions, pointing out that such harvests would have been nearly impossible with the same amount of rainfall and the tillage-based practices used in the 1930s. However, Josh tempered his grandfather's remarks, noting that the previous year's crop was not exceptional, but they had something to harvest.

Many participants were aware of the effectiveness of Zero Tillage and soil armor in preventing erosion. Kelly, who farms on thirty-five-degree slopes, acknowledged that tilling would jeopardize his soil. Similarly, Derek, who farms fragile soils in the brown zone, 50% of which is native or reclaimed pasture, said that the ability to practice Zero Tillage is the difference between farming and ranching. He speculated that the inability to practice Zero Tillage would cause his yields to decrease, amplify soil erosion, and decimate his profits, forcing him to sow grass or leave farming altogether.

Soil armor was the highest-ranked BMP due to its connection to Zero Till. Crop selection, rotation, sequence, stubble management, C/N ratio, and grazing practices were among the secondary factors identified for managing soil armor. Conversely, some respondents viewed lack of disturbance as simply the adoption of Zero Till. Thus, Cliff, Darren, Derek, Kristjan, Bill, and Dorian assigned it a rating of 625, while Brandon, Mike, Sam, Kelly, and Josh—all of whom practice Zero Till on all their land—assigned it scores of 306, 113, 250, and 500, respectively.

These lower BERT/E scores were largely due to the disturbances caused by harsh pesticides, excess fertilizer use, and crop senescence. However, despite assigning a mid-range BERT/E score to lack of disturbance, Brandon shared that he takes extra measures to minimize disturbance, for example, only using light tillage to smooth out ruts in low spots and applying a Johnson/Su compost extract seed treatment to stimulate healthy soil biology. In addition, Brandon said he also avoids using glyphosate to minimize herbicide resistance and its impact on soil microbes. Also see Kanissery et al. (2019) and Araújo et al.(2003). Furthermore, Brandon grows full-season cover crops in years with "prevent plant" conditions and adjusts his combine to encourage volunteer crop growth. Despite these efforts, Brandon feels that he can be doing more and therefore assigned himself a relatively low BERT/E score of 306.

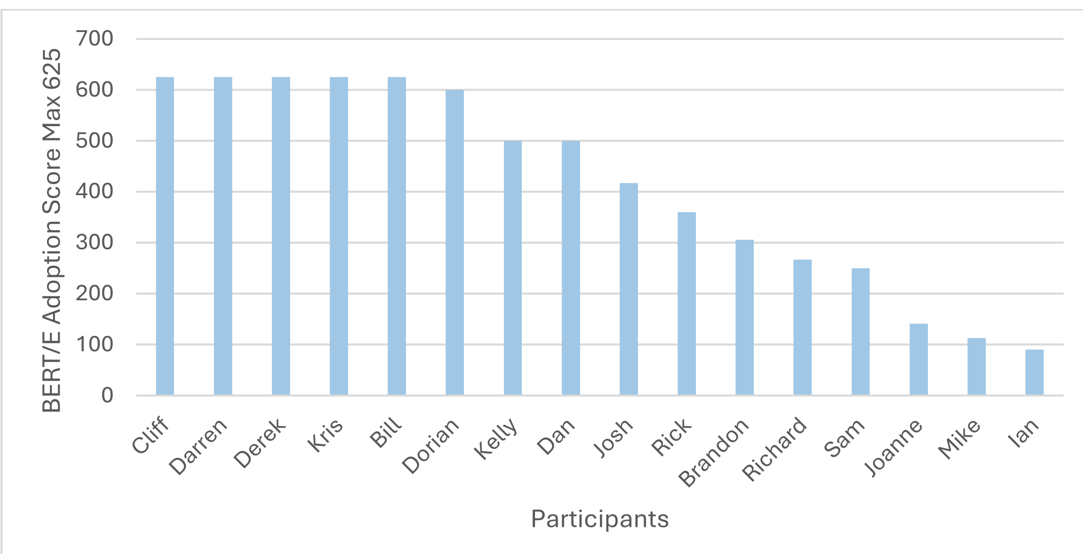

Figure 6.2. Participant BERT/E adoption scores for BMP- lack of disturbance.

As shown in Figure 6.2, six of the participants had a maximum adoption score of 625, while another seven had scores between 500 and 250. Sam's rating was particularly surprising, as his research farm has been dedicated to improving Zero Till practices for the past 33 years. Generally, further research is needed to identify ways of minimizing disturbances to the soil and soil food web. Conversely, Derek rated both BMPs high across all measures. While Derek and Brandon's farms are both regenified certified, Derek assigned a perfect 625 BERT/E score to lack of disturbance compared to Brandon's BERT/E score of 306. The differences in their scores are rooted in their views on the economic and regulatory aspects, as Brandon gave a score of 3.5 in these areas whereas Derek gave ratings of five out of five. For example, Brandon had the following thoughts regarding economics:

> *probably at my stage right now, they're probably about a 3. Biggest thing there is because I don't own the land. It's rented land, and therefore we still need to generate a certain amount of revenue. Just, you know, just to pay the bills, and currently I can't reduce my fertility or herbicides any more than I currently have until this soil gets healed enough to take care of itself. So, therefore, the main reason for continuing to not push it, you know, to the 5 in belief. Yeah, it's just the hangup of still being profitable because I've seen what happens if we eliminate it completely in a broken soil structure system. You know what I mean. So, I think we're yeah. I'd say the economics right now are probably around a 3, maybe a 4, but probably a 3.* (Brandon, December 12,2023)

In terms of regulation, Brandon remarked,

> *...the only thing regulation wise, I guess. I don't know how to put it on a scale. But there again, you know, crop insurance in the States is very related to yield. So anytime you start cutting back and hurting yield just to concentrate on taking care of the soil and minimizing disturbance you're going to sacrifice your safety net as well. So, I would say, you know, that's probably in that 3 to 4 area as well. And that's all. Government related. Food Company. I'd say it's more like a 5 because they want healthier food with less disturbance and less residues on it, you know, like chemical residue*. (Brandon, December 12,2023)

Rick and Dan, who operate in the Red River Valley where Zero Till is uncommon, are committed to using no till, flex no-till, or direct seeding whenever feasible. Rick is particularly enthusiastic about strip tillage as a potential option. Their adoption of these two beneficial management practices is documented in Table 6.2.

Table 6.1. Red River Valley participants' scores for BMP- lack of disturbance.

Participant	BMP	As an Idea	As Practiced	BERT/E
Rick	Lack of Disturbance	100	75	360
Dan	Lack of Disturbance	100	100	500
Rick	Armor on the Soil	100	80	625
Dan	Armor on the Soil	100	70	625

The results shown in Table 612 reveal that context is crucial. The participants' ratings ran counter to expectations, as both participants used some tillage, which disturbs and reduces soil armor. Thus, their high ratings for armour on the soil seem too high. However, in their individual contexts, Rick and Dan may have significantly more armor compared to the highly cultivated neighboring fields. Nevertheless, despite being unable to practice continuous Zero Till on all their land, Rick and Dan employ direct seeding as much as possible, which allows them to provide their soil with greater protection compared to 100% tillage. They realize that the lack of cover after soybean harvests and the absence of any windbreaks can leave their gumbo-heavy soil vulnerable to wind erosion.

Despite having more abundant rainfall on his tall grass moist black soil zone farm, Dan says that he experiences moisture deficits throughout the year and, in many years, finds himself hoping for rain in July and early August. Dan and Rick use fall rye to increase direct seeded acres, and Dan also uses it for cover to support green seeding, which may enable more Zero Till on heavy soils. Green cover can be a valuable tool for managing soil moisture in the spring. In a wet spring, later termination can help dry out the seedbed enough for direct seeding; in a dry spring, early termination can ensure that the green cover does not steal moisture from the cash crop. Rick is currently experimenting with winter camelina as a direct seed crop and as a potential diesel fuel replacement.

Two farmers and one research agronomist had considerable experience in organic farming. Although most of Cliff's farm is Zero Tilled, he used to organic farm his pastures and hay land that he was breaking up. However, Cliff says he is halting his use of organic farming practices because he feels it is time to rebuild his soils. Cliff has been allocating 25% of his cropped land to full-season cover crops each year for at least four years. They are in year three of this cycle, and Cliff reports that he is pleased with the changes he has observed in the soil and crops. As such, Cliff gave both BMPs a perfect BERT/E adoption score of 625.

The other two participants with organic experience were less concerned with these two BMPs. For instance, Ian assigned BERT/E scores of 141 and 90 to soil armor and lack of disturbance, respectively. These low scores are largely due to the fact that organic grain farming uses tillage, which disturbs the soil and displaces any accumulated armor. Nonetheless, Ian says he has incorporated numerous minimum tillage practices on his farm. In addition, he says he has tried organic no till but found that it did not control creeping-rooted perennials. As a result, he began using a wide-blade cultivator, which leaves much more residue on the surface but is still effective in controlling perennials. Ian has been successfully organically farming for 38 years, but he remains concerned about soil health, particularly declining phosphorus levels and crop yields.

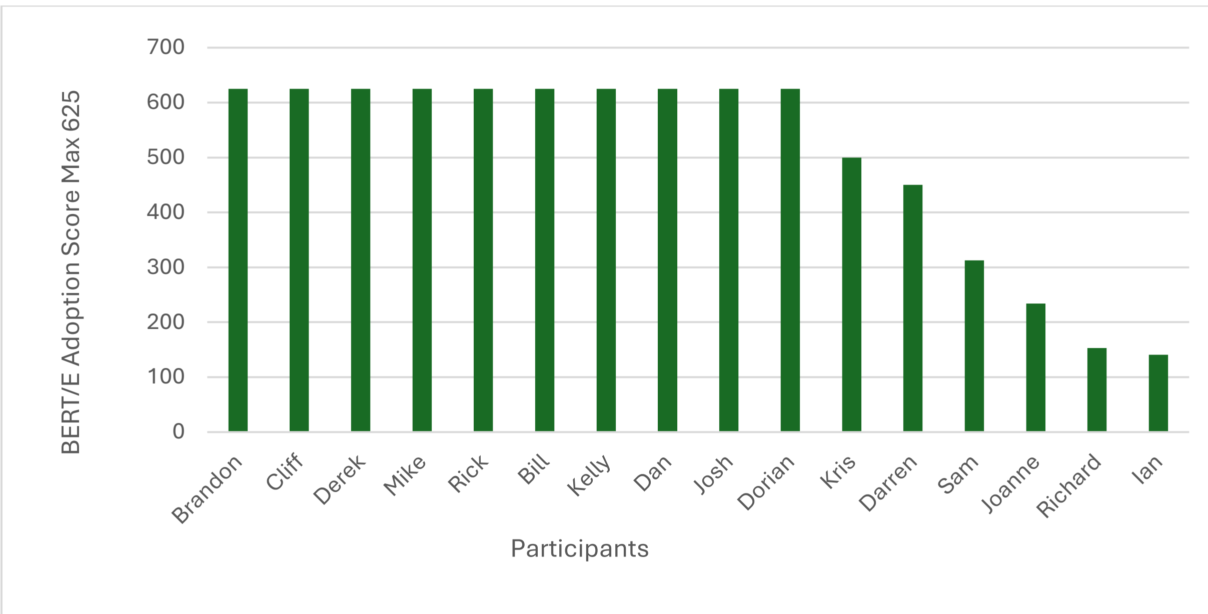

Figure 6.3. Participant BERT/E scores for BMP- armor on the soil.

Armor on the soil received the highest BERT/E adoption scores of all BMPs, with ten participants assigning it a maximum score of 625. While it is one of the most important practices in achieving Net Positive, it is also one of the most vulnerable. Zero Till helps decrease emissions by reducing the need for tractor hours, and it can help to increase profitability and maximize crop output by improving moisture management. However, the major limitation of this BMP is its susceptibility to herbicide resistance. Tools such as wide blade cultivators, which feature blades ranging in width from 18 inches to 5 feet, may be an option for controlling weeds without having to continuously apply herbicides, as they were originally developed in the 1930s (Nobleford, Alberta), prior to the advent of herbicides. Noble blade cultivators can kill weeds while maintaining most of the soil armor, thus helping to control soil erosion and preserve soil moisture. However, there is an opportunity for innovation, as it is possible to improve these blades' ability to run at shallow depths, tolerate stones, and operate in wetter conditions.

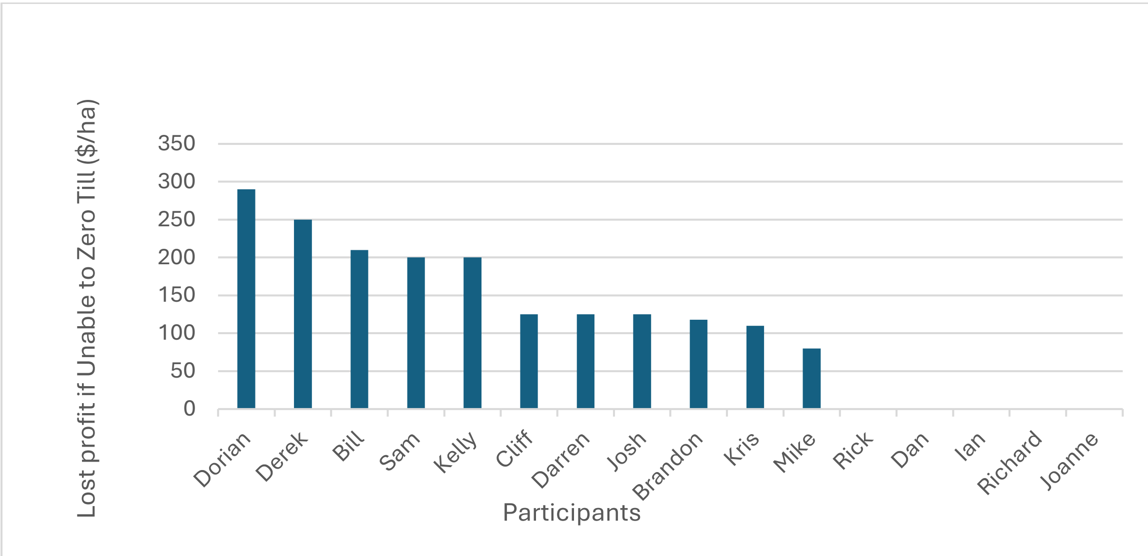

Figure 6.4. Each participant's estimated lost profit ($/ha) if they had to stop Zero Till.

As illustrated in Figure 6.4, lack of disturbance and armor converge are the widely accepted practices of Zero Till. Zero Till is somewhat unique among AGWM practices, as practitioners tend to adopt it for its economic advantages before its global warming mitigation benefits. For reference, many Western Canadian farms have an annual profit of $50 to $100/acre. Participants from Dorian to Mike exclusively use Zero Till. Rick and Dan's farms are located in the Red River Valley, which is in the wetter part of the prairies where Zero Till is more difficult to implement and therefore offers less immediate advantages. In addition, Ian's adherence to organic practices means he is unable to employ Zero Till on his farm, while Richard and Joanne did not provide estimates, as they mainly work as research agronomists.

6.3.2. Discussion

The use of soil armor and minimal disturbance depend on a well-functioning Zero Till system, and the most significant barrier to long-term Zero Till is finding an effective herbicide to replace tillage. Glyphosate has been the backbone of Zero Till since its introduction in the late 1970s, as it enables wide spectrum weed control with relatively few negative externalities. However, overuse has resulted in the development of weed resistance. Kochia is a notable example of glyphosate-resistant weeds, as it is a prolific seed producer with an effective tumbleweed-type seed distribution mechanism. Kochia has also become resistant to other herbicides. After only 50 years, we may be witnessing the beginning of the end for a farming practice that is profitable, conserves water, prevents soil erosion, reduces fuel and labor requirements, builds SOC, increases yields, and feeds more people. A short-term solution to this problem is the use of herbicide mixtures to increase the likelihood of a successful "burn off." As such, herbicide companies have been devoting resources to exploring potentially effective combinations, in addition to continuing their search for the next "magic bullet" glyphosate like herbicide.

AAFC weed scientists have found that increasing crop competition by using higher seeding rates, narrowing row spacing, precision banding fertilizer, minimal soil disturbance, and growing more competitive crops are effective at minimizing yield loss from weeds and slowing the development of herbicide resistance (Tidemann et al. 2023). Franzen (2009) suggests that sowing wheat on land that has not been tilled for at least 6 years can decrease nitrogen fertilizer needed by 55 kg/ha, and he identifies three notable seeding practices can be used in no-till farming: sowing with a disc drill (lowest disturbance), sowing with a Zero Till hoe drill (moderate disturbance), or sowing with a sweep operated at no deeper than two inches (full surface disturbance) (No Till Farmer 2024). While this last option may appear to contravene the principle of lack of disturbance, compromise may be possible in situations wherein microbes are able to recover and weeds are controlled via alternative strategies (e.g., shallow tillage). For example, the use of a seeding sweep with a low lift operated at a slow speed—also known as stubble mulch farming—can minimize soil mixing and maintain surface residue, thus eliminating the need for an herbicide "burn-off" (at least in some fields or crops) and helping to ensure that available herbicides remain effective into the future. Small-grain cereals, such as wheat, barley, and oats, and large-seeded cool-season pulse crops, such as peas, fababeans, chickpeas, and lentils, can tolerate or thrive under this wide-sweep approach. However, precision low-disturbance seed placement benefits crops such as canola, soybeans, and corn. Nonetheless, further research is needed to identify and develop additional options that retain the advantages of no disturbance while not constantly relying on herbicides to control weeds.

Glyphosate is a very effective tool for controlling creeping-rooted perennial weeds, such as Canada thistle and quack grass, which are less likely to develop herbicide resistance. These weeds can be the bane of organic farmers, as controlling them in organic farming typically requires intensive tillage. As such, Brandon stated that he tries to restrict his glyphosate use to creeping-rooted perennials, which helps to avoid selecting for glyphosate-resistant weeds. Additional investigations are necessary to assess these hybrid systems. Overreliance on limited herbicides could result in the end of Zero Till, an issue with which some farms may soon confront.

Kelly's low-disturbance Zero Till farming system is an interesting and potentially sustainable option, as it relies on rhizophagy (White et al. 2018) and IMOS, Indigenous Micro Organism System to maintain fertility. In rhizophagy, nutrients from symbiotic microbes (bacteria and fungi) are transferred to the roots of host plants, with the microbes alternating between a root intracellular endophytic phase and a free-living soil phase during this cycle (White et al. 2018). Although Kelly's system does rely on the use of herbicides, his efforts to maximize the use of agroecological practices, minimize soil disturbance, and use a wide range of herbicides makes it more sustainable. Indeed, Kelly's new system uses 60% less herbicide compared to his previous high-input Zero Till system. He has observed that increased soil biology is reducing the weed seed bank. This is supported by Lundgren's (2024) (unpublished data) findings, which show that wild oat predation increased from 25% to 60% when Regenerative Ag was practiced for three years.

6.3.3. Recommendations: Lack of Disturbance and Armor on the Soil

1. Develop strategies to ensure Zero Till does not become obsolete due to lack of weed control.
2. Find ways to extend the use of Zero Till to more acres in Western Canada.
3. Find ways to reduce disturbances from other sources, such as herbicides, fungicides, insecticides, excess fertilizer, and a disrupted supply of root exudates to soil microbes.
4. Work to ensure healthy soils and a healthy soil food web.

6.4. Snow to Snow and Plant Diversity: Data Analysis and Findings

6.4.1. Participant Responses

Growing plants from snow to snow and high plant diversity enable greater increases in SOC compared to monoculture Zero Till. Researchers from the Northern Great Plains and Canadian Prairies (Obour et al. 2021; Wick et al. 2018; Blackshaw et al. 2010) have shown that greater plant diversity and longer growth times increase the plants' ability to nourish the soil food web, thus resulting in increased SOC. This increase in SOC translates to more sequestered carbon dioxide, more soil water absorbed, and higher, more stable yields. This outcome is critical, as available moisture and the ability to manage cover crops can be the difference between positive and negative financial impacts.

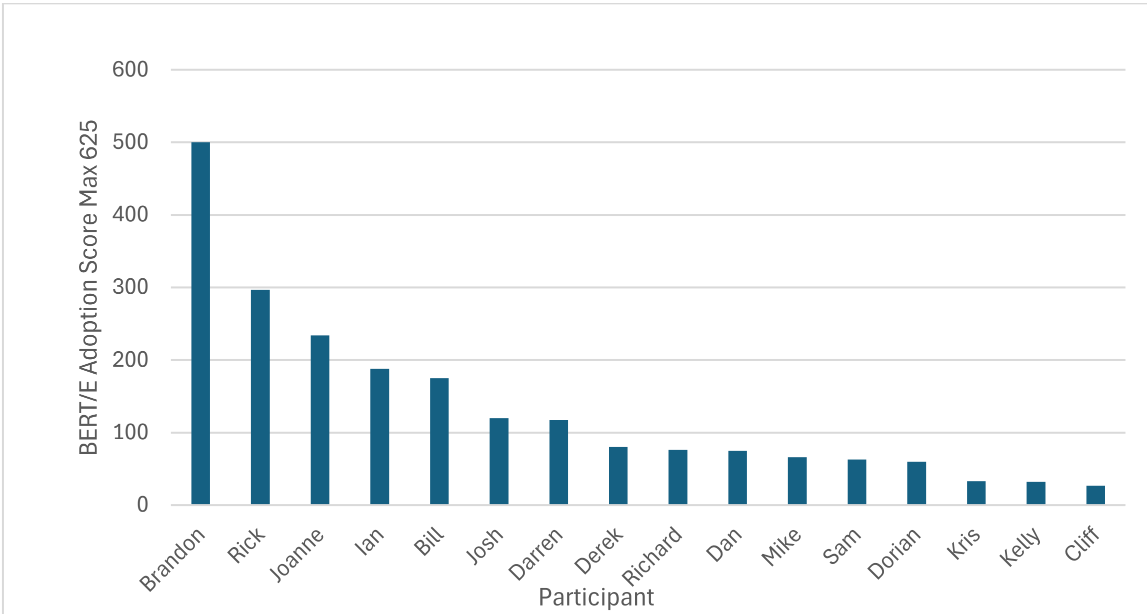

Figure 6.5. Participant BERT/E scores for BMP-snow-to-snow plant growth.

None of the participants assigned a maximum score (625) to plant growth from snow to snow, with Brandon having the highest score (600) and Cliff having the lowest (25). The average BERT/E Adoption score for this BMP was 134, indicating poor overall adoption. Brandon employed a mix of under-seeded clover, winter cereals, and volunteer grains, as well as full-season cover crops when excess spring rains prevented cash crop planting.

According to Archuleta (2023) a retired NRCS soil health/Regenerative Ag extension specialist, perennializing with cover crop is the most effective method of preserving and enhancing soil health in an annual grain rotation. While he acknowledges that this can be a difficult problem to solve (especially without livestock), he also observes that it can ensure minimal disturbance, continuous soil cover, and good diversity.

Lawley and Leybourne (2024)and Morrison(2021) surveyed Western Canadian farmers to learn about their experiences using cover crops. Their results revealed that, even though many of the participants were highly innovative, their attempts to implement cover crops were hampered by significant logistical and economic challenges. In addition, while the data from Lawley's and Morrison's studies is valuable, their exclusive focus on farmers who have attempted to integrate cover crops leaves a research gap relating to the reasons why most farmers do not even consider this practice. In my experience, many farmers are unwilling to consider this strategy due to the lack of a scalable, easy, profitable, and reliable way to establish cover crops in regions with short growing seasons, as well as problems with moisture deficits and unreliable rainfall.

Nonetheless, Bryant and Rath (2023) stated that farmers in all fifty states and Canada have been able to make cover crops work using the currently available technology. However, as of 2017, cover crops only accounted for 15.4 million of the 300 million total cropped acres in the US, with the practice being most common on Zero Till farms in regions with higher rainfall and longer growing seasons. This aligns with their cover crop adoption map, which indicates minimal usage in the Northern Great Plains and Western Canada. In the northern regions, the main users of cover crops tend to be cattle producers and organic farmers, especially those with cattle. In addition, processors also require potato growers to include cover crops as a Scope 3 requirement. This requirement has proven beneficial, as one Manitoba potato producer explained that, despite the increased cost, cover crops are very effective at controlling soil erosion. This potato producer further noted that he uses irrigation to help replenish the soil moisture absorbed by the cover crop, but eventually he would need a better price for his potatoes to cover the extra costs. Although the use of cover crops can be difficult and somewhat costly, Wallander et al. (2021) reported that there has been a recent surge in the implementation of cover crops as a result of USDA incentive programs that pay $12 to $92/acre for cover crops.

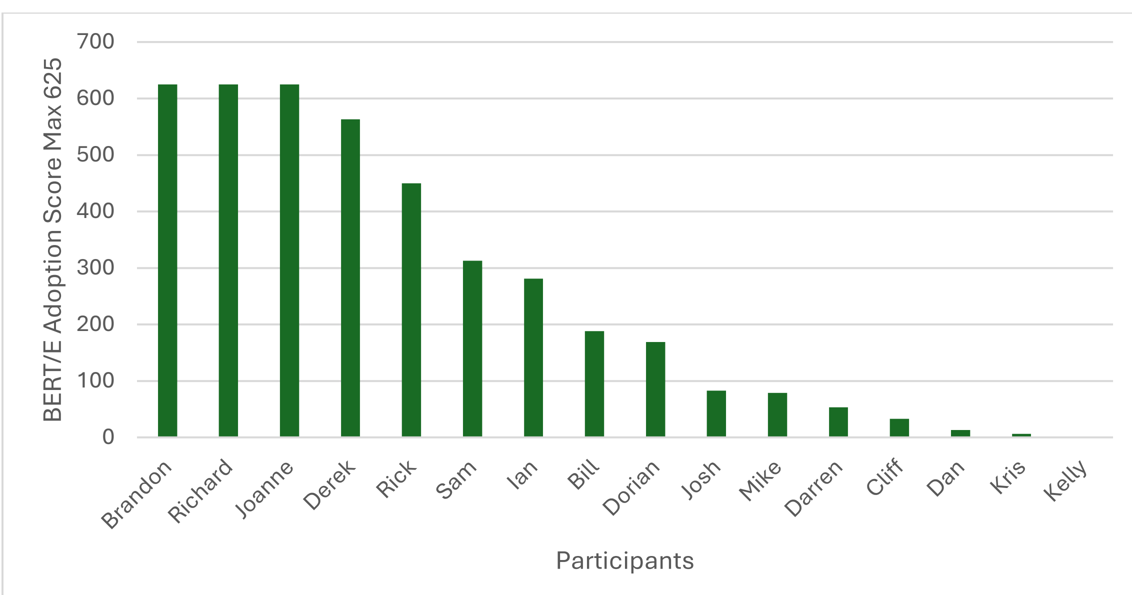

Figure 6.6. Participant BERT/E scores for BMP-plant diversity.

The participants' scores for plant diversity ranged from the maximum 625 score to several near zero, with an average of 257. While plant diversity and maintaining crops from snow to snow were viewed relatively equally as ideas, plant diversity had much higher BERT/E adoption scores compared to plant growth from snow to snow, although, both BMPs trailed far behind soil armor and lack of disturbance. The participants said they struggled to adopt these BMPs, especially growing crops from snow to snow, with eleven citing lack of moisture/drought as a major barrier.

6.4.2. Discussion

Darren (SW MB), Dorian (SW MB), Kelly (SC ND), and others shared that they were enthusiastic about the prospect of extending the growth period for plants on their farms, and that many had experimented with full-season cover crops, integrating spring-seeded companion crops with cash crops, and planting post-harvest seeded cover crops, including annuals and winter annuals. However, many of these strategies proved to be unsuccessful because of drought, with the cover crops either failing outright or being outcompeted for water by cash crops. In addition, the applied strategies were often too costly for the return. Also, the cover crops would sometimes steal moisture from the cash crop, thus compromising the net return. In contrast, practices such as broadcasting red clover on winter wheat in the spring (known as frost seeding) have been more successful in wetter regions like Ontario and the Eastern USA. Farmers in the prairies have attempted to use this method, but it was ultimately unreliable. Furthermore, aerial seeding fall rye into standing soybeans or corn has also been successful in wetter areas of the USA. However, the need to perform a separate seeding trip for cover crops increases costs and stretches management and labor resources.

Volunteer crops were the most popular cover crops among the participants, with some noting that they intentionally allow a few seeds to be thrown out through their combines. However, Brandon emphasized that volunteer winter wheat should be terminated in the fall instead of the spring to prevent wheat curl mites from transferring wheat streak mosaic virus to spring or winter wheat. Rick said that his measurements indicated that the areas where he had left a heavy volunteer crop of oats had 70-80 lbs less nitrogen/acre compared to areas where he had sprayed them out. The nitrogen is stored in the oats and is released after the oats are killed during winter. This can be advantageous for crops such as peas, which benefit from better nodulation early in the season if soil nitrogen levels are low and use the released nitrogen later in the season. This strategy may also yield positive effects for edible beans and soybeans, whereas non-legume crops may require additional fertilizer for spring growth.

Another successful but opportunistic practice is the use of full-season cover crops in prevent-plant situations. Brandon (Central ND) prioritizes seeding full-season cover crops in years or on fields that are too wet for planting normal crops after the cash crop seeding deadline. Brandon's USDA crop insurance covers 60% of the "prevent plant" cash crops, which helps offset the cost of establishing the cover crops. Brandon believes that this is an excellent way to improve soil health, but he is only able to implement this strategy when "prevent plant" situations arise, as he rents most of his land. Brandon also shared that he sometimes allows neighboring farmers to graze their cattle on his cover crops. On the other hand, Cliff (Central AB) owns his land and has taken a long-term view by allocating 25% of his land to full-season cover crops. He will do this in rotation with his cash crops for at least 4 years.

Among the other participants, Josh (SW AB), Mike (NE SK), Ian (SE SK), and Derek (Central SK) all said they plan to incorporate a perennial phase into their annual crop rotation. In addition, Derek, and Josh both have access to cattle, with Josh managing 650 cows. However, Josh says he is cautious about grazing cattle on his fragile brown crop land, as he does not want to overgraze or damage the land when it is wet. As such, he carefully monitors the weather forecast and ensures that cattle are off the annual crop land before rain arrives. Cliff has also employed this approach in the past, but his decision to reduce his herd from 1600 to 400 cows means he now needs less annual pasture. In contrast, while Mike is searching for cows to graze his perennials, his practice of cutting, baling, and selling his hay has contributed to a significant increase in SOM, even without the cattle. For his part, Ian (organic) uses alfalfa to build SOM, control weeds, and provide his cash crop with a source of nitrogen after the alfalfa is terminated. Ian leaves the alfalfa to grow for 1 to 5 years in some fields, but none of these fields are baled or grazed, as removing alfalfa as hay would further strain the natural supply of phosphorus. A small amount of the alfalfa is harvested for seed. While Ian was not enthusiastic about the economics of cattle, he admitted that, if he was 23 years old again, he might consider incorporating them on his farm. However, he did say that "you have to love cattle to have them," and he "just was not a cattleman."

Many of the participants reported success in sowing clovers or alfalfa with their cash crops, particularly in wetter years. However, they noted that the cash crops tended to win out in drier years, causing clovers to die. Weed control, particularly for broadleaf weeds, is another challenge when establishing a companion crop of clovers. Uncontrolled weeds will cause a yield drag on the cash crop. Some farmers sow clover as a biennial forage seed crop, while others, Dorian, and Darren, reported varying success with perennial rye grass in conjunction with canola or spring wheat. Kelly's farm (North Dakota, brown soil zone) is currently in its fourth year of severe drought. Consequently, they focus exclusively on cash crops, as there is no extra moisture for a companion crop.

A 21-year study in Saskatchewan found that the adoption of Zero Till had increased carbon sequestration by 498 and 449 kg CO_2 eq/ha/year in the brown and black soil zones, respectively (McConkey et al. 2020). The majority of fields in these zones were continuously Zero Till with increasing diversity in crop rotation, including monoculture cereals, pulses, and brassica. The findings showed that even monoculture Zero Till can sequester carbon and build soil health, with an estimated SOC accumulation rate of 0.15% for black, sub-humid soils and 0.17% for brown, semi-arid soils. While these rates are below the Paris Accord target of 0.4%, or 4 per 1000, they are still positive and are compatible with the available moisture.

In addition to lack of moisture, participants also cited a lack of technology or knowledge as barriers to growing plants from snow to snow. Dorian suggested that the use of delayed germination seed technology (DGST) could provide significant advantages in establishing late-summer cover crops. This approach involves planting coated cover-crop seed alongside a cash crop in the spring, with the germination of the cover crop coinciding with the early senescence of the cash crop, thus eliminating the need for a second seeding pass and reducing costs and wear and tear on the seeding equipment. Since this process is conducted in the spring at minimal extra expense, it would be scalable. The current BMP, which requires simultaneous seeding and harvesting, can be challenging, especially with limited labor and equipment. Some farmers seed a small portion of their land in the fall; however, even seeding winter annual cash crops can be difficult to manage. Dorian learned about this potential technology from me, and I have partnered with Ag-Quest to find suitable polymers and release agents for Delayed Germination Seed Technology (DGST). Previous DGST research has aimed to achieve earlier establishment and higher yields by seeding coated spring crops in the fall (Johnson et al. 2004; Clayton et al. 2004), but the unreliable timing of winter and spring's arrival poses a significant challenge, as missed timed planting often result in the seeds imbibing and dying due to frost or thaw. Occasionally, this approach has worked as planned, but it also has led to the uncontrolled growth of winter annual weeds, such as stink weed, in rapeseed fields. This experimental practice was employed prior to the development of herbicide-resistant canola. Developing DGST coatings for cover crop seeds is a significant research challenge, but it does not have freeze/thaw cycles to contend with.

Other improvements in technology and knowledge that may enhance the ability to grow plants from snow to snow include:

1. Screening species for their ability to establish when broadcast. Farmers in the USA broadcast cover crop seeds with aircraft, high-clearance applicators, and broadcasters mounted behind headers on combines. Having healthy friable soil with high soil aggregation and high infiltration rates would be an advantage compared to difficult-to-penetrate high-run-off soil.
2. Screening species for synergies in multispecies mixtures.
3. Screening species and cover-crop varieties for their suitability in the various regions of Western Canada.
4. Screening species for drought tolerance.
5. Searching for hardy winter annuals for use as cover crops and a base for green seeding cereal crops. Fall rye works ahead of broadleaf crops. A winter annual broadleaf crop, particularly a legume, would be helpful for green seeding cereals or canola.
6. Breeding cover crop varieties suitable for Western Canada. The USA already has breeding programs aimed at making fall rye and hairy vetch more suitable as cover crops (Moore 2021; Wayman et al. 2017).
7. New technologies for shooting/spraying seeds into the soil. An example of such technology is the QuadApplicator by R. A. West from Vulcan, AB.
8. Improving the management of volunteer crops as cover crops.

6.4.2.1. Crop Insurance

Josh initially identified the absence of suitable crop insurance policies as a significant obstacle to enhancing diversity via intercropping. Josh says he is ambivalent about crop insurance, as it often treats intercrops as a "novel" crop and ties coverage to the performance of major cash crops: if the major monoculture crops perform well and the intercrop fails, there is no payment for the intercrop. Conversely, if the major cash crops perform poorly and the intercrop performs well, a payment is made for both. Josh believes that this approach has three major flaws: first, despite the government incentives promoting Regenerative Ag, including intercropping, crop insurance does not provide adequate coverage; second, there is no direct coverage available; and, finally, there is likely less risk when two crops are grown together, such as peas and canola. Josh and Derek, the two participants who have embraced intercropping, have invested in grain-separating plants to make intercropping more feasible. In fact, they both shared that they have found intercropping to be more economically viable than monocultures. With respect to insurance, Derek said he does not purchase crop insurance, while Josh said he does not insure his intercrops.

Brandon felt that insurance is inadequate for many crops beyond wheat, corn, and soybeans. Anything that lowers a farm's "proven yield" will affect its crop insurance coverage. Brandon acknowledged that, while his adherence to regenerative principles has improved his net income, his crop insurance payout will be limited if a crop disaster occurs. In Canada, the same situation arises with the Individual Productivity Index (IPI) calculation, which makes optimal coverage contingent on having the highest yields in the cropping district. Thus, while reducing certain farm inputs may be economically and environmentally beneficial, it can also result in slightly lower yields and, consequently, less crop insurance coverage. This creates a dilemma wherein one government arm is promoting regenerative practices, while the other (i.e., crop insurance) discourages it, albeit inadvertently. The government's main economic goal is to increase production and GDP gross domestic product) growth, but it often pursues these objectives without investing in technology to minimize negative externalities.

Cover crops can have both positive and negative effects on insurance coverage. Although greater plant growth can result in greater CO_2 sequestration and increased SOC content, moisture management is crucial in dryland areas. Over time as soil health is improved, yields will also rise. However, if cover crops consume too much moisture, crop yields and, consequently, insurance coverage may decrease. There is a risk involved in adopting cover crops, and on-farm trials have shown the range of effects that green seeding can have. Green seeding involves establishing a fall rye cover crop in the fall and sowing a crop, such as soybeans or peas, into the standing rye in the spring. In organic farming, the rye can be terminated using a roller crimper at the anthesis stage. However, this method is not reliable in Western Canada because of the short growing season and limited soil moisture. Instead, farmers often use chemicals such as glyphosate to terminate the rye in Zero Till farming. Terminating rye with herbicides offers flexibility, but it is crucial to terminate it early in drier seasons. It is a guess when termination should occur and doing it too late can result in lower yields for soybeans or peas compared to neighbors who did not seed green. The government might need to consider enhancing crop insurance coverage for those who seed green, as it can increase CO_2 sequestration, reduce herbicide and pesticide use, and strengthen the soil against erosion. Additionally, it may help manage excess soil moisture in places such as the Red River Valley. Dan has been experimenting with using fall rye and hairy vetch to manage spring soil moisture and reduce the need for fall tillage.

6.4.3.2. Recommendations: Snow to Snow and Plant Diversity

1. More research and extension on intercrops, particularly in relation to optimal species, seed rates, seeding configurations, fertility requirements, weed control, diseases, and insect implications, and harvesting and marketing.
2. Provide crop insurance to encourage plant diversity and cover-crop use (snow to snow).
3. Develop economical and scalable cover-crop-establishment systems.
4. Support the development of delayed germination seed technology, DGST.
5. Reward farmers for carbon sequestration. It is a public good and a farm benefit, but it is a long-term investment.
6. Volunteer crops have become cheap cover crops. Learn how to manage them and measure their benefits for subsequent crops.

6.5. Alternative Nitrogen: Data Analysis and Findings

6.5.1. Participant Responses

The adoption of alternative nitrogen sources specifically addresses the challenge posed by the UNIPCC, which emphasizes the need to eliminate the use of fossil fuels to prevent the Earth from overheating. Figure 6.7 illustrates the participants adoption of alternative nitrogen sources.

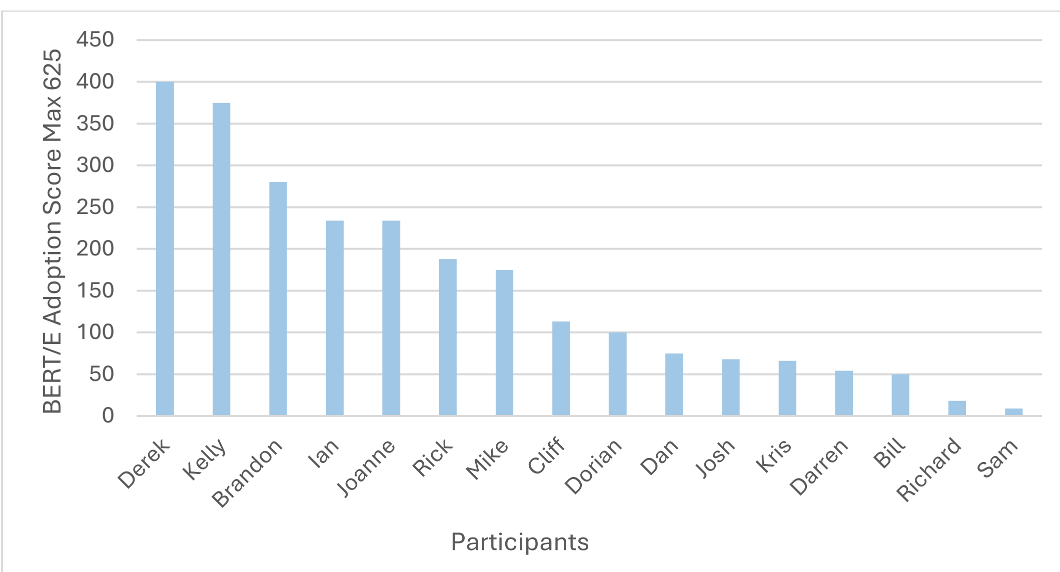

Figure 6.7. Participant BERT/E scores for BMP- alternative nitrogen sources.

Overall, the adoption of alternative nitrogen was low, with Derek, Kelly, and Brandon having the highest scores, and Dan, Josh, Kristjan, and Darren having the lowest. Currently, the Canadian government is working with farmers to reduce emissions from nitrogen fertilizers by 30% by 2030. To this end, Fertilizer Canada, many farm commodities, and general farm groups have developed and supported voluntary 4R programs, which emphasize using fertilizers at the Right rate, at the Right time, in the Right place, and from the Right source. Soil scientists such as Mario Tenuta (University of Manitoba), Richard Farrell (University of Saskatchewan), Wagner-Riddell (University of Guelph), and Dave Franzen (North Dakota State University) have examined these practices and concluded they are capable of reducing nitrogen-based emissions by 30% (Tenuta et al. 2023; 2016; 2019; Thilakarathna et al. 2020). Unfortunately, the current 4R initiative falls short of achieving the goal of eliminating fossil-fuel-based products by 2050.

Many food and consumer product companies that source their base ingredients from agriculture have pledged to reach net zero by 2050 through the Scientific Based Target initiative (SBTi 2023). Although some of these companies may plan to achieve net zero by purchasing carbon offset, the largest food company in the world, Nestle, announced in the summer of 2023 that it would stop using carbon offsets. Instead, Nestle will invest in programs and practices that help reduce GHG emissions in its own supply chain and operations to reach its net-zero ambitions.

Nitrogen and diesel fuel used on the participants' farms was previously shown in Side Bar 5 in Chapter 5. Currently, there is a strong correlation between crop yield potential (normalized for average rainfall, soil organic matter, and soil zone) and fossil-fuel use. Kelly and Ian reported using no fossil-fuel-based nitrogen, while Derek said he used very little. Conversely, Dan and Rick (Red River Valley) used the most fossil-fuel-based products and also had the highest yields. Erisman et al. 2008 has demonstrated a direct relationship between synthetic nitrogen use and population growth, noting that synthetic nitrogen is now responsible for half of crops produced globally. This finding confirms that the use of synthetic nitrogen is well-established, and that it will take significant innovation and effort to move away these fossil-fuel-based products. Furthermore, these findings also reveal that North America has exhibited the highest growth in nitrogen use (Ludemann, C.I.I *et al.* 2022). Some research advocates for a redistribution of nitrogen resources (Ritchie et al. 2024) from the Global North to the Global South, especially to the African continent.

The participants were then asked about scalable alternative nitrogen sources, which yielded six potential alternatives.

6.5.1. Alternative Nitrogen: Legume Crops

6.5.1.1. Participant Responses and Discussion: Perennial Legumes

The first alternative to fossil-fuel-based nitrogen was to increase the number of legumes in the rotation. Ian, the organic farmer, allocates at least 40% of his land to alfalfa and clovers in order to build up the nitrogen available to future cash crops. A small portion of the alfalfa, which was grown for alfalfa seed, was included in the production output calculation. Derek, Mike, Josh, Sam, have also begun to include perennial legumes in their rotation to build SOC and promote soil aggregation along with the co-benefit of fixing atmospheric nitrogen through the leguminous symbiotic rhizobium. Dorian, Darren, and Brandon reported using biennial clovers to build their soils, supply nitrogen, and produce forage seed crops in the second year. All participants reported having incorporated annual legumes, such as peas, lentils, chickpeas, fababeans, soybeans, or dry edible beans, in their rotation at one point or another.

The main constraints for growing perennials and biennials included the inability to successfully establish small seeds in dry years, complications with managing weeds in cash crops, having companion crops negatively affecting the yield and quality of cash crops, limited markets for hay or forage seeds, and the extra work required to produce high-quality hay or to manage leaf cutter bees for alfalfa seeds. Furthermore, subsequent cash-crop yields may be lower than average following the termination of perennial or biennial legumes because of the soil-water depletion caused by the full-season growth of the legume. However, with adequate rainfall these crops can facilitate higher yields for many years due to the increased nutrient supply, lower weed pressure, and improved soil health enabled by the legumes.

6.5.1.2. Recommendations for Perennial and Biennial Legumes

1. Expand markets (e.g., cover-crop seed and pollinator-strip seed markets) and make establishment more dependable.

6.5.1.3. Participant Responses and Discussion: Annual Legumes

Inadequate markets and prices may restrict the inclusion of more annual legumes in the rotation. This possibility is supported by Brandon who points out that growing any pulse crop other than soybeans in his area can negatively impact his crop insurance coverage. In addition, other factors, such as disease, can significantly affect the growth of peas and lentils. Aphanomyces and other root diseases can limit the ability to grow them more than once every eight years or may even force farmers to stop growing them altogether. Ascochyta is also a problem for lentils and chickpeas, which restricts their production to the driest parts of the prairie. To combat foliar diseases, some growers, including Josh and Derek, intercrop chickpeas or lentils with flax. Peas are also commonly intercropped with canola, yellow mustard, or oats. Fababeans, a minor pulse crop, are the most prolific nitrogen-producing annual legumes, and they are not susceptible to current strains of Aphanomyces found in Western Canada. However, fababeans are not regularly grown in the region, as they tend to thrive in cooler, wetter regions of the Prairies. Soybeans and edible dry beans are the least efficient at fixing nitrogen; in fact, dry beans often benefit from the addition of nitrogen. These legumes thrive in warmer, wetter conditions and are grown by Dorian, Rick, Darren, and Dan.

Many of the participants who grow intercrops expressed that crop insurance is insufficient for mixed crops. Derek, who operates in a region with low rainfall and fragile soil, does not carry crop insurance. Instead, he has invested in Regenerative Ag to improve soil health and increase resilience. He acknowledged that, during the drought of 2023, the land he had been practicing Regenerative Ag on since 2007 noticeably outperformed the land he had just purchased.

Kelly said that he has ceased growing legume crops because of a 4-year drought. Instead, he has focused on making his soils more biologically active. In the dry years, the high nitrogen content of pulse crop residues causes excessively rapid break down and little armor on the soil. In addition, the pulse stubble is too short to trap winter snow, so Kelly grows taller cereal crops that can be cut to 24 to 30 inches high with a stripper header, thus maximizing snow catch. These changes have allowed him to maintain good cash crops and protect his soil. His healthy, well-aggregated soils ensure that rainfall infiltrates into the soil instead of being lost as runoff.

Several participants cautioned against overusing pulses in the rotation, as they have to be cut at ground level at harvest, and their residue break down quickly, leaving the soil vulnerable to erosion. Brandon has ceased growing soybeans for this reason, noting that many farmers respond to the market demand for soybean-based biofuels by planting soybeans after soybeans, which causes their soils to suffer. Instead, Brandon grows peas, as they are sown and harvested earlier, allowing him to sow a cover crop or let pea volunteers grow to provide protection. In addition, intercropping peas with brassica or oats can help increase the stubble height at harvest and provide some residue with higher carbon content to slow down the breakdown process.

6.5.1.4. Recommendations for Increasing Annual Legumes

1. Work to improve disease and insect resistance.
2. Work to develop more biologically active soils that can help regulate/control disease and insect vectors, as well as help reduce soil weed seed banks.
3. Continue breeding for improved agronomic and market traits.
4. Continue to develop markets for these crops, particularly for their valuable protein isolates.

6.5.2. Alternative Nitrogen: Long-Term Zero Till

6.5.2.1. Participant Responses and Discussion

Franzen's (NDSU) analysis of 130 nitrogen response trials found that wheat grown using long-term (at least six years) Zero Till can have a nitrogen credit of up to 50 lbs N/acre in North Dakota fields with a heavier texture (Franzen 2009), while Lafond et al. (2011) found that long-term Zero Till on lighter loam soil with 50% sand produced a nitrogen credit of approximately 27 lbs N/acre. Consequently, Richard has called for up-to-date nitrogen response recommendations, as Zero Tillage's effectiveness at increasing SOM and mineralization rates creates a favorable environment for native free-living nitrogen-fixing microorganisms, such as diazotrophic bacteria.

While the adoption of Zero Till practices in Manitoba has decreased in recent years (Statistics Canada 2021), the persistent belief that soybeans and corn require soil warming via high-speed disc passes often disrupts continuous Zero Till. Bill noted that research findings have shown this belief in the need to till to grow soybeans and corn to be a myth, especially when using a hoe drill for mini strip tilling. Bill's assertion is supported by Gauer et al.'s findings, which show minimal soil temperature differences when straw was removed from the seed row (Gauer et al. 1982).

Zero Till has always been difficult to implement on the clay soils of the Red River Valley. Dan is able to select fields and crops where he can have good success using direct seeding, sharing that one of his fields has been Zero Till for 10 years. However, Dan acknowledged that he cannot direct seed into corn residue or on some fields, particularly those that typically flood in the spring, as the residue floats on the water surface, and the wind pushes it to form a thick mat of straw at the leeward end of the field. As the water recedes, Dan is left with a soggy mess that is difficult to spread or burn. Fall tillage and the incorporation of straw prevents this outcome. Dan says he has experimented with sowing fall rye with the intention of using it for green seeding, which can help manage floating straw, soil moisture, and trafficability. In dry years, Dan would terminate the rye early to avoid restricting moisture availability to the cash crop, while in wet years, he would delay termination, allowing the rye to grow longer and use up the excess water. One of the problems with this strategy is the cost, time, and opportunity to sow the rye in the fall (see barriers: snow to snow BMP).

Rick, who also farms the clay soils of the Red River Valley, uses many of the same strategies as Dan, but with one key exception: rather than using 100% tillage or 100% Zero Till, he is experimenting with controlled traffic farming and strip tilling for his 20-inch-row corn and soybean crops, with the aim of stabilizing the stubble and preventing it from ending up as soggy piles at the end of the field. Rick believes precision fertilizer and seed placement in the tilled strip will help in his effort to reach a nitrogen use efficiency (NUE) of 95%. NUE can be calculated a couple of ways. Traditionally, NUE is defined as the amount of nitrogen applied versus the amount in the harvested product; this number is often 50 to 60% NUE. Another way to calculate NUE is to measure the grain nitrogen, straw nitrogen, root nitrogen, and soil residual nitrogen. According to Cindy Grant (ret. AAFC), this approach can result in NUE values as high as 110%, particularly if diazotrophs are fixing nitrogen in the soil and one accounts for the 5–10 kg of N/ hectare/year that occurs when lightning strikes create nitric acid. (Shepon et al. 2007).

6.5.2.2. Recommendations for Zero Till Alternative Nitrogen Strategy

1. Conduct nitrogen response trials with long-term Zero Till.
2. Investigate whether adding biology such as Kelly's IMOS to short-term Zero Till can speed up the nitrogen credit process.
3. Develop extension material supporting continuous Zero Till. Dispel the myth that full tillage is required for soybean and corn production.
4. Develop a Zero Till-Plus approach that incorporates regenerative practices to further strengthen soil building.
5. Develop strategies to allow clover, alfalfa, and perennial grasses to be used with Zero Till to biologically break up hard pans and redistribute nutrients in the soil.

6.5.3. Alternative Nitrogen: Bugs in a Jug

6.5.3.1. Participant Responses and Discussion

Many participants were skeptical of "Bugs in a Jug" approaches, which involve finding or modifying biology to help non-leguminous plants obtain nitrogen. Several companies, ranging from startups to major agricultural input manufacturers, have been working on Bugs in a Jug products. Sugar cane is an example of a crop where certain varieties have an asymbiotic relationship with free-living non-rhizobia bacteria, which provide all the nitrogen needed by the plant (Boddey et al. 1995; Ohyama et al. 2014). Ohyama found that out of 135 field trials, only 19% showed a significant response to added nitrogen. Most varieties did not respond to the addition of nitrogen. The more successful Bugs in a Jug products are typically associated with plants that have higher sugar content, such as sugar cane, sorghum, and corn. Rick said that using Pivot Bio on his corn over the past 2 years had increased his yields by ten bushels/acre. Pivot Bio claims that their product can be used to further increase yields or reduce the nitrogen required (Pivot Bio 2022). Dorian has tried a range of Bugs in a Jug product on both wheat and canola, but she says these experiments did not result in any consistent benefits. Similarly, Franzen et al.(2019) conducted Bugs in a Jug trials in six states, with the findings showing minimal benefits. Additionally, Derek and Kelly said they were reluctant to introduce foreign microbes onto their farm.

At the 2024 KAP AGM, Pierre Petelle of Crop Life Canada expressed optimism that gene editing would soon be approved in Canada, paving the way for various innovations such as self-fertilizing wheat and canola (or better Bugs in a Jug) (Petelle 2024). Life science companies expect gene editing to drive sustainability and view it as having similar transformative potential to the adoption of Zero Till. For instance, a team of scientists working out of AAFC Lethbridge have made advancements in developing N fixing triticale using advanced genetic manipulation (Ziemienowicz, Pepper, and Eudes 2015; Cotee 2020; King 2018; Alberta Wheat Commission 2021).

6.5.3.2. Recommendations

1. Develop policy and support development of effective biological and genomic nitrogen fixation for non-legume crops.

6.5.4. Alternative Nitrogen: Green Nitrogen

6.5.4.1. Participant Responses and Discussion

Green NH_3 is synthesized using the same basic Haber-Bosch process that is used to make fossil-fuel-based NH_3, with one major difference: instead of using steam-reformed natural gas as the source of H_2, Green nitrogen plants synthesize H_2 via water hydrolysis powered by green electricity. Green NH_3 can also be used as a carrier for Green H_2 as fuel for engines. Indeed, Green NH_3 is currently being considered as a substitute fuel for ocean freighters.

Most major nitrogen manufacturers either make some Green NH_3 or have plans to do so (YARA 2021). Small companies such as Fuel Positive (Fuel Positive 2021) and AMMPower (Benninger 2024) are working on on-farm-sized Green NH_3 plants. These plants cannot produce urea ($CO(NH_2)_2$) without a source of carbon. Traditional manufacturers use the C byproduct from the steam-reformed CH_4 to make urea. While the ability to store NH_3 and access to Green electricity may make on-farm plants advantageous, most participants said they were uninterested in this technology, either because they felt it was too far from being available, or because they did not think it was something that directly affected them. Most of the participants said they would continue to source their nitrogen from local distributors, but Kelly and Ian were content to continue to use their biologically based nitrogen systems.

6.5.4.1. Recommendations

1. Develop policy to support and encourage cost-effective Green N production at the world and farm scale.

6.5.5. Alternative Nitrogen: Future 4R Nitrogen Management

6.5.5.1. Participant Responses and Discussion

Participants were divided into two camps regarding the 4Rs. Farmers like Kristjan, Dan and Rick promoted erring on the side of increased nitrogen use to lower N related emissions / kg of output and were interested in increased NUE using 4Rs. They soil tested, used variable rate and effective placement, and often precision banded at seeding. Most farms did not rely on expensive low-emission fertilizer treatments to achieve higher NUE.

The other camp relied on biological sources of nitrogen and did not need the 4Rs to reduce emissions. The extreme members of this camp were Kelly and Derek, the two Net Positive farmers.

4R nitrogen management of Green NH_3-based products is similar to fossil-fuel-based N, but it will be different for biological-based alternative nitrogen. While biological-based systems are generally more balanced and have less available excess nitrogen, both sources produce emissions that must be managed. Regardless of the source, nitrogen can be converted into N_2O. For instance, N_2O can be very high when heavy spring rainfalls occur after a green manure crop has been terminated the previous fall (Westphal, Tenuta, and Entz 2018). Problematically, N_2O is 300 times more potent than CO_2 as a GHG and must therefore be managed carefully.

6.5.5.2. Recommendations

1. The principles of 4R must be developed and research must shift to focus on solutions that minimize nitrogen-associated emissions while eliminating fossil-fuel-based nitrogen by 2050. We also need better technology and systems to track actual on-farm NUE.

6.5.6. Alternative Nitrogen: IMOS

6.5.6.1. Participant Responses and Discussion

Kelly developed IMOS to be a cost-effective, user-friendly system that mimics the natural process of providing nutrients to plants. In designing his system, Kelly drew inspiration from various sources, including Korean natural farming, Dr. Elaine Ingham's soil food web compost and compost tea, Dr. David Johnson's Johnson-Su's no-turn compost and compost tea, Dr. Christine Jones' Quorum Biology, and Dr. James White's rhizophagy. Kelly has successfully employed his IMOS system on his farm for several years, and he now promotes it via a five-part video series, ready-to-use microbial food, and a members-only blog. Kelly's wife, DeAnna, claims the cost of IMOS seed treatment can be as low as $0.30 per acre.

Other participants enhanced the biological activity of their soils using a variety of purchased or home-made biological seed treatments or in-furrow applications. EcoTea is one notable example of an off-the-shelf product. Dorian said that she has used EcoTea with some increased early vigor but, unfortunately, it has had no significant impact on grain yields. In contrast, Derek uses a homemade inoculant based on material he composts on the farm. Brandon also makes his own inoculant, but it is based on a system derived by Dr. Johnson and his wife, Su, from New Mexico State University (Johnson 2019; Johnson et al. 2015). Another source of inoculants is from earth worm castings.

Kelly's IMOS system is undoubtedly intriguing and raises many questions. For example, can it be adapted for different regions and crops, or is it limited to the brown soil zone where Kelly's farm is located? Kelly's system involves initially favoring pioneering succession species, such as brassica and legumes, moving along the biological succession path until the soil supports grasses at a higher succession level. While Kelly now mostly grows cereals due to a lack of rain, it remains to be seen whether it will be possible for him to favor brassica and pulses again. If Kelly's system has a 20% lower yield, but is more profitable, it will not harm him; however, is this acceptable as the world warms and food becomes scarcer? Or does the built-in resiliency of the healthy soil created by Kelly's system allow it to withstand drought, thus making it a more sustainable and higher-yielding food system in the longer term?

6.5.6.1. Recommendations

1. Research scientists and farmers should take a serious look at Kelly's IMOS system and Derek's low input system, making sure to use appropriate checks and replication. An IMOS user club has already been established.
2. Look for ways to ensure that these systems are suitable for a wide range of crops and soil zones, and that any yield gaps are minimized.

6.6. Alternative Fuel BMPs: Data Analysis and Findings

6.6.1. Participant Responses

Accessible and affordable alternative fuels are critical for reducing emissions.

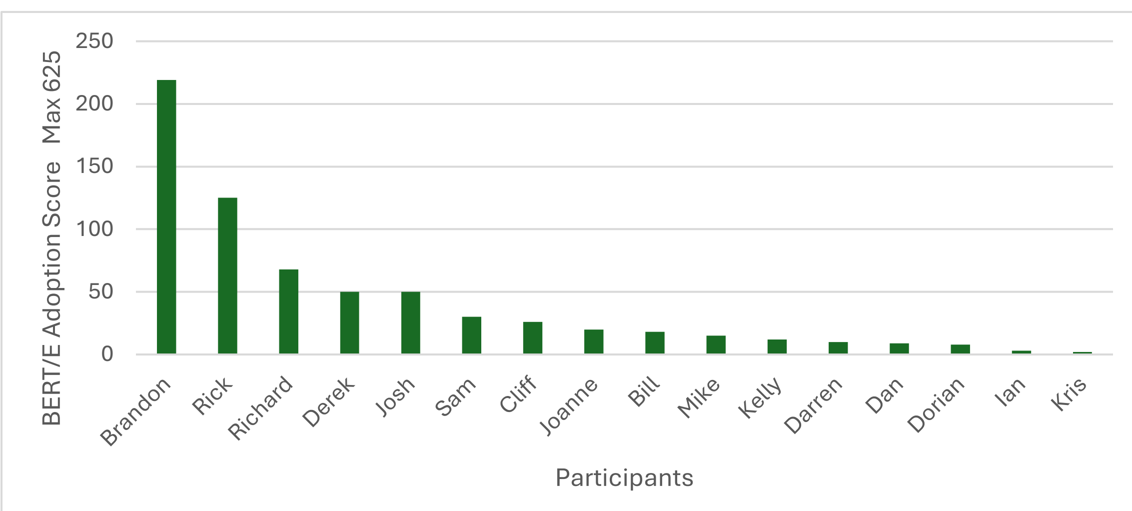

Figure 6.8. Participant BERT/E scores for BMP- alternative fuels.

On average, the participants rated alternative fuel as a very good idea (83%). However, the BERT/E adoption rating was only forty-one out of a maximum of 625, indicating a lack of readily available and economical alternatives. Most participants said they were not actively pursuing alternative fuels because diesel and electricity are currently cheap, readily available, and trouble-free. Derek was the most enthusiastic about adopting alternative fuels (BERT/E score: 400), and he was particularly excited about using renewable electricity to power his large food-grade grain-cleaning facility and flour mill. Airloom was discussed as a newer, cheaper alternative to generating electricity from wind (Lumley 2024).The participants were given the opportunity to evaluate alternatives to diesel fuel, including straight vegetable oil (SVO), biodiesel, renewable diesel, Green NH_3, and Green H_2, as well as other energy sources such as electrification, Green electricity, biomass, and biogas. Although the majority of participants believed alternative fuels would not be accessible in the immediate to medium term, Federated Co-op is constructing a renewable diesel plant in Regina, which is expected to have an annual production capacity of 3 billion liters once completed (Federated Co-operative Limited 2019). Renewable diesel, which is chemically identical to regular diesel, is made from hydro-treated animal fats and vegetable oils rather than crude oil and requires no changes to farm equipment. The participants were surprised to learn that only 0.75% to 0.90% of farmland would be required to grow enough canola to meet the on-farm motive power requirements of a well-managed Zero Till farm. See Appendix 6.6.1 for this calculation. None of the participants had used any form of diesel fuel substitute, and most were unaware of the distinction between biodiesel and renewable diesel. There are approximately 78 million acres of cropland in Western Canada, with each acre requiring 10 liters of diesel. This amounts to 780 million liters of diesel, or less than one-third of the Co-op plant's capacity. Thus, renewable diesel is an obvious solution to the question of alternative fuel sources and can remain so until a more cost-effective option emerges. In addition, renewable diesel allows farmers to maintain the same "continuous" duty cycle they are currently using, which means it is never certain when they will stop the tractor or combine. Indeed, farmers will seed 24 hours a day if conditions warrant it, and they will combine for longer than 24 hours at a time if they are trying to beat the rain. If renewable diesel should be used anywhere, it should be prioritized for grain farms.

The low scores assigned to this BMP were largely based on the participants' experiences with a few electric cars, an electric pickup truck, an electrified side-by-side conversion led by students, and a small oilseed crusher. Nonetheless, many of the farms had solar photovoltaics, and Mike said he is strongly in favor of using Saskatchewan uranium for electricity generation.

A few participants were not convinced alternative fuels and nitrogen were necessary, pointing out that Western Canada, and Saskatchewan in particular, already has the lowest emissions per unit of grain produced in the world (Desjardins et al. 2020; Bamber et al. 2022). Therefore, any decrease in output from Saskatchewan would have to be compensated for by increased production in areas with higher emissions. While there is merit to this argument, it may be moot when companies such as Nestle ask what steps farmers are taking to achieve net zero by 2050. Ultimately, Western Canadian grain farmers need to pay attention and keep up with, if not lead, the global transition towards eliminating fossil-fuel-based products by 2050.

6.6.2. Discussion

I believe that certain fossil-fuel-based products, such as those with long-term uses (e.g., in-ground plumbing pipes) or those that are 99% reusable or recyclable, will be exempt from the net zero initiative. Additionally, critical herbicides and pesticides will continue to be used in the majority of crop production, as their function is difficult to duplicate without their petroleum base. As indicated earlier they must be used wisely. To minimize their use, it is important to make them as effective as possible by combining them with agroecological solutions (Tidemann et al. 2023). The major targets of the move to net zero should be single-use products, such as fuel and nitrogen.

Petroleum-based-fuel reduction practices can be divided into two groups: technology that reduces fuel demand, such as Zero Till or crop rotation wherein one seeding can result in harvests for two or more years; and technology that replaces fossil-fuel-based products. Renewable diesel is the easiest and most logical alternative, but electrification should also be pursued for units with limited and regular duty cycles.

Even with renewable diesel N_2O emission can still be high. There is a need for kits to bring older farm equipment into compliance with more current standards. Rick says his tractor emissions are less than 3% of what they would have been 20 years ago. Tractors are used much less in Zero Till, and they can remain functional, even after 30 years. However, old tractors have high emissions. Cummins currently offers retrofits for emission reductions, but not for popular engines such as the 855 and N14 engines used in many large tractors, as there is little demand. Furthermore, some farmers have had trouble with the latest emissions equipment, finding it unreliable. As a result, they have deleted this equipment, which translates to higher emissions. Thus, older tractors must be retrofit to produce significantly less emissions, and new tractors must be more dependable.

As companies make their SBTi pledges to be net zero by 2050, it is important to note that Nestle (the largest food company in the world) realized that buying carbon credits may not be sufficient for achieving net zero or Net Positive status. As stated by a Nestle spokesperson:

> *Our net zero roadmap does not rely on offsets. We focus on GHG emissions reductions and removals within our value chain to reach our net zero ambition.* (Segal 2023*)*

This message from SBTi and Nestle will have a profound impact of the products available to farmers to grow crops in the future. Fossil-fuel-based nitrogen and diesel fuel will need to be replaced.

6.6.3. Recommendations

1. Farmers and farm groups should lobby governments to prioritize agriculture when developing incentives for renewable diesel use.
2. Develop a strategy to support biodiesel production unless renewable diesel is clearly a better option.
3. Develop a strategy to provide farmers with carbon offset or inset credits for using renewable fuel on their farms, particularly if they grow Net Positive oilseed crops.
4. Avoid wasting time and resources exploring the use of H_2 or electrifying large continuous-duty farm equipment.
5. Develop affordable emission-reduction kits to bring older farm equipment into compliance with more current standards.
6. Embrace renewable electricity, especially as advances in technology causes costs to fall.

6.7. Agroecological Solutions: Data Analysis and Findings

6.7.1 Participant Responses

Agroecological Solutions will not strongly impact a farmer's Net Positive status or their SFI score, but they will enable a greater diversity of solutions to bolster resilience.

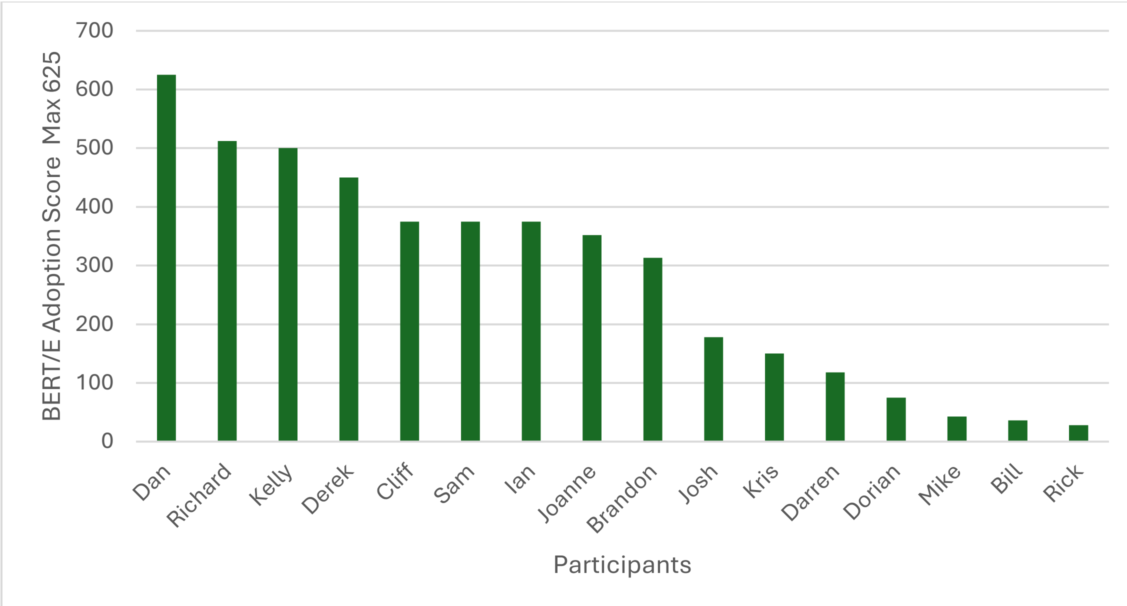

Figure 6.9. Participant BERT/E scores for BMP- agroecological solutions

As shown in Figure 6.9, there was wide variance in the participants' BERT/E scores for this BMP, with Dan at the top end at 625, and Rick and Bill on the other end of the spectrum at near zero (average: 281). The low scores given by Mike, Bill, and Rick were due to their belief that agroecology practices are organic practices; as such, they had little interest in such practices. The data shown in Table 6.4 (page 191) indicates that the lowest-scored BERT/E component was T (available dependable technology). Among the high-input participants (i.e., Rick, Bill, Mike, Kristjan, and Dan; see Figure 5.5.), Dan was the only one to prioritize agroecological solutions. In addition to being a farmer, Dan is also a consulting agronomist, and he prides himself on finding long-term, cost-effective solutions that will increase the income for his farm and his customers. Thus, he is always on the lookout for new agroecological solutions. However, Dan acknowledged that it can be challenging to break weed and insect cycles.

Many participants often overlooked the significance of various agroecological practices, such selecting pest- and disease-resistant crop varieties and employing diversified crop rotations to minimize pest damage. Other agroecological methods include narrow row spacing, precision fertilizer placement, higher seeding rates, and green seeding, which can help reduce weed competition and the need for herbicides. These practices align with the first three levels of the Gliessman-Snapp hierarchy of agroecology, which involve reducing or eliminating the need for synthetic chemical intervention (Snapp et al. 2021; Gliessman 2018). Brandon initially assigned a rating of zero to agroecological solutions, but, after discussing his farming practices, which included growing yellow mustard instead of canola (more resistant to flea beetles, thus less need for insecticide), using diverse crop rotations, employing cover crops, and observing an increase in spider webs on his armored Zero Till stubble, he increased his rating to 50%. This increase was well justified, as Brandon's use of agroecological practices had also allowed him to eliminate all insecticides and fungicides from his farm.

Other participants identified diversified crops and crop rotations as the backbone of agroecology on their farms. Kelly had the simplest and least diverse rotation, but he had modified it to compensate for the drought he was experiencing. All others used a diversified collection of crops suitable for their growing environment. For example, Rick and Dan (Red River Valley, black soil zone) included warm, long-season crops like corn and soybeans in their rotation, while Josh's (AB foothills, brown soil zone) rotation consisted entirely of cool-season crops and drought-tolerant legumes. Sam (SD) suggested that crop diversification was foundational to their success using Zero Till on his semi-arid soils.

Kelly reported that moving away from high-input farming has drastically improved his SOM, aggregation, water infiltration, and soil biological activity, and that he has not used insecticides or fungicides for 10 years and had reduced his herbicide usage by 60%. In addition, Kelly no longer relies on imported fertilizer and instead uses his IMOS biological inoculant. He believes that increased soil biological activity minimizes disease and insects, and that the increased beetle population helps reduce the weed seed bank. Derek and Brandon have observed similar results with their increased biologically active soils.

The most effective agroecological strategies start with healthy soil.

6.7.2. Recommendations

1. Continue research into methods for building healthy biologically active soils.
2. Continue research into methods that can reduce or eliminate the need for agrochemicals, including fossil-fuel-based nitrogen.

6.8. Sustainable Intensification: Data Analysis and Findings

6.8.1 Participant Responses

Sustainable intensification was described by Sam as "just more tools for the toolbox. You will use them if they help get the job done cheaper, faster, or better."

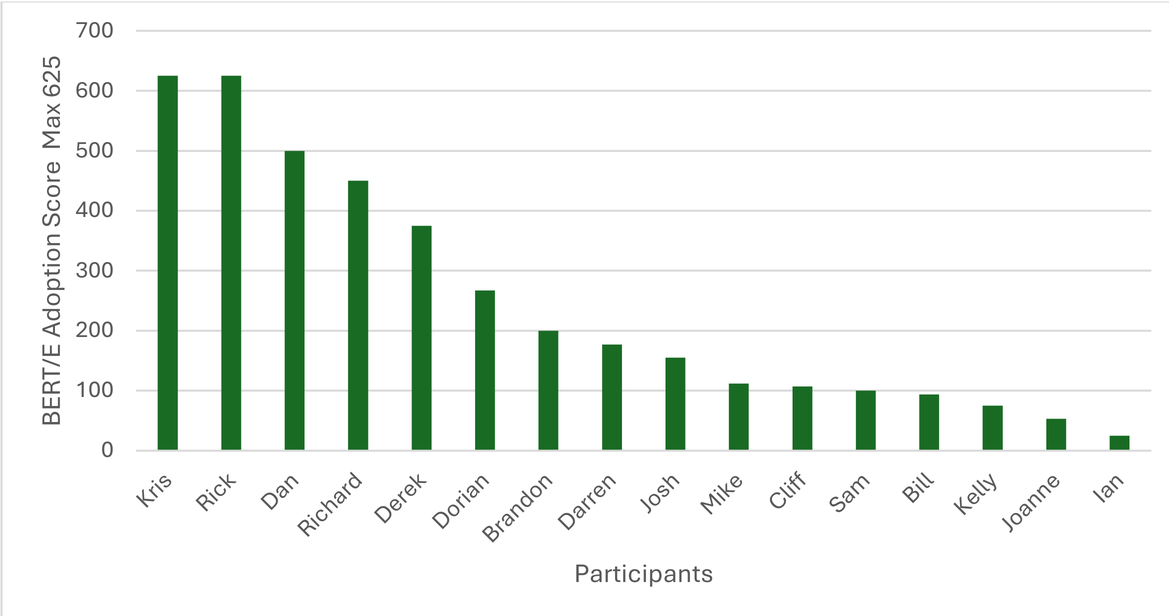

Figure 6.10. Participants' BERT/E adoption scores for BMP- sustainable intensification.

The average score for sustainable intensification was 246, with economics and energy being the two BERT/E factors most responsible for bringing scores down. As noted earlier, energy has a reverse score, with 1 being the best. Ian, Joanne, Kelly, and Sam assigned low scores to sustainable intensification due to either their experience with or perception of the related economics. Sustainable intensification solutions were often referred to as "tools," with some being considered things the participants "can't do without," for example, GPS and autosteer. The ratings for others, such as sectional control and variable rate, were highly dependent on variability in the land. A second theme was related to how these tools were used, and who owned the data generated by some of the more advanced options. A third theme related to whether these tools really help reduce emissions, as some farmers tended to use them to measure emissions/unit of output, possibly leading them to use a little more fertilizer (vs. less). The sustainable intensification tools discussed in the interviews included GPS, precision ag, autosteer, autonomous guidance, Artificial Intelligence/ Big Data, sectional control, 4Rs, variable rate, and Green on Brown and Green on Green sprayers.

The use of variable rates can help ensure the right rate is used in the right place, which can help farmers get the most out of their best land. In their study, conducted near Brandon, Manitoba, Glenn et al. (2021) found that, while the "best" land was the highest yielding, it only needed 50% of the recommended fertilizer to optimize yields, whereas the "poor" land needed the full recommended rate. They tested three different rate ranges for each zone, with results showing the “average” site to have the lowest yields and the “low” and “high” sites producing similarly at the same fertilizer rates (i.e., the high rate for the “low” and the low rate for the “high”). In the end, the optimum actual nitrogen rates for all three sites in the field were similar. Researchers have shown that the best land tends to have high SOM, better water-holding capacity, and a higher mineralization rates, thus requiring less nitrogen than most current soil test recommend using the 2.25 lbs of N/bushel of wheat model (Mangin and Flaten 2023).

Conversely, the results of Gurr et al.'s (2023) 10-year study revealed that crops responded to higher nitrogen and phosphorus applications over time. Since the Gurr trial used half-mile long strips, there would be an average over “low” to “high” yielding sites as described by the Glenn study. The Gurr results reflect the trend towards increased nitrogen use across Western Canada. Zero Till with increased WUE enables the available water to be turned into more bushels with more nitrogen and phosphorus input. However, Franzen’s work indicates that, on mature Zero Tilled fields, lower rates of phosphorus and nitrogen can produce equivalent yields to tilled fields (Franzen 2009). Alternatively, while the application of more nitrogen may result in higher yields, it will also produce more NOx emissions/acre. This could mean the same, higher, or lower emissions/tonne of output, depending on the yield response to the last increment of nitrogen in any particular part of the field.

Glenn et al.’s (2021) findings may seem counterintuitive to many farmers, and farmers may be putting too much fertilizer in the wrong place, namely, the high-yielding areas. It is already difficult for farmers to conduct proper trials with replication and checks on simple comparisons; variable fertilizer application rates add another level of complexity.

Some participants, particularly Rick, Kristjan, and Derek, use as many sustainable intensification tools as possible to help fine-tune their farm management. Rick is the farm cooperator for the Enterprise Machine Intelligence and Learning Initiative (EMILI), which is a nonprofit organization dedicated to advancing technology and developing skills to accelerate digital agriculture. He estimates that the use of imagery and long-term precision yield mapping has allowed him to achieve 95% NUE, which is significantly higher than the normal levels of 50% to 60%. Rick’s claim is likely based on nitrogen measurements obtained from the grain, all the residue, and residual levels in the soil. While this is not the standard method of calculating NUE, it is does provide useful insight. Rick’s next step is to collect on-the-go grain protein levels so he can further refine his nitrogen applications to achieve a higher NUE.

Some sustainable intensification tools can be used to make informed decisions for variable rate nutrient application. Some farmers have used variable rate to change crop seeding rates and vary pesticide applications. Among the participants in this study, Mike uses variable rate to plant different cover crops.

As an example of adding more sophisticated tools to the farm Kristjan is working with the Canadian Alliance of Net Zero Agriculture (CANZA) on their first pilot project, which is,

> *to access the climate-smart farming opportunity to develop a regionally representative, low-cost, and scalable monitoring, measurement, reporting, and verification (MRV) framework for quantifying environmental outcomes of climate-smart practices, as well as enabling agri-food corporations to report these outcomes as part of their Scope 3 emissions inventory—supporting their ESG goals.* (CANZA 2024)

The CANZA focus on Kristjan's farm is,

> *on developing inexpensive, accurate, and simple, but innovative, tools and processes that could make monitoring and estimating soil carbon sequestration a more tractable activity. High-intensity, stratified soil testing with laboratory analysis is generally considered the most accurate method of assessing soil carbon; however, several new tools have been gaining traction in the soil carbon measurement space.* (CANZA 2024)

The cost of sequestering and storing carbon in agricultural soils to reduce Scope 3 emissions may soon play a significant role in farmers' management practices. Thus, it will be critical to incentivize farmers with offset credits or payments for implementing AGWM practices that do not provide immediate financial benefits. Zero Till is a unique case for farmers, as they practice it for direct financial gain from the market. However, many other BMPs require further research to improve their effectiveness, affordability, and ease of implementation. Annual compensation may be necessary for some BMPs to become financially feasible.

Derek was the first of the participants to acquire a Green on Brown sprayer, which is capable of identifying and targeting weeds like Canada thistle while using only 9.5% of the herbicide that would have been required to cover his farm's 10,000+ acres with a conventional sprayer. The technology is currently being developed to enable Green on Green spraying, but it still needs refinement to accommodate rolling topography and variable boom heights. Although there is a high capital cost associated with the Green on Brown technology, Derek suggests it offers a good ROI and is environmentally friendly. A new sprayer with this technology will cost over $1 million, while retrofit kits from other companies are priced over $300,000.

Common concerns expressed about sustainable intensification tools were their hefty price tags, which made them unrealistic for some farms; the rapidly evolving state of the technology, which contributes to high depreciation in resale value; the time commitment required to learn the new technology; the relative scarcity of people who are capable of running such sophisticated equipment; and the reduced likelihood of there being a “farmer” fix if there is a glitch, break down, or accident. Some participants expressed frustration with losing a day or more of work while trying to figure out how to work a tool or waiting for someone to come fix it. Darren mentioned that the Canadian Digital Adoption Program (CDAP) will pay for a consultant to assess the needs of a farm and make recommendations about which sustainable intensification tools are most appropriate (Government of Canada 2022). However, Josh said he wished most of subsidy programs would be discontinued, as they tend to drive up the costs of services while only a few farms benefit.

6.7.2. Recommendations

1. These sophisticated and high-capital-cost technologies require intensive IT support. This may mean a specialized staff on-farm to determine what pays, how to get the most from the tools, and how to keep them running. This puts smaller farms without specialist staff at a disadvantage. The CDAP grants are good, but they only help a few people.
2. Companies should not be able to collect data from farmers for free and then charge them back for the information unless there is a guarantee of a fair ROI for the farmer.
3. Measures must be put in place to prevent companies from holding farmers hostage through annual subscriptions fees, service fees, and either planned or unplanned obsolescence. Major farm machinery companies may decide to include some of this technology in their fleet discounts to win over mega-farm accounts, leaving the non-fleet, smaller, independent farms behind.
4. Policies are needed to ensure that the farm and rural population are not decimated in the quest for high-input autonomous farming models.

6.9. Conservation and Restoration of Wildlands: Data Analysis and Findings

6.9.1. Participant Responses

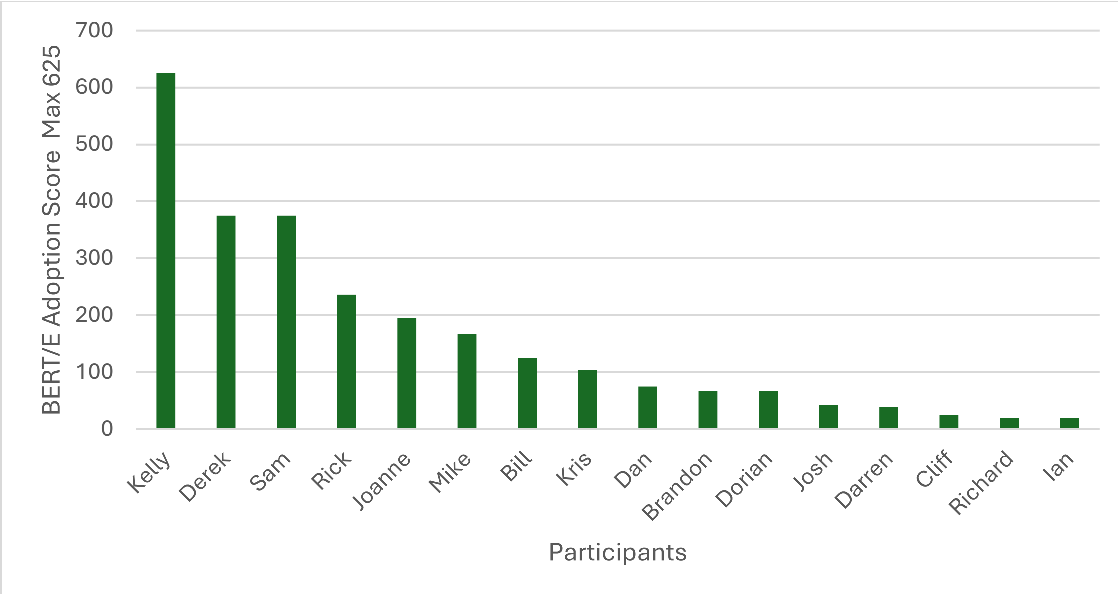

Figure 6.11. Participants' BERT/E scores for BMP-conservation and restoration of wildlands.

The interviews with the participants revealed a wide range of enthusiasm for conservation and restoration practices. While the average BERT/E adoption rating score was only 160 (out of 625), the average belief score was a compelling 4.56 out of 5. One potential for the discrepancy between these results may be the economic aspects of implementing such practices, as the participants assigned an average score of 2.88 out of 5 in this category, which in turn impacted the Energy rating. Whereas some farmers may feel they lack the time and resources to implement such practices, others may feel compelled to further convert wildlands to crop land to keep up with their peers. Brandon stated that he would be more likely to adopt conservation and restoration practices if there were incentives available to help him break even. Kelly, on the other hand, gave economics a full mark of 5, as he recognized the value and beauty of preserving wildlands on his property, noting that they serve as a carbon sink, provide diversity, and support pollinators and other wildlife. Despite having one of the largest wildland areas, Ian assigned this BMP a score of 19, which is very low. Ian scored regulatory a 2 out of 5 and technology a 1 out of 5, which can be interpreted as a reflection of his disappointment in the ease with which farmers are able to destroy their wildland and the relative lack of consequences for doing so. He rated belief a 5 out of 5.

Before the settlement of the Prairies, there was limited cultivated land. Indigenous peoples tended their three traditional sister species in carefully managed and protected gardens, often situated on the prime land along rivers and valleys. In the book, *Native American Gardening: Buffalobird-Woman's Guide to Traditional Methods*, Wilson (1917) highlighted the dedication, skill, and hard work required to maintain these gardens and feed families. It also describes the innovative ways in which garden produce was preserved and stored. Currently, 78 million acres of cropland exist because of settlement, which has resulted in a significant loss of SOC. To achieve net zero by 2050, farmers will be encouraged to sequester atmospheric carbon and replenish the soil. However, some farmers, often backed by outside investors, continue to buy the best pastureland, and improve it with modern equipment for short-term monetary gain, rather than focusing on sustainable land-management practices.

Foley et al. (2011) argue that sustainable farming requires us to utilize existing land rather than clearing more, and that the conversion of wildland to crop land results in increased GHG emissions. Cliff emphasized the need to balance human needs with the requirements of a sustainable global ecosystem.

Overall, the participants viewed conservation and restoration as a great idea. The two exceptions to this trend were Kristjan and Brandon, who were from areas with numerous potholes. Kristjan, who collaborates with his brother and father on their cattle farm, remarked that there is a distinction between cattle land, which is left untouched, and cropland, which is improved by cleaning up wildlands and enhancing drainage. Brandon, who rented most of his land, acknowledged the strict laws and enforcement in North Dakota and emphasized the need to avoid draining Class 3, 4, or 5 wetlands.

Rick assigned a surprisingly high rating to conservation and restoration, considering he farms in the Red River Valley, which was once the bottom of ancient Lake Agassiz. As such, his land lacks natural wildlands or trees, with only planted shelterbelts being present. In contrast, Kelly has devoted 600 acres of land to wildlife, while Ian has left 1300 acres of land untouched. Ian says he is very curious about this land's carbon sequestration capabilities. Derek also assigned a high rating to conservation and restoration, as he has chosen to leave a sizeable portion of his land untouched as well as sowing perennials with the aim of restoring wildlife habitat while squaring off his fields.

While all participants acknowledged the importance of conservation and restoration, their BERT/E scores ranged from strong support to low support, with some scores being affected by the absence of government action to prevent conversion. Many participants also identified the lack of financial incentives for conservation and the inability to assign tangible value to wildlands as key barriers to the successful implementation of this BMP.

LaCanne and Lundgren (2018) investigated the trade-off between food production and profit, finding that regenerative fields had 29% lower grain production, but 78% higher profits compared to traditional corn production systems. Interestingly, profit was positively correlated with soil organic matter but not yield.

6.9.2. Recommendations

1. Land conversions should require special government approval and be assessed through a framework, such as the Sustainable Farm Index (SFI), which requires applicants to demonstrate realistic contribution margins and kcal/hectare output as well as emissions and changes in soil organic matter. Approval should be based on data from model farms with similar soil and climatic conditions, which can be obtained partly from crop insurance records. This approach will help prevent unsuitable lands from becoming a burden on the public due to high crop insurance payouts or further degradation and erosion. Potentially restructure crop insurance to use a lower ag capability for converted land.
2. Conversion of lands not needed for food production should be banned. Foley et al. (2011) suggest we should restrict ourselves to using only the crop land that currently exists.

6.10. Phosphorus Management: Data Analysis and Findings

6.10.1. Participant Responses

The management and recycling of phosphorus are important sustainability objectives, as it is a finite element that is critical for plant and animal growth. Joanne stated that our current practices are extremely harmful to the environment and are not sustainable.

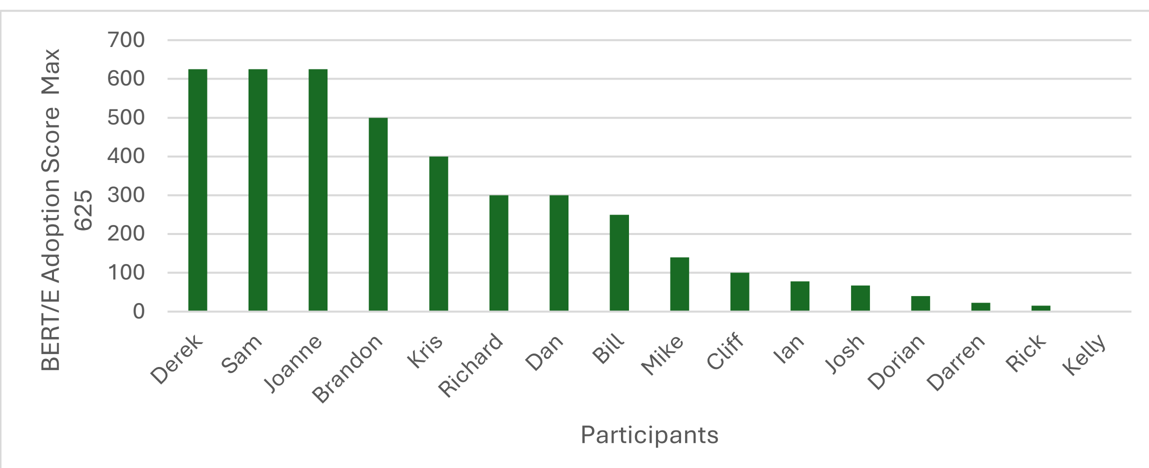

Figure 6.12. Participant BERT/E scores for BMP- phosphorus management.

The average BERT/E adoption score for this BMP was 255 out of 625, indicating variation in the participants' responses to the role of recycled phosphorus. With regards to beliefs about the value of this BMP, the participants' scores ranged from 4.3 to 4.6, with an average inverse energy score of 2.25. The participants believed that economics and technology were key barriers to adoption; interestingly, however, they did not consider regulations a barrier, as the production of struvite is allowed. Lack of affordable technology and poor economics resulted in the participants' energy for adopting the use of recycled phosphorus at an immediate level for most. The four research agronomists, Sam, Joanne, Richard, and Bill had intermediate to high concern about sustainable phosphorus use.

The two outliers, Kelly (score: 1) and Derek (score: 625), are intriguing. Kelly assigned an extremely low rating to the adoption of recycled phosphorus, as he did not rely on imported fertilizer and lacked the need to pursue off-farm sources of phosphorus. On the other hand, while Derek assigned the highest adoption rating, he used only a small amount of naturally occurring phosphorus, which is found in the guano he applies. In addition, Derek says he is open to exploring any cost-saving, soil-improving, and profit-enhancing solutions. For his part, Kelly has designed a successful system that allows him to continue to refine and reap the rewards it provides.

While the BERT/E tool does not explain the significant differences in these ratings, it does raise questions about the reasons for them. The portion of the in-depth interviews focusing on barriers, enablers, and solutions helped to answer these questions. The range of ratings might also be related to awareness, as both Joanne and Sam, the research agronomists who worked most closely on phosphorus recycling, gave this BMP a high rating. However, most participants did not consider recycled phosphorus a priority, nor did they possess readily available solutions. Joanne recently completed her PhD, which focused on recycling phosphorus from city wastewater in the form of struvite, also known as Crystal Green. Sam is currently working on his PhD, which focuses on recycling phosphorus on the farm via grazing animals. At the time of this study, Kristjan was the only participant who used recycled phosphorus as his farm's only source of phosphorus fertility. He used both Crystal Green and composted cattle manure.

As noted above, Kelly was the most significant outlier in the group, with a BERT/E score of 1. Kelly shared that he had not used any phosphorus on parts of his farm for about 10 years. Instead, he relies on his IMOS seed inoculation system to tap into the large store of phosphorus that is otherwise unavailable in our soils. While Kelly had the highest SFI score, it is unclear whether he will eventually have to add some phosphorus. Kelly further notes that he estimates there is 6000 +

lbs/P/acre in the top four feet of soil. While he knows that phosphorus is from the parent material that makes the productive topsoil, he mentioned a reference to, Louis Kervran' s, "Biological Transmutations," which speculated that there could be an alchemy of sorts within soil microorganisms that combine other elements into P. He was not confident that it is a real thing but will continue to explore this phenomenon (Kervran 1998).

While phosphorus management does not directly help with emissions reduction or carbon sequestration, it is essential for crop production. Phosphorus is a non-renewable resource that is often deficient in Prairie soils. As such, many farms apply it each year, making it the second most used fertilizer in Western Canada. Most phosphorus fertilizer is imported from places such as Morocco and Florida. Some experts predict that peak phosphorus usage could be reached as soon as 2033 (Mohr and Evans 2013; Nature Plants 2022). While phosphorus is not directly implicated in AGWM, its proper management is a key component of long-term sustainability.

6.10.2. Discussion

The management of recycled phosphorus is not a highly discussed subject. Commercial phosphorus fertilizer is priced the same or lower than struvite. Derek and Kelly have found ways to use zero commercial phosphorus fertilizers, while Kristjan exclusively uses recycled phosphorus. The other participants use commercial phosphorus fertilizers at or near the recommended rates.

As Josh observed, there are advantages and disadvantages to using cattle manure. For example, it usually takes a couple of years to accrue a net benefit, and cattle manure can bring weed seeds and compaction to fields. Dan and Dorian said they are pleased with their access to hog manure. Josh suggested that manure management regulations in Alberta restrict manure applications in feed lot alley and can make it possible for farms outside that area to get manure. Josh explained this as follows:

> *there are enablers and barriers. If [the Natural Resources Conservation Board in Alberta] decides they're gonna crack down on high-throughput numbers in Feed Lot Alley, it's gonna be a lot easier for me on the periphery to get manure because they're actually gonna have to start paying to get rid of it. But [Conservation Board is] also a big barrier, right? So, it's just government regulation one way or the other, and that will affect this practice. (November 25, 2023)*

Ian has been trying to obtain approval for the use of struvite sourced from human waste on organic farms. He states:

> *well, it's here, the Struvite. ready and able to go from human race streams. But it's not accepted. So yeah, definitely working hard on that one. So that's full mark for Energy Yeah, I've been working on it this week again. So, working groups are meeting, and Struvite's on the list, but not sure when it's coming up* (*Ian* December 6, 2023).

6.10.3. Recommendations

1. Phosphorus is a non-renewable resource that must be recycled.
    - Future food production is dependent on our ability to capture and recycle phosphorus.
    - The environmental cost of phosphorus in rivers, lakes, and oceans is enormous and is the cause of dead-zones in many water bodies around the world.
2. The certification of struvite from human waste would be beneficial to the organic farming sector, as it is difficult to find suitable phosphorus replacements for this type of farming. Notably, progress has been made to this end, with struvite receiving provisional approval for use in organic farming in late 2024 (personnel communication with Dr. Martin Entz).

6.11. Integrating Grazers: Data Analysis and Findings

6.11.1. Participant Responses

Cows can be an ecologically easy button for soil health and Net Positive farming.

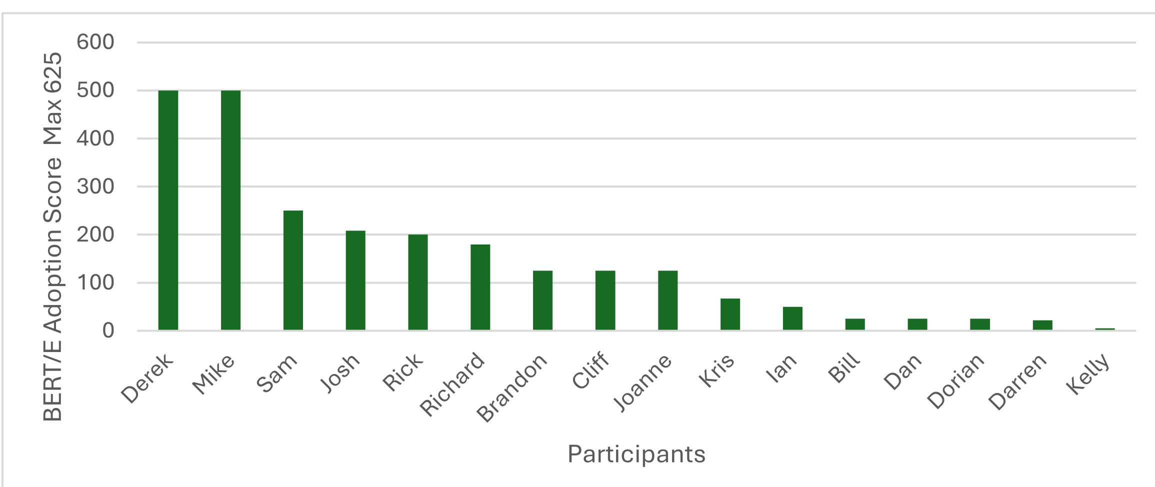

Figure 6.13. Participant BERT/E scores for BMP- integration of grazers.

Despite being one of the five principles of Regenerative Ag, all the participants except for Mike and Derek assigned a low BERT/E adoption score (average 152 out of 625) to the integration of grazers. These low scores were mainly due to the economic component, which received an average rating of 2.5 out of 5.0. The energy component also played a role in the low score due to the time and management commitments for incorporating cattle.

Grazing ruminants are widely recognized as a natural feature of the pre-settlement prairies, with vast herds of bison, deer, elk, and antelopes roaming the plains in a pattern known as mob, adaptive, or holistic grazing. These grazing actions were integral in building the soil. The net benefits brought to the land by cattle have been well documented (Stanley et al. 2018; Teague et al. 2016; Gosnell et al. 2020; Rowntree et al. 2020; Franzluebbers et al. 2001; Franzluebbers 2005). While most LCA, life cycle analysis, studies have shown that finishing cattle in feedlots results in reduced emissions (Capper 2012), others have demonstrated a more holistic understanding of cattle (Stanley et al. 2018; Pelletier et al. 2010). There are 3.4 billion hectares of grazing land in the world and only 1.2 billion hectares of crop land; however, without ruminants, there would be no food from those 3.4 billion hectares. This raises a pertinent question: how can we make the best use of grazing land and cropland such that we maximize food output and minimize contributions to AGW? The Clear Center at UC Davis (Werth 2020) suggests that the common method of calculating emissions maybe short-sighted and has proposed the Biogenic Carbon Cycle as an alternative. If cattle can act as a biomimicry substitute for natural grazers, would grain farmers consider incorporating them on their land? The answer to this question does not appear promising, as the number of beef cattle in Western Canada has been steadily declining, falling 1.4% between 2019 and 2020. In addition, the number of farms with cattle has decreased, as farmers have increasingly moved towards specialization (Canadian Beef 2020). Whereas nearly every farm had some cattle 60 years ago, today there are fewer mixed farms with cattle. The simplest explanation for this trend is that grain farming is more profitable, easier, and has better government-offered business risk management (BRM) programs. In contrast, cattle require more dedicated management and labor, need tending 365 days a year, are relatively expensive to feed, and are not adequately covered by any safety nets. In addition, cattle can dilute the grain BRM coverage. In other words, if grain is poor and cattle do okay there will be a lower payment, which can feel like working for nothing compared to the grain only farm neighbor. Before government support programs existed, mixed farm with multiple enterprises was a form of self insurance.

Manitoba Agriculture's Cow/Calf Cost of Production Budget (Manitoba Government 2021) shows that, when all costs are fairly represented, cattlemen lose money each year. However, there are operators that tip that balance and do well with their cattle herds. North Dakota cattle budgets (NDSU 2021) show profit. It is safer to raise cattle in the USA due to better economics and being less susceptible to extraneous factors such as border closures, as a greater share of the US's total beef production is consumed domestically (89% versus 52.5% in Canada).

Some of the participants believed that incorporating cattle on their farms was a sound idea. Two exceptions to this trend were Rick and Dan, whose farms in the Red River Valley featured clay soils, minimal slope, and no marginal land. In addition, Dan said it was difficult to find a rancher with significant numbers of cattle within a 100 km radius. On the other hand, Kelly, whose North Dakota farm is in a semi-arid-to-arid zone with 35-degree slopes, expressed concern about the potential for cattle to compact the soil and disrupt the soil armor, especially during times of drought. Consequently, he feels that the effort required to raise cattle is not worth the meager rewards or the risks it poses with respect to soil erosion.

The BERT/E adoption scores indicated that most participants were not yet ready to incorporate cattle into their grain farms. Bill believed that cattle should be limited to marginal land and not integrated onto good cropland. Ian, Dorian, Mike, Darren, Kelly, Kristjan, and Josh all felt that the poor financial returns, high risks associated with production and the markets, the constant work, and the potential physical risks in handling cattle made this BMP an unattractive option. Brandon was a little more open to this option, but he said he would prefer if someone else to owned and managed the cattle. Economics and the energy required to integrate grazers were the two lowest-scoring aspects of BERT/E.

Ian, Dorian, Kelly, Bill, Darren, and Kristjan assigned the lowest adoption scores to integrating grazers, with results ranging from 5 to 67. Kristjan allows temporary grazing on his land through an agreement with his brother and father, but he admits that it does not provide significant economic returns. Dorian and Darren have experimented with cattle grazing on full-season cover crops but question the future value of doing so. Despite being a good fit for Ian's large organic farm, which contains up to 40% alfalfa, he does not see a return on investment for adding cattle given the required labor and management. Kelly travelled to Kansas to gain experience with mob grazing cattle and concluded that it is not a viable option for his land, even with 600 acres of habitat. Kelly cited poor economics, extensive labor requirements, and the likelihood of soil compaction and destruction of armor as his reasons for not pursuing cattle grazing.

Derek had a high BERT/E adoption score (500 out of 625), but shared Kelly's concerns about soil fragility. Despite these concerns, he believed that integrating cattle onto his land is a net benefit, and he has been hosting a neighbor's cattle for several years with plans to include a 3-year alfalfa/grass mix in his crop rotations to monetize the forage. According to Stanley et al. (2018), the presence of cattle can accelerate the buildup of SOM, a premise which has been supported by Brown's (2018) findings. Unlike in the past, where terminated forage stands often led to dried out soils and poor crops, Derek now grows drought-tolerant crops such as lentils, chickpeas, camelina, and mustards, which perform better than traditional crops like wheat or flax in this situation. Derek helps with the cattle when needed. However, he did not assign a max score to the integration of cattle because he knows of productive and well-functioning regenerative farms that do not have cattle.

Mike was the other participant with a 500 score. Mike, who farms in northeastern Saskatchewan's highly productive moist black soil zone, has incorporated a perennial phase into his crop rotation. However, he has not been successful in attracting a cooperative cattleman. He said he would even invest in cattle if he did not have to look after them.

6.11.2. Recommendations

1. Exercise caution when considering the potential of integrating cattle into cropland. Many grain farmers are not interested in this approach and, without a significant shift in the way cattle are raised, the high emissions attributed to grazing cattle and the unfavorable public perception of their role in the food chain make a return to a pre-settlement grazing systems seem unlikely.
2. Western Canada primarily uses high-quality land for grain production. Rather than introducing cattle to grain farms, researchers and grain farmers should concentrate on lowering emissions and directly enhancing carbon sequestration.
3. Optimize the utilization of grazing land for ruminants.
4. Herbicide-resistant weeds have been shown to be a limiting factor to Zero Till crop production worldwide. Australian farmers have had to rely on re-integrating sheep into the land to monetize weed resistance into a profitable cropping system. The manager of the Ag-Quest Herbicide Resistance lab, Dr. Haisheng Xie, stated that he has a sample of wild oats that are now resistant to every "wild oat" herbicide available (March 12, 2024, Minto, MB). Weed resistance to glyphosate, the main "burn off" herbicide,

could make Zero Till more difficult in the future. We now have glyphosate-resistant kochia, which is also resistant to three other previously effective herbicide groups (Heap 2024). Ruminants may eventually need to be included in the toolbox.

6.12. Adoption of Organic Grain Farming BMP: Data Analysis and Findings

6.12.1. Participant Responses

Being able to farm organically or eat organic food may be critical to some farmers and consumers.

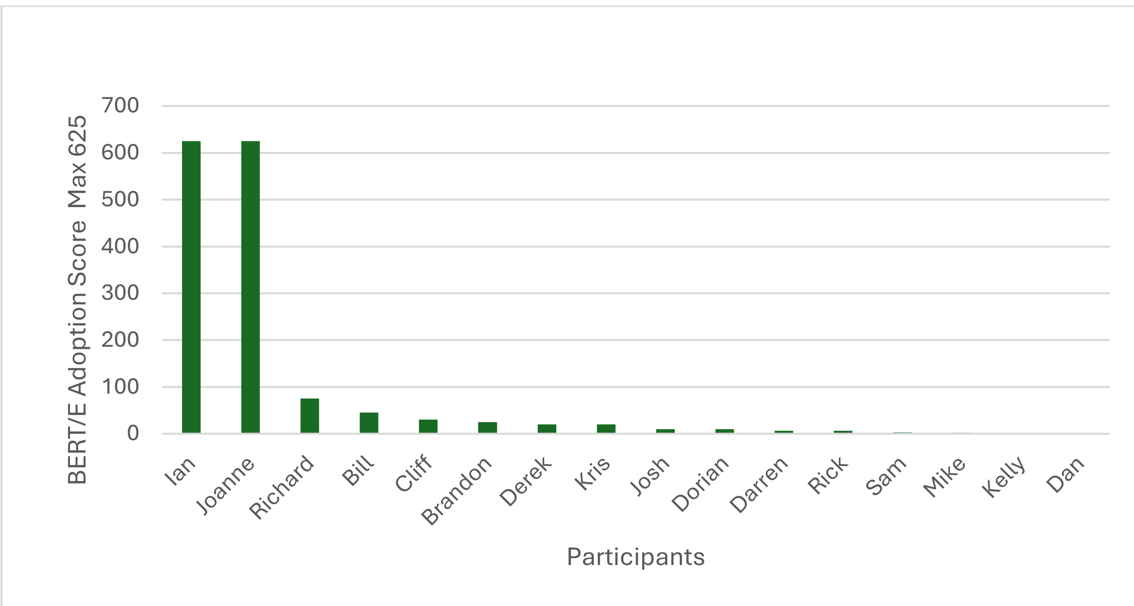

Figure 6.14. Participants' BERT/E scores for BMP- organic farming practices.

Most participants showed limited enthusiasm for organic farming, with only Joanne and Ian actively engaging in this practice. Richard, Bill, Brandon, Derek, and Kristjan expressed some interest, but only if advances in technology made large-scale organic no-till grain production feasible. The possibility of commanding premium prices for organic products was a significant motivator for these participants. However, Derek highlighted that, if such technology existed, the advantages of organic farming would be lost. The remaining participants had no interest in organic farming. Dorian had attempted to transition to no-till organic farming but was unsuccessful, leading her to adopt a Zero Till-Plus system. The average BERT/E adoption rating for organic farming practices was 94 out of 625.

Organic products have become a niche in global agriculture. Around 3% of Canadian farms use organic practices, but this accounts for only about 2% of the total arable land (Bush 2024). Some farmers embrace organic farming because it eliminates harm or perceived harm from pesticides. Just as some people have severe allergies to peanuts, soy, cows' milk, and gluten, there may also be some who react adversely to pesticides. Organic farming gives these people an alternative. However, many reports have shown that registered pesticides used in accordance with the manufacturer's instructions pose no risk to consumers. Indeed, each crop-protection product is intensively tested for acute and chronic toxicity, and use recommendations are developed based on maximum residue levels set by Health Canada and Agriculture and Agri-Food Canada (Health Canada 2023). Maximum residue levels are set with a safety factor of at least 1000 times lower than the no- observed adverse effect level and the potential daily intake.

Most participants did not consider organic grain farming a good idea for their farm or in their research. Ian, the only organic farmer in the sample, predictably gave this BMP a max score of 625. Cliff is transitioning out of organic farming, whereas Joanne, who has a background in organic and natural system farming, is interested in continuing organic research. None of the other participants practiced or wanted to adopt organic farming practices.

6.12.2. Discussion

Tillage in sub-humid, semi-arid regions was the most common limitation of organic farming cited by the participants, followed closely by lack of weed control and fertility, especially phosphorus. Kelly said he assigned a low rating to belief in organic, "*because that would require me to till all my soil and watching them blow away*" (December 6, 2023), a sentiment that was echoed by Darren, who remarked that, "*organic with tillage just doesn't excite me*" (December 8, 2023). Joanne acknowledged these concerns, noting that "*Soil disturbance is definitely something that keeps people out of organic farming, especially in drier regions*" (December 19, 2023).
Other participants were concerned with the lower output of food/hectare. Brandon talked about a yield drag, while Ian said that about 40% of his farm was allocated to green manure crops, which meant that his output would be 40% lower on top of a yield drag compared to neighboring crops.

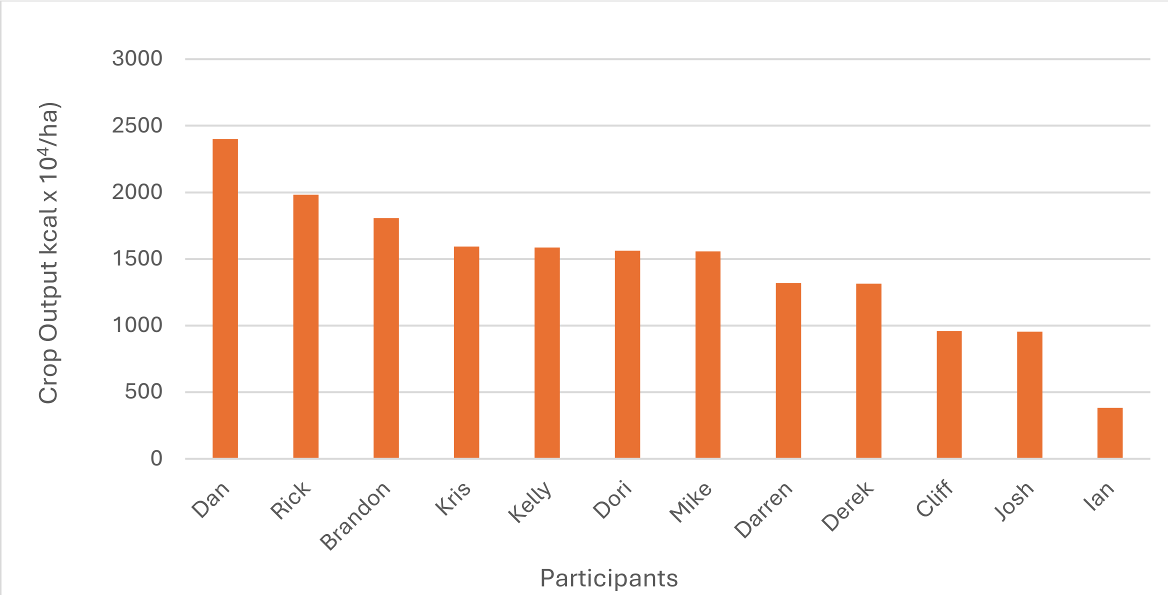

Figure 6.15. Crop output (10^4 kcal/ha) on each farm (reorganized from Section 5.3.4).

Figure 6.15 only includes cultivated hectares and illustrates a six-fold difference in output/ha among the participants. Dan, Rick, and Mike, whose farms are on moist black soil, have the highest rainfall and the highest yields, while Derek, Kelly, and Josh's farms are in the brown soil zone, which is also the lowest rainfall area. Josh has some irrigated crops, but he has been dealing with a drought in recent years. Ian's organic farm, which is in a thin black soil zone, relies on using some of his land for green manure crops to help supply nutrients, especially nitrogen, to his cash crops.

6.12.3. Recommendations

1. Organic grain farming is a costly alternative that is difficult to make sustainable and scalable in Western Canada.
2. Some people, including farmers, may be sensitive to some pesticides. Organic farming is a method of farming and supplying products to sensitive individuals. Some consumers prefer organic farming because it seems safer.
3. Human activities, including pesticide use, can have significant negative impacts on ecosystems. Pesticides have been the subject of scrutiny and regulations since Rachel Carson published her book, *Silent Spring* (Carson1962). Good agronomy and agroecology should be used to control pests before resorting to pesticides. Food safety should be ensured by using pesticides minimally and with care, as well as by establishing strict regulations regarding the registration and monitoring of maximum

residue limits. Farmers are always seeking ways to reduce costs and use fewer pesticides, for example, by using crop scouting and thresholds before deciding to spray. New sprayer technologies (e.g., Green on Brown) can reduce herbicide use by up to 90%.

4. Some of the participants have developed farming systems that use much less inputs and have little yield drag. Kelly, Brandon, and Derek are some examples of this. We must learn more about the conditions under which these systems can be sustainable and scalable solutions.
5. Nutrient density can be higher in organic and Regenerative Ag. Possible research topics to this end could include determining whether this is universally true, and whether it is a direct consequence of higher biological activity or partly lower yield, dilution. Furthermore, researchers could explore whether organic practices significantly affect health; for instance, do dietary habits matter more than the production method used to produce the food? (i.e., eating donuts versus whole grains from Regenerative farming or organic farming). Finally, if nutrient density proves to be a central issue, researchers could explore whether it can be addressed via Net Positive Carbon Grain Farming practices.

A list of all the individual recommendations for all BMP improvements can be found in Appendix 6.12.3. A summary of the recommendations for the most urgent BMP improvement can be found in Chapter 7 .11.

6.13. A BMP x BERT/E Summary

6.13.1. General Observations of Composite BERT/E Adoption Ratings vs. As an Idea and As Practiced.

The interviews yielded a significant amount of data relating to the BERT/E scores. Therefore, I have prepared a composite response for all twelve BMPs, which is presented in Table 6.3. This table shows the composite responses for BMP × BERT/E and contrasts them with the first two interview questions, namely, the BMP as an idea and as a practice. Detailed tables summarizing each participant's responses to the BMPs can be found at the end of each case study/participant story in Appendix 4.5 and 4.6. As shown in Table 6.2, the participants felt most BMPs were desirable as an idea. This is consistent with the results relating to beliefs shown in Table 6.3. As both an idea and a practice, organic farming scored poorly. Alternative fuels and the incorporation of grazers were also rated very low as an idea, but only marginally lower than the other BMPs when the participants were asked to rank their level of belief in these practices. In all cases, the BMPs were rated lower as practices than as ideas. Among the BMPs, lack of disturbance and soil armor were ranked the highest, which was consistent with the final BERT/E scores. Organic farming had the lowest BERT/E score and was the lowest ranked BMP as a practice, followed by alternative fuel.

The next two lowest ranking BMPs as practices were the incorporation of grazers and phosphorus management. The third lowest BERT/E score was assigned to growing plants from snow to snow, while the fourth lowest ranked was the integration of grazers. Although growing plants from snow to snow is heavily promoted in Regenerative Ag and is widely accepted as a good Idea, the participants assigned it a very low score when considering it as a practice.

Table 6.2. Averaged BERT/E scores for each BMP as an idea and as a practice.

BMP	As an Idea %	As a Practice %	Ranking	BERT/E Score (Max 625)	Ranking
1. Lack of Disturbance	98	86	1	417	2
2. Snow to Snow	91	44	8	134	10
3. Plant Diversity	91	64	3	257	4
4. Armor on the Soil	99	83	2	503	1
5. Alternative Nitrogen	94	48	7	152	8
6. Alternative Fuel	83	9	12	41	12
7. Agroecological Solutions	94	63	4	281	3
8. Sustainable Intensification	88	62	5	246	6
9. Conserve and Restore	93	50	6	160	7
10. Phosphorus Management	92	36	9	255	5
11. Integrating Grazers	76	33	10	152	9
12. Organic	29	10	11	94	11

Depending on how BERT/E is used, it may not be necessary to consider BMPs as an idea or as a practice in the future. The “as an idea” question mimicked the Belief component of BERT/E, while the “as a practice” question mimicked the composite BERT/E score. The participants’ average scores for each component of the BERT/E assessment are shown in Table 6.3.

In tabulating the individual BERT/E components, Economics accounted for the first or second lowest score for eleven of the twelve BMPs, followed by Technology (6 out of 12), Energy to change (5 out of 12), Regulatory (1 out of 12), and Belief (1 out of 12). Thus, participants most often discounted BMPs due to financial concerns, followed by concerns over inadequate technology.

The BMP that stood out with the lowest belief score was organic. The Energy component was evaluated using an inverse scoring system wherein one is the highest rating and five is the lowest. A low rating for Energy is often preceded by a low score for another component, such as Economics, Belief, or Technology. For example, adoption of organic farming had a low rating for Belief, which gives over to low Energy to pursue that avenue.

Table 6.3. Average scores for each component of the BERT/E tool relative to each BMP.

BMP	**B**elieve	**E**conomics	**R**egulatory	**T**echnology	**E**nergy	Average
Disturbance	4.75	4.38	4.66	4.41	1.47	417
Snow to Snow	4.43	2.81	4.25	3.91	2.38	134
Biodiversity	4.56	3.48	4.16	3.53	2.38	257
Armor	4.9	4.56	5.0	4.75	1.5	503
Alt N	4.28	3.38	4.38	2.97	1.94	152
Alt Fuel	4.19	2.13	3.81	2.59	3.62	41
Agroecology	4.5	4.09	4.19	3.78	1.66	281
Sustainable Intensification	4.34	4.06	4.59	4.28	2.4	246
Conserve and Restore	4.56	2.88	3.78	4.5	2.31	160
Phosphorus	4.31	3.38	4.56	3.69	2.25	255
Grazers	4.13	2.47	4.81	4.78	2.97	152
Organic	2.22	2.38	5.0	2.94	4.03	94
Average	4.26	3.33	4.43	3.84	2.4	224

The exception to this trend was sustainable intensification. Here, Energy received the lowest score, followed by Economics. This result may have been due to concerns about being overwhelmed with technology, the high prices associated with acquiring it and maintaining it, the time and energy commitment required to learn new software and delays due to software or hardware crashes.

While the findings of this work have enabled a set of useful recommendations, they also indicate that, with the exception of Zero Till, Prairie farmers still face many financial barriers and technical gaps hindering their implementation of a functional, scalable, and economically viable BMPs that can allow them to become Net Positive by 2050. Nonetheless, the results also show there has been progress to this end. As was shown in the previous chapter, at least two of the twelve participating farms are already Net Positive.

6.13.2. A Summary of Net Positive and Critical BMPs.

One of the overall goals of the thesis was to identify strategies that would allow farmers to achieve Net Positive. In Chapter 5, Kelly and Derek were identified as being Net Positive and having high SFI scores. Thus, it would be worthwhile to examine what they are doing differently from other participants who are much further away from achieving Net Positive.

The BMPs that are most critical to becoming Net Positive can be summarized as follows:

NP = Zero Till (Lack of Disturbance and Armor) + Alterative N (low FF based N) +/- carbon sequestration (Diversity and Plants from Snow to Snow).

While the other BMPs can improve this equation and are important to sustainability, the above BMPs are the foundation of Net Positive. Within this equation, alternative nitrogen is the key to reducing emissions, as the amount of nitrogen used was the largest direct contributor to the Net Positive and SFI rankings.

Table 6.4. BERT/E adoption scores based on average for group vs. two Net Positive farmers.

BMPs	BERT/E Max 625 Average	Kelly's Score BERT/E	Derek's Score BERT/E
A. Regenerative Ag BMPs			
Armor on the Soil	503	5x5x5x5/1=625	5x5x5x5/1=625
Lack of Disturbance	417	5x5x4x5/1=500	5x5x5x5/1=625
Plant Diversity	257	1x1x2x1/5=1	5x5x4.4x5/1=563
Snow to Snow	134	4x4x1x4/2=32	4x2x5x5/2.5=80
Grazers	152	1x1x5x5/5=5	4x5x5x5/1=500
B. Sustainability Tools BMPs			
Agroecological Solutions	281	5x5x4x5/1=500	5x5x4x5/1=450
Phosphorus Management	255	1x1x5x1/5=1	5x5x5x5/1=625
Sustainable Intensification	246	3x3x5x5/3=75	5x5x5x4.5/1.5=375
Conserve and Restore	160	5x5x5x5/1=625	5x3x5x5/1=375
Organic	94	1x1x5x1/5=1	2.5x2x5x4/5=20
C. Fossil-Fuel-Free Alternatives			
1. Alternative Nitrogen	152	5x5x3x5/1=375	5x4x5x4/1=400
2. Alternative Fuel	41	3x4x5x1/5=12	4x2x5x5/4=50

The data in Table 6.4 reveals some distinct similarities and opposing views regarding certain BMPs. Kelly and Derek, who both farm in the brown soil zone, have higher than average BERT/E scores for the three most critical BMPs to being Net Positive, namely, lack of disturbance, armor on the soil, and alternative nitrogen (all three are marked in green). Kelly and Derek also had higher than the average scores with regards to agroecological solutions and conservation and restoration. However, their ratings for alternative fuels were similar to those of the rest of the group, which tended to be very low.

Kelly and Derek's use of alternative nitrogen is the largest single driver of their Net Positive status and high SFI scores, as low nitrogen use translates to low emissions. Kelly used his IMOS seed inoculant to supply his soil with nitrogen through a natural combination of rhizophagy and the promotion of soil with high biological activity. He does not apply any fertilizer, either fossil-fuel-based or manure-based, noting that tillage would kill the system he has developed. Conversely, Derek uses 20 lbs of nitrogen fertilizer in the form of ammonium sulfate (but only on his cereal crops), and he inoculates his seed with a compost extract and a concoction consisting of micro-nutrients and microbe foods to help boost the biological functioning of the soil. He found that inoculum was not needed, as the soil health and resident biology improved.

Derek and Kelly's adoption scores were lower than average for growing plants from snow to snow and organic farming. Despite attempts to promote and incentivize growing plants from snow to snow (aka cover crops), the group, and especially Kelly and Derek, have shunned this BMP, as it has not worked in their experience. Ultimately, the participants felt it was a good idea, but not for their particular locations. They noted that cover crops cost time and money and can reduce cash crop yields, particularly in droughty conditions.

The individual BERT/E scores for organic farming show that Kelly and Derek both assigned low scores to their belief in and the economics of this BMP, as well as for their energy to adopt it. However, their scores for plant diversity were the opposite, with Derek embracing and profiting from the BMP via intercropping. In contrast, Kelly said that intercropping was not compatible with his farm operations. He shared that, because of the drought, he is only growing tall cereal crops to help ensure adequate soil armor, as the tall-stripper-cut cereal stubble is optimal for catching as much snow as possible.

Interestingly, Kelly and Derek also held opposing perspectives about grazers. Kelly's experience working on other farms has led him to the conclusion that cattle could negatively impact his soils, as they can cause compaction and destroy the armor. In addition, he pointed out that the economics and work involved are not enticing. Conversely, Derek's farm is in cattle country, which means there are a number of cattle ranches nearby. He allows some of these cattle to graze his land, which has resulted in improvements to the soil, as well as financial benefits. Derek is also starting to include short-term (2-3 years) stands of perennials in his rotation.

Derek and Kelly also held opposing perspectives regarding phosphorus management and recycling and sustainable intensification. Kelly does not use phosphorus and instead relies on soil biology to solubilize and make available otherwise insoluble phosphorus in the soil. In contrast, Derek uses small amounts of phosphorus in the form of guano (ancient bird poop) and also relies on biological solubilization of existing phosphorus. With respect to sustainable intensification, Kelly and Derek differ in their belief in it (3 and 5, respectively), their perspectives regarding its economics (3 and 5 respectively), and their energy to adopt it (Derek rated this twice as high as Kelly did). Generally, Kelly was less likely to buy a "corporate" solution, whereas Derek sees value in things like Green on Brown See and Spray technology.

As this discussion illustrates, BERT/E can be a useful tool for organizing interview discussions into meaningful analysis of adoption behaviors. The main BMPs for Net Positive Carbon Grain Farming were easily identified through the general analysis of BERT/E. The ability to look at individual components in combination with NP and SFI calculations provides further insight.

6.14. Summary of Enablers and Barriers to Net Positive BMPs

During the interview, we spent a fair amount of time examining the enablers and barriers that can help or hinder the journey towards Net Positive Carbon Grain Farming.

Table 6.5 shows the main categories of enablers and barriers to the adoption of the studied BMPs. Each category had a positive and negative facet, except for "Tools" as an enabler and "HR" as a barrier. NVivo is a software program that allows researchers to code their interview data according to various themes (e.g., enablers and barriers) and with multiple subgroups (e.g., financial considerations or appropriate technology. Upon completing the data entry process (i.e., transcribing the narratives), the researcher can instruct the software to search the narratives (queries) to determine the frequency of certain topics or words (NVivo references) or for potential quotes from particular participants.

Table 6.5. Major enablers and barriers to the adoption of Net Positive BMPs.

Enablers	NVivo References	Barriers	NVivo References
Financial Incentive	163	Financial Cost	88
Appropriate Tech	120	Lack of Appropriate Tech	237
Support	110	Lack of Support	19
		Lack of Human Resources	38
Crop Insurance	3	Lack of Crop Insurance	33
Cattle/Grazers	11	Problems with Integrating Cattle/Grazers	69
Tools	61		
Regulations	23	Regulations–Too Many	25
Nature–Positive	2	Nature – Negative	76
Mindset Change	33	Lack of Willingness to Change	5

In this example, the participants cited financial support as an enabler a total of 163 times across all the BMPs; in contrast, crop insurance was identified as an enabler only three times. With respect to barriers, lack of appropriate technology was mentioned 237 times, while lack of crop insurance was mentioned 33 times. The recommendations presented in this study were developed based in part on these coded factors.

.6.14.1. Enabling Factors

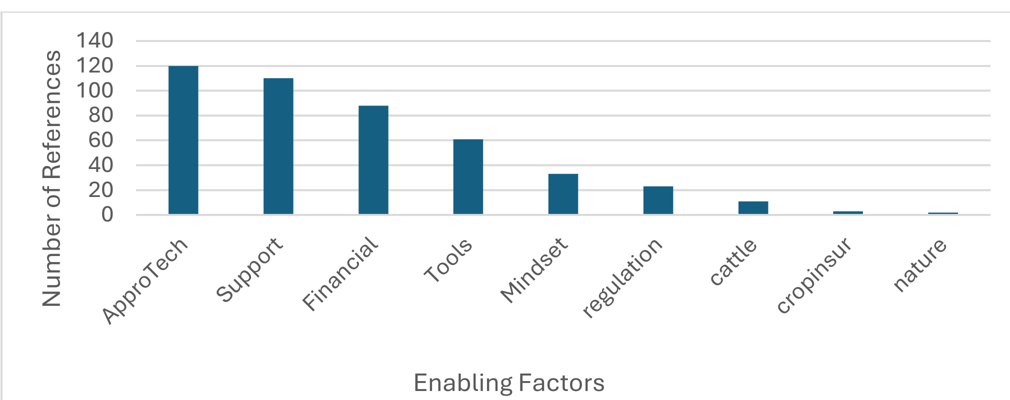

Figure 6.16. Main categories and frequency of enablers discussed during the interviews.

The three most prominent enablers were access to appropriate technology, having support to make changes, and favorable economics for the change. Other enablers included having the right tools (Zero Till equipment), a positive mindset, and regulation that supports the changes. Josh and Derek in particular saw cattle as a positive in helping to monetize the use of cover crops, with the potential to improve soil health. Crop insurance and a favorable climate were also considered to be enablers. An additional breakdown of these categories into subcategories can be found in Appendix 6.14.1. For example, the category, "financial barriers," is further broken down into subcategories such as, "too expensive," "lack of EG&S dollars," "no return on investment," "inadequate transition money," "no premium for Net Zero," lack of realism with incentive dollars," "lack of funding for certification," "too risky," "limited access to funding," "lack of ownership to make long term investment," "lack of adequate funding," and "lack of compensation for AGWM."

6.14.2. Barriers

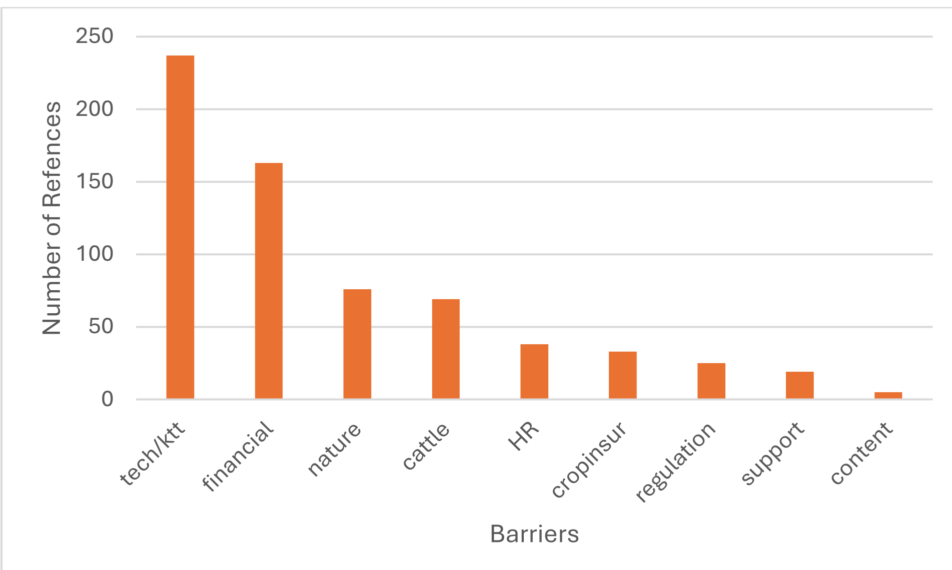

Figure 6.17. Main categories and frequency of barriers discussed during the interviews.

The most commonly identified barriers included lack of technology and knowledge transfer, lack of financial benefit, and lack of support. Cattle were listed as barriers more often than they were mentioned as enablers. Lack of human resources for management and labor was also considered a barrier, and many participants, both in Canada and the US, expressed their dissatisfaction with crop insurance. Regulations and lack of support were also considered barriers by some, and a small minority cited contentment as a barrier—that is, they liked things how they were and had no desire to change them. Given that I tried to pick a group of innovators who might otherwise be seen as "malcontents," it was not surprising that there were only a few that were content. However, these participants were mainly suggesting that their neighbors were content with BAU. A further breakdown of these categories can be found in Appendix 6.14.2.

6.15. Conclusions of Objectives 3 and 4

The discussion in this chapter aimed at addressing two objectives.

Objective 3: To determine if BERT/E (adoption rating) analysis can help identify enablers, barriers, gaps, and innovations to assist in achieving Net Positive.

1. The findings indicated that BERT/E is a useful tool that can help in conducting in-depth farm practice interviews and organizing and analyzing the results. Specifically:
    - BERT/E can be used to identify general trends in adoption or for forward-looking perspectives.
    - BERT/E can be used to investigate and analyze the reasons for the trends or individual responses using the individual BERT/E components.
    - BERT/E can be used to evaluate a wide range of BMPs.
    - It is not necessary to include the questions, "As an Idea" or "As Practiced," when using BERT/E.
    - It may or may not be necessary to ask questions about enablers, barriers, or AGWM credits, depending on the purpose of the study.
    - It is necessary to have clear definitions of BMPs to obtain concise answers.
    - The acronym, BERT/E, is easy to remember, and every farmer can relate to it.
    - BERT/E can provide insights into the factors needed to make changes to existing BMPs or the prospect of solutions for future problems.
    - The application of a numerical code to qualitative data makes analysis and summarization quicker, clearer, and easier to visualize.

Objective 4: To determine how innovative farmers rate the utility of the twelve BMPs for mitigating AGW.

- All twelve BMPs are important to sustainability. Some can and need to be scalable to the Prairies, and some will and should remain niche solutions.

- BMPs that support Zero Till, low or no use of fossil-fuel-based nitrogen, and greater plant growth are most directly connected to becoming Net Positive.
- The availability of alternative sources of nitrogen is the most critical BMP for achieving net zero emissions.

Other researchers have also examined farmers' adoption of AGWM BMPs. For example, Van Wyngaarden et al. (2024) found that, when it comes to climate policies, producers prioritize financial support over other measures such as certification, extension, carbon offsets, and carbon taxation. In terms of collaborating on AGWM in agriculture, producers prefer to work with provincial, county, or municipal governments over environmental NGOs. The authors also found that producer characteristics, such as beliefs about climate change, can influence their policy preferences. Those who believed in AGW were more likely to support policies aimed at climate-mitigation, with the exception of taxes on carbon and carbon offsets. Moreover, farm typology and being an early adopter of BMPs were found to influence producers' policy preferences, but not their organization preferences. Perhaps the most significant finding of Van Wyngaarden et al.'s (2024) study is that farmers' policies and organizational preferences influenced their adoption of proven AGWM BMPs; for instance, farmers who were male and highly conservative opposed carbon taxation uniformly. Nonetheless, farmers hold diverse views on organizations in the agri-environmental space, and there are significant messenger effects. Surprisingly, the study found high levels of BMP adoption, despite considerable skepticism or denial regarding climate-change science. This may indicate that farmers' decisions to adopt AGWM BMPs may not be grounded in their beliefs about climate change, as many such practices also result in improved soil health among other practical benefits.

Van Wyngaarden et al.'s (2024) findings suggest that climate beliefs can influence farmers' decisions to adopt AGWM BMPs. However, changing these beliefs is challenging. Therefore, policies and programs should consider immediate private benefits and long-term strategies to counter climate skepticism and media narratives. Successful policy implementation requires trusted organizational partners, and the economic implications of policies must also be considered for different types of farms. For instance, Helling et al. (2015) examined the cost of implementing and maintaining climate-change-specific BMPs on twelve diverse farms in Vermont. Specifically, three BMPs were examined: cover cropping, management intensive rotational grazing, and riparian buffer strips. They found that cover cropping cost an average of $129.24/acre, management intensive rotational grazing cost an average of $79.82/acre, and tree-based riparian buffer strips cost an average of $807.33/acre. They concluded that existing incentive payments for cover cropping, and management-intensive rotational grazing did not cover the costs of implementation, thus resulting in under-adoption. Notably, however, Helling et al. (2015) only examined economics as a factor determining adoption, leaving the possibility that other factors may also play a role.

Elsewhere, Yanni et al.(2018) evaluated the effectiveness and adoption of soil-related BMPs for mitigating GHG emissions. They found that BMPs such as aligning the nitrogen rate with crop requirements, utilizing nitrification inhibitors or combining them with urease inhibitors, planting cover crops, afforestation, growing biomass crops, and implementing conservation tillage were among the BMPs with the greatest potential for reducing GHG emissions and improving SOC. Generally, farms are most likely to adopt BMPs if they find them profitable. However, the extent of returns (or losses) on investment for these practices depends on the site characteristics and year.

Carlisle (2016) analyzed factors affecting farmers' adoption of soil health practices, such as cover cropping, crop rotation, and conservation tillage. Despite the environmental and economic benefits of these practices, both on and beyond the farm, Carlisle was perplexed by a persistent gap in adoption. Carlisle’s review identified five key themes: differences in perspective among farmers at different stages of adoption; interactions among soil health practices; qualitatively distinct pathways to incremental and transformative change; non-economic motives; and the critical role played by the larger farm and food system context. Carlisle concluded that a combination of education, research, policy measures, and efforts to overcome equipment barriers, along with addressing the farm and food system context, holds the greatest promise for increasing adoption.

BERT/E has emerged as a valuable tool for quickly assessing the factors affecting BMP adoption, providing a single numerical score that reflects overall adoption, as well as scores for each of the five components. This tool is unique in its ability to obtain an understanding of BMP adoption on farms.

The BERT/E model is a quick way for farmers to express their thoughts about a new practice. Adoption theory either based on Rogers (1962) “diffusion of innovation” which focuses on an individual’s decision to adopt a practice or technology or the more contemporary interdependence view of Leeuwis and Aarts (2021) are both complimentary to BERT/E . Although they take more of a seller’s approach in that they need to understand as much detail as possible about the practice and the context of its use in order to effectively market and advertise the practice to the farmer. They want to know the fine details of the determinants affecting the decision. Knowing this, they can look for the triggers that are more likely to result in adoption. On the other hand, BERT/E is the individual farmers response to the BMP within their context, which can depend on many factor including their societal interaction and interdependence at the time. A farmer and his advisors may use BERT/E from the buyer's point of view. Does this BMP fit on my farm; why or why not? Do I want to invest time and money or personal energy in to this? What would it take for the seller to make me consider the adoption of the practice or technology?

Chapter 7: Discussion, Significance, and Future

7.1 Introduction

The final chapter of this dissertation illustrates how the results of this thesis have enabled the development of a useful theory, visual frameworks, and tools for identifying and quantifying the practices used by leading farmers to mitigate global warming. I will describe and summarize the practical outcomes of this research and how it has addressed the four objectives outlined in the introduction. I conclude by introducing a series of recommendations and providing a glimpse into what a pragmatic Net Positive farm might look like in the future. Furthermore, I also review how the case studies helped identify gaps in knowledge and technology perpetuated by inadequate or missing policies.

7.2 Rourke's General Farm Practice Change Theory: An Example of Its Utility

New change theories are meant to effect change beyond a single project. In this section I explain the steps of Rourke's General Farm Practice Change Theory with respect to AGWM BMPs.

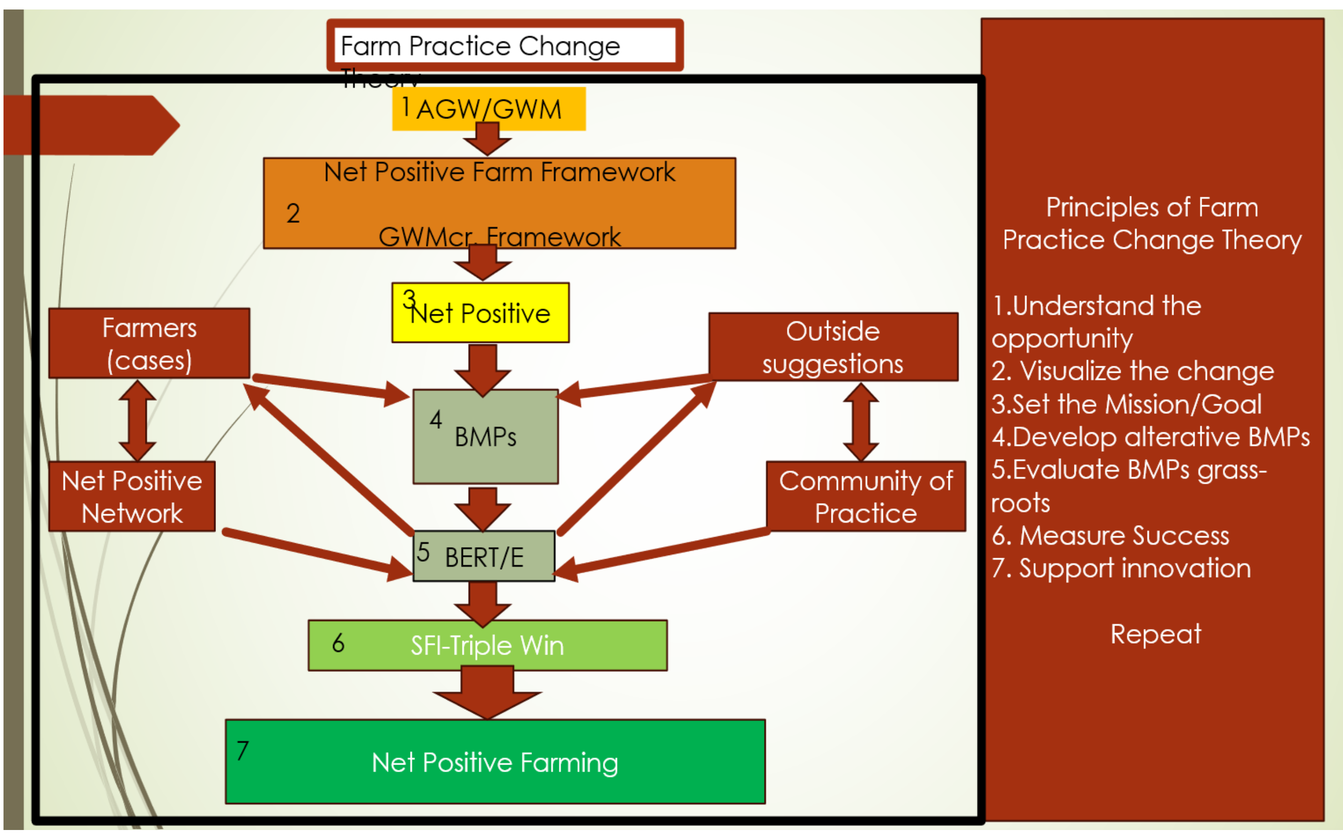

Figure 7.1. Rourke's General Farm Practice Change Theory.

Rourke's General Farm Practice Change Theory consists of seven steps. Once a problem is taken on it becomes a Theory of Change as illustrated below.

Step One: Identify the problem or opportunity. In this case, the problem is AGW.

Step Two: Visualize the change. Here, the previously mentioned frameworks, the Net Positive Farm Framework and GWMcredit Framework, are used to show the relationships between the need for AGWM, the viability of Net Positive Carbon Grain Farming, and the possibility of using AGWM BMP credits to incentivize farmers to participate.

Step Three: Set the mission and goals. In this case, the mission and goals are those of this thesis, namely, to support Western Canadian grain farms in becoming Net Positive.

Step Four: Develop a set of alternative AGWM BMPs. In total, twelve alternative BMPs were identified (see Chapter 2), but the participants were also given an opportunity to note "other" BMPs they were aware of or were using at the time of the interviews.

Step Five: Evaluate the alternative BMPs at the grass-roots level. To this end, the BERT/E assessment tool was employed to help interpret the data obtained from the in-depth semi-structured interviews. The BERT/E assessment helped to identify which BMPs were most effective in helping with AGWM, as well as any enablers or barriers to their implementation. Ultimately, the BERT/E analysis yielded fifty recommendations to enhance the adoption of the discussed BMPs. The results of this analysis are discussed in detail in Chapter 6 and Appendices 6.2 and 6.3.

Step Six: Measure the success of the adoption of the AGWM BMPs. This was achieved by using the Holos emissions calculator to determine the participants' net emissions scores (emissions created minus carbon sequestered) and by calculating their SFI scores. The estimates for emissions and sequestration were conservative, with sequestration being based on a 21-year Prairie Soil Carbon Balance report. The results indicated that two of the participants qualified as Net Positive; this is a significant milestone for this thesis, and it also stands as proof that it is possible to move away from the current paradigm of high fossil fuel use.

Net emissions were not used in the SFI calculation for two reasons. First, it is difficult to measure the SOCC, particularly in a short time frame, and second, emissions reduction needs to be a primary focus in AGWM. Indeed, it is critical for farmers to stop using fossil-fuel-based products (e.g., diesel fuel and nitrogen fertilizers) if we are to meet the UNIPCC's target of keeping warming below 1.5°C. In addition, farmers are in a unique position to sequester carbon from the atmosphere in their soils, which is largely accomplished via profitable Zero Till practices in Western Canada.

Similarly, the SFI calculations revealed that the Net Positive farmers also had the highest SFI scores. Therefore, rather than sacrificing to be Net Positive, these farmers actually benefited financially. The results of the analysis discussed in Step Six are presented in detail in Chapter 5.

Step Seven: Support innovation and the change to workable AGWM BMPs. The participants were asked to complete an exit survey probing their thoughts on "what's next," with the results revealing a consensus that Net Positive was a credible goal, and that a grassroots-led Net Positive Network supported by a Net Positive Community of Practice would be desirable addition. This survey is summarized in Appendix 7.2

The final step is to repeat and refine. A Net Positive Network and Community of Practice would help enable continuous improvement and evolution of Net Positive farm practice.

A fundamental problem with some AGWM BMPs being promoted in Canada is that they are not well-suited to Western Canada, especially growing plants from snow to snow. In analyzing Nosek's (2019) Behavior Change Pyramid as a theory of change for sustainable agriculture, Monaghan (2022) identifies the bottom layer as the infrastructure and research needed to implement AGWM BMPs. Unfortunately, this layer of the pyramid has not been adequately addressed in Western Canada. For example, delayed germination seed technology (DGST) should have been developed 10 years ago and should be available for use now. Furthermore, although the AAFC has launched a Living Labs program, it is a poor cousin to the previous Prairie Farm Rehabilitation Agency or the NFU's proposed Canadian Farm Resiliency Agency. The main problem with the Living Labs program is that it is based on 5-year projects wherein the last year is a wrap up year and the first year is an application and acceptance year, which often spills over into year two. Thus, year two also becomes a start-up year, reducing productivity to only two of the five years. This format is not conducive to systems research or long-term intensive solutions. The Western Canadian foundation of the Nosek pyramid is shaky, even if the intentions are good.

The four levels of Nosek's pyramid are:

- Make it possible: build the infrastructure and conduct the research; make the foundation.

- Make the culture change: new vision, change how we see things. This is a good place to use Lewin's three-step change theory: unfreeze, change, and refreeze (Moussa 2018).
- Provide incentives: new reward system.
- Policy: it is difficult to prescribe individual practices but bans and the ability to apply or withhold subsidies or incentives will be necessary to achieve compliance. These must account for the context and place-specific nature of farming.

7.3. Conceptual Frameworks: Net Positive Farm Framework and GWMcr. Framework

Figure 7.2 illustrates the interaction between the Net Positive Farm Framework and GWMcr Framework and their constituent components. This is the primary conceptual framework that was developed and utilized in this qualitative research, which employed an exploratory, participatory, and narrative case study design.

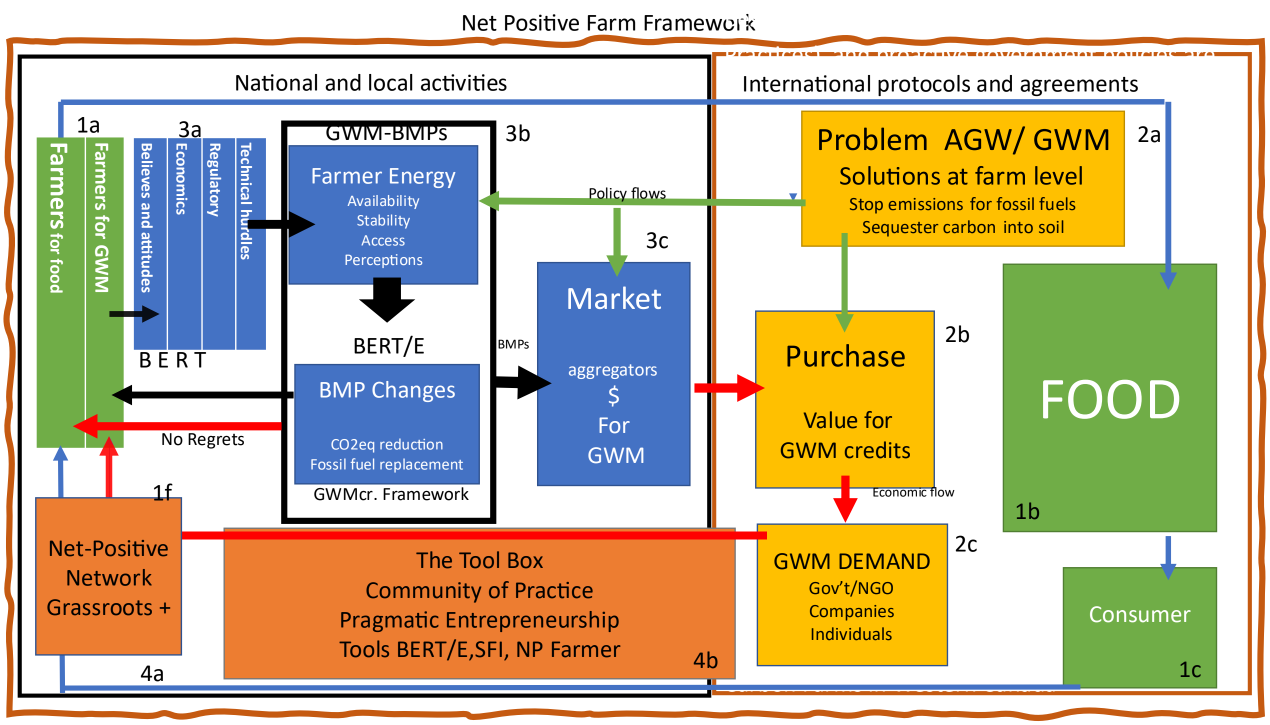

Figure 7.2. The Net Positive Farm and GWM Credit Frameworks.

The problem—namely, the international recognition of AGW as an existential threat and the need for mitigation strategies—is identified in the yellow boxes (2a, b, and c). Box 2b represents the value of AGWM credits, while box 2c represents the demand for AGWM. The problem is transferred to the left side of the framework with the creation of a secondary role for farmers in green box 1a, (Farmers for AGWM). Food and consumer interests (green boxes 1b and 1c) are connected to the entire diagram by the blue arrow and return to the farmer for food box (green box 1a). Since food is a main priority, the food arrow goes through the Net Positive Network (orange box 4a), where it undergoes further innovation balanced with AGWM. The second orange box (4b) is the toolbox that fosters innovation, including the Community of Practice, pragmatic entrepreneurship, and tools such as BERT/E, the SFI, and methods of measuring Net Positive farming achievements. Blue boxes 3a,3b, and 3c represent the GWMcr-ASAP Framework. Using the GWMcr–ASAP framework, the adoption of AGWM BMPs depends on the viability of credits using **ASAP**, which is evaluated according to their **Availability**, the market's ability to make GWM credits available, **Stability**, whether the credits will persist, **Access**, the ability of all individual farmers to benefit from the market for AGWM credit , and whether farmers **Perceive** the new AGWM BMPs as being effective at achieving the desired goals and deserving of rewards. When these criteria are satisfied, the adoption of AGWM BMPs becomes viable, and the rewards become tangible. AGWM BMPs are vetted using BERT/E (boxes 3a and 3b) and AGWM credits become available in box 3c. These concepts are explained in more detail below.

The black and red arrows that start at box 3a and go to box 1a represent BMPs that result in positive cash flow and, thus, do not need AGWM incentives. The red arrow goes to the farmer for food box. An example would be a BMP for Zero Till, which is profitable and increases food supply. This would be considered a "No Regret BMP." The black arrow may be a BMP that does not cost much more and is not difficult to implement, but does not change the food supply (e.g., renewable diesel); this may be a" Neutral BMP." As such, farmers now have two jobs within the overall framework (box 1a): to produce food and to work towards AGWM. Box 3a shows the BERT/E framework, which consists of the five internal hurdles—Beliefs, Economics, Regulations, practical alternative Technology or tools, and Energy to change—farmers face in adopting AGWM practices. BERT/E can be used wherever BMPs are being considered and is included in boxes 3a and 3b.
The second framework, the GWMcr, helps to integrate international influence into our farms (boxes 2a, b and c). Boxes 3b and c represent the GWMcr framework for the appropriation and adoption of GWM practices. Within the GWMcr framework is contained the Appropriation Model, which holds that adoption is determined by availability, stability, access, and perceptions of rewards, as well as by the farmer's energy to make the change. The market (box 3c) is the locus where aggregators join

the supply of AGMW credits to AGWM demand (box 2c) via the purchase of credits (box 2b). The outflows from the creation of value for AGWM credits (box 2a) are policy flows (green arrows), which empower AGWM BMPs via the market and purchase (boxes 3c and 2b). The remaining BMPs that move from 3c to 2b can be called "Sacrifice BMPs". Some one is going to have to pay; pay for research, pay for incentives, or pay with higher food costs. Paying for research that makes these BMPs into No Regret or neutral BMPs will likely have the lowest overall cost. With adequate thought and planning, the quest for AGWM solutions should not negatively impact food availability (box 1b) but will likely increase the cost to consumers (box 1c). The toolbox (orange box 4b) represents concern for the global commons and contains tools and resources to support the changes needed at the farm level (box 4a).

7.4 GWMcr–ASAP x BERT/E Synergy

Within Rourke's General Farm Practice Change Theory, the interaction between BERT/E and GWMcr–ASAP framework allows farmers to evaluate and adopt BMPs that can optimize the incentives they receive for generating AGWM/EGS credits. The second part of the Net Positive Farm Framework, the GWMcr–ASAP is a highly modified framework based on the People in Nature model, which aims to

> *Promote the uptake of existing knowledge and generate new knowledge on the interrelationships between humans and nature* (Davidson-Hunt et al. 2016)p.7

I adapted the People in Nature model (Davidson-Hunt et al. 2016) to help visualize the process by which farmers manage the adoption of AGWM practices. Farmers need to keep producing food, but they now also need help with AGWM.

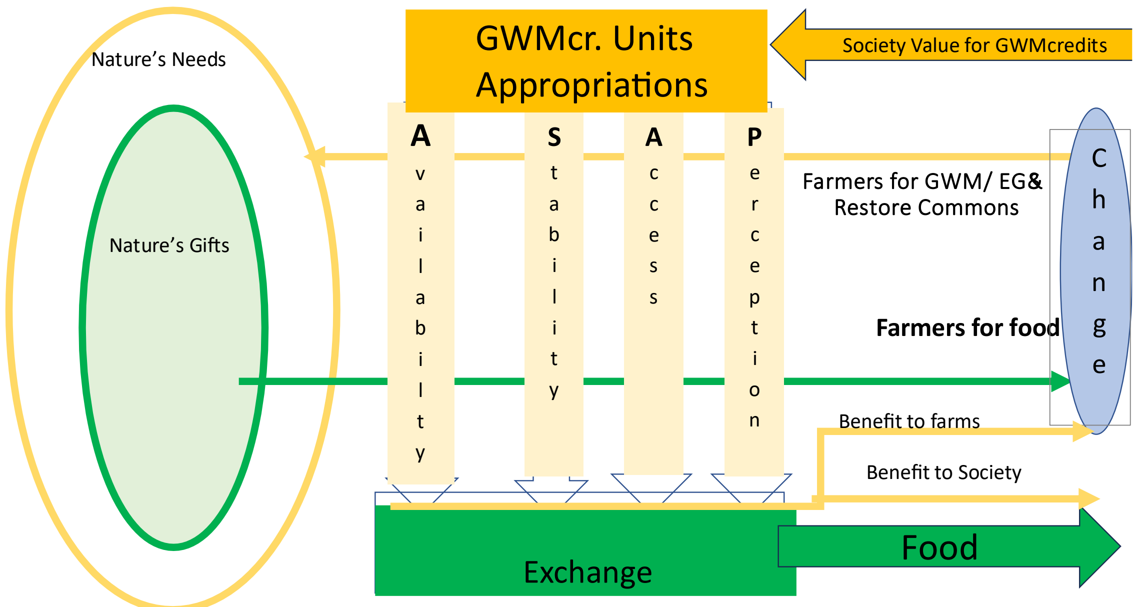

Figure 7.3. GWMcr–ASAP framework (expanded view).

As shown in Figure 7.3, the GWMcr–ASAP framework addresses the need for a balanced restoration of nature, which includes AGWM measures aimed at sequestering excess CO_2 from the atmosphere. In addition, this framework can be used to prevent negative-emission land use, such as turning forests into pastureland, grasslands into croplands, or any land into building land. It includes a whole host of other environmental goods and services, such as restoration of habitats to enhance biodiversity and the restoration of wetlands to improve water quality. In this model, AGWM credits are distributed based on the ability of farmers to adopt GWMcr BMPs. The change in BMPs comes with a greater appreciation of our connection with nature, a better balance between Nature's gifts and Nature's needs. Humanity must strive to become one with nature.

These credits can include, but are not limited to:

1. Cash payments for BMP adoption.
2. Cash payments for output, such as increased SOC or decreased emissions.
3. Support for research to develop improved AGWM BMPs.
4. Support for AGWM BMP demonstrations and workshops.
5. Payment for the conservation or restoration of grasslands, wetlands, or treed areas.
6. Tax credits towards the purchase of new AGWM technologies.
7. Discounts on crop insurance and/or enhanced crop insurance coverage
8. Premiums for Net-Positive-produced food (SBTi Net Zero Pledges).

9. Inset and offset credits.

10. Bans or fines

It is also worth considering that devoting resources (research and innovation) to minimizing the costs of such BMPs to farmers and society is a prudent first step prior to adoption, as it will limit the costs and maximize the efficiency associated with implementing these changes.

7.5. Net Positive Carbon Grain Farm Networks

AGWM is not a problem that can be solved by any one individual. If a specific farm is the only one that is Net Positive, this will not have much impact at a global level. Therefore, knowledge and technology must be shared, and Net Positive Networks are an excellent first step towards this goal.

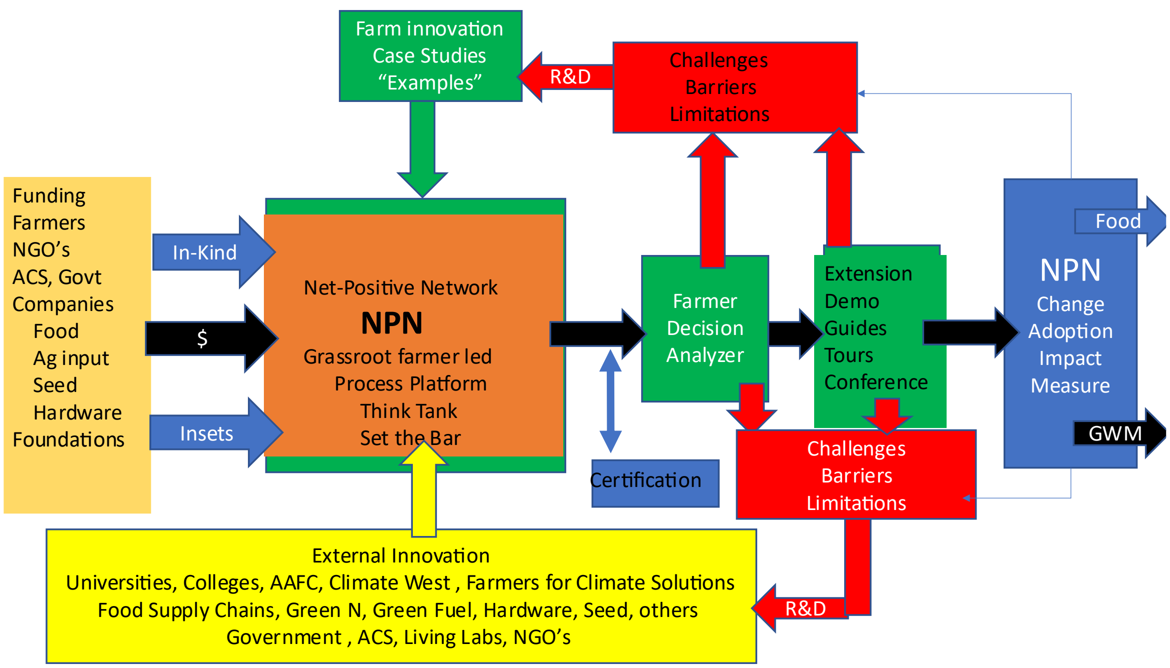

Figure 7.4. Detailed view of a Net Positive carbon grain network.

Figure 7.4 provides an expanded view of a Net Positive Network, which had previously been shown as a single box in Figures 7.1 and 7.2. In the expanded view, on-farm extension and adoption are shown on the far-right green and blue boxes. In addition, the depicted model includes innovation from both the farm community and external organizations. To aid the Net Positive Network in growing quickly, outside organizations may wish to help support it (far left box) and expand innovation (bottom yellow box). A further extension of the Net Positive Network is to develop a Net Positive Community of Practice (Wenger et al, 2002), which is shown in Figure 7. 5.

7.6. Net Positive Community of Practice

The Net Positive Community of Practice recognizes that tackling AGWM is not an individualistic endeavor. The Net Positive Community of Practice helps bring innovators together and provides them with support and momentum to continue innovating (Wenger et al. 2002). In addition, a Net Positive Community of Practice ensures that all players can be involved in developing and implementing pragmatic, economical solutions with as much external support as required.

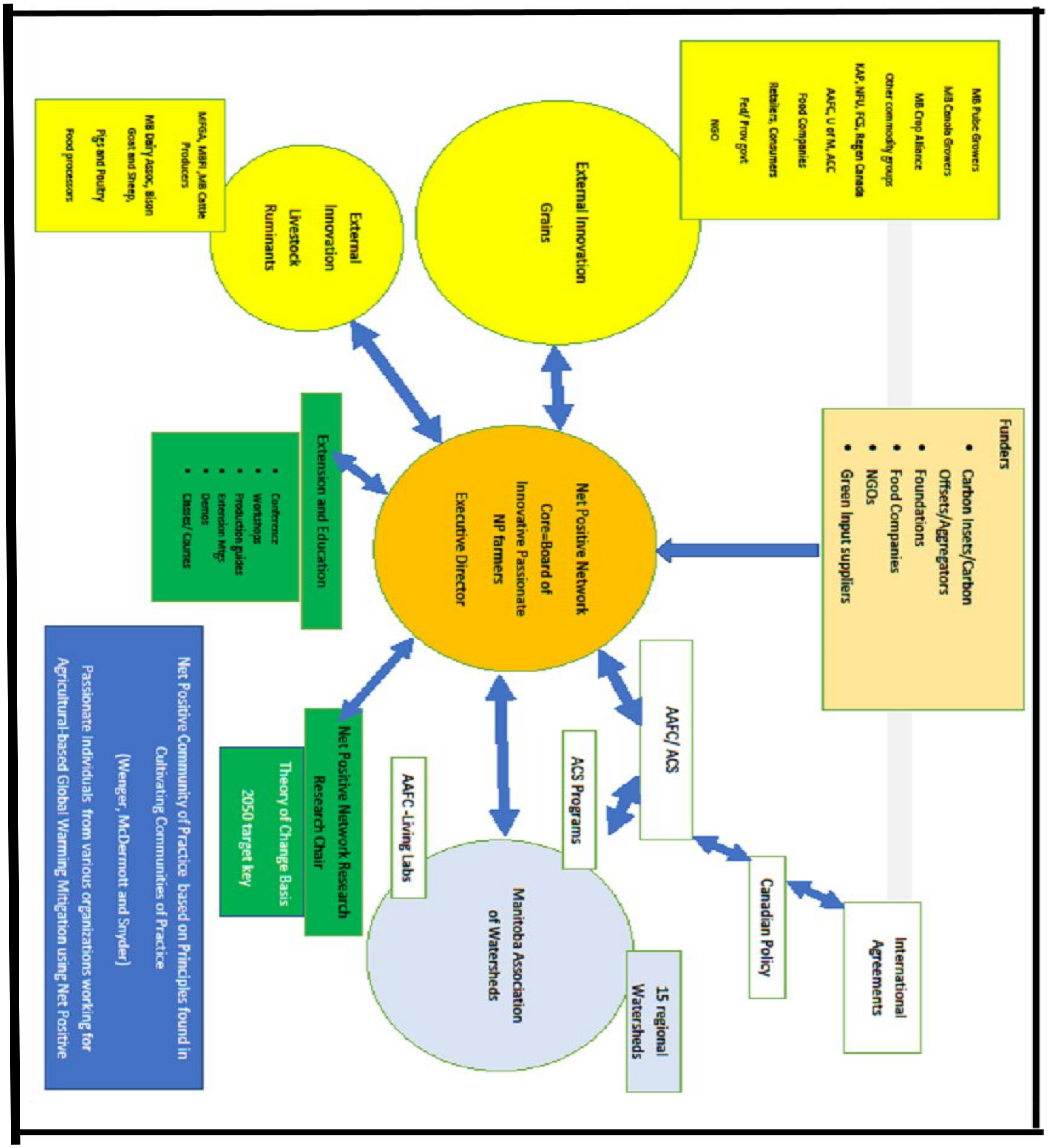

Figure 7.5. A grass-roots-led Net Positive Community of Practice.

7.7. Significance of Rourke's General Farm Practice Change Theory

Rourke's General Farm Practice Change Theory provides a theoretical model for tackling change on the farm. I am a first-generation farmer who got my start when I was presented with the opportunity to rent 300 acres back in 1980. When I began my farming adventure, the only resources I had were an MSc in Plant Science, some hands-on experience working as a farm hand in the summers, trade skills I'd learned in high school and from my family, a dream and a great partner (my wife, Diane), and $4000 cash. Since then, I have experienced and initiated many changes. While all of these changes ended up working out fairly well (using only "napkin math"), only a few have been truly financially successful. At the time of writing this thesis, the most impactful change network I have been involved with has been the Manitoba North Dakota Zero Tillage Farmers Association. This thesis employs many of the unlabelled processes used within that organization, which ultimately became defunct due to its own success. This thesis has helped me to recognize, understand, and formalize these processes for a new purpose: to mitigate AGW.

The two frameworks, two supporting diagrams, and the tools developed to evaluate new AGWM BMPs (i.e., BERT/E, Net Positive, and SFI calculations) have enabled the development of a specific theory of change that can empower Western Canadian grain farms to fight AGW.

Rourke's General Farm Practice Change Theory can be used to assess and implement many kinds of changes, ranging for everyday considerations, such as which crops to grow, which types of fertilizer, weed, and pest control options to use, or how to optimize machinery, to larger philosophical questions, such as how to help mitigate global warming, how to improve soil health, and the willingness to consider new practices that challenge beliefs.

For many outside the academic field of change, we might struggle with all the nuances of change language. In their paper, Change Theory and Theory of Change: What is the difference anyway? Reinholz and Andrews (2020) define change research, change theory, and theory of change as,

> *any scholarship that focuses on how to make change happen. Some change research has a strong theoretical or empirical basis, while other scholarship may be more conjectural. An important subset of change research is change theory, which we define as a framework of ideas, supported by evidence, that explains some aspect of change beyond a single project. (p. 5)*

The following definitions, which were also derived from Reinholz and Andrews (2020), help clarify change language:

> *A change theory is a formalized framework disseminated through scholarly channels and meant to be generalizable beyond one project. A theory of change is developed by a project team, specific to a single project, and lays out the goals and logic for a single project*. (p. 2)

Moussa (2018) compiled a list of fourteen evidence-based change theories and models developed since the 1950s. The first is Lewin's (1951) simple change theory, which consists of three steps: unfreeze, make change, and refreeze (Burnes 2020). Each theory has its own context and nuances with similarities as well as unique differences. Change action often starts with changing how one looks at a situation, their worldview, and their beliefs. Don Campbell, a rancher, and a Holistic Management instructor from Saskatchewan has been quoted by many as saying, *"If you want to make small changes, change the way you do things. If you want to make major changes, change the way you see things" (*quoted in Brown, 2018: p.198*)*.

As one would expect, there is overlap between the various theories, with some concentrating on individuals and others on changes within organizations and institutions. Some explicitly mentioned urgency and leadership.

Table 7.1. Comparison of Kotter's Eight-Step Change Model and Rourke's Seven-Step General Farm Practice Change Theory.

	Kotter's Model	**Rourke's General Farm Practice Change Theory**
1	Establish a sense of urgency	Understand the opportunity
2	Form a powerful guiding leadership	Visualize the change
3	Create a vision	Set the mission and goals
4	Communicate the vision	Develop the alternative BMPs
5	Empower others to act on the vision	Evaluate the BMPs using BERT/E, make recommendations
6	Plan for and create short term wins	Measure Success (SFI and Net Positive Farms) *
7	Consolidate improvements and produce more change	Support Innovation (NP Network and

		NP community of Practice) *
8	Institutionalize new approaches	Repeat

*The Sustainable Farm Index, Identification of Net Positive Carbon Grain Farms, Net Positive Network, and Net Positive Community of Practise were used to extend the Rourke's General Farm Practice Change Theory into a theory of change aimed at AGWM.

Kotter, a Harvard-educated economist, founded his model based on four decades of watching leaders and organizations try to transform or execute their strategies. In the middle of Kotter's model diorama is the "big opportunity" (Kotter and Bedard 2024), which is included in the first step of Rourke's General Farm Practice Change Theory. Kotter infuses human resources and motivation components throughout his model whereas Rourke's theory assumes the motivation is contained in beliefs and is tested in step five with BERT/E. Thus, a major difference between the models is that Kotter's model tends to emphasize selling change to a group, while Rourke's model entails working with people who already recognize the problem. Put differently, the difference amounts to a need to push change (Kotter) vs. having the participants wanting to pull the change forward (Rourke). Here beliefs come first, beliefs drive passion and passion drives action.

Another key difference between the two models is that Rourke's General Farm Practice Change Theory provides methods for evaluating the anticipated changes, such as the BERT/E adoption assessment tool to analyze the adoption of BMPs and the Sustainable Farm Index to gauge progress towards sustainability and the Net Positive calculation. Part of the power of BERT/E is to provide a platform for farmers to talk, to express their views on a particular topic and have the world listen. Many of the GWM-BMPs we have to day come from well meaning science. These particular BMPs may be a perfect solution some place in the world but it might not be for the particular farmer's context. BERT/E can help social science, quantitative science, regulatory people, and tech providers to listen first, so they are providing solutions to the right problem for that particular context. Key to solving a problem or at least being able to ask the right questions is to find the innovators, the ones who already recognize the opportunity or problem and are working on solutions. In this thesis, Rourke's Theory of Change is applied to the challenge of converting farms to Net Positive using the proposed AGWM BMPs. Rourke's General Farm Practice Change Theory is the result of observations made over a lifetime of business, including farming and leadership training from Syngenta's Leadership at Its Best program in 2014. However, Rourke's General Farm Practice Change Theory is ultimately an intuitive development. It is not surprising that Kotter and other change theories have similar components (Moussa 2018). Lewin's three step change theory was one of the first recognized change theories originated in 1952 and while it is simpler than Kotter's 8 strep change theory, the basis for change in both theories is the desire to solve a problem or seize an opportunity. Burnes (2020) describes Lewin's process as: "Un freezing, Moving (Make the change), Refreezing" (p. 46). Both theories rely on the participants being open to exploring new possibilities, being able to evaluate the possibilities over some time period and then allowing the best possibilities to become the new norm.

7.8. Practical Outcomes

Net Positive carbon grain farms are not only possible, but, as this thesis shows, they are present today, as at least two of the participants qualified as Net Positive. The results also show that high SFI scores are critical to ensuring ongoing success and longevity. This is in the context of the Triple Win: feed the farmer, feed the cities, and heal the planet. The immediate implications for the outcome of this thesis are as follows:

- Net Positive carbon grain farms are real and viable. This is proved by the fact that two of the participants can be categorized as Net Positive. However, it must be determined if these examples can become the basis of a Prairie-wide Net Positive movement. Western Canadian grain farms need to engage in the international recognition of this global problem, and they must acknowledge international agreements and local initiatives to tackle AGW. While governance, from the international level down to the local policy level, should be the main driver of change, it has had limited success in reducing emissions. Nonetheless, companies around the world have collectively set net zero emission goals by 2050. Scientific Based Target initiative (SBTi) is a major player in this respect, having over 8400 companies pledge to become net zero by 2050. (January 10, 2025, company count is 9966.) These companies, including food giants such as Nestle, are beginning to look for Scope 3 supply chains to deliver net zero food ingredients. This is likely to become the biggest driver of Net Positive. Farmers cannot afford to be voiceless in the development of Scope 3 net zero BMPs. If farmers ignore AGW and fail to participate in AGWM, they risk losing consumer trust and, ultimately, market share.
- Farmers must be at the decision table to ensure that Scope 3 demands are realistic and that any related gaps and barriers are acknowledged and dealt with. Some AGWM BMPs are not financially feasible at present. Therefore, research is required to make them self-supporting or to establish continuous AGWM credits to offset the costs incurred for

adopting them on farms. For example, one of the most widely promoted BMPs is to grow plants from snow to snow. However, this BMP was scored very low, even among the Net Positive participants, with many reporting that their interest in this practice was decreasing rather than increasing (see Chapter 6 for full details). On the other hand, the BMPs, lack of disturbance and armor on the soil, are widely utilized in Zero Till farming and are examples of "no regret" GWM BMPs, as they can be profitable for the majority of Great Plains grain farmers without the need for additional incentives. Despite these advantages, farmers and researchers recognize that Zero Till still has vulnerabilities that must be addressed.

- Continuously feeding the soil food web helps ensure rapid and lasting SOCC. Promoting BMPs that are not adaptable on an economic and logistically scalable basis is akin to telling farmers that they should "just get with the program." This kind of action discredits the entire AGWM initiative and is a waste of time and money. Therefore, AGWM BMPs must be practical and profitable. To ensure this, it is critical to carefully vet potential BMPs, which can be done using the BERT/E adoption tool. As shown in Table 7.2, the results of the BERT/E analysis show that soil armor was a very popular BMP, while organic farming was not.

Table 7.2. BERT/E adoption scores based on average for group vs. two Net Positive farmers.

BMPs	BERT/E Max 625 Average	Kelly's Score BERT/E	Derek's Score BERT/E
A. Regenerative Ag BMPs			
Armor on the Soil	503	5x5x5x5/1=625	5x5x5x5/1=625
Lack of Disturbance	417	5x5x4x5/1=500	5x5x5x5/1=625
Plant Diversity	257	1x1x2x1/5=1	5x5x4.4x5/1=563
Snow to Snow	134	4x4x1x4/2=32	4x2x5x5/2.5=80
Grazers	152	1x1x5x5/5=5	4x5x5x5/1=500
B. Sustainability Tools BMPs			
Agroecological Solutions	281	5x5x4x5/1=500	5x5x4x5/1=450
Phosphorus Management	255	1x1x5x1/5=1	5x5x5x5/1=625
Sustainable Intensification	246	3x3x5x5/3=75	5x5x5x4.5/1.5=375
Conserve and Restore	160	5x5x5x5/1=625	5x3x5x5/1=375
Organic	94	1x1x5x1/5=1	2.5x2x5x4/5=20
C. Fossil-Fuel-Free Alternatives			
11. Alternative Nitrogen	152	5x5x3x5/1=375	5x4x5x4/1=400
12. Alternative Fuel	41	3x4x5x1/5=12	4x2x5x5/4=50

Table note**:** BERT/E score comparisons were borrowed from Chapter 6.

The data in Table 7.2 Illustrates the differences between the participants' average BERT/E scores and those assigned by the two Net Positive farmers. As can be seen, the most important BMPs to becoming Net Positive were the use of alternative nitrogen instead of fossil-fuel-based nitrogen, followed by armor on the soil and lack of disturbance. See Chapter 6 for more detail. The Net Positive farmers also embraced agroecological solutions and tended to have a higher appreciation for maintaining wildlands. Conversely, organic farming and the integration of grazers were the BMPs that were least likely to be practiced on a large scale. Alternative fuels will become the norm once renewable diesel is readily available, but this is not reflected in the data. Federated Co-op and others expect renewable diesel to be widely available by 2027.

7.9. Summary of Research Objective Completion.

The original objectives need to be examined in reverse order to follow the flow from theoretical to practical outcomes. This study had four research objectives.

Objective 1: **To develop practical theory, framework, and tools to complement this exploratory narrative research process.** This objective was addressed earlier in Chapter 7, starting with Rourke's General Farm Practice Change Theory. AGW was the problem (opportunity) that moved it from general theory to a specific project, which used the Net Positive Farm Framework and GWMcr–ASAP Framework to visualize the required changes. The developed tools included calculations for Net Positive, SFI, and BERT/E to help score BMP adoption.

Objective 2: To determine whether any of the participants were Net Positive and how this status related to their SFI score. This objective was addressed in Chapter 5. As noted earlier, two of the participants qualified as Net Positive, with these two farmers also having the highest SFI scores. This finding is significant and welcome, as it demonstrates that agriculture can have a low carbon footprint. Nonetheless, further improvements are possible, for example, switching to renewable diesel when it becomes available, and it is practical to do so.

Objective 3: **To determine whether BERT/E (adoption rating) analysis is effective at identifying enablers, barriers, gaps, and innovations with respect to achieving Net Positive.** The analysis of the BERT/E scores for the twelve BMPs yielded a list of fifty recommendations (Chapter 6), and, when combined with NVivo analysis of the in-depth interviews, it enabled the identification of distinct enablers, barriers, gaps, and innovations that can facilitate or hinder the quest to Net Positive. As discussed in Chapter 6, the top enablers of Net Positive were access to appropriate technology, knowledge support, financial support, and appropriate tools, while lack of technology and knowledge transfer, lack of financial return or incentives, climatic factors (e.g., inadequate rainfall or extreme heat), and the challenges associated with integrating cattle into prairie grain farm systems were the top barriers.

Objective 4: To determine how the participants rated the utility of the twelve AGWM BMPs. This analysis is presented in Chapter 6. The BERT/E results indicated that not all BMPs are equally appealing and must therefore be promoted accordingly. Additionally, some BMPs need to be improved through research before they can be promoted, while others fill niches and need to be promoted on that basis

7.10. Role of the Case Histories: Farm Stories

The case studies, captured in the form of farm stories, were presented in Chapter 4. The participants' farms were located in the wet black, thin black, dark brown, and brown soil zones across Manitoba, Saskatchewan, Alberta, and North and South Dakota and varied in size from 2200 seeded acres to over 30,000 acres. While the majority were straight grain farms, a few had their own cattle or had a cooperative arrangement for grazing. All farms were located either in sub-humid or semi-arid locations with large variations in annual precipitation.

The final stories were vetted by the participants, with their comments included at the end of each one (to read the full version of each participant's story, please see Appendices 4.5 and 4.6). These stories provide insight into each participant's individual context and philosophies, in addition to revealing the differences, similarities, and ongoing challenges in their journey towards Net Positive.

These in-depth interviews provided all the data for the thesis, the stories are their synapsis, our rare chance to see inside. While the inclusion of the stories is not critical to the research, they will be important to outward extension. DeMeyer et al. (2020) , suggests that a library of compelling positive science based stories are extremely important to move behavior and actions.

7.11. Highlights of Recommendations: Top Priorities for Key BMPs to Become Widely Adopted.

7.11.1. Barriers to Net Positive Grain Farming

Despite the many positive outcomes of this study, there are very few actual Net Positive farms across Western Canada. As noted in the literature review, many surveys have found that farmers hold beliefs, which, depending on the beliefs, can be significant a barrier to change. In conducting the case studies, I tried to go beyond the participants' beliefs to understand the barriers and enablers for those who are trying to move toward Net Positive. The participants identified the adoption of Zero Till (soil armor and lack of disturbance to sequester carbon and build soil health) and minimizing or eliminating the use of fossil-fuel-based nitrogen fertilizers and fossil-fuel-based diesel as the BMPs that were most critical to becoming Net Positive. In the following section, I review the main barriers.

7.11.2. Barriers to Zero Till

- Many farmers have little interest in AGWM initiatives, especially those implemented by the government and those involving carbon taxes (Van Wyngaarden et al. 2024). However, framing such initiatives in terms of soil health improvement is likely to be more successful with the average farmer. Thus, future AGWM initiatives should emphasize pragmatic outcomes, such as soil improvement or enhanced economic outcomes, in order to garner greater support.
- The critical relationship between soil health and a vibrant soil food web (i.e., soil biology) is not well known by many farmers and should be promoted.
- There is a lack of knowledge regarding the benefits of a long-term lack of tillage. A little tillage may cost us more than we have realized or tillage less than 2 inches deep may be acceptable under certain conditions(No Till Farmer 2024; Franzen, Inglett, and Gasch 2019).
- There is a lack of tools to make Zero Till work on wetter soils. However, cover crops and delayed germination seed technology may be useful in this respect. There has been little recent Western Canadian research on the expansion of Zero Till, and regression is being observed in some areas due to increased tillage associated with soybeans and corn.
- Tools are required for long-term weed control and herbicide resistance, which are both threats to Zero Till and grain farming in general. Potential tools include shallow tillage tools to control foxtail barley and kochia; alternative herbicide strategies tied to crop rotation and crop competition; promoting the biological and mechanical degradation of weed seeds; antibiotic herbicides; the use of RNAi to reverse resistance; gene drive and gene editing technology; and robotic-spray, zap, pick, or micro cultivation. Furthermore, “See and Spray” technology may be useful to help control costs and minimize off-target consequences, but it may not slow the development of herbicide resistance.
- There is a need for research on micro precision tillage. Such research should investigate whether strip-till or biostrips are possible as corn production expands in Western Canada and whether we have adequately compared ultralow disturbance versus precision banding and micro-aeration effects. Biostrip cropping is a technique developed by Joe Brecker (Havana, North Dakota) that entails sowing a strip of faba bean on the strips where corn is to be planted the next year, with the rest of the field receiving a blanket application of cover crops. This technique is useful as the faba bean stems

turn black when they die from winter kill, which in turn fosters better heat absorption, and therefore warmer seed beds for the corn, the following spring.

7.11.3. Barriers to Greater Plant Growth

Research is required to develop practical BMPs for growing plants from snow to snow and enabling a greater diversity of plants to help feed soil biology. Fourteen recommendation for improvement in this area are discussed in Section 6.4.2 and 6.4.3.2 and are listed in Appendix 6.2.

7.11.4. Barriers to Eliminating Fossil Fuel-Based Products on Farms

The very low relative prices of diesel and nitrogen fertilizers (compared to the cost of AGW) and the lack of viable alternatives has promoted a business-as-usual mindset. Therefore, alternatives are required. Five alternative nitrogen strategies were discussed: increased use of legumes, long term Zero Till, Bugs in a Jug, Green NH^3, and enhanced soil biology with rhizophagy. A late addition to this list, which was not discussed, may be the "Holy Grail" of N nutrition: the development of N fixing non-legumes such as triticale (Ziemienowicz et al. 2015; Cotee 2020), wheat, canola, and corn. AAFC Lethbridge is scheduled to begin field trials with this patented technology in 2025 (personal communication with Science Director, Dr. Francois Eudes).

A scalable and practical alternative fuel for on-farm operations is renewable diesel. It is scheduled to be available by 2027 in the Prairies.

7.11.5. AGW is Real, and AGWM BMPs Are Needed

Agriculture is exempt from carbon pricing, which promotes a business-as-usual mindset. However, the SBTi member companies and global pressure from the UN will eventually place value on carbon. While world leaders are currently meeting at CoP 29 (Azerbaijan, Nov 11 to 22, 2024) to make good on their commitment to carbon pricing (Article 6, Paris Accord), the Saskatchewan Association of Rural Municipalities has passed a resolution stating that *“carbon is not a pollutant and any programs involving net zero should be cancelled* “(Easton 2024). This dichotomy illustrates the lack of consensus on the legitimacy of AGW, despite overwhelming evidence in support of it. CO_2 can be a pollutant, but like oxygen and water, it is necessary for survival at the right concentrations. For example, CO_2 is integral to plant growth and 0_2 is a byproduct, both of which are essential to life on Earth.

- Many tools are needed to help farms become Net Positive, including new solutions in technology, knowledge transfer, and taxes and regulations that are enablers rather than barriers. In addition, the market will play a role, for example, by supplying premiums for Net Positive grown foods. Direct subsidies will also be needed for BMPs that are required for mitigation but are not economic at the farm level.
- The historical model for grain production is the self-insured mixed farm. When government programs evolved to underwrite the risk of specialization, the model began to favor large-scale grain farms that grow two, three, and perhaps four main crops. These farms optimize their yields through a wide variety of inputs, particularly nitrogen and phosphorus. If these farms flounder due to the market or the weather, crop insurance and AgriStability are there to underwrite the loss and allow them to continue next year. Farms no longer need gardens, chickens, or cows to help ensure they have something to eat if the crop is destroyed. We are not accountable for negative externalities and can always find a rationale to avoid mitigating their effects. Technology and government support have allowed the specialization model to flourish, which has led to historic access to food. The lack of technologies and BMPs tailored for Western Canada, a crop insurance program that discourages the use of regenerative practices, and the need for subsidies for unprofitable practices that help the common good are holding us back from doing the right thing.
- There are positive signs that financial institutions and food companies want to be net zero, which means they will also want Net Positive grown foods. However, it remains to be seen whether these companies will help develop the technology required to scale up production, or whether they are aware of the implications of what they are asking. Furthermore, it is unclear whether governments will adjust their programs to help accomplish these goals. Research to improve Sacrifice BMP to No Regret BMP is greatly needed.

7.12. Sustainable Grain Production in Western Canada:

7.12.1. Farms in the Near Future

This thesis introduced us to twelve innovative farmers and four research agronomists and documented their stories, histories, contexts, and innovative practices. The BERT/E tool was deployed to document their farm progress and gain an understanding of the journey to Net Positive Carbon Grain Farming, including the enablers and barriers to achieving this goal. The interviews with the participants and the subsequent analysis of the data yielded twelve sets of recommendations for policy makers, as well as suggestions for how research and extension personnel can tackle the gaps needed to move to a Net Positive position (see Appendix 6.2 and discussion throughout Chapter 6). The collected data was also used to calculate the participants' Net Positive and SFI scores. Taken together, the results of this study provide a glimpse into the potential for Net Positive carbon grain farms in Western Canada to realize the triple WIN of supporting farmers, feeding the cities, and healing the planet.

Given the available present or near-present options, it is interesting to consider what net zero or Net Positive sustainable cropping systems on the Canadian Prairies might look like in 2050. The following offers a few speculative possibilities.

- The best system for carbon sequestration is a well-fertilized, multispecies perennial pasture grazed by ruminants, wherein nutrients recycle with little or no outside inputs and there are no pesticide resistance problems. Currently, this is economically challenging, which has limited the number of grain farmers willing to have cattle back on their farms. There will continue to be small mixed grain and cattle farms comprising both grain and cattle land. There will also be dedicated cattle ranches that employ grass-fed strategies to optimize the use of land best suited to grazing. Notably, the implementation of deep-rooted perennials is the best way to build SOM to depths unachievable by annual crops.
- Organic grain farming is not a scaleable solution for 78 million acres of Western Canadian grain land, as it offers limited food production, is labor-intensive, results in high-priced food, and often degrades soil when practiced on a large scale. Although it is a niche option, organic farming is a necessary alternative for those with sensitivities to pesticides, and it can teach us to how to maximize the use of agroecological strategies.
- Monoculture Zero Till is the norm, but it does not go far enough. In my own context, I have identified fifteen barriers to sustainability if I was to practice only monoculture Zero Till on my farm (Appendix 7.12.1).
- Net Positive Carbon Grain Farming using the examined BMPs offers the best chance at a sustainable balance. Lack of soil disturbance and Armor on the Soil in sub-humid semi-arid regions is the foundation of these practices. In addition, since CO_2 sequestration is

dependent on plant growth, the greater plant diversity and growth enabled by this practice results in greater soil carbon sequestration. The physical limiting factors to implementing the BMPs discussed in this study are agronomy, rainfall, fertility, WUE, type of plants, continuity of growth, and efficiency of microbes in converting plant biomass and exudates into SOC and grain yield.

- The lack of biological or genetic alternatives to fossil-fuel-based nitrogen fertilizer is the largest missing piece in establishing a sustainable AGWM cropping system in Western Canada. Many companies and universities are working on "Bugs in a Jug" approaches (Azotic 2021; Corteva 2022b; Pivot Bio 2022), while others are exploring more genetic solutions (Payá-Tormo et al. 2024; Pankievicz et al. 2019; Patel and Patel 2023; Mahmud et al. 2024; Ziemienowicz et al.2015; Cotee 2020). However, there remains a contingent of highly trained, experienced and well informed researchers who are sceptical that this approach will ever work (Giller et al. 2024).
- The second largest challenge to a sustainable AGWM cropping system in Western Canada is the ability to grow extra biomass and convert it into SOC. Cover crops and intercropping are not effective when the seed stays in the bin, or when the cover crop is not established in a timely manner. Delayed Germination Seed Tech, DGST) is a great idea, and, if it works, it will provide a greater chance of establishing continuous plant growth on a timely basis. Other innovation is also needed.

Ultimately, this thesis is intended to serve as a source of information to accelerate the move towards Net Positive. It is my hope that it will provide the foundation for farmer-oriented books, extension materials, letters to editors, policy briefs, and research proposals, and generally become a source of inspiration for AGWM advocacy.

While every 2050 farm will be unique due to the wide range of contextual settings, there will be some fundamental principles (low emissions and optimal carbon sequestration). Image what your farm could look like in 2050.

7.12.2. The 2050 Net Positive Rourke Farms

In this light I will take the opportunity to speculate on what our farm may look like in 2050.

The farm is still 4000 acres, the same as it was in 2024. My granddaughter has followed in her mother's footsteps and now runs the farm. There is no need to be larger; every well-run farm is profitable regardless of size. Many of the southern countries continue to experience extreme weather, flooding, fires, drought, and excessive high temperatures. Some coastal regions have been lost to increased ocean encroachment. Crop production is more tenuous in these regions. Thus, there is demand for our northern crops. The world works together to maintain crop production. However, as populations stabilize and even decrease and the culture of consumption and materialism is transformed to contentment and happiness, we are able to balance consumption and supply. Famine has been defeated. Food waste is eliminated. Respect for nature and its power to overwhelm any one individual or country is well-established. People work together for the common good. Healthy living, adequate exercise, and public health are cornerstones. Farmers are treated with the utmost respect, as true stewards of the land, all with high SFI ratings and all Net Positive.

While farming is still a dynamic business where Mother Nature "bats last," my granddaughter has a workable set of BMPs she relies on to be Net Positive and maintain a high SFI score. Collectively, these BMPs ensure that the farm's soils are highly functioning and biologically healthy, and that there is an abundance of diversity in the soil, the crops, and the native and planned wildland on and surrounding the farm. There is a good insurance program available to ensure the farm is stable and continues to be productive despite bumps that may come along. There are still no ruminants on the farm, as the economics are unfavorable, and the extra work is untenable. The trend is for people to eat less meat, and those animals are raised on land not suitable for crop production. Rourke Farms has almost no land that would be considered unsuitable for crop production. The seeded-down patches of poor land are small and discontinuous and are best sown to perennials used for hay or biomass production. Consumers have come to realize that it is best for farmers to have a full toolbox when it comes to food production. Restrictive agricultural practices such as organic just cost too much; regenerative food is less expensive, uses much less land, and is nutritionally safe and abundant. Organic grain farming is considered a niche practice for the few that are sensitive to particular ingredients, similar to how we manage food sensitivities like peanut allergies.

The practices she uses on the farm all have a high BERT/ E score. They include:

1. Leaving armor on the soil and striving for minimal disturbance. While Zero Till is the main pillar of her farming system, herbicide resistance necessitates a wide array of weed control practices, including RNAi manipulation of weeds, developing biologically active soils that are able to denature weed seeds, applying specific biological control agents, and using agroecological practices such as cover crops, high seed rates, intercropping,

green seeding, and shallow tillage. She uses multiple seeding tools to attain the flexibility to manage this diverse set of practices. One of the seed drills can undercut weeds thus reducing the need for complete reliance on herbicides while maintaining healthy soil biology. Another is a precision banding hoe drill which gives superior seed placement, precision fertilizer placement which limits weed access to fertilizer. The third drill is a narrow spacing single disc drill which maximizes crop canopy closure for maximum weed suppression.

2. She is able to increase the diversity of plants growing from snow to snow due to the development of technologies such as Delayed Germination Seed Technology (DGST), the wider availability of winter-hardy annual legumes, and investments in developing companion crops that are able to tolerate shade and drought while also supplying ample biomass in the fall and spring. Some of these are self-seeding. She is able to select cover crops that are known for their superior ability to feed the soil microbiome and increase SOC. She also grows full season cover crops to help jump start soil health in any problem fields or spots. The SOM in her soils has increased from 4.5% in 2024 to 4.8% in 2050, which is in line with the 4 per 1000 target set at the 2015 at the UNIPCC meeting in Paris. Adding cover crops still costs more than the farm can afford thus there is a 50/50 cost share with the government to help cover the added cost. There is also financial recognition for the value of maintaining and restoring wildlands and pollinator strips on and around the farm. The high level of added biodiversity has allowed her to eliminate the need for fungicides and insecticides.
3. However, the most significant factor allowing her to be Net Positive has been the development of alternatives to fossil-fuel-based nitrogen and diesel fuel. The diesel alternative was simple: it entailed an overnight conversion to renewable diesel, essentially made from her own Net Positive canola and soybeans. She estimates that, when she accounts for the meal, she only needs to use 0.8% of her land to supply the vegetable oil needed to satisfy her on-farm fuel needs. Although she buys new combines each year to obtain the latest precision farming technology and emission controls, she still runs the 1990s 400 hp tractors that we rebuilt in the 2020s. She has added emission-control devices to these tractors to ensure they meet the same standards as new tractors and make sure these old workhorses are compatible with the latest precision

farming tools. Upgrading vs replacing the old tractors reduces the demand for new steel on the farm.

Alternative nitrogen was harder to achieve and required a lot of government and industry investment and research to overcome the barriers. For example, by overcoming disease problems, annual legumes are productive on more acres. Research aimed at better understanding and promoting the more continuous Zero Till revealed that the absolute lack of disturbance was not mandatory and mindful tillage at shallow depths (less than 5 cm) could be used in certain situations. These zero till and minimal disturbance practices were found to have a nitrogen credit of 50 kg/ha, similar to the original studies by Franzen in the 2000's. The investments that began in the 2020s (or earlier) are now producing significant and reliable Bugs in Jug products, which are replacing up to 50% of the N requirements for crop growth. Research on N-fixing soil microbes based on farmer practice and observation (e.g., IMOS) also added to the N pool for her crops. My granddaughter used the IMOS practice until soil health improved as synthetic N was reduced. Synthetic N has always been known to reduce N fixing microbial activity. The most astounding return on research investment was the development of non-leguminous crops to fix their own N. She now has N fixing cereals as well as N fixing broadleaved crops like canola, flax, and sunflowers.

There was a flurry of activity to develop Green N both on an on- farm and global scale back in the 2020s, but the results of these efforts have been made obsolete through the power of biology and genetics. She has heard of an old initiative called "4Rs," but she admits that it has also become obsolete, despite the fertilizer industry's efforts to convince farmers and society that fossil-fuel-based technology was the only way forward.

She runs a successful farm in a world that is adjusting to the new normal of 1.5°C. She says the transition to Net Positive farming has been achieved through a series of simple changes. Each new BMP met the BERT/E criteria before being adopted. Training, demonstrations, and (sometimes) financial incentives were needed to ensure a smooth transition. Her local Net Positive Farming Network, backed up by a Net Positive Community of Practice, is a tremendous source of information, encouragement, and support. She still consults Grandpa's, Rourke's General Farm

Practice Change theory when faced with new opportunities or challenges and says that change is part of evolving to a higher plane, something farmers are always doing.

7.11 Next Steps

The next step was partly captured in the exit survey which can be found in Appendix 7.2.3. The results of the survey motivated this list of next steps.

- Expand enablers and reduce barriers. Focus research and policy development on improving BMPs.
- Work to develop a deeper understanding of farmers' attitudes, knowledge, and culture via surveys and interviews. In particular, research should focus on whether attitudes have shifted towards a more favorable view of Net Positive practices or support to soil health initiatives.
- Develop a better understanding of motivation and the power of SBTi pledges.
- Encourage or facilitate the development of Net Positive Carbon Grain Networks and Net Positive Communities of Practice. These groups and organizations will provide the core leadership required for providing education and extension regarding Net Positive practices, thus facilitating a cultural change in the beliefs surrounding them.

7.14 Limitation of Research

The research described herein is exploratory and narrative in nature. While such research can be important to expanding our understanding of farmers' reactions to AGW, it does have limitations that must be acknowledged. These limitations are detailed below.

- This research was conducted through the lens of my own biases and was mostly limited to the context of Western Canadian and Northern Great Plains grain farms.
- The findings of this work identified gaps in technology and knowledge, but developing solutions to these gaps was beyond the scope of this exploratory project. However, the fifty recommendations to come out of this work can help guide decision makers to make informed investments in innovation, research and appropriate policy helping farmers adopt more AGWM BMPs.
- The sample size was limited and targeted towards AGWM-oriented grain farmers.
- The data was based on trust, best guesses, and perceived normal or average crop production. The data collected was not audited or verified.

- While Holos is a useful tool, it is an informed approximation of reality that is limited by the available peer-reviewed literature and the many assumptions it uses. Thus, Holos is only as good as the data inputs it receives during its development. This thesis is qualitative; it is not a quantitative examination of every aspect of each component of each farm. Nonetheless, the obtained results are consistent with those generated by the Cool Tools program, which is a more globally utilized GHG emission model. Undoubtedly, as new information becomes available, models will change accordingly. Better tools for measuring SOC will increase the accuracy of the carbon sequestration component of the model.
- While this work emphasized identifying Net Positive farms and the BMPs that enabled Net Positive Grain Farming, a more practical extension of this work may be its application to soil health, which is a high priority for most grain farmers. Davidson et al (2019) and Arbuckle et al. (2015) have examined this topic in Alberta and Iowa, respectively and while their work is relevant, it does need to be updated.
- The impact of the pledges to reach net zero by 2050 in the SBTi framework has yet to be determined. I believe these pledges will be more impactful than government policy and current non-science-based rhetoric, but only time will tell whether this hypothesis is correct.

- This thesis did not address lab meat, insect proteins, containerized produce, plant-based meat substitutes, or food waste. Earth is currently home to approximately 8 billion people, which is a lot of mouths to feed. As such, we need as many options as possible, and Western Canada's 78 million acres of farmland will be a significant source of sustainable grain production in the future. To ensure this, it will be necessary to develop scalable alternatives that can be put in place with as little disruption as possible and as soon as possible if we are to meet our goal of becoming net zero, and possibly Net Positive, by 2050.
- The ultimate challenge is to work with the beliefs of farmers. If they do not believe in the change, it will not occur. Fortunately, they believe in soil health, greater water-use efficiency, and greater profitability and leaving a legacy. We can work with this; everything after is just a matter of practical scalable BMPs.
- Due to the exploratory nature and small sample size this thesis should not be used to generalize to larger populations, It does however provide valuable insight.

Ultimately, this thesis is intended to serve as a source of information to accelerate the move towards Net Positive. It is my hope that it will provide the foundation for farmer-oriented books, extension materials, letters to editors, policy briefs, and research proposals, and generally become a source of inspiration for AGWM advocacy.

7.15 Final Thoughts

As I end this period of reflection, learning, distilling, and hoping I can eventually make a difference, I reflect on the prolific Smil, who ends his latest book by warning,

> *[we must] secure adequate supplies of food, water, energy, and materials needed to lead healthy lives with decent life expectancies; in mental, social, and economic terms it would mean ensuring the opportunities for education and employment and providing generally accessible, good-quality health care; and all of that should be done while leaving sufficient resources for the long-term survival of other species—even as the total number of the human species is still increasing* (Smil 2023, p. 179).

Smil says that we invent and innovate, but he doubts it will be in time to unwind the harm we have caused. He ends his last sentence with *"nihil Novi sub sole*" (nothing new under the sun) (Smil 2023, page185). If this statement were true, then human ingenuity would not have extracted oil and coal from deep within the Earth, and there would only be a few of us on the planet; living as other animals do in a constant struggle for survival.

The two Net Positive farmers in this study would surely disagree with Smil, as they are proof that we have examples of the future (i.e., Net Positive farms) today and we have the technology to push these practices further. These farms operate based on Zero Tillage, minimal disturbance, appreciation for agroecological weed and pest control, and a well-functioning soil biology, which drastically reduces the need for fossil-fuel-based nitrogen fertilizers. Unfortunately, these farmers are an exception, as there are gaps in policy and research that are in desperate need of solutions if the Northern Great Plains and the Canadian Prairies are to become Net Positive.

We have invented and innovated. We are intelligent, but maybe not very wise, in that way nihil Novi sub sole. Can we focus on the task ahead and save ourselves from ourselves?

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Appendices

Chapter 3 Appendices : Methods

Appendix 3.1.9. Appendices approved by the REB for use in this project.

Uploaded Date	Comments					
Recruitment Documents	Recruitment Poster (Appendix 1.2) DRSR - copy 3.docx	1	Approved	View	Appendix 1.2 Case study farmer recruitment poster March 3.docx 03/03/2023	
Other Approval Documents	The non approval protocol for nonexistent groups or organizations--- ethics 2022.docx	1	Approved		The non approval protocol for nonexistent groups or organizations--- ethics 2022.docx 07/27/2022	
Manual Attachment	Mental Health Resources	1	Approved	View	Information Sheet - Helpful Resources (Appendix 2.4).docx 11/11/2022	
Recruitment Documents	General awareness of project docx	1	Approved	View	appendix1.5 General Awareness March 4.docx 03/04/2023	
Recruitment Documents	Recruitment Email - Approaching Organizations (Appendix 1.1).docx	1	Approved	View	Appendix 1.1 Recruitment email orgs March3.2.docx 03/03/2023	
Recruitment Documents	Recruitment Emails to Individuals (Appendix 1.3) - Copy.docx	1	Approved	View	Appendix 1.3 Recruitment email to both farmers and eDelphi participants March 4.docx 03/04/2023	
Recruitment Documents	Follow-up Phone Call Script (Appendix 1.4).docx	1	Approved	View	Appendix 1.4 Follow up phone call script interviewees March 4.docx 03/04/2023	
Recruitment Documents	Follow up phone call eDelphi appendix 1.4B.docx	1	Approved	View	follow up phone call eDelphi March 4.docx 03/04/2023	
Manual Attachment	U of M Oath of Confidentiality	1	Approved	View	Oath_of_Confidentiality-_UM_personnel.pdf 11/11/2022	
Interview Document	Semi-Structured Interview Guide (Appendix 2.3) DRSR (1).docx	1	Approved	View	Appendix 2.3 Semi-Structured Interview Guide March 15.docx 03/15/2023	
Recruitment Documents	Recruitment Poster Field to Fork eDelphi participants .docx	1	Approved	View	Recruitment poster for field to fork eDelphi participants March 4.docx 03/04/2023	
Focus Group Document	eDelphi intro and first round of questions Aug 15.docx	1	Approved	View	Appendix 2.3.2 eDelphi intro and first round March 15.docx 03/15/2023	
Consent Documents	Consent Form In-depth interview Aug 20b.docx	1	Approved	View	Appendix 2.1 Farmer interviewee consent form.docx 03/15/2023	
Consent Documents	Consent form eDelphi focus group participants Aug. 15.docx	1	Approved	View	Appendix 2.2 eDelphi Consent form March 15.docx 03/15/2023	

3.9.5 Participant Consent Forms

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Consent Form—In-depth Interviews v4

Title of Study: In Search of Net Positive Carbon Grain Farms in Western Canada

Principal Researcher: David Rourke Ph.D. candidate

Research Supervisor: Associate Professor Iain Davidson-Hunt (Email: iain.davidson-hunt@umanitoba.ca, Tel: (204)-474-8680)

Sponsor: Self-funded

This consent form, a copy of which will be left with you for your records and reference, is only part of the informed consent process. The consent form should give you a basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and understand any accompanying information.

Purpose of this Study: My name is David Rourke. I am a Ph.D. student at the University of Manitoba, and I invite you to participate in my research. The purpose of my study is to support a transition of Western Canadian/Northern Great Plains grain farms into Net Positive Carbon Grain farms. The objectives are

1. Test 12 BMPs,(Best Management Practices) for Net Positive Carbon Grain farms.
2. Document the practices and experiences of ten innovative Net Positive Grain farmers in their efforts to mitigate global warming and continue to be profitable and supply food for the market. This will also document the barriers, limitations and enablers in this process.
3. Explore the possibility of creating a relationship between field-to-fork stakeholders to encourage, support, and enable farmers to adopt Net Positive farming BMPs. This could involve the use of a grassroots farmer-led Net Positive Network.

Consent Form: In-Depth Interviews

Title of Study: In Search of Net Positive Carbon Grain Farms in Western Canada

Principal Researcher: David Rourke Ph.D. candidate (E-mail: rourked@myumanitoba.ca

Research Supervisor: Associate Professor Iain Davidson-Hunt (Email: iain.davidson-hunt@umanitoba.ca, Tel: (204)-474-8680)

Sponsor: Self-funded

This consent form, a copy of which will be left with you for your records and reference, is only part of the informed consent process. The consent form should give you a basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and understand any accompanying information.

Purpose of this Study: My name is David Rourke. I am a Ph.D. student at the University of Manitoba, and I invite you to participate in my research. The purpose of my study is to support a transition of Western Canadian/Northern Great Plains grain farms into Net Positive Carbon Grain farms. The objectives are:

1. Test 12 BMPs (Best Management Practices) for Net Positive Carbon Grain Farms.

2. Document the practices and experiences of ten innovative Net Positive Carbon Grain Farmers in their efforts to mitigate global warming and continue to be profitable and supply food for the market. This will also document the barriers, limitations, and enablers in this process.

3. Explore the possibility of creating a relationship between field-to-fork stakeholders to encourage, support, and enable farmers to adopt Net Positive farming BMPs. This could involve the use of a grassroots farmer-led Net Positive Network.

4. Explore the formation and role that a Net Positive Community of Practice could play in bringing in additional support, innovation, and actions.

The overall strategy will be exploratory, leading to participatory outcomes and actions.

Participant Selection: You are being asked to participate in this study because of your experience as an innovative grain farmer who is taking action to help fight global warming. You are moving to align with the 2050 goals of the UNIPCC SR 1.5C, which are to eliminate fossil fuel-based fertilizers and fuel from the farm and to sequester as much excess $CO2$ from the atmosphere and store it in the soil to improve soil health.

Study Procedure: Participation in the study will be one interview of 2-4 hours in length, to be conducted on UM Zoom. With your consent, the interview will be audio recorded using UM Zoom's built-in recording feature to record directly on my laptop. If consent is not given, notes will be taken. The interview will take place at a time of your choosing. Interviews will be conducted in English.

During the interview, you will be asked questions about 12 BMPs, your actual practices and future changes anticipated, plus the barriers, limitations and enablers which impact your ability to reach your goals as it relates to fighting global warming as well as the continual need to produce food and make a profit to stay in business. The interview could be extended for a longer period or another session if we mutually agree. I will ask about your motivation for moving in this direction. I will also ask questions to understand your experience as someone concerned for the environment and how that concern influences and interacts with your global warming mitigation practices. Please know that you are encouraged to share only what you are comfortable sharing and that you are free to choose to refrain from answering any question you prefer to omit without prejudice or consequence.

If you have any questions regarding the procedures and purpose of the study, please do not hesitate to ask at any moment throughout your participation.

Data Storage: All data (audio recording, written notes, interview transcripts, master list) will be stored on UM One Drive, an Office 365 online program, through my University of Manitoba email account. Physical copies of data will be stored in a locked cabinet.
UM Zoom automatically records both video and audio and makes video and audio recordings available in separate files. For participants giving consent to only audio recording, I will delete the video recording files immediately after the interview and use the audio recording for transcription purposes. The interview will be transcribed into text within one month after the interview. Transcription will be done with the transcription option available on UM Zoom. I will review transcribed files to ensure accuracy. If participants do not consent to audio recording, I will take typed or written notes throughout the interview. I plan to keep the research data until 2030. This date will ensure that I am directly finished with the data. Participants' information will be kept in an encrypted file on my password-protected account on One Drive with a copy downloaded onto an external hard drive and held in a separate encrypted folder. This data will be destroyed by December 2030. To delete all data files on my laptop and the external hard drive (audio recording, written notes, interview transcripts, master list), I will use a program such as BleachBit or CCleaner. All physical copies of notes will be shredded by December 2030.
Note that you will have the choice to be named in the outcome material if you feel it is in your best interest and is beneficial to the project and or the wider community.

Anonymity and Confidentiality: Your personal information will be kept confidential; unless you waive your anonymity, I will not include information that could identify you with the information you provide. I will use a pseudonym such as NP Farmer A, or you can select your own pseudonym to refer to you in my study records and the writing and presentations resulting from the research. I may use your words, via paraphrase or direct quotation, when discussing or highlighting a specific point in the writing or presentations resulting from this research. In the case of paraphrasing or using a direct quote, you will not be identified as the speaker unless you choose to waive anonymity.

If you choose to waive your anonymity, you can choose how you wish to be referred to. I will keep a contact list of participants' names and addresses in a secure file on my password protected One Drive account, which I will use to send you the summary of my study results. Consent forms and identifying information will be accessible only to myself and my supervisor and stored separately from interview data. The master list of codes and pseudonyms to keep participants' contact information and interview data will be stored separately.

At the time of the interview, I request you participate in a private and quiet room to ensure confidentiality on your end. You may choose to have your camera on or off during the interview.

Risk and Benefits: Because part of this research aims to understand the experience of individuals concerned for the environment, there are social risks that you as an innovator and leader in this area will likely have already considered or experienced, I would suggest that if you are concerned about any social or emotional risk you may expect as a result of participating in this study, that you may wish not to become a participant. You can choose not to respond to any questions you wish to omit, and you are encouraged only to share as much information as you are comfortable with, without prejudice or consequence.
When writing or talking about the experience and information you share with me, I will not use your name or information that could identify you unless you choose to waive anonymity.

A potential benefit to participants is the opportunity to reflect on and express their experiences tackling the challenges of fighting global warming on their farms. The process will allow them to benchmark their efforts to other similarly minded farmers and possibly improve their outcomes. Participation may also allow them to have a leadership and influencer role in the battle to mitigate global warming. These benefits may be helpful to organizations or initiatives seeking to develop alternative NP BMPs.

We may also have the ability to make recommendations for policy and research to improve the application and adoption of Net Positive farming practices.

If you have any concerns, please discuss them with me before participating.

Dissemination of Research Results: The research results will be disseminated through the publication of a Ph.D. thesis and a report which will summarize the research results and be sent to participants. Participants can expect to be emailed the information by October 1st, 2024. The research results may also be disseminated through other mediums, including academic publications and presentations and a plain language book. Interviews, magazine/ newspaper articles, videos, or audio podcasts with myself as the subject can be anticipated. For information and updates on the research and the dissemination of research results, please consult my research website: [to be determined]. A copy of the thesis will be publicly available with the MSpace link: https://mspace.lib.umanitoba.ca.

Compensation: Participants will not be offered any honorarium or payment for participation.

Feedback/Debriefing: I will create a report summarizing the research results, which I will send to participants. If participants are interested, they can receive an electronic copy of my thesis.

All participants will be given a chance to review their interview transcript before the information is generalized and used for academic and non-academic publications. In reviewing the transcript, you will have the opportunity to clarify the information you shared during the interview.

Once I email participants their transcript, they will be given two weeks to review it. If I have not heard back from participants after two weeks, I will send an email to participants with a reminder to review their transcripts.

As a participant, would you like to review your interview transcript? Yes ☐ No ☐

If yes, please provide your best method of contact:

- Email:

For any participant who has not returned their reviewed transcript, I will email a final reminder to offer them one week as the last opportunity to review the transcript before it is no longer possible to modify or remove their data because of data generalization.

Withdrawal from Research: You are free to withdraw from this research without prejudice or consequence. To withdraw, please contact me or my supervisor by email or phone via the contact information provided above. Participants may withdraw during the interview by just stating they no longer want to participate.

If you withdraw on or before the interview, I will eliminate all collected information and data within one month after our interview, which I anticipate to be March 1st, 2024. However, if you withdraw later in the process, it will not be possible to remove your information from data that has been generalized. For participants who chose to withdraw later in the process and have previously waived anonymity and have their names associated with the information they have provided, I will be able to withdraw the data that is directly attributed to them and that has not been generalized until the time of publication. This date is anticipated to be February 2025.

Questions: If you have any questions or concerns, please contact me or my supervisor with the contact information provided on the first page.

By signing this form, you indicate that you have understood to your satisfaction the information regarding participation in this research project, that you have had an opportunity to ask questions, that your questions have been answered, and that you agree to participate in the research as a subject and that this decision is taken voluntarily. Your signature does not waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from studying at any time and choose to refrain from answering any questions. You should feel free to ask for clarifications or additional information throughout your ongoing participation.

This research has been approved by the Research Ethics Board at the University of Manitoba, Fort Garry campus. If you have any concerns or complaints about this project, you may contact any of the persons previously named or the Human Ethics Coordinator at 204-474-7122 or humanethics@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

Consent Signatures: For your participation in the interview, please indicate your consent to the following elements:

1. I am over 18 years of age. Yes ☐ No ☐

2. I consent to have my interview audio recorded with or without video recording. If not, notes will be taken. Yes ☐ No ☐

3. I wish to remain anonymous. Yes ☐ No ☐

4. I wish to remain anonymous, but you may refer to me by a pseudonym. Yes ☐ No ☐
   o The pseudonym I choose for myself is:

5. I wish to waive my anonymity and be identified by name with any information I provide in this interview that is included in writing or presentations resulting from this research.
   Yes ☐ No ☐
   o The name I wish to be identified by is:

6. I agree to be contacted after the interview if it is deemed necessary by the researcher.
   Yes ☐ No ☐

7. I would like a summary report of this research (by February 2025). Yes ☐ No ☐
   o If yes, please include your email:

Participant's Printed Name: Date:

Participant's Signature: Date:

Researcher's Signature: Date

Thank you for your time!

Please note in cases where more than one member of the farm/family participates, each will have to complete a consent form.

3.9.7.2. Interview Guide

Date

Interviewer

Assistant

Interviewee

Please remember that you can take a pass on any question where you do not wish to share information.

If you have chosen to be anonymous, I will describe you and your farm in such a way as not to be easy to identify, for example rather than Minto MB, I will use – Thin Black soil zone, etc. I will leave out the demographic information. Demographic information will be used in the analysis, but not in your description.

All participants will be allowed to review their input as well as the draft and final document to ensure the content is representative and you agree to have it released. While I do not anticipate that what you share with me will likely not be out of context compared to your everyday life, I still want to be sure that this process does not cause harm. The intent is to use your experience to contribute to the innovation needed to tackle global warming mitigation but also to give voice to identifying barriers, gaps and brick walls which may prevent us from achieving Net Positive.

A. Opening Questions

2. I would be interested in knowing a little bit about yourself.
    a. During our phone call, you said you farm.
    b. Description of farm acres, crops.
    c. Who all is involved in the operation of the farm?
    d. Generational history and outlook.
    e. How long have you farmed there?
    f. How long have you been aware/concerned about global warming?
    g. About anthropogenic global warming?
    h. Does anything keep you up at night?
    i. Do you have a preferred title or description for your type of farming?

3. I have possible BMPs. I want to go through each one and have you comment on them and describe similarities or differences these may have relative to your practices or thoughts.

David Rourke's Input

BMP	Idea 1-100	Practice 1-100	Barriers	Enablers	B 5	E 5	R 5	T 5	1/E 1	Adopt. Score	GWM Credit Required $+/-
1. Min Disturb											
2. Plants Snow to Snow											
3. Diversity											
4. Soil Armor											
5. Alternate Nitrogen											
6. Alternate Fuel											
7. Agro-ecology											
8. Sustainable Intensify											
9. Conserve + Restore											
10. Phos Recycle											
11. Grazers											
12. Organic											
Other											

4. I would like to know if there are any other practices you would be doing or considering which would add to Net Positive farming in addition to the 10 BMPs we have already discussed.

B. Background on Your Journey with Net Positive Farming

5. Can you tell me about your journey with NP farming?
    a. How long have you been doing it?
    b. When and how did you learn to practice NP farming?

6. What are the things that helped you start and continue NP farming?
    a. What was/is important to enabling and supporting your learning process?
        i. Has learning NP farming and doing NP farming been mostly an individual process, or have you found that other people have been important to keep you motivated?
        ii. What other things keep you moving forward?

7. Do you follow certain websites, blogs, or pages on social media which support you in your practice? If so, would you mind telling me what they are?
    a. How often do you consult them?

8. What obstacles / barriers have you encountered in Net Positive Carbon Grain Farming?
    a. What are the things that make it difficult to NP farm?
    b. Have the obstacles changed since you first started NP farming?
    c. If you intend to further develop NP farming, like learning new skills and using different agronomics, inputs, or machinery, are you experiencing any obstacles there?

D. Climate Distress

I want to talk about your experience as someone concerned for the environment and how that concern interacts with NP farming. Do you like the term NP farming? What is a better descriptor for your practices?

9. Can you tell me a little bit about how you experience your concern for the environment?
    a. Why are you concerned for the environment?
    b. What are the emotions tied to your concern for the environment?
        i. Which emotion(s) do you experience the most when it comes to your concern for the environment?
        ii. Is it worry, anxiety, anger, despair, guilt, fear, a sense of grief, or other emotions? Rate 0 to 10, with 10 being debilitating and 0 just part of life- work through it.
        iii. How do you cope if it is an issue?
    c. How would you say your concern for the environment impacts your life?
        i. For example, your well-being, life choices, daily life, relationship with your family or friends and financial health?

10. What is the relation between your concern for the environment and your move to NP farming?

11. What are the positive and constructive things that NP farming brings to your life?

12. What are the negative things NP farming brings to your life?

13. Is there anything I have missed regarding your experience as someone concerned for the environment and who practices NP Farming? Is there anything else that you would like to add?

14. What is your wish for the future? What do you not wish for? And what is the likely future?

E. Demographic and Background Questions

1. What is your age?

2. What is your gender?

3. How do you best describe your racial or ethnic background or any other identifier you might wish to express?

4. What size of farm do you operate? I assume there is no livestock. Would you consider livestock? If yes, what kind and why?

   Is farming your full-time occupation? Do you have outside sources of money, income, and capital, which makes it easier for you to move to NP farming? Or do you NP farm because it is more profitable and helps sustain the farm financially?

5. Will family members succeed you, and are they working with you now? Can you explain?

6. Is farming profitable for you: relative to neighbours, in the future, 1-5 years, 5-10,10-20 years out?

7. Could you share an average "contribution margin/acre = gross income - production expenses - labour, power, and machinery (do not subtract land, building and finance) which you achieve? Please use these categories: rather not say, $0 to 50, 51 to 100, 101 to 200, 201 to 400, greater than $400/acre. Elaborate if you wish.

8. Can you help us calculate the gross calories produced per acre on average Bu/acre for each crop, % of each crop in rotation, and the total cultivated acres? (This is available from the Holos data template provided and I can calculate from there).

9. Do you consider your self an innovator, pioneer, average farmer, top farmer, NP farmer, ZT Plus farmer, or any other way you would describe yourself?

F. In Closing

1. Is there anything else you would like to add?

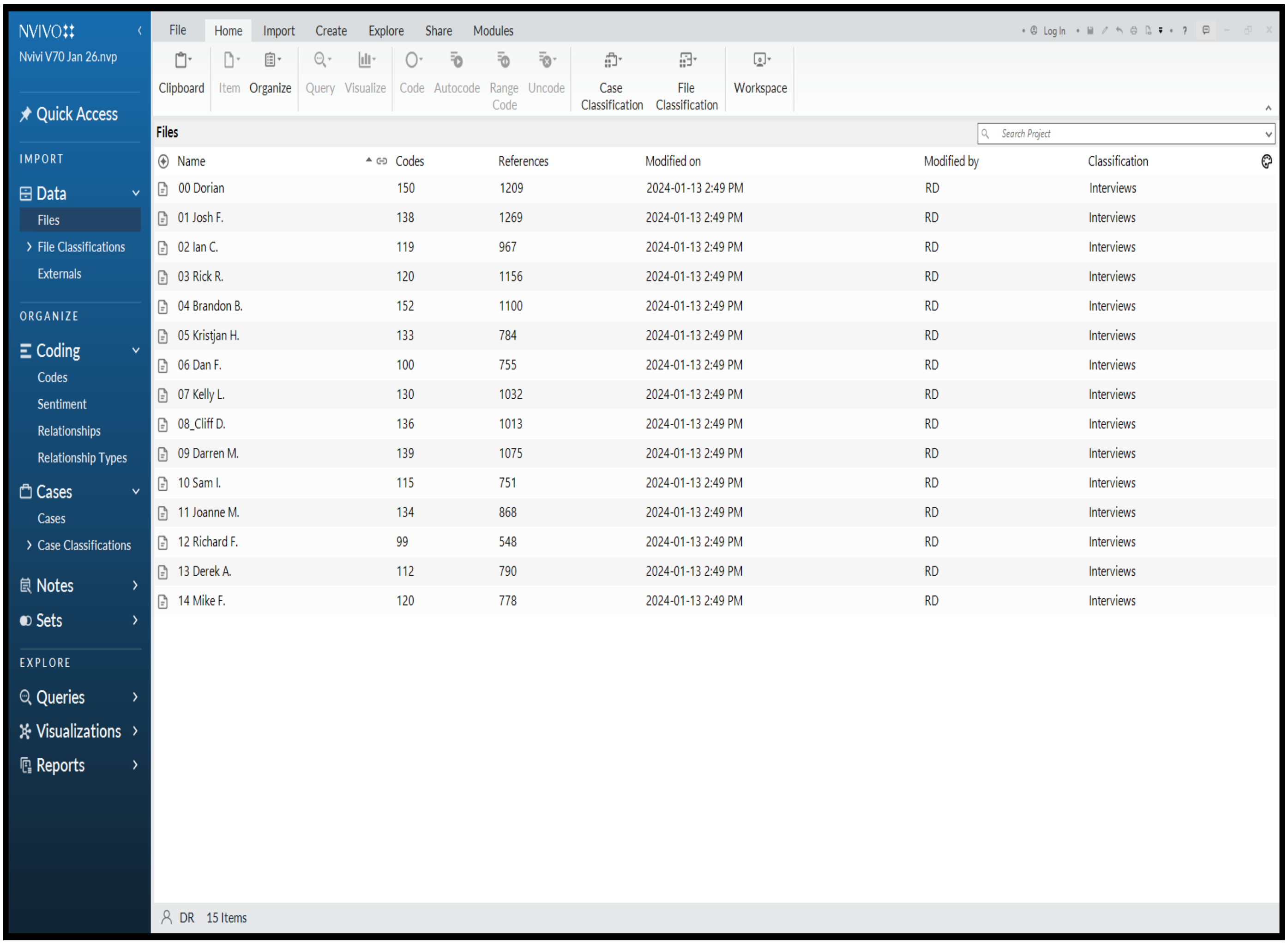
2. Thank you very much for your time and the information you were able to provide.

[redacted] If you have anything you would like to add later, please contact me at [redacted]

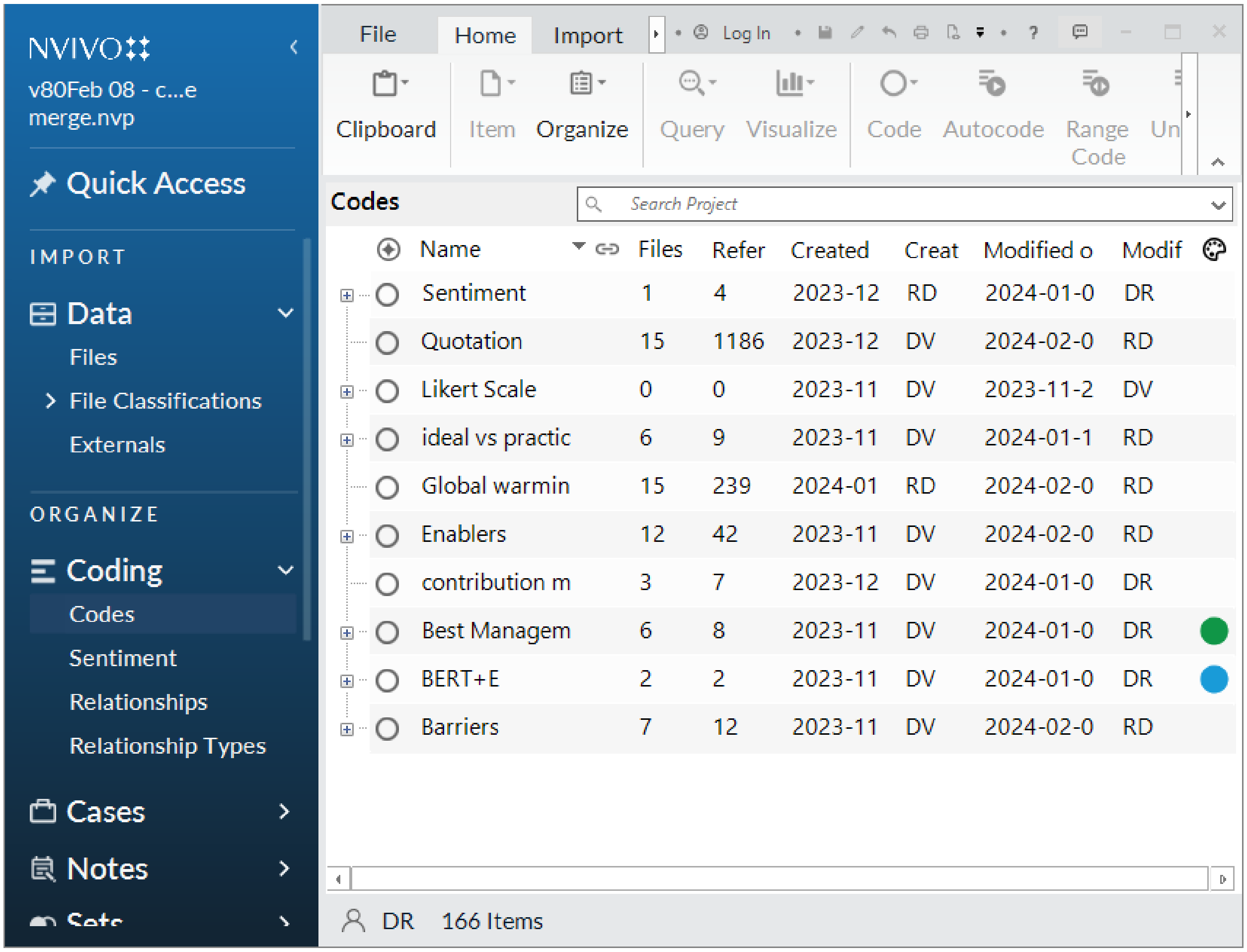
4. If you have any concerns, feel free to contact me or my supervisor, Dr. Iain Davidson-Hunt, at Iain.Davidson-Hunt@umanitoba.ca.

5. If this process has caused any mental anxiety, please refer to the Help poster for immediate well being assistance.

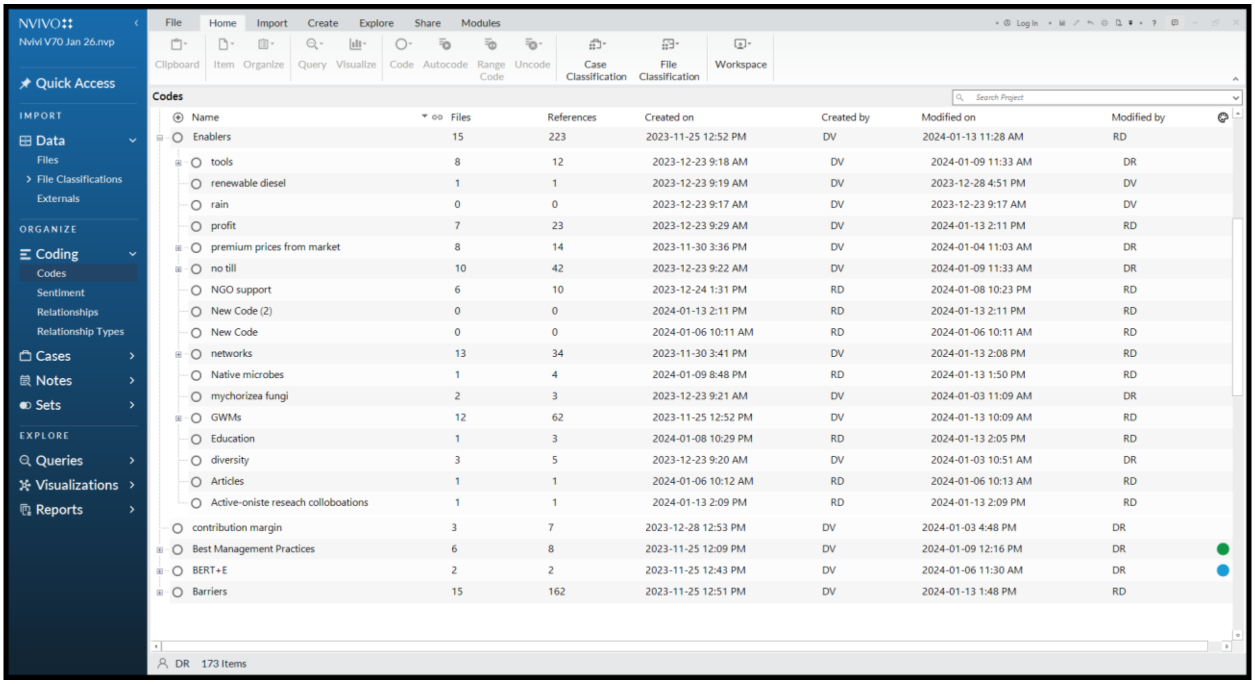
3.9.7.3. NVivo—Participant x Codes x References



3.9.7.4. NVivo—Parent Codes

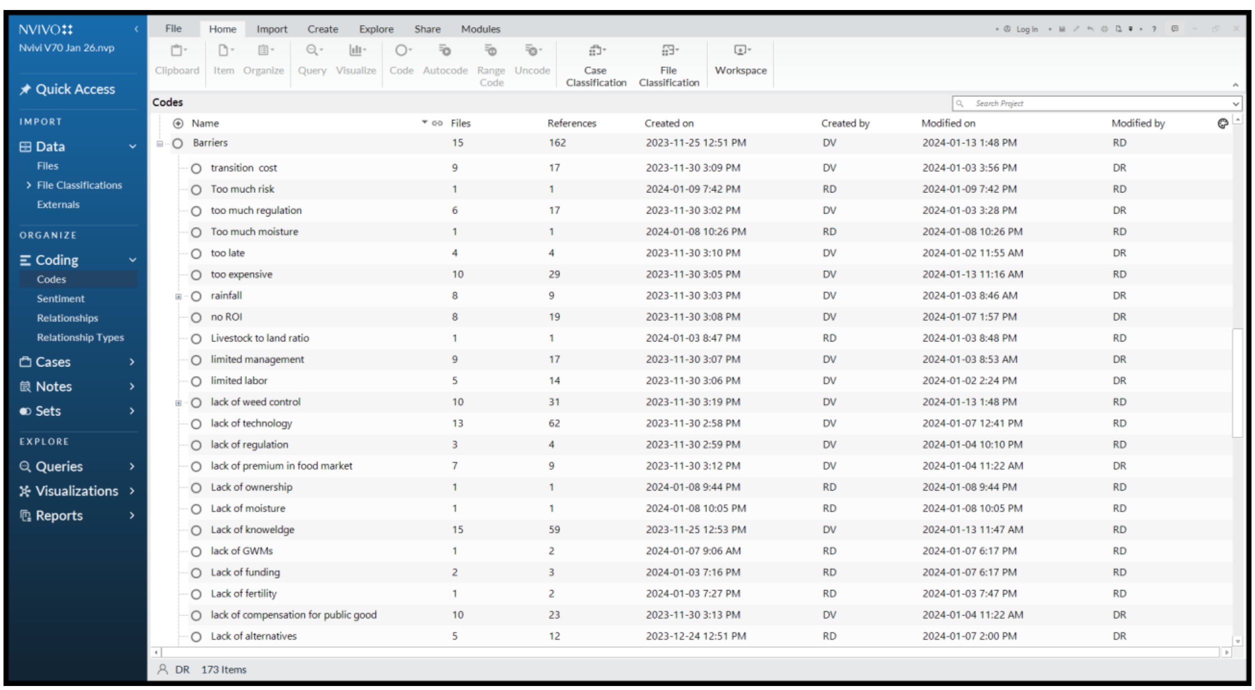


3.9.7.5. NVivo—Enabler Child Codes



Name	Files	References	Created on	Created by	Modified on	Modified by
Enablers	15	223	2023-11-25 12:52 PM	DV	2024-01-13 11:28 AM	RD
tools	8	12	2023-12-23 9:18 AM	DV	2024-01-09 11:33 AM	RD
renewable diesel	1	1	2023-12-23 9:19 AM	DV	2023-12-28 4:51 PM	DV
rain	0	0	2023-12-23 9:17 AM	DV	2023-12-23 9:17 AM	DV
profit	7	23	2023-12-23 9:29 AM	DV	2024-01-13 2:11 PM	RD
premium prices from market	8	14	2023-11-30 3:36 PM	DV	2024-01-04 11:03 AM	DR
no till	10	42	2023-12-23 9:22 AM	DV	2024-01-09 11:33 AM	RD
NGO support	6	10	2023-12-24 1:31 PM	RD	2024-01-08 10:23 PM	RD
New Code (2)	0	0	2024-01-13 2:11 PM	RD	2024-01-13 2:11 PM	RD
New Code	0	0	2024-01-06 10:11 AM	RD	2024-01-06 10:11 AM	RD
networks	13	34	2023-11-30 3:41 PM	DV	2024-01-13 2:08 PM	RD
Native microbes	1	4	2024-01-09 8:48 PM	RD	2024-01-13 1:50 PM	RD
mychorizea fungi	2	3	2023-12-23 9:21 AM	DV	2024-01-03 11:09 AM	DR
GWMs	12	62	2023-11-25 12:52 PM	DV	2024-01-13 10:09 AM	RD
Education	1	3	2024-01-08 10:29 PM	RD	2024-01-13 2:05 PM	RD
diversity	3	5	2023-12-23 9:20 AM	DV	2024-01-03 10:51 AM	DR
Articles	1	1	2024-01-06 10:12 AM	RD	2024-01-06 10:13 AM	RD
Active-oniste reseach colloboations	1	1	2024-01-13 2:09 PM	RD	2024-01-13 2:09 PM	RD
contribution margin	3	7	2023-12-28 12:53 PM	DV	2024-01-03 4:48 PM	DR
Best Management Practices	6	8	2023-11-25 12:09 PM	DV	2024-01-09 12:16 PM	DR
BERT+E	2	2	2023-11-25 12:43 PM	DV	2024-01-06 11:30 AM	DR
Barriers	15	162	2023-11-25 12:51 PM	DV	2024-01-13 1:48 PM	RD

3.9.7.6. NVivo—Barrier Child Codes



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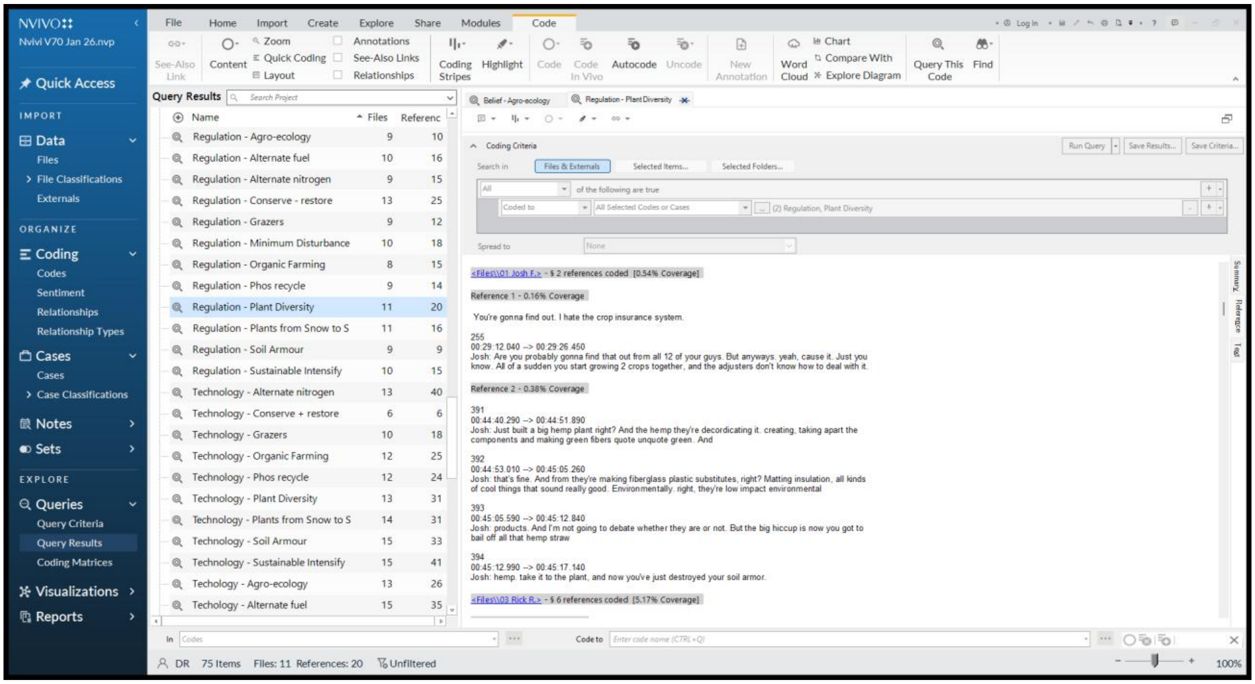
Barriers	15	162	2023-11-25 12:51 PM	DV	2024-01-13 1:48 PM	RD
transition cost	9	17	2023-11-30 3:09 PM	DV	2024-01-03 3:56 PM	DR
Too much risk	1	1	2024-01-09 7:42 PM	RD	2024-01-09 7:42 PM	RD
too much regulation	6	17	2023-11-30 3:02 PM	DV	2024-01-03 3:28 PM	DR
Too much moisture	1	1	2024-01-08 10:26 PM	RD	2024-01-08 10:26 PM	RD
too late	4	4	2023-11-30 3:10 PM	DV	2024-01-02 11:55 AM	DR
too expensive	10	29	2023-11-30 3:05 PM	DV	2024-01-13 11:16 AM	RD
rainfall	8	9	2023-11-30 3:03 PM	DV	2024-01-03 8:46 AM	DR
no ROI	8	19	2023-11-30 3:08 PM	DV	2024-01-07 1:57 PM	DR
Livestock to land ratio	1	1	2024-01-03 8:47 PM	RD	2024-01-03 8:48 PM	RD
limited management	9	17	2023-11-30 3:07 PM	DV	2024-01-03 8:53 AM	DR
limited labor	5	14	2023-11-30 3:06 PM	DV	2024-01-02 2:24 PM	DR
lack of weed control	10	31	2023-11-30 3:19 PM	DV	2024-01-13 1:48 PM	RD
lack of technology	13	62	2023-11-30 2:58 PM	DV	2024-01-07 12:41 PM	RD
lack of regulation	3	4	2023-11-30 2:59 PM	DV	2024-01-04 10:10 PM	RD
lack of premium in food market	7	9	2023-11-30 3:12 PM	DV	2024-01-04 11:22 AM	DR
Lack of ownership	1	1	2024-01-08 9:44 PM	RD	2024-01-08 9:44 PM	RD
Lack of moisture	1	1	2024-01-08 10:05 PM	RD	2024-01-08 10:05 PM	RD
Lack of knowledge	15	59	2023-11-25 12:53 PM	DV	2024-01-13 11:47 AM	RD
lack of GWMs	1	2	2024-01-07 9:06 AM	RD	2024-01-07 6:17 PM	RD
Lack of funding	2	3	2024-01-03 7:16 PM	RD	2024-01-07 6:17 PM	RD
Lack of fertility	1	2	2024-01-03 7:27 PM	RD	2024-01-03 7:47 PM	RD
lack of compensation for public good	10	23	2023-11-30 3:13 PM	DV	2024-01-04 11:22 AM	DR
Lack of alternatives	5	12	2023-12-24 12:51 PM	RD	2024-01-07 2:00 PM	DR

3.9.7.7. Example of Using Queries—Regulation and Plant Diversity



Appendix 3.10.2. Survey Questions

1. What are the next steps in this process? (1= personally interested, 2= someone should do it, 3= maybe it should happen someday, 4= probably not necessary, 5 = no way I would support that).

Table 3.2. Survey questions.

1.1	Is Net Positive Carbon Grain Farming an important goal?
1.2	Is it better to call it Net Zero Carbon Grain Farming?
1.3	Is it better we call it Farmers for Soil Health?
1.4	Your suggestion

2. What are the next steps? (1= personally interested, 2= someone should do it, 3= maybe it should happen someday, 4= probably not necessary, 5 = no way I would support that).

	The term, “Net Positive,” can be replaced with your preference above
2.1	Are you interested in participating in a Net Positive participant meeting?
2.2	Are you interested in participating in a Net Positive workshop?
2.3	Are you interested in being a member of a grass roots farmer-led Net Positive network?
2.4	Should a Net Positive network focus only on agronomic solutions?
2.5	Should a Net Positive network negotiate value for a Net Positive supply chain or value chain?
2.6	Should a Net Positive network form an alliance with food companies to develop a strategy and plan to reduce Scope 3 emissions. Scope 3 emissions are the emissions coming from the supply chain including all aspects of growing, storing, and transporting the crop to the food companies. Over 7900 companies, including the largest food companies, have made pledges to be Net Zero by 2050 or sooner.
2.7	Should a Net Positive network negotiate carbon inset value for research funds to fill gaps? Develop a mutual partnership to develop BMPs which are economically and logistically possible on a scalable basis?
2.8	Should a Net Positive network negotiate policy voids with governments and food companies to ensure Net Zero or Net Positive goals are met?

3.11.1. Using Holos to Estimate Farm GHG Emissions

Summarized by Matt Wiens and David Rourke

Holos was used to compare the GHG emissions of twelve grain farms in the Northern Great Plains. Several farms included cattle.

GHG Assessment Based on Individual Fields Rather than on a Crop Rotation

Holos has the capacity to analyze crop rotations or individual fields. We decided to assess GHG emissions from individual fields on a farm in one year (2022), rather than assessing a crop rotation over a number of years. The main reason for this choice was the much larger amount of data that needs to be collected and entered in order to analyze a multi-year crop rotation compared to just one year of farm activity.

There are several drawbacks to analyzing only a single year "snapshot" of farm activity, including: a) estimates of farm GHG emissions based on that single year of farm activity may or may not represent an average or typical year for that farm; b) soil nitrogen and carbon dynamics, which affect soil N_2O emissions and soil carbon changes, are less likely to represent what is actually happening on the farm if based on just a single year than if based on a longer duration.

Despite these drawbacks, for the purpose of comparing GHG emissions between the twelve farms, a single year GHG analysis is capable of highlighting the main differences between the farms, as well as giving reasonable estimates of the GHG emissions from each farm.

Data Entry

To start entering farm data into Holos, a location must be chosen. For farms in the US, the nearest similar Canadian location was chosen. After a location is chosen, soil and climate data are automatically downloaded by Holos, but can be changed by the user. We always used default climate data, but we sometimes chose a different soil type from the default option if it aligned better with information provided by the farmer.

Each crop grown by the farmer was considered a single "field" for the purpose of minimizing the burden of data collection and entry (i.e., if the farmer grew 1000 acres of wheat on 8 fields, we entered it as one field of 1000 acres). All management practices were assumed to be the same on the entire "field" of that crop type, even though in practice a farmer may apply different management on different locations where that crop is grown. Again, this was done to minimize the time and effort for data collection and entry.

The number of field components selected for each farm corresponded to the number of crops grown on that farm. In cases where significant management differences existed for one crop on a farm, separate field components where selected. An example of different management for a single crop is manure applied to some wheat acres, but not other wheat acres.

Step 1 of data entry for each field component in Holos included the following:

Area

Start year of field history
End year.

For all farms, 2022 was entered as the start year and end year.

Step 2 of data entry asks for the crops grown on this field:

Crop
Winter/Cover/Undersown Crop

Step 3 requires adjusting the default details of the crop for each field component. These details fall under the following tabs:

General
Fertilizer
Manure
Winter & Cover Crops
Soil
Residue
Economics

Data Entry for Each Tab

General Tab

- Yield (wet weight) in kg/ha.
- Yield (dry weight) in kg/ha—calculated automatically based on moisture content of crop.
- Moisture content of crop (%)—default values are standard grain moisture content values.
- Tillage—select from a list either Intensive Tillage, No Tillage, or Reduced Tillage.
- Harvest method—select from a list either Cash Crop, Green Manure, silage, or Swathing
- Amount of irrigation—none of the twelve farms used irrigation.
- Number of pesticide passes—We entered the total number of herbicide, fungicide, and insecticide passes for a particular crop; it did not seem to impact GHG emissions results.
- Fuel energy (Gj/ha)—defaults to 2.63, 2.39 and 1.43 for Intensive Tillage, Reduced Tillage, and No Tillage, respectively. For Fuel Energy we always used our own values based on the fuel use estimates provided by the farmers.
- Herbicide energy (Gj/ha)—defaults to 0.16, 0.23, and 0.46 for Intensive Tillage, Reduced Tillage, and No Tillage, respectively. We used the default values unless farmers told us they used zero pesticides, in which case we entered zero for herbicide energy.

Fertilizer Tab

- Fertilizer application:
    - Season of Application (Spring or Fall)

- Blend (list of 18 fertilizers to choose from plus Custom (Synthetic) and Custom (Organic))
- Method—select from a list either Broadcast, Incorporated, Partially Injected, or Fully Injected.
- Application rate (kg/ha.)

Each fertilizer has default values for N%, P2O5%, K2O% and S%, as well as a default value of 75% for Fertilizer Efficiency; however, each of these can be changed by the user. Fertilizer Nutrient % values were adjusted based on information provided by the farmers. We never changed the fertilizer efficiency default value of 75%.

- Additive—select from a list either Controlled Release, Nitrification Inhibitor, Urease Inhibitor, Nitrification and Urease Inhibitor, None, Custom. Several farmers did use fertilizer additives.

Manure Tab

Details of manure application were included for those farms that indicated manure was applied. The manure tab asks for the following information:

- Date—for all manure-using farms, we chose May 1, 2022, as our application date.
- Origin of manure—select from list either farm livestock or imported. We always choose imported.
- Manure type—select from a long list of livestock manure types. One farm used poultry manure, two farms used swine manure, and one farm used beef manure.
- Manure handling system—select from a list either Solid Storage (with or without litter), Solid Storage (Stockpiled), Deep Bedding, Compost–Passive Windrow, Compost– Intensive Windrow, Composted–In-Vessel, Liquid/Slurry with Natural Crust, Liquid/Slurry with No Natural Crust, Liquid/Slurry with Solid Cover, or Deep Pit Under Barn.
- Application method—Solid Spread (no tillage or reduced tillage), Solid Spread (intensive tillage), Slurry Broadcasting, Drop Hose Banding, Shallow Injection, or Deep Injection.
- Amount of manure (kg/ha).
- Fraction of nitrogen in manure.

Winter & Cover Crops Tab

The Winter & Cover Crops tab asks for the following information:

- Yield (wet weight) (kg/ha)
- Harvest method—select from a list either Cash Crop, Green Manure, Silage, or Swathing.
    - Note: If green manure, silage, or swathing is chosen the crop yield that is entered represents total above ground biomass.

Additional default information can be adjusted for the following winter/cover crop characteristics:

- Nitrogen content in product (kg N/kg of product)
- Nitrogen content in straw (kg N/kg of straw)
- Nitrogen content in roots (kg N/kg of roots)

- Nitrogen content in extra roots (kg N/kg of extra roots)
- Carbon coefficient of product
- Carbon coefficient of straw
- Carbon coefficient of roots
- Carbon coefficient of extra roots
- Product returned to soil (%)
- Straw returned to soil (%)
- Roots returned to soil (%)

Soil Tab

The soil management tab can be used to change the soil type for a specific field. A list of all soil types available for the selected location appears, showing the proportion of clay and sand in the soil type, the pH, the drainage class, the soil great group type, and the soil texture. If changes to the default soil characteristics are desired the following can be adjusted:

- Soil texture
- Top layer thickness
- Bulk density
- Proportion of clay in soil
- Proportion of sand in soil
- Percentage of soil organic carbon
- Soil pH
- Soil cation exchange capacity

We always used default soil types and soil type characteristics for the locations we chose.

Residue Tab

This tab allows adjustments from the default values for main crop carbon coefficients, lignin content, and nitrogen content. Also, entered here are the percentages of product, straw, and roots returned to the soil. The default for product returned to the soil is 2%, which we did not adjust. Straw returned to the soil was adjusted to less than 100% if the farmer told us that straw was baled off.

Economics Tab

Holos searches for regional economic data for crop prices and costs. We ignored the economic component of Holos.

Details Screen

As you progress through the Holos data entry process you come to a Details screen where it is possible to review the data already entered and choose the yield assignment method. The options for yield assignment are Small Area Data, Average Yield, Input File, or Custom Yield. We chose Custom Yield as our Yield assignment method so that Holos would use the yield data that we had entered, based on the input from the farmers. Using the yield data provided by the farmers allows a better comparison of the unique management between farms than using the small area data that Holos has access to from provincial crop insurance records.

Soil Carbon Change Estimates

Initially we took our soil carbon change estimates from the same analysis as we took the GHG emissions estimates. The soil carbon change values for each field are found in the Multiyear Carbon Modelling tab of the Results screen. The table shown in this tab includes a column with the heading *Change in soil carbon (delta_C_t) (kg C ha^-1)* with a value for each field. However, since these initial values were based on just one crop year (2022) we ran an additional analysis with Holos that set the start year to 1985 and the end year to 2022. We also changed the yield assignment method from *Custom Yield* to *Small Area Data* so that the crop yields would change from year to year based on annual average yields of the farm's location, rather than simply holding our custom yields constant for 38 cropping seasons. This longer-term view of soil carbon change is what Holos is designed to provide and is more realistic than looking at just one year. The 38-year assessment of soil carbon change gave lower values than the single-year assessment.

3.11.2. Holos, Net Positive, and Sustainable Farm Index. Raw Data Collection Forms

Holos data questionaire Rourke Farms

1 **Fuel Use** (fuel use table copied from MB Agriculture's Cropplan tool)

		Number of Field Operations & Litres Fuel Per Acre Per Operation								Trucks L/acre	
Crop	**Total L/acre**	cultivator or tandem disk	high speed disk	harrow or land roller	air drill	row planter	SP sprayer	swather	combine & grain cart	3/4 ton pickup	grain hauling
		2.3	3.5	1.0	2.8	1.7	0.2	1.0	5.0	1.0	
Canola	#DIV/0!			0	2		4	0.5	1	1	#DIV/0!
Wheat	#DIV/0!			0	2		2	0	1	1	#DIV/0!
Winter wheat	#DIV/0!			0	2		3	0	1	1	#DIV/0!
Soybeans	#DIV/0!			1	1		3	0	1	1	#DIV/0!
pea/oats	#DIV/0!			1	1		2	0	1	1	#DIV/0!
				0	0		0	0	0	0	#DIV/0!
	#DIV/0!			0		0	0	0	1	1	#DIV/0!
	#DIV/0!			0		0	0	0	1	1	#DIV/0!
	#DIV/0!			0	0	0	0	0	1	1	#DIV/0!
	#DIV/0!			0	0	0	0	0	1	1	#DIV/0!
	#DIV/0!			0		0	0	0	1	1	#DIV/0!
	#DIV/0!			0	0		0	0	0	0	#DIV/0!
	#DIV/0!			0	0		0	0	1	1	#DIV/0!
	#DIV/0!			0	0		0	0	1	1	#DIV/0!
	#DIV/0!			0	0		0	0	1	1	#DIV/0!
	#DIV/0!			0	0		0	0	1	1	#DIV/0!
	#DIV/0!			0	0		0	0	1	1	#DIV/0!
Other	0.00	0	0	0	0	0	0	0	0	0	
				0				0			
								0			
								0			

2 **Average Crop Yields** (table adapted from Manitoba Agriculture's Cropplan tool)

Crop	**My Average Yield per acre**	**Units**	
Canola	50	bu	
Wheat	60	bu	
Winter wheat	60	bu	
Soybeans	23	bu	
Barley	1	bu	pea/oats most of oats were eaten by cereal army worms
Oats	5	bu	
Corn		bu	
Navy Beans		lb	
Flaxseed		bu	
Sunflowers Confection		lb	
Sunflowers Oil		lb	
Peas	47	bu	
Hybrid Fall Rye		bu	
Canary Seed		lb	
Lentils		lb	
Buckwheat		bu	
Hempseed		lb	
Other		bu	

3 **Cropping Plan**

Field name or number)	Home section											
Main Crop	Canola	w.wht	soybean	pea/oat	spr wht	clover seed	p.rye grass	other	other	sub total	custom	total
Acres seeded	750	600	600	300	900	in w.wht	in canola			3150	750	3900
Seeding rate (lb/ac)	4	90	120,000seed	180/18	110	10 lbs	9 lbs					
Harvest method	1/2 swth	str cut	str cut	str cut	str cut	failed for 2024	failer for 2024					
Straw/chaff management	chop/ spread	chop/ spread	chop/ spread	chop /spread	chop/ spread							
% of straw/chaff removed	0	0	0	0	0	0	0					
Companion/winter/cover/undersown crop		f rye Greenseed	?	Fall rye								
Seeding rate (lb/ac)		60		60								
Companion crop use		Greenseed		green seed		forge seed	forage seed					
Expected Yield		2000		2000		200	200					
Units for expected yld	lb/ac dry matter											
Tillage System	ZT	zt	zt	zt	zt	zt	zt					
Amount of irrigation (inches/ac)												
Total number of pesticide application passes												
Herbicide # of passes	3	3	3	2	2	0	0					
Fungicide # of passes	1	0	0	0	0	0	0					
Insecticide # of passes	1	0	0	0	0	0	0					
Nitrogen Fertilizer												
Form	urea	urea			NH3							
Rate of N applied (lb of actual N/ac)	120	80	2	4	100							
Method of placement	side band	inject	inject	inject	fall band VR							
Time of placement	seeding	seeed/spring		at seeding	flate fall							
Use of additive												
P2O5 Fertilizer												
Form	11-51-0	11-51-0	11-51-0	11-51-0	11-51-0							
Rate of P2O5 applied (lb/ac)	35	35	10	20	35							
Method of placement	side band	with seed	with seed	with seed	with seed							
Time of placement	seeding	fall seed	with seed	at seeding	at seeding							
Use of additive		rain										
K2O Fertilizer												
Form												
Rate of K2O applied (lb/ac)	0	0										
Method of placement												
Time of placement												
Use of additive												
Sulphur Fertilizer												
Form												
Rate of actual S applied (lb of S/ac)	0	0										
Method of placement												
Time of placement												
Use of additive												
Other Fertilizer												
Form												
Rate of product applied (lb/ac)	0											
Method of placement												
Time of placement												
Use of additive												
Biological Fertilizer												
Name of product												
Application method												
Application rate (lb/ac)												
Manure Application	450 acres											
Manure Type	liquid pig											
Manure handling system	deep pit barn											
Method of application	shallow inject											
Application rate (lb/ac)	60,000											
Fraction of manure that is N, %	0.002											

4 **Additional Information**

Field location (Lat., Long.)	49.5 N 112W				
Major soil type	clay loam				
Type of biological seed treatment used, if any		eco tea		eco tea	eco tea
Change in tree cover in the last 20 ye	0				
Native prarie change in the last 20 ye	0				
Wetland change in the last 20 years (	0				
Estimated change in soil organic mat	1%				
Timeframe of change in soil organic	30 years				

3.11.3. Examples of Holos Output Report: Low, Medium, and High Emissions

Low

	Farm	Compone	Emission source	Acres	Direct N_2O (kg CO_2e)	Direct N_2O (kg CO_2e/ac)	Indirect N_2O (kg CO_2e)	Indirect N_2O (kg CO_2e/ac)	Farm Energy CO_2 (kg CO_2e)	Farm Energy CO_2 (kg CO_2e/ac)	Upstream CO2 (kg CO_2e)	Upstream CO2 (kg CO_2e/ac)	Subtotal (kg CO_2e)	Subtotal (kg CO_2e/ac)	Total (kg CO2e)	Total (kg CO2e/ac)	Production (kg)	GHG intensity (kg CO2e/kg production)	MJ/kg of crop	Food MJ produced	MJ/ac	kg CO2e/MJ	MJ/kg CO2e	kcal/acre	kg CO2e/kcal	kcal/kg CO2e	Fuel use, L/ac	lb synthetic N/ac	Change in soil C (delta_C_t) (kg C/ha)	CO2 removed from atmosphere, kg CO2e/ha	CO2 removed from atmosphere, kg CO2e/ac	yr, sm a data, Change in soil C (delta_C_t) (kg
Crops																																
	Kelly Loze	Wheat	Wheat, 768.92 (ha)	1900	35825.25	18.86	6077.06	3.20	43597.76	22.95	2051.48	1.08	85500.07	45.00001	87551.55	46.07973	2585501	0.033863	18.2	47056118	24766.36	0.00186	537.468	5915343.734	0.0000078	128371.924	8.46	0	854.645	3133.983	1266.768	130.1892
	Kelly Loze	Oats	Oats, 60.7 (ha)	150	2803.08	18.69	479.73	3.20	3484.18	23.23	161.95	1.08	6766.99	45.11636	6928.94	46.19611	408209	0.016974	19.5	7960076	53070.81	0.00087	1148.816	12675746.380	0.0000036	274389.935	8.61	0	909.227	3334.135	1347.67	97.05405
	Kelly Loze	Barley	Barley, 60.7 (ha)	150	2063.03	13.75	479.73	3.20	3441.69	22.95	161.95	1.08	5984.45	39.89907	6146.40	40.97881	244926	0.025095	18.4	4506638	30046.32	0.00136	733.216	7176440.146	0.0000057	175125.619	8.49	0	715.709	2624.505	1060.835	112.7568
			Totals or Averages	**2200**	**40691.36**	18.50	**7036.53**	3.20	**50523.63**	22.97	**2375.37**	1.08	98251.52	44.66017	100626.89	45.7399	3238636	0.031071		59522832	27056.07	0.00169	591.520	6462231.361	0.0000071	141282.160	8.472272	0	848.8939	3112.894	1258.243	126.7416
	Kelly Loze	Wheat	Wheat, 768.92 (ha)	1900	35825.25	18.86	6077.06	3.20		0.00	2051.48	1.08	41902.31	22.05383	43953.79	23.13356	2585501	0.017	18.2	47056118	24766.36	0.00093	1070.582	5915343.734	0.0000039	255704.022	8.46	0	854.645	3133.983	1266.768	130.1892
	Kelly Loze	Oats	Oats, 60.7 (ha)	150	2803.08	18.69	479.73	3.20		0.00	161.95	1.08	3282.81	21.8869	3444.76	22.96664	408209	0.008439	19.5	7960076	53070.81	0.00043	2310.778	12675746.380	0.0000018	551919.843	8.61	0	909.227	3334.135	1347.67	97.05405
	Kelly Loze	Barley	Barley, 60.7 (ha)	150	2063.03	13.75	479.73	3.20		0.00	161.95	1.08	2542.76	16.9529	2704.71	18.03264	244926	0.011043	18.4	4506638	30046.32	0.00060	1666.219	7176440.146	0.0000025	397969.507	8.49	0	715.709	2624.505	1060.835	112.7568
			Totals or Averages	**2200**	**40691.36**	18.50	**7036.53**	3.20		0.00	**2375.37**	1.08	47727.89	21.69469	50103.26	22.77441	3238636	0.01547		59522832	27056.07	0.00084	1188.003	6462231.361	0.0000035	283749.688	8.472272	0	848.8939	3112.894	1258.243	126.7416

Medium

	Farm	Component name	Emission source	Acres	Direct N_2O (kg CO_2e)	Direct N_2O (kg CO_2e/ac)	Indirect N_2O (kg CO_2e)	Indirect N_2O (kg CO_2e/ac)	Farm Energy CO_2 (kg CO_2e)	Farm Energy CO_2 (kg CO_2e/ac)	Upstream CO2 (kg CO_2e)	Upstream CO2 (kg CO_2e/ac)	Subtotal (kg CO_2e)	Subtotal (kg CO_2e/ac)	Total (kg CO_2e)	Total (kg CO_2e/ac)	Production (kg)	GHG intensity (kg CO2e/kg production)	MJ/kg of crop	Food MJ produced	MJ/ac	kg CO2e/MJ	MJ/kg CO2e	kcal/acre	kg CO2e/kcal	kcal/kg CO2e	Fuel use, L/ac	lb synthetic N/ac	Change in soil C (delta_C_t) (kg C/ha)	CO2 removed from atmosphere, kg CO2e/ha	CO2 removed from atmosphere, kg CO2e/ac	1985 st yr, sm a data for yield, Change in soil C (delta_C_t) (kg C/ha)
Crops																																
	Rourke Farms	Canola	Canola, 121.41 (ha)	300	42067.05	140.22	19494.25	64.98	36708.56	122.36	40473.97	134.91	98269.86	327.5617	138743.83	462.47	340203	0.407827	28.8	9797846.4	32659.04	0.014161	70.61825	7800478	0.00005929	16866.88	13.3	127.5831	1665	6105.555	2470.884	229.7568
	Rourke Farms	Winter Wheat	Wheat, 121.4 (ha)	300	39457.94	131.52	14098.47	46.99	27559.44	91.86	28521.90	95.07	81115.85	270.3825	109637.75	365.45	489851	0.223819	18.2	8915288.2	29717.22	0.012298	81.31586	7097836	0.00005149	19421.96	12.63	87.52378	1901	6970.967	2821.112	509.2973
	Rourke Farms	Soybean	Soybeans, 364.23 (h	900	10696.42	11.88	7742.64	8.60	25241.14	28.05	4657.77	5.18	43680.20	48.53289	48337.97	53.71	563376	0.085801	23.6	13295673.6	14772.77	0.003636	275.0565	3528415	0.00001522	65696.12	10.33	2.141255	471	1727.157	698.9709	75.13514
	Rourke Farms	Pea Oat	Mixed grains, 121.41	300	16323.04	54.41	2872.11	9.57	8073.77	26.91	2781.26	9.27	27268.92	90.89515	30050.18	100.17	406883	0.073855	18.372	7475254.48	24917.17	0.00402	248.7591	5951365	0.00001683	59415.08	9.94	4.282509	1710	6270.57	2537.665	452.1892
	Rourke Farms	Spring Wheat	Wheat, 546.34 (ha)	1350	151933.35	112.54	75587.42	55.99	45127.68	33.43	205291.08	152.07	272648.45	201.9609	477939.53	354.03	2204493	0.216802	18.2	40121772.6	29719.7	0.011912	83.94738	7098428	0.00004987	20050.49	12.39	107.598	933	3421.311	1384.586	151.6757
	Rourke Farms	Canola w manure	Canola, 182.11 (ha)	450	62075.57	137.95	32738.96	72.75	37450.19	83.22	6927.83	15.40	132264.72	293.9256	139192.55	309.32	510290	0.272771	28.8	14696352	32659.01	0.009471	105.5829	7800470	0.00003965	25218.04	13.3	7.58361	2103	7711.701	3120.883	334.5946
	Rourke Farms	W.wheat w clover	Wheat, 121.4 (ha)	300	30470.18	101.57	14101.24	47.00	27563.87	91.88	28528.03	95.09	72135.29	240.4477	100663.32	335.54	489851	0.205498	18.2	8915288.2	29717.22	0.011291	88.56541	7097836	0.00004727	21153.49	12.63	87.613	1214	4451.738	1801.594	179.8378
			Totals or Averages	**3900**	**353023.55**	90.52	**166635.09**	42.73	**207724.65**	53.26	**317181.83**	81.33	727383.29	186.5072	1044565.12	267.84	5004947	0.208707		103217475	26465.82	0.01012	98.81383	6321254	0.00004237	23601.28	11.93807	62.23024	1173.536	4303.358	1741.545	213.9167

High

Farm	Component name	Emission source	Acres	Direct N_2O (kg CO_2e)	Direct N_2O (kg CO_2e/ac)	Indirect N_2O (kg CO_2e)	Indirect N_2O (kg CO_2e/ac)	Farm Energy CO_2 (kg CO_2e)	Farm Energy CO_2 (kg CO_2e/ac)	Upstream CO2 (kg CO_2e)	Upstream CO2 (kg CO_2e/ac)	Subtotal (kg CO_2e)	Subtotal (kg CO_2e/ac)	Total incl upstream (kg CO2e)	Total incl upstream (kg CO2e/ac)	Production (kg)	GHG intensity (kg CO2e/kg of production)	MJ/kg of crop	Food MJ produced	MJ/ac	kg CO2e/MJ	MJ/kg CO2e	kcal/acre	kg CO2e/kcal	kcal/kg CO2e	Fuel use, L/ac	lb synthetic N/ac	Change in soil C (delta_C_t) (kg C/ha)	CO2 removed from atmosphere, kg CO2e/ha	CO2 removed from atmosphere, kg CO2e/ac	yr, sm a data for yield, Change in soil C (delta_C_
Crops																															
Daniel Fo	Canola	Canola, 259 (ha)	640	169761.76	265.26	65176.05	101.84	106807.46	166.89	131307.30	205.17	341745.27	533.9862	473052.57	739.1573	827347	0.572	28.8	23827593.6	37231.25	0.01985	50.370	8892532.588	0.00008312	12030.635	12.49	193.5159	1778.961	6523.45	2640.004	325.4054
Daniel Fo	Wheat	Wheat, 129.5 (ha)	320	72344.27	226.08	29991.53	93.73	10878.00	33.99	82986.45	259.34	113213.80	353.7992	196200.25	613.1363	609624	0.322	18.2	11095156.8	34672.96	0.01768	56.550	8281494.562	0.00007404	13506.775	12.52	182.7204	1009.829	3703.043	1498.601	194.2162
Daniel Fo	Oats	Oats, 194.25 (ha)	480	84120.62	175.25	35620.71	74.21	21348.08	44.48	97763.11	203.68	141089.41	293.9413	238852.52	497.618	1014152	0.236	19.5	19775964	41200.63	0.01208	82.796	9840602.302	0.00005057	19775.416	16.42	142.6611	43.816	160.6733	65.02358	102.7027
Daniel Fo	Soybean	Soybeans, 129.5 (ha)	320	4462.74	13.95	1929.85	6.03	8611.75	26.91	345.51	1.08	15004.34	46.88937	15349.85	47.96911	348356	0.044	23.6	8221201.6	25691.7	0.00187	535.588	6136356.391	0.00000782	127923.093	9.98	0	515.463	1890.203	764.9546	81.08108
Daniel Fo	Corn	Grain corn, 218.54 (h	540	143673.08	266.06	46120.81	85.41	53717.13	99.47	167420.43	310.03	243511.02	450.936	410931.45	760.9668	1851807	0.222	18.7	34628790.9	64125.93	0.01187	84.269	15316214.308	0.00004968	20127.310	1.51	158.8097	-1206.27	-4423.38	-1790.12	163.3514
Daniel Fo	Peas	Dry peas, 129.5 (ha)	320	29302.93	91.57	5176.02	16.18	8611.75	26.91	4199.69	13.12	43090.70	134.6608	47290.39	147.785	365774	0.129	18.3	6693664.2	20918.06	0.00706	141.544	4996192.904	0.00002958	33807.170	9.91	23.64302	1300.674	4769.572	1930.219	204.5135
Daniel Fo	Corn with	Grain Corn, 40.47	100	30961.21	309.61	11747.72	117.48	6955.08	69.55	10894.63	108.94	49664.01	496.6333	60558.64	605.5781	342924	0.177	18.7	6412678.8	64125.91	0.00944	105.892	15316210.562	0.00003954	25291.883	15.75	58.8845	-1095.43	-4016.95	-1625.64	166.2432
		Totals or averages	**2720**	**534626.61**	196.56	**195762.69**	71.97	**216929.25**	79.75	**494917.12**	181.96	947318.55	348.2817	1442235.67	530.238	5359984	0.269		110655050	40682.33	0.01303	76.725	9716808.508	0.00005457	18325.372	10.52817	128.6801	418.3684	1534.157	620.8648	189.68

Chapter 4 Appendices:

4.5 Farm Stories

4.5.1. Josh's Story, Lamb Farm, November 2023

The Lambs established their farm in 1904 after moving to Alberta from Ontario, with a short stop in North Dakota. After arriving, they bought a steam engine and a breaking plow and turned the sod for themselves and their neighbors, which was the best management practice at the time. When soil erosion became a significant problem in 1918-19, the Local Agriculture Improvement Association, Dominion of Canada agricultural scientists, and innovative farmers in the area teamed up to develop practices to mitigate the problem. As a result, they adopted the use of summer fallow and tillage to control weeds and moisture until the early 1990, when Josh's dad (who was raised in Switzerland) and uncle realized that prolonged dry weather combined with tillage was driving them toward bankruptcy. In response, Josh's uncle devoted himself to learning all about Zero Till, while his dad studied proper grazing practices for their fragile land. This led to the use of diverse rotations of wheat, canola, oat, and pea crops and the expansion of irrigation, which allowed them to prosper. After returning from college, Josh and the team further diversified their crop rotation and integrated cattle on most of their land. Josh credits the cows for making cover crops profitable.

The farm practice with the highest adoption score is soil armor followed by Zero Till (i.e., lack of disturbance). Josh noted that it is not possible to grow crops while giving away moisture. He explained that every tillage pass costs an inch of moisture, and every inch saved can enable ten more bushels per acre. When asked if his farming system had a name, Josh said that he had t-shirts with the logo, "Farming Weirdly," printed up, but thought that Zero-Till Plus or Net Positive would also be accurate. Josh, who earned a 2-year diploma in agronomy and business from the University of Lethbridge, works alongside his family to find innovative ways of maximizing the output of their roughly 10,000-acre farm (3000 in grass, 5500 dryland, and 1500 irrigated). Josh also credits Rob Dunn for creating a supportive peer group that is not afraid to criticize (sometimes harshly) members' ideas before "giving you a slap on the back and saying go for it…or not." Josh noted that the older farmers are also present to provide advice and criticism, and that his dad and uncle's group spend a lot of time trying working on "succession planning" (he speculates that this might be code for determining whether the younger generation is capable of handling the complexities of moving the farm into the future). At present, the farm is home to ten grandkids who could be future farmers.

The Zero-Till Plus practices employed on Lamb farm include:

1. Using a disc drill to minimize soil disturbance. Their drill gives 10 inches spacing, but the irrigated crop land gets a second seeding pass to attain 5 inches spacing, thus maximizing weed competition. A third pass may be done to seed an intercrop or a companion crop.
2. Josh expressed concern about reliance on and overuse of glyphosate, and how glyphosate loss—either from herbicide resistance or registration loss—could impact their ability to zero till. Josh suggests limiting where and when glyphosate is used to enhance the longevity of the product.
3. Josh routinely spring broadcasts fertilizer and irrigates immediately after, further ensuring low soil disturbance with minimal emission losses. He reiterated that their overall use of fossil-fuel-based N has been declining as they build their soil health.
4. The team carefully brings in cattle manure when stubble conditions, crop rotation, and field conditions align. Off-farm manure sources are also used, but this approach comes with additional management considerations due to the "new weeds" that come with the manure. The manure has a positive impact on soil fertility for about six to seven years, and costs about three to four years of normal fertilizer replacement to break even, depending on the distance travelled. It is not uncommon for manure to be trucked in, which can be 100 km round trip from the source (Feed Lot Alley). Josh questioned the sustainability of this approach. Josh also noted an opportunity cost to the manure: for at least three to four years, he is unable to grow higher-value intercrops due to increased weed problems and lack of suitable herbicides.
5. They have moved heavily towards intercropping to increase diversity and improve the bottom line, and they have incorporated a seed plant to add value to the grain. While intercrops generally have less problems with diseases and insects, herbicide choices are more limited. Furthermore, despite having to be planted on their cleaner fields, intercrops account for nearly 30% of their cropped land. Nonetheless, Josh noted multiple times that crop insurance was not adequate or proportional to the opportunity that intercrops have shown on their farm. He shared that they played around with quick cleaners and outside seed separation operations for a few years until they committed to putting up a full seed cleaning plant. This has allowed them to become automated, get out of the elements, and serve customers more directly with shipping containers (Sea Cans).

6. They have integrated a 650-cow herd across their land, as stubble and cover crops will support grazing without exposing the soil.
7. They have tried to promote plant growth from snow to snow through the combined use of perennials on pastures and using Italian ryegrass and various clovers as companion crops. Josh knows that increased plant growth contributes to greater soil health. Josh says they have not had huge gains in SOM (on the contrary, my calculation suggests about a 0.65% increase/year or 6.5 per 1000, which is a lot), but that they have seen big improvements in soil structure and water infiltration.
8. Josh is also interested in using agroecological solutions (e.g., double seeding or intercrops) in conjunction with sustainable intensification practices to make farming more efficient (e.g., using GPS, variable rate, overlap control, and control traffic farming).
9. Josh is cautious about incorporating too much diversity, as crop insurance programs do not support the addition of intercrops. He expressed a desire for more direct coverage of intercrops, noting that intercrops often pose less risk than monoculture crops.
10. While Lamb Farm has embraced the use of solar energy and biomass (kochia weeds) for heating, they have no immediate replacement for diesel fuel.
11. Josh shared that they are always looking for ways to reduce their use of fossil-fuel-based N. They have tested many "Bugs in a Jug" products, use Zero Till (which can reduce N requirements), and plant as many legumes as they can. Unfortunately, Green N is not on the horizon as far as Josh can tell.
12. Of the twelve discussed farm practices, Josh said he is most interested in organic farming but sees no immediate future for it on their farm. He did observe that a successful organic farmer in his peer group often has a different way of looking at farming and employs novel solutions that are sometimes worth considering in their Zero-Till Plus system. Josh felt that innovations such as no-till robotic weeders would need to be economical and well-proven before any serious consideration could be given to organic farming in his dry region.

The Fankhausers have a healthy appreciation for the effects of extreme weather and are currently in the third year of a severe drought. According to Josh, Grandpa Lamb says that if they farmed like they did prior to 1990, they would have no crops, and the soil would be exposed. However, he also notes that Zero-Till Plus is making a difference. Josh says he has been aware of anthropogenic global warming for at least twenty years, but he is too busy during the day to lose sleep over it at night. He says that he does what he can to reduce emissions and continue to sequester carbon into the soil. Although a rough estimate, Josh says that their SOM has increased from 3.5% to 4.0% SOM over a twenty-year period. During COP 21 (the Paris Accord), the French Minister of Agriculture, Stephane LaFoll, promoted a target of 4 per 1000, or 0.4% per year, for member countries (Josh's figure of 6 per 1000 is 1.62 times that target). Josh says these are not hard numbers, but informed estimates based on soil test results after manure applications. Nonetheless, their SOM values have gradually increased, which has in turn increased their dedication to zero till plus. Notably, in our discussion of the twelve BMPs, we also discussed the five regen principles, although we never used the term, "regenerative."

Josh also shared that one of the worst land-related moments he experienced was when a wildfire ripped through the farm, burning 600 acres of grassland and 750 acres of annual cropland. Despite this loss, they adapted quickly and borrowed a ridging hoe drill to deep seed barley into the land. Between the ridges they created and the barley they were able to keep most of their soil in place.

For the most part, Josh and his family adopt practices that pay and are not keen on relying on government support. When asked about GWM credits to help adopt BMPs aimed at improving air quality and global temperatures, Josh said he did not have any big requests. Either he would make it pay with the cattle, or he might require $10-15/ acre for extra seed; he said he probably would not adopt practices that went beyond this scope. Josh says he has a love/hate relationship with crop insurance; on the one hand, it protects their bottom line from extreme weather, but, on the other hand, the intercrop program is inadequate. However, the Fankhausers have used subsidies to install solar panels, and Josh built a biomass burner, which heats the farm in the winter and dramatically reduces the need for natural gas. Thus, Lamb Farm is a great example of combining environmental consciousness with practical on-farm solutions to actualizing Net Positive farming.

Table 4.5.1. Summary of Josh's BERT/E ratings of the various BMPs.

Josh								Max 625
BMP	**As Idea**	**As Practiced**	**B**	**E**	**R**	**T**	**E**	**BERT/E**
1 Disturb	100%	90%	5	5	5	3	1	416
2 Snow to	100%	40%	4	3	3	3	1	120
3 Diverse	100%	80%	5	3.8	2	4	2	83
4 Armor	100%	90%	5	4.5	5	5	1	625
5 Alt N	90%	45%	3.5	3.5	4	2.5	2	68
6 Alt fuel	95%	30%	3	3	5	3	3	50
7 Ag Eco	95%	80%	5	4	2	4	1	178
8 S I	100%	25%	4	3.5	4	5	2	155
9 Conserv	90%	40%	4.5	2	2.5	5	3	42
10 Phos	100%	40%	4	3	3	5	3	67
11 Grazer	100%	100%	5	3	5	5	2	209
12 Organic	100	0%	2	1.5	5	3	5	10

Table Note: BERT/E stands for (Believe x Economics X Regulations X Technology)/ Energy to Change. Max is 5x5x5x5/1=625. The BERT/E math may not align exactly due to an adjustment made relative to every participant having at least one 625 score and all scores being increased by that factor to put everyone on the same footing.

4.5.1.1 Josh's Comments on His Story,

David

Attached should be the document you requested. It was really good. Minor mix ups on the facts about my family, which is fairly normal, as the farm is from my mom's (the Lamb) side. Dad married in. It's usually the other way; many in the ag world think my last name is Lamb! So, the first *paragraph looks fairly rough. After that, I did not have to Highlight much. You did a really good job. The facts were accurate. Looking so forward to reading the finished thesis.*

Josh

4.5.2. Derek's Story, December 2023

Derek (46), his wife, Tannis, and their two children operate their family's farm in Minton Saskatchewan. Originally homesteaded by his grandfather and great grandfather in 1916, the farm now encompasses approximately 11,000 acres and is equipped with a complimentary food-grade grain cleaning plant and a flour mill. Derek has four full-time employees, two seasonal interns, and a part-time bookkeeper. Derek and Tannis took over the farm in 2002; in 2007, they sold their cows and adopted regenerative-soil health practices. Prior to this transition, they employed high-input, conventional Zero Till practices.

Derek is currently planting buffer strips to square the perimeter of his fields to complement control traffic farming (CTF) practice. In total, they have about 1600 acres in permanent cover and are experimenting with adding a three-to-four-year perennial phase to their crop rotation. Cattle are also being reintroduced to the farm through custom grazing arrangements. The farm is situated on a short-grass prairie in the brown soil zone. The soil varies from sandy loam to clay loam and receives an average of twelve to fourteen inches of precipitation per year. However, they only received around four inches last year. Fifty percent of the surrounding area is permanent pasture. When Derek started farming, the SOM was about 1.5% on the eroded knolls and 4.5% on the flat land. SOM has risen about one point over the last ten years (to 2.5% on the knolls and 5.5% on the flat ground). Derek says their investments in soil health have become very apparent during these past few dry years and is especially noticeable compared to his newly acquired land.

While Derek typically grows around twelve to fourteen crops on his farm, the recent dry period has forced a slight shift in their crop rotation toward slightly higher carbon crops (i.e., cereals) to help to maintain soil armor on their fragile soils. These cereals include fall rye, winter wheat, a seven-variety blend of spring wheat, and historic and ancient wheats such as red fife, ancient durum, spelt, and einkorn. Despite conducting trials to explore the benefits of various intercropping partners, these cereals are ultimately grown as monocultures. With the exception of buckwheat, Derek intercrops his broadleaf crops, which include mustard, camelina, flax, lentils, chickpeas, peas, forage peas, sweet clover, and red clover. His favorite intercrop combos are lentil/ flax, mustard/peas, and chickpeas/flax.

When asked what he calls his particular style of farming, Derek says he prefers the term, “regenerative Zero Till farming”. Notably, Derek’s farm is one of the first in Canada to be regenified certified. Derek notes that many people, including food companies and investment bankers, confuse the term, “regenerative,” with “organic,” but that, in Western Canada, these terms, along with “Zero Till,” do not belong in the same sentence. Tillage in dry regions (i.e., Western Canada) results in localized moisture loss and disrupts the soil biology, making it very difficult to practice “regenerative organic” farming in such areas. However, Derek concedes that it may be possible for farmers who primarily run pasture-based cattle operations to employ “regenerative organic” farming. Derek says he needs a term that resonates with customers; he feels “organic” succeeds in this respect. He says that, ultimately, “net-positive” is an okay term, but it is not customer friendly. As a result, he says he will be sticking with regenerative zero till for the time being.

Derek’s thoughts regarding the twelve management areas of this study and his regenerative zero-till/ NP/zero till plus innovation are summarized below.

1. Derek has been practicing Zero Till since 2002. He uses a disc drill to minimize soil disturbance and has managed to reduce his application of N to his cereals to 20 lbs./acre. While he has not applied monoammonium phosphate for over ten years, he does add 4 lbs./acre of quano (ancient bird poop) and has discovered (via soil health tests) that he has an abundance of phosphate solubilizing mycorrhizae. Derek and a group of his peers have developed an in-furrow seed dressing consisting of micronutrients, growth promoters, biological stimulants, and foods to stimulate soil biology. This seed dressing also includes rhizobia inoculants for legume crops. Derek does not use fungicides and only uses insecticides when grasshoppers are threatening his crops, which was a particularly notable problem in 2023 due to the dry conditions. Nonetheless, Derek only had to spot spray and do some field margins to this end. Additionally, his efforts to supply habitat around his fields will promote populations of beneficial predator insects and birds, which should help control pest populations.
2. Derek is concentrating less on growing plants from snow to snow, as dry years have undermined the effectiveness of this concept. In dry conditions, moisture must be directed at the main cash crop. When moisture is adequate, Derek still uses basic cover crops such as oats, peas, fall rye, red clover, and sweet clover. He further shared that, if it continues to

stay hot with a longer growing season, he may look at C4-warm season grasses like millets and sorghum. Most years, Derek must prematurely terminate cover crops (e.g., fall rye) and biennial cover crops to avoid stealing moisture and reducing cash crop yields.

3. Increased plant diversity is a cornerstone of Derek's pursuit of soil health and profitability. Derek intercrops nearly all his broadleaf crops, including lentil/flax, mustard/peas, and chickpea/flax. Buckwheat and cereals are grown as monocultures; however, Derek says he will try to intercrop them when normal rains return. To further improve diversity, Derek has adopted a seven-variety hard red spring wheat mix, sown buffers on his field margins, and plans to incorporate a three-to-four-year perennial forage phase to his already diverse annual crop rotation. One reason Derek invested in a grain cleaning plant was to make it easier to handle intercrops. Because of the dry weather, Derek has increased his acreage of cereals to help maintain soil armor, as cereals produce more biomass with a higher C/N ratio. Thus, cereal residues take longer to break down compared to residues from legume crops.
4. Maintaining soil cover is harder when rain limits plant growth. Derek relies on Zero Till, disc drills for seeding, the careful selection and positioning of crops in his rotations, and the use of stripper headers on his combines to help ensure the land is covered. Derek also leaves all the crop residue in place. Furthermore, in 2023, Derek discovered that early seeding resulted in better plant growth. As a trial he seeded 500 acres of spring wheat in mid-December to try to get crops growing as early as possible
5. Derek uses only a fraction of the N normally recommended for his crops, and he applies just 100 lbs/acre of ammonium sulfate broadcast prior to using the Zero-Till drill. That is 20 lbs/acre of N and 24 lbs/acre of sulfur on the cereals. Derek relies primarily on the functioning of the soil food web, particularly the soil microbes, for the N required by his crops. As noted earlier, Derek uses a blend of components as in-furrow seed dressing to help the soil biology. Derek's practices are an extension of Dr. Dave Franzen's (NDSU) research, who found that the application of N could be reduced when the land was Zero Tilled for at least six years. Derek's success with low-N application is also supported by the work of Dr. James White (Rutgers University), which explores nutrient transfer across root membranes using a natural process called rhizophagy. The ability to use lower amounts of N help Derek to minimize the major source of emissions on most grain farms.

6. Like most farmers, Derek does not devote much energy to figuring out how to reduce or replace diesel fuel on his farm: until there is an easy-to-use affordable alternative, he will continue to use diesel. Nonetheless, Derek said he is interested in the potential of using solar energy to offset the electricity required by his grain cleaning plant and flour mill. He sees the logic and ease of switching to renewable diesel when it becomes affordable and available. He says biomass is not an option if it means taking crop residues from his fields, as there is not always enough to maintain the minimum soil armor.
7. Derek employs a mix of agroecological practices. His main emphasis is diversity of crops and rotations, along with promoting habitats for beneficial insects and birds near each field. Due to high soil health and a vibrant high functioning soil ecosystem, which cycles the SOM, including weed seeds and pathogenic fungi and bacteria, crop pests tend to be lower, thus reducing the need for fungicides and insecticides. In fact, Derek has not applied fungicides for over ten years, instead primarily using insecticides to control grasshoppers along the field borders. Derek's production of historic and ancient wheat leaves him moderately vulnerable to invasion by certain plant diseases, particularly stem rust. Fortunately, he is located outside the main stem rust area, which tends to be Eastern Manitoba.
8. Derek is an early adopter of technology, which has helped to increase efficiency and reduce costs. The sustainable intensification tools Derek uses include GPS, precision ag, CFT, controlled traffic farming, Weed-It (Green on Brown sprayers), VR (variable rate), for seed, soil applied herbicides and Weed-It spraying. He also uses sectional control on the sprayer and a Zero-Till drill. He expressed a desire for a drill that featured both sectional control and variable rate, but that his current equipment supplier does not offer that technology. As such, he is shopping around to see if he can find one. Late last fall, his crew undertook efforts to control Canada thistle. For this task, they used the Agrifax Weed-It sprayer, which can control every nozzle to turn on and off every 20 inches, while only spraying the target weed. Derek says the new sprayer saved him 90.5% of the cost of using normal herbicides ($95,025 vs. $105,000, assuming $10/acre over 10,500 acres). Less pesticide use is also an advantage for soil microbial health.
9. Derek shared that he likes natural and planted habitat, especially trees, maybe because so few grow in his area. His farm currently features about 1400 acres of creeks, and 200 acres in crooked spots. He plans to sow another 300 acres in crooked spots to line up with his CTF, which is done using sixty-foot spacing. Derek tries not to disturb old yard sites or

places with trees, as “where there’s a tree, there’s a bird”. As he gets his field sides straightened out for CFT, he has plans to selectively plant caragana and chokecherry trees in the lower areas where they will thrive. Derek highly values having natural and planted habitat on the farm. He remarked that, “It’s not a bad thing, right? It’s not always about short-term dollars—regenerative agriculture is about the long game”.

10. Derek has taken a much different approach to phosphorus nutrition and management. He has not used struvite, he has no significant source of manure, and he believes that monoammonium phosphate (MAP-P) impacts the soil in much the same way excess sugar impacts humans: it makes it weak and sick, creating the need for remedies to fix the aliment. MAP-P discourages soil microbes like mycorrhizae from functioning. Derek has not used commercial P for ten years, and his mycorrhizae and other beneficial soil microbes have flourished as a result. Derek’s solution to P nutrition is to take care of the microbes; Zero Till builds and protects their habitat by increasing the soil aggregates. Eliminating MAP-P removes the “sugar effect” preventing the natural system from working as it did before the availability of commercial fertilizers.
11. Derek grew up on a mixed farm and Tannis grew up on a cattle farm 10 miles up the road from their current farm, so they both know, understand, and like working with cattle. As such, Derek is experimenting with adding a three-to-four-year perennial phase to the annual crop rotation. At present, 300 cows winter on their farm, which he strongly suspects is a good idea (he says he is about 80% convinced of this). His only reservation is that he knows of regenerative farms that are successful without cattle. Derek pointed out that the cattle will bring revenue from the creek bottoms and crooked areas where there otherwise would be none, and that he is lucky to have ranching neighbors who can walk their cattle over to his land. Ultimately, it is a win-win situation. Derek further shared that he cannot understand how some scientists think feedlot cattle are better for the environment, as feed must be trucked in, manure must be hauled out, visual leachate invariably enters runoff water and flows into ditches and creeks.

Organic farming is of little interest to Derek due to his arid and fragile soil. He estimates it would cost him about $250 to $300/acre in lost yield and added cost if he had to till in order to grow crops. This would force him either to sell out or devote more resources to ranching (on this matter, he joked that “his saddle is still in the barn”). However, he noted that he tilled part of a field last year and noticed an immediate reduction in soil aggregate stability and water infiltration from just one pass. This difference was also noted by inspectors from Regenified Certification. Derek observed that, “We farm with constant moisture stress; we cannot afford to lose it with tillage”. Despite his lack of interest in organic farming, Derek is not against it. He says they buy organic fruits and vegetables, but that organic practices are not suitable for building a resilient cropping system on his farm.

Derek is interested in whatever will improve his soil and allow him to continue to provide for his family and community. He not only wants to regenerate his farm, but he also wants to help regenerate the local area. This was one of his main motivations for building his grain cleaning plant and flour mill in 2018. When asked what keeps him going, Derek said, “the excitement of what is next”. He also expressed concern about the slow and progressive deterioration of the prairie soil, worrying that Western Canada will undergo desertification if farmers do not start to pay attention to soil health. When I asked him about global warming, Derek said, “I don’t know. There is so much going on—concrete cities absorb heat, fossil fuel are being burnt, and there are natural cycles. Is it all just a bad coincidence?” Regardless, Derek said he is concerned, and that he and Tannis are doing as much as they can on the farm to reduce their carbon output. He also said that, as advisors and board members, they are actively trying to demonstrate and share how regenerative agriculture can have positive outcomes for our soils, our lives, our communities, and our planet. He concluded our interview by remarking that, "before we can get change, we need to have a change in mind set—here I only have a question, not the answer”.

Table 4.5.2. Summary of Derek's BERT/E ratings of the various BMPs.

Derek								Max 625
BMP	**As Idea**	**As Practice**	**B**	**E**	**R**	**T**	**E**	**BERT/E**
1 Disturb	100%	98%	5	5	5	5	1	625
2 Snow to	80%	10%	4	2	5	5	2.5	80
3 Diverse	100%	80%	5	5	4.5	5	1	562
4 Armor	100%	98%	5	5	5	5	1	625
5 Alt N	100%	80%	5	4	5	4	1	400
6 Alt fuel	80%	5%	4	2	5	5	4	50
7 A/E	100%	80%	4.5	4	5	5	1	450
8 S/I	100%	90%	5	5	5	4.5	1.5	375
9 Conserv	100%	70%	5	3	5	5	1	375
10 Phos	100%	100%	5	5	5	5	1	625
11 Grazer	80%	60%	4	5	5	5	1	500
12 Organic	0%	0%	2.5	2	5	4	5	20

Table Note: BERT/E stands for (Believe x Economics X Regulations X Technology)/ Energy to Change. Max is 5x5x5x5/1=625. The BERT/E math may not align exactly due to an adjustment made relative to every participant having at least one 625 score and all scores were increased by that factor to put everyone on equal footing.

4.5.2.1. Derek's Comments on His Story.

Hi David, I think that looks really good. It's an accurate description of our operation. Thanks, Derek

4.5.3. Kelly's Story, December 2023

Kelly (45) and his wife, DeAnna, run a farm with their two young children in Max, North Dakota. They farm 2800 acres, of which 600 is "devoted" to wetland, wildlife, and pollinators. Kelly says they have sown extra buffers around the wetlands, as much of this land is saline and not good for cropping. The soil is a clay loam in the brown soil zone with an annual precipitation of 15 inches. However, Kelly says he has measured as little as 1 inch in the growing season and as much as 30 inches, which occurred in September of 2019. Kelly is the fourth generation to farm this land, and he has been doing so for 25 years.

Kelly calls his type of farming "conservation agriculture," and explains that it is based on the work done by the Soil Conservation Service during the 1930 Dust Bowl era. The Soil Conservation Service was renamed the Natural Resources Conservation Service (NRCS) in 1994. The foundational principle of Kelly's cropping system is Zero Till. Kelly currently grows hard red spring wheat, hard red winter wheat, barley, oats, spelt, heritage varieties of spring wheat, and Egyptian hull-less barley. He is currently in the third year of a drought ranging from D2 to D4 in severity. In the worst of those years, Kelly said he sowed 2 bushels/acre of wheat and did not get his seed back on some fields. He said that this outcome is scary and demonstrates the power of extreme weather. Kelly also seeds yellow peas and yellow mustard when the conditions are suitable. He has under seeded red clover and yellow blossom sweet clover. He says that it is crucial to remain flexible with respect to crops and rotation during drought periods, as he must balance plant growth with water availability; however, he stressed that whatever he does must be good for the soil.

Kelly and DeAnna are unique in that, apart from judicious herbicide use, they have less farm inputs than an organic farmer. In fact, they no longer use insecticides, fungicides, or any commercial fertilizers, and they use very little diesel fuel compared to organic grain farmers. Kelly says his yield are more stable compared to his neighbors: lower in the good years but higher in the tougher years. Kelly further points out that their fields stay greener longer in drought conditions. He estimates that their farm yield is about 20% lower compared to what he calls "the traditional corporate yield," but his bottom line, the "farm yield," has greatly improved. He suggests that high-input corporate yields are a key reason for declining soil health, increasing erosion, and warming climates. Kelly says a big reason for their success is their use of Zero Till, staying off the fields when they are wet to avoid soil compaction, and paying attention to the natural systems. Kelly and DeAnna rely on natural predators to control insect populations, and they have many habitats for beneficial insects. They have developed a seed inoculant based on the best local natural microbes, "borrowed" from Indigenous sites on the farm. They call this the IMOS system (Guardian Grain). The inoculant helps cycle organic matter, including soil microbes (example disease spores and insect eggs), in the soil. The system allows the natural microbes to form relationships with the crop plants wherein the microbes supply nutrients and the plants supply the microbes with sugars (root exudates). Kelly credits Dr. James White (Rutgers University) with his groundbreaking work on rhizophagy for providing the microscopic proof of this phenomenon.

Kelly's comments regarding the twelve management areas of the study and his conservation ag/NP innovations are presented below.

1. Kelly understands the impact disturbance can have on an ecosystem. Kelly not only practices Zero Till (since 2000), but he has also stopped using insecticides, fungicides, and commercial fertilizers, as he believes they impair the function of natural systems. However, he notes that there can be an "ugly time" during the switch from high input to no input. To ease this transition, Kelly suggests installing pollinator strips and building the SOM to 3.5% or higher. Once this has been done, he recommends reducing fertilizer use by 20%/year for 5 years. Adding the IMOS seed inoculant is also critical to jump starting the biology when beginning to work with crop plants. Because the IMOS is so effective at cycling organic matter (more bugs, bacteria, and fungi) Kelly has had to be careful to use the right plants to prevent the armor from being eaten too quickly. Kelly uses a stripper header to leave tall-standing stubble and chooses tall wheat varieties (deeper roots and more height to catch the snow), as leaving the straw standing can help manage/slow down the rate of break down. Kelly uses a sixty-foot 3710 Bourgault ten-inch spacing single disc drill with mid-row banders, while DeAnna uses the smaller 1984 1000 Haybuster 7-inch spacing disc drill. Both drills are minimal disturbance machines. Kelly says that, despite the difference in age, there is no difference in yield between the drills. The Haybuster is often used to seed small, less accessible areas, and to go back over seed area that may have been too wet when seeding the high ground with the big drill. Kelly estimates that he would lose $200/acre in increased costs and lost yield if he had to go back to a tillage-based system. Eventually he would lose his soils, as he farms on 35-degree slopes.
2. Kelly said that five years ago he would agree about the desirability of having plants from snow to snow. Unfortunately, the last three years of drought have made him only about 50% sure about this practice, as he has wasted much time and fall cover crop seed sowing into dry soil when no rain follows. He also shared that he has had to terminate clovers early to prevent them from stealing moisture from the cash crops during the dry years. When rain patterns normalize, he says will jump back in. He has seen a lot of benefit from sowing full season cover crops in years where it is too wet to seed the cash crop in the spring. His current strategy is to rely on whatever volunteer plants establish after the harvest. He says his soils have great aggregation (crumbly and easy for seeds to fall into a crack and get

covered by rain), which makes it likely for a volunteer crop to take off if there is rain after the harvest.

3. It was also easier for Kelly to cultivate greater plant diversity prior to the drought. Again, Kelly says he was 100% in favour of increasing plant diversity five years ago, but that he is now down to about 20%. Drought is one factor for this change, but finding the time and infrastructure to separate a multispecies intercrop is becoming too much work, especially when monoculture crops do just as well. Kelly also reports that cereal crops are outperforming crops like peas, soybeans, or even yellow mustard under the current drought conditions. He believes this is partly due to species succession taking place in his soils due to his use of his IMOS inoculant to select microbes that favor grassland species. He says it is also obvious that low-stubble high N crops like peas and especially soybeans do not protect the soil. As such, he has stopped growing soybeans.
4. Kelly is 100% in favor of soil armor, as it essentially means no till. He says soil armor is absolutely necessary to control wind and water erosion. While crop rotation and crop selection play an important role retaining armor on the field, drought makes it harder to do so. Kelly has also cut back on legume crops, as their high N and low C/N ratio make them subject to rapid break down.
5. Kelly is very interested in alternative N sources. As described earlier, Kelly and Deanna have spent countless hours searching for ways to enable soil biology to feed their crop. Kelly has studied the work of Dr. Elaine Ingham, Dr. Christine Jones, and he has read books on the Johnson-Su method and Korean Natural farming. He is an adamant student of YouTube University and has learnt from podcasts from Keith Berns at Green Cover Seed, as well as many no-till farmer publications, podcasts, and meetings. Kelly is fundamentally pragmatic, which has allowed him to develop his IMOS system using local Indigenous biology from productive undisturbed natural areas. Kelly was immensely excited upon being exposed to Dr. James White's rhizophagy cycle in an online seminar, where Dr. White demonstrated the physical interaction between plants and bacteria on a microscopic level(White et al. 2018). In this cycle, the bacteria trades nutrient for food while living within the plant's roots. White calls it a new kind of symbiosis, while Kelly calls it proof that his IMOS is a practical application of that science. Using IMOS and rhizophagy has allowed Kelly to avoid buying commercial N for ten years on the initial 500 acres, and he has not had to apply N on any of their fields for five years, nor has he had to rely on legumes. In addition, Kelly's system

provides a key advantage over organic farming: it relies on minimal disturbance and requires continuous cropping. This is unlikely to be duplicated in an organic system due to the tillage required to control weeds. Kelly says all his fertility requirements can be met with two 5-gallon pails of Indigenous soil and a bit of microbe food. However, the question remains: is a 20% lower yield acceptable? Kelly thinks it is, provided the profit is higher. Kelly refers to the lost 20% as the "corporate yield," noting that it provides a lot of jobs but is produces a lot of pollution (and therefore contributes to global warming

6. With respect to alternative fuels, Kelly is concerned about ending up with dependable technologies. He says famers have trouble with Tier 4 and 5 emissions control causing them down time, often paying to have this tech deleted so they can get their crop harvested and sent off. Kelly recognizes the value of renewable diesel but is concerned that it puts pressure on farmers to grow more soybeans, which he has stopped growing due to their negative impact on soil health. He says if they had to change to a completely new technology, it would cost them millions of dollars.
7. Agroecological solutions are a cornerstone of Kelly's system. Kelly has been able to eliminate the use of insecticides, fungicides, commercial fertilizers, and drastically reduce herbicide use by taking steps to minimize soil disturbance, applying soil armor, using IMOS seed inoculant, avoiding soil compaction, careful crop selection, and fostering pollinator habitats.
8. Kelly uses GPS and autosteer. He used to use variable rate and the 4 Rs, but said these tools are no longer necessary now that he does not use commercial fertilizers. Kelly doubts that "see and spray" technology will work in his 36-inch stripper header stubble, and he is not interested in technology that cannot improve soil health, build SOM, or reduce fossil-fuel-based emissions. Kelly says he is in a "reductionist" frame of mind: less complexity, less problems.
9. Kelly's decision to dedicate 600 acres of his land to wetlands, wildlife, and pollinators reflects the tremendous value he places on conservation and restoration. He says he is still amazed by the sound of the native bees and insects. Some of the 600 acres is natural and some is planted. Kelly took this approach to increase buffer areas around low spots and increase habitat for wildlife. Most of the 600 acres sits on low land that is often too wet to seed with the rest of the field, or that can become saline and a net loss if trying to crop it.

10. Kelly does not have access to animal manure and has never bothered with struvite. He did question if there would be harmful containments associated with struvite, such as heavy metals, pharmaceuticals, or hormones. His system, including IMOS seed inoculation, has allowed him to grow decent crops without any outside sources of phosphate, either commercial or recycled. He has evidence that, when combined with the beneficial microorganisms he "borrows" from his Indigenous wild lands, the microbes can solubilize the P and other nutrients from the soil and exchange these for food, sugars, from the crop plants. This was the basis of plant growth prior to human activity, and it seems to be working for Kelly at present. Kelly has also explored Albrecht and Lewis Trevon's "far out" theories relating to the bacterial conversion of certain elements into phosphorus.
11. Kelly has investigated the practice of integrating cattle on to his farm, including working on a farm in Kansas where cattle were integrated with cropland. While there, he moved portable fences to support mob/intensive/holistic grazing multiple times per day. He concluded that this required more time than he could afford on his farm. Kelly also says cattle can cause compaction and would need to be moved off crop land onto perennial pastures before every significant rain event. Kelly has concluded that his farm—or any grain farm—is not suitable for cattle, largely due to a lack of infrastructure and perennial pastures, and the unfavorable work-to-reward ratio that comes with caring for them.
12. Kelly said he has no interest in organic practices. He explained that he cannot till his 35-degree slopes, as even one tillage would lead to soil erosion with the first rain, and the lack of armor, even for a brief time, would cause the soils to blow away. He also pointed out that his system uses fewer inputs than a typical organic grain farm while also being more productive. According to Kelly, no amount of money could convince him to adopt a tillage-based cropping system.
13. The only other practice Kelly has considered is making and using biochar as a carrier for IMOS biology. However, he concluded it would be easier and cheaper to put the inoculant directly on the seed.

On the term, "Net Positive," Kelly remarked, "I like [it]; taking in more carbon than we are emitting. I like that—we can be a carbon bank." Kelly has noticed the increase in extreme weather, such as multiyear droughts, two years of rain in a month, and devastating hail. He said he worries about his kid's future, wondering what they will be forced to contend with. He noted that he has had quite a few poor crops due to extreme weather, remarking that people need to "do something to mitigate the extreme weather to reduce reliance on crop insurance." Kelly also confessed he has a bit of buried anger: he is trying to do better for his family, his soil, and the world, while others appear to be doing just the opposite. To counter these feelings, he and DeAnna have started to speak out about some of the good things they see happening. He says there is no use in him having the perfect 2800 acres and everyone around him turning into a desert. He knows that farmers can be part of the solution.

Kelly says moving to conservation ag/NP has allowed him to reduce the labor needed on the farm, increased income, and given him more family time. With some of this extra time, they have started a "passion" project. They got the idea when someone asked DeAnna if they could purchase a bucket of whole wheat berries for home milling. From that first inquiry they have expanded their list of products for sale, which now includes stoned milled whole wheat, rolled barley for breakfast cereal, and a line of pasta products. Kelly says that they did not start this project because they needed the money; rather, they did it to serve his community. The business, Guardian Grain, LLC, has two full-time employees and Kelly, who cleans the grain to food standards.

Table 4.5.3. Summary of Kelly's BERT/E ratings for the various BMPs.

Kelly								Max 625
BMP	**As Idea**	**As Practice**	**B**	**E**	**R**	**T**	**E**	**BERT/E**
1Disturb	100%	100%	5	5	4	5	1	500
2 Snow to	60%	50%	4	4	1	4	2	32
3 Diverse	20%	20%	1	1	1	2	5	1
4 Armor	100%	100%	5	5	5	5	1	625
5 Alt N	100%	100%	5	5	3	5	1	375
6 Alt fuel	50%	0%	3	4	5	1	5	12
7 Ag Eco	90%	90%	5	5	4	5	1	500
8 S I	30%	50%	3	3	5	5	3	75
9 Conserv	100%	100%	5	5	5	5	1	625
10 Phos	20%	0%	1	1	5	1	5	1
11 Grazer	0%	0%	1	1	5	5	5	5
12Organic	0%	0%	1	1	5	1	5	1

Table Note: BERT/E stands for (Believe x Economics X Regulations X Technology)/ Energy to Change. Max is 5x5x5x5/1=625. The BERT/E math may not align exactly due to an adjustment made relative to every participant having at least one 625 score and all scores were increased by that factor to put everyone on equal footing.

4.5.3.1. Kelly's Comments on His Story

Attached is a PDF of the story you sent me with some corrections, some things added, some things removed.
Thank you, Kelly.

4.5.4. Cliff's Story, December 2023

Cliff (mid 60s) farms alongside his wife, Beverley, their son and daughter and their spouses, and their several grandkids. They also employ a number of hired hands. The farm, which was settled by Cliff's grandfather, is located in Hardesty, Alberta (southeast of Edmonton), in the dark brown soil zone (primarily sandy loam) and receives an average of 14 inches of rain annually. Cliff has about 7500 acres of crop land plus some perennial forages for pasture, with around 6000 acres devoted to annual cash crops and 1500 acres devoted to full-season cover crops. Cliff says the whole family is on the same page with regards to improving the soil and, although they are new to regenerative practices, he has noticed that full-season cover has enabled higher yields, lower input costs, better emergence, less runoff, improved water infiltration, and more available soil moisture.

Cliff and his family grow a variety of crops, including wheat, oats, flax, peas, canola, and barley (mainly for sileage or swath grazing). In each of the last three years, Cliff has allocated 25% of his land to full-season cover crops and subjected them to light grazing. They have been rotating these crops in and out of perennial alfalfa/grass pastures. Cliff formerly used this land for organic production, but he decided the tillage required to break the pasture and the tillage used in organic production is too hard on the soil. As such, he has chosen to cease all organic production soon.

Originally, this project was not going to include grain farms with cattle. However, Cliff's farm became one of a few exceptions, as he was the only farmer to answer my call for volunteers in *The Western Producer* and *The Manitoba Cooperator*. At the time of contact, Cliff was in the process of reducing his herd from 1600 cows to "just" 400, and he noted that, as a grandfather, he was deeply concerned with discerning the truth about global warming (via science) and what can be done to mitigate. Cliff believes we are at a turning point in agriculture and that we need to develop an effective plan for addressing climate change. He says his family is invested in farming for the long haul and do not ever intend to sell their land. In addition to farming, Cliff runs several businesses, including a fertilizer business, a bulk fuel business, and a (now defunct) natural grass-fed beef business. When it was operational, Cliff's beef business was the largest exporter of grass-fed, no-hormones-added hormone beef to the EU, and he also had a market share in Vancouver Island and Toronto.

Cliff received a stem-cell transplant last year to treat cancer. During treatment, the doctor asked if he had ever been around solvents like benzene, gasoline, or those found in old herbicides. Cliff responded that he had, and that "I guess I'm screwed." As a result, Cliff says he now has a "burr up my butt" about the hazards of exposure to such chemicals, and that he has developed a strong desire to support a better future for the next generations. When asked if he had a preferred name for his style of farming, Cliff chose the term, "regenerative agriculture," but he noted that "Net Positive" also resonated with him.

A summary of Cliff's comments regarding the twelve management areas of study and his regenerative ag/Net Positive/Zero-Till Plus innovations is provided below.

1. Cliff assigned the highest rating to minimal disturbance. He noted that they had recently purchased a K-Hart Zero-Till disc drill with mid-row banders to help minimize soil disturbance, and that they use minimal herbicides and no foliar insecticides or fungicides. They have also been trying to grow something after harvesting the cash crop to maintain feed for the microbes. He says their whole team is passionate about achieving their top goal, which is to improve their soil (while remaining profitable).
2. Cliff advocates for growing plants from snow to snow, but making it work has been a challenge. He is willing to sacrifice some immediate income for better future results. They have been experimenting with finding the optimal balance of clovers or hairy vetch—both legumes with a companion crop. They have experienced some loss in cash crop yield when the legume is too aggressive or creates a moisture shortage. As noted above, 25% of their land is allocated to full-season cover crops mixtures, which often include winter annuals or biennials to keep plants growing late into the fall and into the spring. While they do lightly graze these crops, they are careful about when they allow grazing, as they have found the cattle can turn an annual cropped field into a compacted mess. Nonetheless, Cliff says the use of full-season cover crops has noticeably improved the soil health and fostered better subsequent crop yields.

3. Increasing plant diversity is important to Cliff. He has left a sizeable section of his land as native pasture, and he has miles of fence lines with areas for pollinator habitat. About 25% to 30% of the farm is covered with multi-species full-season cover crops, while another 20% is covered with intercrops (e.g., peas/oats, peas/canola) or a combination of cash crop and companion crops. Cliff says attempts to intercrop with flax have been met with limited success. Cliff expressed a desire for more ready access to information about which combinations of species work best in their local area. Cliff rated the use of intercrops less favourably compared to the other practices, as marketing and separating the two crops are common hinderances to implementing this practice. Cliff 's diverse rotation and wide range of crops also significantly contribute to plant diversity.
4. Armor to protect the soil is an important strategy on Cliff's farm. Cliff has invested in minimal disturbance seeding equipment and stripper headers to leave as much straw standing as possible. This enables greater snow catch—and thus, greater moisture storage—which results in higher yields and more biomass to cover the soil. In his recent travels through Northern Montana, Cliff observed huge stacks of baled straw, likely going to dairy further south, and soil, while not tilled, appeared sandy and highly susceptible to erosion. This is exactly what he does not want. Instead, Cliff keeps his cattle at pasture year-round and only bales small amounts of straw for the few cows that need to stay close to the barn.
5. Cliff uses legumes in his rotation—as cash crops, as part of cover crop blends, and from termination of the alfalfa / grass pastures—as a source of alternative nitrogen. The use of zero till and increased soil biology health also helps reduce the amount of fossil-fuel-based N required. Cliff is watching and is hopeful for novel biological solutions. He remarked that having an agronomist that works for a fertilizer company is like going to an AA meeting with the liquor store rep. He looks to a wide range of sources for information and product alternatives to fossil-fuel-based N.
6. Cliff recognizes the potential for powering large farm equipment, sprayers, and trucks with renewable diesel, and he also sees a place for using electricity to power lighter duty equipment. Cliff recently bought a Tesla 3 and, while he would not want it to be his only vehicle, he is very impressed overall and considers it an ideal vehicle for local travel. However, he is much less impressed with the political rhetoric surrounding oil/petroleum and renewables in Alberta. Cliff believes it is time to move on and prepare for the future. He

says Alberta's moratorium on renewable energy has stopped the major oil companies from pursuing alternative energy options, and that they seem to be "milking this last hurrah" for all they can, with the Premier's blessing. Cliff says he hates seeing the big emitters get let off the hook.

7. Cliff is a big advocate for minimizing or eliminating synthetic and toxic chemicals from the farm. Cliff says they have minimized their use of herbicides and have not applied foliar insecticides or fungicides in years. Furthermore, their use of crop varieties resistant to insects and disease, as well as their use of a diverse range of crops and rotations, has also helped to minimize pest pressure. The farm's undisturbed borders also help ensure the presence of beneficial insects and birds nearby.
8. Cliff is a modest user of sustainable intensification tools, including GPS, autosteer, and sectional control on both the sprayer and the drill. Soil testing is used to determine the proper rate for applying 4R fertilizer, and employing the mid-row banding option at seeding helps to determine the optimal time and place. Cliff says they are currently not using any lower emission fertilizers, reasoning that the first three "rights" may reduce the need to spend money on unneeded lower-emission products. In his travels, Cliff has seen many interesting autonomous and robotic products that he believes may eventually have a place on his farm.
9. Wildland conservation and restoration are high priorities for Cliff. He has seen benefits from leaving existing trees alone, noting that all his land originally had trees. Given the favourable habitat and his lack of insecticide use, Cliff brings a beekeeper in each year to place hives at various locations around the farm. Cliff also shared that he struggles a bit with the line between strong regulation and allowing farmers the freedom to do what they feel is needed on their land. He said he would like to see the government develop incentives for leaving wildland undisturbed. These incentives would not need to be too large, perhaps $50/ acre and formal recognition that wildlands are valuable resources being protected by concerned landowners in partnership with the public.
10. Phosphorus management is generally recognized as a good idea, but it is not something Cliff has been able to tackle. Since Cliff's cattle are grass fed, the manure is recycled on those lands automatically at no cost. He has very little pen manure to spread, and he has not tried struvite.

11. Some of Cliff's land is well-suited to having cattle. They currently have 400 cows, which has been reduced from 1600. Cliff says the economics of cattle have been poor, and it is a constant struggle to keep the costs low. They also have found that integrating cattle on annual cropping land can become a massive mess if it rains too much, as the cattle compact the soil, creating basketball-sized clumps that are hard to get rid of. Consequently, cattle grazing is concentrated on perennial pastures, with fair weather grazing on full-season covers. Late fall-winter grazing is extended to the whole farm once the ground has frozen.
12. Cliff has attempted both organic and Zero Till regenerative farming. However, he admits, "I don't have the skills to farm organically and increase SOM and improve soil health." Cliff notes that tillage in dry arid regions makes soil building difficult, and that they will soon be completely out of organic production. However, Cliff is a believer in "never say never," and says that he has seen robots and weed zappers at the Paris Farm Show that could make "no till organic" possible.

Cliff has been aware of and concerned about global warming for at least twenty years. Even though a lot of people thought Al Gore and David Suzuki were wrong, Cliff has remained open minded regarding their view and respectful of the science behind it. Nonetheless, Cliff says he does not lose sleep over global warming per se; rather, he is concerned about the polarization surrounding it. He says it is difficult to have a good conversation locally, as there is a lot of pushbacks from conventional farmers. Cliff says he is as happy about switching to regenerative ag a few years ago as he was when they moved away from 50/50 cropping in the late 1970s. He said he used to spend all summer on the tractor cultivating the summer fallow and losing soil and soil organic matter.

Cliff says he agreed to participate in this study because he knows further change is imperative, and he wants to learn more about climate change science and where we currently are. He wants to do what he can to ensure his family have a good future to look forward to.

Table 4.5.4.1. Cliff's ratings of the various BMPs.

Cliff								Max 625
BMP	**As Idea**	**As Practice**	**B**	**E**	**R**	**T**	**E**	**BERT/E**
1 Disturb	100%	100%	5	5	5	5	1	625
2 Snow	100%	25%	4	2	5	2	3	27
3 Diverse	100%	50%	4	2.5	5	2	3	33
4 Armor	100%	80%	5	5	5	5	1	625
5 Alt N	100%	50%	5	3	5	3	2	112
6 Alt fuel	80%	2%	5	3.5	1	3	2	26
7 Ag Eco	100%	80%	5	5	5	3	1	375
8 S I	100%	70%	4	4	5	4	3	107
9 Conser	100%	90%	5	2	1	5	2	25
10 Phos	100%	10%	4	5	5	3	3	100
11 Graze	100%	80%	5	3	5	5	3	125
12 Organic	20%	5%	3	3	5	2	3	30

Table Note: BERT/E stands for (Believe x Economics X Regulations X Technology)/ Energy to change. Max is 5x5x5x5/1=625. The BERT/E math may not align exactly due to an adjustment made relative to every participant having at least one 625 score and all scores were increased by that factor to put everyone on equal footing.

4.5.4.1 Cliff's Comments on His Story

Hi David, I think this reads well—probably better than I deserve. I have cc'd my family—Lee Drever and Ryan Mowat—to have a read and let me know if I am stretching anything. Cliff

4.5.5. Brandon's Story December 2023

Brandon (41) is one of the first farmers in North Dakota to be Regenified Certified. Brandon farms with his wife, Jessie (40), and their children, Grace (16) and Lyle (15), about 20 miles NW of Minot, North Dakota. Brandon's family has farmed in the area since his great great grandfather homesteaded there in the early 1900, making Brandon the fifth generation. Brandon started farming on his own in 2003 using conventional tillage, but he moved on to high-input no till farming in 2005 and regenerative no till farming in 2018.

Brandon's farm is 5200 acres of mostly black clay loam soil in tall grass prairie pothole country, receiving annual average precipitation of 18 to 19 inches, with a variable +/- of about 12 to 15 inches. Brandon grows spring wheat, winter wheat, barley, corn, flax, yellow peas, and sunflowers, as well as a little bit of durum wheat and yellow mustard. Brandon is just starting to experiment with intercrops: in 2023 he tried peas/yellow mustard and peas/sweet clover. The sweet clover was left over from a previous cover crop mix wherein he planted peas into in the spring. Brandon says that this mixture should increase his net income by about 125%, well worth the effort. He plants various cover crops and has used full-season cover crop mixes in excess moisture years on "prevent plant land," or land that has retained too much water to establish a cash crop before the crop insurance deadline. Brandon credits these full-season cover crops for helping to jump start an improvement in soil health. He says that, because he rents a large portion of his land, "prevent plant" opportunities make it easier to improve the soil. He points to a diverse crop rotation, cover crops and some intercrops, retaining soil armor, and lack of soil disturbance as the major factors that have helped him improve the soil. Brandon says he has seen SOM improve by 3/10 of a percent since 2018 (3.1% to 3.4%), along with better soil aggregation and water infiltration. This is about five times the 4 per 1000 goal set forth in the Paris Accord.

When I asked Brandon what he calls his type of farming, he said he prefers the term, "regenerative no till," but that he also likes, "Net Positive" (NP). He said he had never thought of Net Positive carbon before but agrees that it should be a goal. His current goals are, first, to heal the soil and, second, to make money. Brandon shared that, while is primary aim used to be profits, he is now less interested in maximum yield, and more concerned with net profit. Indeed, he explained that having a healthier soil has allowed him to substitute purchased inputs with a healthier, more resilient ecosystem. He has found regenerative ag farming has been a blessing, as it has reduced financial stress and given him a greater sense of peace and faith.

Brandon's comments on the twelve management areas of this study and his NP/Zero-Till Plus innovations are summarized below.

1. Brandon's NP/Zero-Till Plus/no-till plus/ regenerative ag farming is founded on low-disturbance no till practice. To this end, Brandon uses a 7.5-inch single-disc precision air seeder for his solid seeded crops and cover crops, and a no till equipped planter for corn and sunflowers. Brandon places dry phosphate fertilizer with the seed and carefully

broadcasts nitrogen ahead of rains to minimize loss and maximize efficiency. While he has not embraced the use of coated fertilizers, he has plans to upgrade his seeding equipment to side band or mid-row band more of his nitrogen. He says he would also like to get sectional control on his seeding equipment in the future.

2. One concern shared by many Zero-Tillers relates to the future utility of glyphosate as a burn-off treatment to kill weeds before the crop comes up in the spring. Brandon says he tries to be a good steward of this tool by restricting its use primarily to killing perennial creeping rooted weeds like quack grass and Canadian thistle. Herbicide resistance is much more likely to occur with annual weeds, which produce a lot of seeds/ year. Brandon tries to disturb the soil as little as possible by using a disc drill (soil disturbance through tillage can stimulate some weeds to grow), employing diverse crop rotation (including cover crops), and a diverse array of herbicides to prevent the development of herbicide-resistant weeds.
3. Brandon is a proponent of growing plants from snow to snow, but he has found the last few years of drought to be challenging about 20% of his land gets seeded to a fall cover crop while another 60% is covered with volunteer grains. Brandon usually leaves the volunteer grains to grow unless there is a weed problem that would interfere with the next year's crops. Brandon does not mind having a thick cover crop but says he must consider available moisture and nutrients for the following year when deciding whether to terminate. He favours a "let it grow" approach, as he believes that, in the long term, the improvement in soil health will outweigh any short-term small yield loss. Brandon likes to use full-season cover crops to jump start soil health but finds them to be most economical in situations where he has "prevent plant" acres.
4. Plant diversity is a corner stone of regenerative agriculture. Brandon's use of a diverse crop rotation and full-season/fall-cover crops help to fulfill this requirement. He has also started experimenting with intercropping, having had good results with peas/yellow mustard and sweet clover/peas. Brandon notes that there are a couple of limitations to these practices, such as little-to-no crop insurance, the need for extra labor to separate the crops, and the need for cleaning/separating equipment. Brandon says he can foresee a time when he will need more help, primarily to seed more cover crops and handle the intercrops.
5. For Brandon, soil armor essentially means Zero Till; whereas tillage destroys soil armor, no till maximizes its likelihood. Brandon acknowledged that the crops in the rotation also affect how much armor remains on the soil. He says that increasing soybeans on neighbouring

fields has minimized the benefits of Zero Till with respect to soil armor (he has noticed that residues also disappear quickly in sunflowers fields). Conversely, crops like wheat and corn can provide more armor, but the longevity of this armor depends on how the stubble is managed. Brandon likes to leave the stubble tall and relatively intact; for example, he uses a stripper header on his cereals and flax and uses a stripping corn header (vs. a chopping header) for his corn. He says you can hardly tell he has combined his corn when driving by. Brandon claims this management approach will allow the corn residue to cover the soil for up to four years, whereas chopping corn headers leave the residue vulnerable to wind blowing and erosion and do not provide the lasting cover needed when rotating to low C/N crop, like peas.

6. With respect to alternative N, Brandon relies on mature Zero-Till soil's ability to supply the crop with nitrogen, as well as planting legumes as cash and cover crops. He is interested in "Bugs in a Jug" approaches, but he is also wary of introducing foreign bugs to his farm.
7. Brandon says he does not devote much time or energy to alternative on-farm power sources due to poor economics and a lack of readily available options. Nonetheless, he indicated that he would adopt new technology as it became available. He suggests that electric vehicles may be like cordless drills a few years ago: "They were good for about four screws [...] now you can't remember the last time you used a plug-in drill." Brandon expressed concern regarding the increased attention soybeans have been receiving for use as biofuels. He pointed out that soybeans are bad for soil health, and that some farmers are continuously planting them. However, Brandon agreed that prioritizing the use of renewable diesel for on-farm applications makes sense.
8. When discussing agroecological solutions, Brandon began by saying he did not use any, but as we talked, he raised his assessment to a five and, by the end, it was 50%. Brandon employs an array of agroecological tools to reduce crop losses from pests, including pest-resistant crop varieties (where possible); diverse crop rotations; intercrops; a narrow row spacing disc drill to maximize crop competition with weeds; and highly biologically and aerobically functioning Zero Till, which helps to degrade weed seeds and pathogens. Brandon has noticed an increase in beneficial insects such as spiders in stripper harvested wheat, as well as less flea beetle damage in a friend's regenerative canola crop. Brandon says he initially rated his use of agroecological solutions as zero because he does not

consciously think about such practices as “agroecological solutions.” To him, they are simply co benefits of his regenerative philosophy.

9. Brandon uses a number of sustainable intensification tools, mainly GPS, auto steer, and sectional control on the sprayer. At the time of our interview, Brandon said he was exploring green-on-green sprayers and sectional control seeding equipment. However, he cited affordability, complexity, and dependability as key concerns with such tools, saying that he would invest when he is confident that the benefits will outweigh the cost and frustration that often comes with learning new technology. He says his 70-year-old neighbour that does most of the seeding may not adapt to much more complexity than they currently have.
10. Brandon’s farm is located in “pothole country,” which means there are a lot of Class 1 and Class 2 low spots. Like all prairie farmers, he will seed through if these depressions are dry. He hopes that following regen practices will allow more water to infiltrate where it falls, reducing the number of wet sloughs he has to work around. Class 3, 4, and 5 sloughs are off limit for all famers in North Dakota; farmers caught draining these sloughs may be subject to fines and/or exclusion from government programs, like crop insurance. During dry autumns, Brandon will often swath the vegetation in preparation of seeding them in the spring. Brandon thought using this vegetation as biomass for an on-farm furnace for heating buildings or drying grain was a good idea but noted that it would take extra manpower.
11. We discussed various ways of making our phosphate dollars go further. One notable option is determining how much is enough. When Brandon was using high-input no till, his agronomist said he would do better if he could raise his P level to 12 PPM. Dutifully, Brandon put high volumes of P and S on one field for two years in a row; however, this did not affect the soil P level or his yield, it only drained his bank account. Brandon said that he has read that P added to the soil can become immobilized within forty-five days. Instead, Brandon now concentrates on increasing the P-solubilizing microbes that make P available, which has allowed him to maintain soil P levels of 6-8 ppm, while using only half the normal recommended amount. This result aligns with research done at the Dakota Lakes research farm (Pierre, South Dalota), where they have found no yield penalty if P soil level stay above 5 ppm. Brandon has not tried using struvite and he does not have easy access to animal manure; however, he has tried chicken manure pellets from Michigan, but says they are expensive and really foul smelling. Part of Brandon’s strategy is to combine healthy soil, lots

of microbes, and high plant diversity to help solubilize and make available the P already in the soil.

12. Brandon believes ruminants should be included on prairie farms, as roaming bison were key to the region's tremendous soil health at the time of permanent settlement. Brandon says he is not interested in owning cows, despite still having cow infrastructure in his home yard. He has tried grazing cows on two occasions, both on full-season cover crops, but both times were more of a favour and did not require him to pay for the feed. He said he would consider letting cattle graze on his corn stalks, a heavy growth of volunteer grains, or full season covers, but that the herdsman would have to do all the work and supply the water and fence. Brandon is wary of soil compaction from wet weather, and he has gotten fencing wire tangled in his planter due to carelessness on the part of the cattle owner.
13. Brandon thought no till organic would be a fantastic way to farm, but he was 100% sure that it would never happen. He has no interest in any system that relies on tillage, as he believes such systems will reduce his soil health and increase soil erosion. Brandon thinks that consumers and food companies are starting to realize organic farming in the prairies is detrimental to the soil, and that regenerative no till is more sustainable with less yield drag. He is starting to see food companies buy Regenified certified grains.
14. Brandon also uses a seed treatment to build soil health. The treatment he is using is based on research by Dr. David Johnson and his wife Su (the Johnson-Su compost). It takes one year to make this no turn aerobic compost, which Brandon then uses to "brew" a compost extract that he adds to all his seed just before seeding. He also applies it to all his land.

Brandon shared that, while he has been aware of anthropogenic global warming for about twenty-five years, it was his growing dissatisfaction with his soil health and bottom line that motivated him to look for alternatives. Brandon first became involved in NP/regenerative farming in 2018, when he began watching YouTube videos, met and visited with Gabe Brown (Bismarck), and attended a soil health seminar at Menoken farm, just east of Bismarck. These experiences fortified his belief in NP/regenerative farming, and he has since developed a community of "regeners." Nonetheless, he is careful to tell interested farmers that regen is "a marathon, not a sprint," and to not give up just because it did not work the first time, as it takes a while to turn things around.

He says his decision to change strategies was not driven by money per se; rather he claims that it was driven by the desire to build better, more resilient soils. He said that, despite his lack of attention on maximizing yield, his bank account has improved, his land no longer blows, organic matter and water infiltration into the soil have increased, he has more time to examine his soil, and he has increased faith and a greater sense of peace. Thus, he cannot understand why everyone is not practicing NP/regen farming. Brandon says he does not lose sleep over anthropogenic global warming, but that he is worried for future generations and that we all need to do better to curb climate change. He says no one knows how fast the climate will change, but he thinks it will likely be his future grandkids' generation that will bear the brunt of it, particularly if we do not change. He thinks farmers often have more than they need, and it may be unethical to grab more gross dollars today at the expense of future soil health and food security.

Brandon says that adopting regen farming has provided many positive outcomes, such as less borrowed money and financial stress, less exposure to insecticides and fungicides, a closer connection to the land, enjoyment in learning, and a deeper faith in God. Brandon shared that he was once refused a line of credit in the hard years around 2007, and that he never wants to be in that position again. Regen ag has helped to ensure that. Brandon further notes that some landowners appreciate his dedication to the soil more than others. He has also switched some land and says that owning more land is a goal of his, as it would make it easier to build the soil health faster. The only other potential negative in switching to regen farming is that it creates more work, which can be a problem if you want to do everything yourself. Conversely, this can also be a positive for those who are community-minded and want to be able to offer long-term employment. Brandon is currently helping put a young seasonal helper through college with the understanding there is full-time work when he is finished.

Table 4.5.5. Summary of BERT/E ratings Brandon assigned to the various BMPs.

Brandon								Max 625
BMP	**As Idea**	**As Practice**	**B**	**E**	**R**	**T**	**E**	**BERT/E**
1 Disturb	100%	98%	5	3.5	3.5	5	1	306
2 Snow to Snow	100%	80%	5	4	5	5	1	500
3 Diverse	100%	85%	5	5	5	5	1	625
4 Armor	100%	95%	5	5	5	5	1	625
5 Alt N	100%	40%	5	4	4	3.5	1	280
6 Alt fuel	100%	5%	5	2.5	5	3.5	1	219
7 Ag Eco	80%	50%	5	5	5	5	2	312
8 S I	100%	70%	5	5	4	4	2	200
9 Conserv	50%	5%	4	2	5	5	3	67
10 Phos	100%	50%	5	5	5	4	1	500
11Grazer	100%	10%	5	3	5	5	3	125
12 Organic	0%	0%	5	5	5	1	5	25

Table Note: BERT/E stands for (Believe x Economics X Regulations X Technology)/ Energy to change. Max is 5x5x5x5/1=625. The BERT/E math may not align exactly due to an adjustment made relative to every participant having at least one 625 score and all scores were increased by that factor to put everyone on equal footing.

4.5.5.1 Brandon's Comments on His Story

Hi David, I made a few minor changes. Mostly simple grammar related. You did a fantastic job of representing our farm. Thanks again for all your hard work with promoting a better way to farm. I look forward to reading the final report. Best regards, Brandon

4.5.6. Darren's Story, December 2023

Darren (38) farms 3300 acres NW of Deloraine, Manitoba, with his wife, two kids, and a bit of help from his parents. Darren's farm sits on thin black clay loam soil in glacial till pothole country.

Darren is the fourth generation of his family to farm in the area, and he holds a BSc in Agronomy from the University of Manitoba (2007). Darren refers to his farm as a "grain farm," but his approach is based on Zero Till, and he is currently trying to incorporate regenerative agriculture practices. He says he is amazed at the resurgence of tillage in recent years, despite the benefits of Zero Till being well-documented.

Darren grows a diverse assortment of crops. His main crops are spring wheat, oats, canola, and peas, but he also grows some flax, soybeans, and perennial rye grass for seed. Darrent says he grows fall rye as both a cover crop and seed crop, and he has added hairy vetch to the fall rye, which he combined and sold for seed.

Darren's comments regarding the twelve management areas of the study and his Zero Till grain farm/ regen/ NP innovations are detailed below.

1. Darren says he hates tillage and does as little of it as possible. Darren also tries to minimize his disturbance of soil microbes by minimizing his use of harsh chemical and fertilizers, although he admits this can be difficult in practice. Regardless, he says he is more cautious about pulling the trigger on spraying for weeds, diseases, or insects; he scouts more and has higher thresholds than he used to have. He has also been experimenting with reducing his use of commercial N and P fertilizers. He says if they lost the ability to Zero Till, it would be a significant financial blow, resulting in around a ten bushel/acre decrease in wheat yields (the average wheat yield for this area is sixty bushels/acre; MASC 2022). Darren also says the cost per acre would increase by $25. While he was unable to estimate the cost of increased soil erosion, he believes it would be significant. His estimated lost revenue of $125/acre would put many farms in the red.
2. Darren thinks growing plants from snow to snow is important, and he has tried to achieve that goal. A few years ago, he allocated as much as 40% of the farm to cover crops; combined with fall rye, clover seed, and grass seed crops, plus some volunteer crops, he would have most of his farm covered. The last few years of dry weather has made it much more difficult to establish many of these options, causing him to reduce his fall seeding of cover crops from 40% to 10%. The dry soil conditions, which create excess wear on his disc drill, and the lack of recent success and never-ending challenge of finding enough time or labor to seed and combine concurrently are key challenges. Darren says it costs a minimum of $30 to $40/acre to seed a cover crop, and that it is difficult to find the return on that investment. He suggested that carbon sequestration provides a large public benefit, and

that the government should consider underwriting these efforts. One option for such an initiative would be to pay a significant portion of farmers' costs every year or to provide cover crop insurance. On the other hand, Darren remarked that, as a taxpayer, he would not be fond of having the government pay for something that big. Nonetheless, he thinks it is imperative to find a cheaper, faster, more effective way to sequester additional carbon.

3. Darren believes that increased plant diversity is critical for improved soil health and future sustainability. However, recent dry years and the amount of extra work this has required has dampened his enthusiasm for putting this into practice. Darren says he has reduced his intercropping of cash crop pairs from 40% of the farm to about 5%, but that he will likely continue to grow pea/oats and maybe some pea/canola. Instead, he reports being more interested in growing an annual cash crop with a biennial forage seed crop, as this would allow him to seed once for two years of revenue. However, dry years can make it challenging for forage seed crops to survive. Darren also mentioned kochia weed as a concern, mainly due to the lack of herbicide options for many intercropping configurations. With respect to biennial forage crops, Darren has tried perennial rye grass with canola and either sweet clover or red clover with cereals. He says, "I have a love/hate relationship with sweet clover. It is the easiest to grow but also the most likely to give problems."
4. Soil armor is closely related to Zero Till and a lack of soil disturbance. Darren hates tillage, so maintaining armor on the soil is an easy target to achieve. He attributes his ability to practice Zero Till to his Bourgault 10-inch row-spacing single-disc drill equipped with mid row banders, and his stripper header's ability to leave the stubble attached to the soil without having too much straw reside on the soil surface. He says he is also able to manage the residue on the surface through his diverse crop rotation. Darren equates armor and Zero Till with protecting the soil from erosion, and he notes that he does not have to go far off his farm to see soil losses from both wind and water erosion.
5. As with many of these management areas, Darren thinks alternatives to fossil-fuel-based nitrogen are a great idea. Darren has tried several methods of reducing his use of commercial nitrogen, but, other than the use of legumes, nothing has worked yet. He thinks growing bigger crops will help to build soil health, as more biomass and root exudates will increase SOM. He says that, while adding humates or applying melted urea have not improved his nitrogen use efficiencies, he remains hopeful that he can improve his soil's ability to cycle nitrogen more efficiently, which will eventually minimize the need for

commercial nitrogen. Darren says he would be trying to inoculate his soil with a compost extract via the Johnson-Su method in the upcoming year, as one of his peers had obtained good results with this approach. Darren utilizes the 4Rs of fertilizer management: he conducts soil tests using SWAT-based VR and employs variable rate fertilizing (right rate); he applies fertilizer at seeding with the mid-row banders and some seed placed (right place and time). Regarding the 4R program's promotion of high efficiency/low emissions fertilizers, Darren says he wonders whether farmers who broadcast low-emission fertilizers on the ground ahead of the drill instead of banding at seeding are really gaining anything.

6. As with most of the participants in this study, alternative fuels are a low priority for Darren, mainly due to the lack of economical options. Darren also observed biofuels made from high-input oilseed or corn crops are not really green fuels. Furthermore, Darren does not see scalable infrastructure for options like H2, and he is skeptical about the safety of using H2 or NH3. He says he will explore economic and practical alternatives as they become available.
7. Darren largely associates agroecology with providing habitat to beneficial organisms, such as soil microbes, insects, and birds. He says a significant portion of his poor land is allocated for habitat creation, and that new sectional control and mapping capabilities have made it much easier to spray around or through these areas without harming sensitive habitat areas.
8. Darren hesitated to fully endorse sustainable intensification (SI) but noted that he had many affordable SI tools on his farm, including GPS, autosteer, and sectional control for seeding and fertilizing. He also uses variable rate technology to optimize fertilizer efficiency (i.e., getting the right rate on the right place in the field). Darren acknowledged that initial cost is a major concern for some technologies (e.g., he cannot afford "Weed It," or "Green on Green" sprayers), as are compatibility and the need for continual upgrades. This can make it harder to switch brands or acquire the right equipment for your needs. Darren is currently looking into Canadian Digital Adoption Program (CDAP), which provides farmers with access to consultants who assess their current status and future needs for improving their farms via digital SI tools.
9. About 15% of Darren's land is engaged in a conservation agreement with DUC. He said this option was a better alternative than making his downstream neighbors mad. Darren says

Manitoba has strict water drainage regulations, but that enforcement has become lax in the past number of years.

10. While Darren thinks we should be recycling phosphate, he has had little opportunity to do so on his farm. He has no access to animal manure and has heard mixed reports on struvite, which has dampened his motivation to try it. Darren thinks the cities need increased regulation and funding to ensure the P does not end up in the rivers, lakes, and oceans. Returning it to the land makes sense, but, again, it must be free of contaminants and the farm-level economics must make sense.
11. Darren has had cattle on the farm three times: once on a full-season cover crop, and twice for fall grazing on annual ryegrass. He believes that cattle should be on the farm and says that the absence of cattle on his farm is driven by economics, not a lack of desire. He says he would be interested if the government wants to provide a cowboy, the cows, the fence, and water, but the bad economics, the energy required to line up cows, and already being short on available laborers make it simply unworkable in practice. Consequently, his interest in pursuing integration with cattle has been waning.
12. Darren ‘s belief in organic is limited to his belief in being able to Zero Till organically, noting that, “organic with tillage does not excite me.” He thinks a government mandate on organic would just be trouble. Darren asserted that people have been moving away from organic farming, but this may have been his way of saying he is not interested in organic and the negative effects it would have on his erosion-susceptible soils. An organic cattle farm could be more conducive to soil health, but Darren maintains that grain is more profitable than cattle and so has decided to stick with that.
13. The only other practice for potentially reducing commercial fertilizer nitrogen mentioned by Darren was using humate to increase N efficiency, as promoted by John Kempf and Melissa Werkema. Darren says he has tried out both approaches recommended by Kempf and Werkema, but the results have not given him much reason to continue using these methods. Darren wondered whether he did not achieve the promised results due to doing something wrong or failing to do something.

Darren says he first became aware of global warming while taking agronomy classes with Dr. Martin Entz at the University of Manitoba. Darren recalled feeling overwhelmed by this information, noting that many of his classmates “zoned out.” He also credits Dr. Entz for motivating him to conduct his first under seeding of red clover into winter wheat in 2011. He says it was a wet year, and the field got "rutted up" during harvest. Darren's dad insisted they work the clover down to smooth out the field, which upset Darren because he had spent considerable effort getting a great crop of red clover. Darren says it took him five years to get over this incident and try again. Despite his aggravation, Darren also reflected that, after all was said and done, his dad remarked that the field had been very "mellow" to cultivate. Darren and his dad seem to be on the same page today.

Darren also recalled one year where they had a lot of hail damage to their oats, which caused volunteers, and regrowth. He says that after yet another heavy rain, he noticed significant ponding on a field across the road, where there was no plant growth. Yet, he had no ponding in his field where he had the continued plant growth. He cites this as further proof of the power of continuous plant growth and living roots.

Darren takes a cautious approach to innovation, typically conducts small-scale experiments before jumping in with both feet to avoid financial loses. He says he is wary of high-input agriculture and that there are plenty of examples of declining soil health due to excessive tillage, fertilizer, pesticides, and poor crop rotations. Darren says he has seen more extreme weather events than in the past, especially alternating patterns of drought and excess water. Darren says he feels that people have become desensitized to the term, "global warming," due to how politicized it has become. While he likes the term, "Net Positive," he admits that it is not his specific goal. Darren's main goals are soil health and profitability, and he says it is ideal if pursuing these goals result in a better environment. Darren laments that there is only so much one person can do, but that thinking of his kids makes him want to do better.

Table 4.5.6. Summary of Darren's BERT/E ratings of the various BMPs.

Darren								Max 625
BMP	**As Idea**	**As Practice**	**B**	**E**	**R**	**T**	**E**	**BERT/E**
1 Disturb	100%	70%	5	5	5	5	1	625
2 Snow to	100%	50%	5	3.5	5	4	3	116
3 Diverse	100%	25%	5	3	3	3.5	3	53
4 Armor	100%	90%	5	4.5	5	4	1	450
5 Alt N	100%	20%	3	3	5	3	2.5	54
6 Alt fuel	70%	2%	4	1	5	2.5	5	10
7 Ag Eco	90%	10%	3	3.5	5	4.5	2	118
8 S I	70%	70%	4.5	4.5	5	3.5	2	177
9 Conserv	100%	15%	3	3	3	5	3.5	39
10 Phos	100%	0%	3	2	5	3	4	23
11 Grazer	100%	2%	5	1	5	3.5	4	22
12Organic	65%	0%	3	2	5	1	5	6

Table Note: BERT/E stands for (Believe x Economics X Regulations X Technology)/ Energy to change. Max is 5x5x5x5/1=625. The BERT/E math may not align exactly due to an adjustment made relative to every participant having at least one 625 score and all scores were increased by that factor to put everyone on equal footing.

4.5.6.1. Darren's Comments on His Story

Hi David,

It looks pretty good. The only corrections I saw were in the third paragraph; I have not grown clover for seed, only as a cover. Section 13. The red clover was under seeded in winter wheat, not fall rye. The hailed oats were across the road from harvested barley, not oats.

Darren

4.5.7. Kristjan's Story, December 2023

Kristjan (41) operates a 30,000-acre grain farm with help from his wife and children, his parents, his CEO (Jeff), his CFO (Evan), twelve full-time staff, and five farm consulting staff. Located in the black soil zone south of Moosomin, Saskatchewan, Kristjan's farm is largely comprised of Oxbow loam and receives about 20 inches of precipitation annually. This region (known as the

Parkland region) contains lots of sloughs, wetlands, and potholes; as such, Kristjan attempts to make the best land easy to farm and uses the more marginal land for cattle pasture (his dad and brother operate a cattle farm in the same area). Kristjan says his grandfather started the farm in 1962, and his dad restarted it in 1978 with about 1500 acres and 200 cows. Kristjan has a BA from the University of Saskatchewan and became a CPA. He began farming part time with his dad in 2004 and returned to the farm full time in 2008. At that time, the farm covered 3500 acres, with the grain and cattle operations being separated. Kristjan credits the TPAP course he took at Texas A&M and a similar farm management course at the University of Guelph for his motivation to take over the farm. Kristjan says that, while the educational aspects of these courses were important, their real value was the network and learning opportunities they afforded him. Kristjan believes in continuous learning, both through reading and interacting with others.

Kristjan says that growth has been natural and steady: he has not had to chase land, and opportunities have mostly come to him. He says he needs one full time person/2500 acres to ensure "the last acre is farmed as well as the first acre," and that his team represents a lot of rural development. For instance, there were thirty kids at their last Christmas party, with the oldest (fifteen) already working on the farm during the summer. Kristjan says his is a "business-first farm," meaning, "if the farm is treated like a way of life, it may be a shitty business, but if it is treated as a business, it can be a pretty good way of life." It is easy to tell he values his team and the future, which exists in their kids. Kristjan grows three main crops: hard red spring wheat, malt barley, and canola. They also periodically include some fall rye, peas, and oats.

Kristjan's thoughts regarding the twelve management areas of the study and his NP/ Zero Till innovations are provided below.

1. Zero Till is the foundation of Kristjan's farming practice, only departing from it to ensure the seasonal rains do not flood his low-lying land. He believes in proper drainage, both surface and tile, as drowned-out crops do not pay well and can produce significant GHG emissions. Kristjan also cites economics, (higher yields and lower costs), availability of Roundup, and being only a few miles from the original birthplace of the Seed Hawk and Seed Master Zero-Till drills as additional reasons for the central role of Zero Till in his farming practice. Kristjan uses 12-inch-spacing Seed Hawk drills on the farm. He says he has tested some disc drills for John Deere, but, while he liked the seed placement and packing, he found that they had greater problems with hair pinning, did not stand up as well to stones, and were more expensive to operate compared to precision hoe drills. Kristjan says he also likes the side

banding option on the hoe drills compared to the mid-row fertilizer placement on the disc drill. He said the 12-inch Seed Hawk is the perfect canola drill, but a paired row, (narrow spacing) would be better for the cereal crops. He says that rutting caused by excessive rains sometimes requires tillage to restore the field's surface integrity. His main concern with Zero Till is the development of weed resistance to Roundup, particularly kochia. Kristjan did not comment on disturbance from pesticides, excess fertiliser, or natural crop senescence.

2. With regards to growing plants from snow-to-snow, Kristjan said he has a "global theory, but a regional strategy." Specifically, he believes that snow to snow is a good idea, but he does not believe there is enough moisture or growing season for fall cover crops to be feasible for him. He says that, in the future, practices will need to be easy and more profitable, or they will not be implemented. Kristjan plants fall rye on up to 20% of his land, and he also allocates at least 15% of his land to volunteer grains such as barley after harvest. However, Kristjan says he only sprays out his volunteer crops after a killing frost, as this allows him to kill any creeping root perennial weeds, such as Canada Thistle. Delaying spraying also allows his brother's cattle a chance to graze and recycle the nutrients found in the volunteer cover crops. And, of course, growing plants help sequester CO_2 and build SOM.
3. Kristjan likes plant diversity, but only insofar as a good crop rotation will allow it. He is not currently interested in intercrops or cover crops, that the work required and does not justify the economic return in his situation. He says more research is needed before they would consider it.
4. Kristjan's responded similarly when asked about lack of disturbance. Zero Till allows him to leave the soil undisturbed on a scalable whole-farm basis. He pointed out that the straw choppers on the new John Deere X9 combines were much better that the ones on the older S790s, and that better chopping and spreading limits problems with straw bunching in the seed drill and enables more uniform seed emergence. Kristjan is working with CANZA to help document the potential of agriculture in mitigating global warming, mainly via his measure, report and verify (MRV) program, which tracks emissions and sequestration. Kristjan believes giving farmers inset carbon credits would encourage them to embrace change rather than fighting it.
5. While Kristjan believes in using alternative N, he says it can be very costly to run short of N. He thinks we need to improve the efficiency of fossil-fuel-based N, minimize emissions, and optimize the emissions per tonne of crop produced. He recently travelled with a CANZA

executive and Premier Scott Moes to promote Saskatchewan as a source of low emission grains at COP28 in Dubai. He says we should not adopt practices that reduce our production of low-emission grains by promoting alternative N technologies that do not exist. He has used variable rate technology to help put the right rate on the right place at the right time, and he regularly uses low-emission fertilizers. Kristjan began using Zero Till in 1990, VR in 1996, and sectional control and nitrogen inhibitors in 2013. He says green N is still far from being commercially available, and that he has not seen any viable N replacements with “Bugs in a Jug” products.

6. Alternative fuel sources are not high on Kristjan’s priority list, mostly because there are none capable of powering his farm. He does not want to waste money on solutions that will be unreliable in Saskatchewan’s extreme temperature ranges. He believes that climate policy should not override food policy and is reluctant to endorse biofuels as a solution.
7. Kristjan believes in agroecological solutions, but only with respect to genetic solutions, better seed, and better crop rotations. He largely buys new seed every year, choosing varieties with superior pest resistance and acceptable grain yields. Seed with superior insect resistance allows him to minimize his use of insecticides. Kristjan says he would like to see continued public investment in new germplasm and variety development.
8. Sustainable intensification (SI) is a corner stone of Kristjan’s farming method, and they were early adopters of many SI tools, including sectional control, VR, autosteer, and precision ag. He says Green on Green spraying is too underdeveloped for use on small grains, but he can see how it can be advantageous in row crops, where plant density is much lower. Kristian says he will definitely invest in additional SI tools if they offer a positive ROI.
9. Kristjan says he has a hard time with the conserve and restore management area. He says they clean up the grain land as much as possible to reduce the need to go around small areas, in addition to using surface drains and drain tile to minimize crop loss due to flooding in the low areas of the grain fields. On the other hand, they preserve grassland where cattle are the best option. Kristjan thinks annual payments could help offset costs and incentivise farmers to leave more of the Class 1, 2, and 3 wetlands intact. He believes that Saskatchewan needs a water policy that ensures water security, as there is no regulation at present.

10. Kristjan is unique in his views on phosphate recycling. Between composted cattle manure and recycled P from the cities (in the form of struvite), he does not need to buy any commercial P fertilizer. He says he pays a premium for the struvite but feels it is worth it.
11. Kristjan does not plan to add perennials to his cropping rotation, but he does allow his brother to bring cattle on to the grain land after harvest. This is mostly grazing volunteer grains. Kristjan says about 40% of the land is within distance to "walk the cattle over," but that the economics stop making sense when the cattle must be trucked in. He sees an opportunity wherein both parties could benefit if the cattle person was responsible for starting the cover crop and handling the cattle, fencing, and water.
12. Kristjan has zero interest in practicing organic farming, noting that most of the local attempts at organic farming have been a disaster. However, he did say he has seen successful examples of organic livestock, mainly pigs, chickens and dairy. He also noted that he had the opportunity to see a farm with a six-year rotation consisting of two years of alfalfa (for hay), two years of organic crops, and then two years of conventional crops. This system proved to be very profitable, but the owner told Kristjan that it led to him being hated by everyone: the conventional for having organic, and the organic for uploading the soil with weed control and nutrients, while still being able to call it organic.

Kristjan's journey to Net Positive or "well-managed Zero Till" began in 1990 with the adoption of Zero Till, was expanded in 1996 with the incorporation of variable rate fertilizer, and advanced further in 2013 with the introduction of sectional control technology and low-emission nitrogen fertilizers. Kristjan says that he and his team adhere to the following internal legacy statement: "We strive to leave our land, families, our community, and our industry in a better state." He is always searching for options that are better for the land and their bottom line. To this end, he frequently visits the CANZA website, stays up-to-date on findings from his agronomy company, Agri Tactics, out of Yorkton, and reads the latest results from government and private research trials.

Kristjan likes the term, "Net Positive," and says he has been using similar terminology, such as "planet positive" or "climate positive." He says agriculture can play a role in mitigating global warming, and that farmers could get paid for their role in doing so. In our discussion of next steps, I suggested the development of a Net Positive network, while Kristjan expanded this idea to the world's first Net Positive supply chain. Despite this being a big opportunity for farmers, Kristjan was noted the immense pushback against climate relief efforts in the country.

Kristjan says he remembers Al Gore's book, *An Inconvenient Truth* (2006), but notes that, according to Gore, we are all supposed to be on fire by now. Nevertheless, he says he has become involved in climate relief strategies because there is an opportunity to decrease emissions and store carbon on farms, while also getting paid via insets. He said one large Canadian food company that claims to be net zero currently is spending $10 M on carbon offset outside of agriculture. He suggested that we can get that money out to our farms (There are over 7000 companies around the world that are looking to become net zero and utilize net zero supply chains; SBTi.com).

While he does not lose sleep worrying about anthropogenic global warming, he is anxious about consumers' deteriorating view of farmers. He says if farmers keep denying there is a problem, they will be viewed as a villain and lumped in with large emitters. He also says many consumers would rather point fingers than calculate their own GHG emissions from heating/cooling, driving (especially trucks and SUVs), boats, manufactured goods (clothes, houses, etc.), and airplane travel. Kristjan believes that global warming is all our problem, and that agriculture has a responsibility to be part of the solution.

Table 4.5.7. Summary of Kristjan's ratings of the various BMPs.

Kristjan								Max 625
BMP	**As Idea**	**As Practice**	**B**	**E**	**R**	**T**	**E**	**BERT/E**
1 Disturb	100%	90%	5	5	5	5	1	625
2 Snow to Snow	50%	35%	4	1.5	5	5	4.5	33
3 Diverse	100R/0cc	20%	3	1	5	2	5	6
4 Armor	100%	90%	5	4	5	5	1	500
5 Alt N	90%	70%	3	3	5	3	2	68
6 Alt fuel	25%	5%	2	1	5	1	5	2
7 Ag Eco	100%	90%	5	5	3	4	2	150
8 S I	100%	99%	5	5	5	5	1	625
9 Conserv	50%	50%	5	2.5	5	5	3	104
10 Phos	100%	100%	5	4	5	4	1	400
11 Grazer	100%	40%	4	2	5	5	3	67
12 Organic	0%	0%	2	2	5	5	5	20

Table Note: BERT/E stands for (Believe x Economics X Regulations X Technology)/ Energy to change. Max is 5x5x5x5/1=625. The BERT/E math may not align exactly due to an adjustment made relative to every participant having at least one 625 score and all scores were increased by that factor to put everyone on equal footing.

4.5.8.1 Kristjan's Comments on His Story.

I had a quick review, seems good. I'd leave name as Kristjan.

KRISTJAN

4.5.8 Ian's Story, December 2023

Ian (63) and his family farm in SE Saskatchewan north of Oxbow in pothole country on thin black clay loan soil. Ian is the third generation of his family to farm the land: his grandparents bought the original farm in the 1920's, and Ian and his brother (d. 1984) took over from his dad in 1981. Ian's son, Liam, has recently become a full partner in the farm, making him the fourth generation of the family to work the land.

One distinguishing factor about Ian's farm is that it has been a certified organic grain farm since 1985. Ian says the farm economy was very tight in the 1980s, 1990s, and mid-2000s, and that many farmers turned to organic because they could no longer afford outside inputs. Despite, minimal support or initial knowledge in organic systems, Ian has built his organic farm into a large-scale success. Ian farms 6185 acres, with 5052 acres being cultivated and 1033 acres being left as wildlands (i.e., sloughs, wetland, fence lines, buffer areas, and current and old yard sites). Generally, 40% of the land is used for green manure crops, which comprise a combination of alfalfa, single-cut red clover, and sweet clover. Notably, Ian does not cut any of this crop for hay; he has grown some alfalfa for seed production but generally uses the green manure crops to benefit subsequent cash crops, as they serve as a source of nitrogen, perennial weed control, and dependable soil moisture. The nitrogen-rich green manure is a critical part of an organic system when there are insufficient locally available animal manures. Ian's best cash crops are spring wheat, hemp, oats, and flax. Due to a buildup of root diseases in legumes like peas and lentils, Ian no longer grows them on his farm, including in intercrops such as flax/lentils, peas/wheat, and peas/ oats. One of Ian's main problems with long-term organic farming in Saskatchewan is the gradual decline in phosphorus in his fields. As a result, he has been lobbying the Organic Standards Council to allow city sources of struvite, a wastewater source of phosphate that would be effective and economical for organic farms. Presently, Ian gets his additional phosphate from chicken manure pellets. Unfortunately, these pellets must be brought in from Michigan, which makes them an expensive option.

Ian is anxious to see how his farm does regarding net emissions. His SOM has stayed flat: while Ian uses alfalfa and clover to build it up, his use of tillage lowers it. Ian has implemented many reduced tillage options to ensure he is leaving as much residue as possible on the soil surface, while also still staying ahead of perennial weeds like Canada Thistle. Ian also recently bought a couple of wide-blade undercutting implements. He says he should have bought them years ago.

Ian acknowledges and is concerned about anthropogenic global warming. He says he is currently struggling with figuring out how his farming practices, which have provided a good living for thirty-eight years, fit into the challenge of mitigating global warming. How will his large-scale organic farm in this sub-humid, often semi-arid region, compare in SE Saskatchewan? Ian uses no fossil-fuel-based nitrogen fertilizers, has comparable fuel use to many Zero Till farms, stable SOM, and substantial sections of wildland that continue to grow plants and sequester carbon. Significantly, Ian says he has no herbicide-resistant weeds, pesticide-resistant insects, or disease to worry about.

Ian's comments regarding the twelve-management area of the study and his Net Positive innovations are summarized below.

1. Answering a question about lack of soil disturbance seems like a difficult task given Ian's organic certification. Nonetheless, Ian says it is important to minimize soil disturbance, and he has found a number of ways to do so that adhere to organic farming rules. For example, he leaves his alfalfa and clover green manure crops in the ground for one to five years without disturbing them and delays termination until the end of June/early July. While he has found that sequentially using a disc drill and wide-blade undercutter is effective at killing any Canada Thistle that survived the alfalfa, he says that this strategy leaves a lot of plant residues on the soil surface. Ian also says that, with the exception of weedy low spots and thistle, he does not do any fall tillage after harvesting his annual cash crops, as this system minimizes disturbance and helps protect his soils from erosion. He has seen many overworked fields on other organic farms that have become very susceptible to erosion due to not having a good green manure crop prior to fallow tillage.
2. Ian likes the idea of growing plants from snow to snow, but says he has a hard time making it work in practice. Despite this criticism, he noted that he has alfalfa crops that are multiple

years old. He also has some fall volunteer crops and weeds from not practicing fall tillage, and he under seeds many of his cash crops with the alfalfa and clover mix to start the green manure phase. Ian does not plant any cover crops.

3. Ian grows a diverse range of plants, including several cash crops, green manure crops, and vegetation in the wild areas around the farm. The diversity of plants encourages beneficial insects, birds, and large animals, such as moose. While Ian has tried intercrops, he ultimately stopped because the peas and lentils in the mixture were performing poorly due to root diseases and low phosphorous levels. Like many organic and conventional farmers, Ian says he finds peas easy to grow and grows them often. We know that root diseases like Aphanomyces accumulate in the soil—more quickly during wet growing seasons—and the disease inoculant can last for many years, making future production risky, if not impossible. Currently, it is recommended not to grow peas (or lentils) more than once every six to eight years, or longer if there is a high presence of the root diseases.
4. Protecting the soil with armor is a high priority for Ian, although he recognizes that organic regulations limit what he can do in this respect. His ability to keep plants growing is one of the main practices he has employed to keep the soil covered. Additionally, his recently purchased wide-blade undercutter has proven effective at keeping residue on the surface, especially when using it for Canada Thistle control. It is important to note that Ian's approach to skipping fall tillage gives him an important advantage compared to many organic farmers, as his multi-year alfalfa helps control creeping perennials that might otherwise take over in the absence of fall tillage.
5. With respect to alternative nitrogen sources, Ian says that the inclusion of legumes in his rotation are "all I've got." As noted earlier, Ian can no longer grow peas and lentils, which is a major blow. Ian says he would like to see research to develop root-rot-resistant peas. Ian notes that, because of the slow decline in phosphate levels in his soils, his legumes are not producing as much N as they once did, which has in turn lowered his cash crop yields. Ian has not tried any "Bugs in a Jug," but says he has been exploring some interesting possibilities. At the same time, Ian says he is sceptical and wonders if the Indigenous soil microbes are not already doing that work.
6. Like most Western Canadian large-scale grain farmers, Ian has not paid much attention to alternative fuels, mostly because there are none. He acknowledges that researchers are working to develop biofuels and hydrogen-powered and electric small tractors but says he

has yet to see a viable alternative source of power for his field tractors or combine. When I suggested renewable diesel, he said he was not keen on alternatives that took land away from food production.

7. Agroecological solutions are another extremely important management area for Ian's organic farm. On this topic, Ian says that his use of diverse crop rotations and careful selection of crop varieties with built-in disease resistance are important tools for minimizing the impact of pests. The wildland around Ian's farm is also home to myriad beneficial birds and insect, which can also reduce crop pests.
8. Ian's enthusiasm regarding sustainable intensification was minimal. He says he is grateful for autosteer on his tractors, but that fancy SI tools are either unnecessary or too expensive relative to the value they bring. He did acknowledge the potential usefulness of the sectional control on his drill, especially the number of potholes he must go around. It is important to keep in mind that Ian does not buy expensive GMO canola or soybean seed, so overlap is proportionally less of a problem. Therefore, doubling seed in an overlap, while not ideal, may not pose as much of an increased cost issue, and the higher seed rate may be more competitive with weeds and perhaps even increase the yield. Ian said he was not interested in investing in a new air seeder, which can cost around $1 million, just to have sectional control.
9. Throughout his forty-two-year farming career, Ian has consistently shown that wildland conservation is very important to him. At present, 1033 of Ian's 6185 acres are devoted to wildland. Ian says he has never pushed bush, but that some of the land was cleared before he bought it. He also notes that, around half the time, the cleared land still contains water holes that have to be avoided in the spring. Ian says that there are some regulations preventing the clearing of wildlands, but enforcement is virtually nonexistent. He says that, while the farmers in his area are mostly respectful of their neighbours downstream, it is more of a "free for all" in other areas of Saskatchewan.
10. Phosphorus availability is a major issue on Ian's organic farm. He says some of his fields have up to 9 or 10 ppm of P, while others are below 5 ppm. However, even with these low levels, Ian is surprised at how resilient his yields have been. Nonetheless, he knows low P levels are limiting his yields and is working to convince the Organic Standards Board to allow organic farmers to use struvite. Ian did not mention the potential of solubilizing some of the 1000s of lbs of P that are tied up in the soil. As stated earlier, limited access to local

manure has forced Ian to purchase pelletized chick liter from Michigan, which has a low concentration of P/lb, thus making it very expensive.

11. Ian thinks cows have a place on farms, but not his (he was fairly adamant about this point). Ian shared that he consulted with Martin Entz (University of Manitoba Natural Farming system lab), who told him not to bother with cows, partly because it would require too many to produce any serious benefit to the farm and two or three brothers to manage them. As such, despite his initial interest, Ian says he will not be getting into cattle, nor will he be borrowing someone else's cows. He says, "you really have to love them and want that kind of lifestyle," and that crops pay a lot better.
12. The last management area deals with the switch to organic farming. Ian made this change thirty-eight years ago and has built a good farm as a result. He says there is good market demand for organic products and retail demand is also increasing. He is committed to organic but wonders whether it will be the best option for the future. Ian is anxious to view his farm and potential changes through the lens of global warming mitigation. He wants to see how his emissions and carbon sequestration opportunities compare with the other Net Positive farms in this study. He also says he is concerned about the food production lost to the green manure component of his system, and whether things will be headed in the right direction when he eventually hands the farm over to Liam.

Ian has been aware of climate change since the mid-2000s, largely from watching *The Nature of Things* with David Suzuki and reading Al Gore's, *An Inconvenient Truth*. However, he says he really started to think about the consequences of climate change when his kids were young. Ian says he does not lose sleep over AGW but admits it is easy to become discouraged due to the lack of political action on this problem. He says he is not obsessed with global warming, just concerned. Ian notes that he has always taken care to protect the water and air and generally try to improve the health of the environment, and he feels that not using fertilizer and pesticides supports these goals. On a note of optimism, Ian says he recently read that TransAlta has decided to switch from coal to natural gas in its existing electric plants and will be investing in wind and solar, citing the greater cost effectiveness of renewable energy.

Although the term, "Net Positive," does not really resonate with Ian, his efforts to reduce his carbon footprint align with the goals of NP farming. Ian says his farm has done well over the years, but he is hesitant to compare himself to neighbours. He says if he decides to make changes, it will not be due to a lack of income.

Table 4.5.8. Ian's ratings of the various BMPs.

Ian								Max 625
BMP	**As Idea**	**As Practice**	**B**	**E**	**R**	**T**	**E**	**BERT/E**
1 Disturb	100%	50%	4	3	3	4	2	90
2 Snow to Snow	100%	12%	4	3	5	5	2	188
3 Diversity	100%	90%	5	4	5	4.5	2	281
4 Armor	90%	50%	5	3	5	3	2	162
5 AltN	100%	100%	5	3	5	5	2	235
6 Alt fuel	50%	5%	3	1	3	1	4	3
7 Ag Eco	100%	100%	5	4	3	5	1	375
8 SI	60%	25%	4	2	5	2	4	25
9 Conserv	100%	100%	5	3	2	1	2	19
10 Phos	100%	8%	5	2.5	1	5	1	79
11 Grazers	80%	0%	4	2	5	5	5	50
12 Organic	100	100	5	5	5	4	1	625

Table Note: BERT/E stands for (Believe x Economics X Regulations X Technology)/ Energy to change. Max is 5x5x5x5/1=625. The BERT/E math may not align exactly due to an adjustment made relative to every participant having at least one 625 score and all scores were increased by that factor to put everyone on equal footing.

4.5.8.1. Ian's Comments on His Story

Hi David, I think you captured our story well. I highlighted a few additions that help will clarify some of our approaches. If you have any other questions, please let me know! Thanks, Ian

4.5.9. Dorian Olver, Rourke Farms, November 2023

Dorian farms with her husband, John, her daughter, Stella, her Mom and Dad, Diane and David, and their long-term hired man, Hughie. Their farm is located near Minto, Manitoba, on rolling glacial clay loam (black soil zone). Dorian says that, while she grew up helping on the farm, she only started farming four years ago. Dorian holds a Bachelor of Commerce with Honors from the University of Manitoba and worked in ag finance before switching to farming.

Dorian was heavily immersed in organic farming for her first two years as a farmer. However, at the two-year mark, the decision was made to go to Zero-Till Plus, which meant she had to learn even more. Dorian is responsible for making cropping plans, including crop nutrition, and keeping yield-stealing weeds and pests under control. She also does all the field scouting and says she wants to do more of the spraying next year. Finally, Dorian takes care of the grain marketing, in addition to doing her share of swathing and combining. Dorian obtained her Class 1 driver's license last winter, allowing her to run the sprayer nurse truck and haul some of the grain, seed, and fertilizer. Diane oversees the day-to-day bookkeeping, keeping the family fed, and looking after those who need it, including Dorian's five-year-old daughter, the eight other grandkids, and her father. David helps Dorian with the crop planning, and he does about half the seeding, swathing, and combining. Dorian's husband, John, and their hired man, Hughie, look after machinery maintenance, modification, and repair. They also help with field operations and haul most of the grain. Rourke's usually look for someone to run the grain cart in the fall, and David often seeks out extra help to run replicated research plots as time and money allow.

Rourke Farms was established in 1980, when Dorian's parents, David, and Diane, moved to Minto and rented 300 acres. David had just finished his research for his MSc. and was working as a research associate for Dr. Elmer Stobbe of the University of Manitoba. David conducted agronomic research and extension on Zero-Till wheat from their land base at Minto. In 1983, David founded AgQuest, an independent ag research company now owned and operated by his oldest sister, Dana Maxwell. At the time of writing, AgQuest employs twenty-nine research crews at five locations across Western Canada. Over the last forty-three years, David and Diane have expanded their farm to about 6000 acres. In 2023, David split off 2000 acres to his brother, while continuing to farm the remaining 4000.

Zero Till has been practiced on Rourke Farms continuously since 1980. The emphasis on Zero Till grew over time as equipment was developed, herbicides became more affordable, and agronomic knowledge increased. However, some tillage is employed periodically when conditions are excessively wet. In the early days, the preferred Zero Till approach was to fall band with narrow openers and to direct seed in the spring with a narrow opener hoe drill. This always was a dependable combination, allowing some drying in wetter conditions but not too much in dryer conditions. The hoe drill eliminates hair pinning of crop residues and allows for semi-deep furrowing in dry conditions.

A major change was made in 2017, when the decision was made to try organic Zero Till in an attempt to be more self-reliant. However, after five years of trying, it became apparent that rainfall in the area is too unpredictable to establish green manure crops consistently. Dorian notes that this is problematic because a poor green manure crop will restrict the nitrogen available for the subsequent cash crop. They also noticed rapid declines in soil phosphorous levels, soil aggregate stability, and water infiltration, despite countless hours of hard work. Indeed, they would have as many as eight tractors working at the same time and make as many as eleven passes on a field in a year. They had to decide if they wanted to try to improve the organic system or go back to a Zero Till based system. While they think there is a niche for organic, the scalable solutions favored a moisture-efficient farming system based on Zero Till. In 2022, they switched to (what they call) Zero-Till Plus, which is essentially Zero Till that applies regenerative agriculture principles to improve soil faster.

In 2018, Rourke Farm was selected along with forty-five other farms in Manitoba, Saskatchewan, and North Dakota to take part in a regenerative agriculture pilot study sponsored by General Mills. Dorian says they have had either bad luck or no luck getting organic Zero Till practices to work on the test field, as well as some of the lowest test scores for soil health. In particular the tests revealed poor physical structure and low soil P and SOM, which is largely due to excess tillage from the organic days and poor establishment of cover crops. However, the field is now being transitioned to Zero Till, with a plan to accelerate soil health recovery by underseeding a barley crop to alfalfa or clover. The network of farmers developed from this regen group has been a great source of knowledge and support.

Dorian says they have tried many regenerative practices over the years and are looking forward to incorporating them into a zero-till-based system. The following are some of the practices Dorian and her family have employed since moving to Zero Till.

1. They have reduced disturbance by not using tillage, minimizing their use of harsh chemicals, and using only moderate amounts of fertilizer. However, Dorian concedes that most of their fields still experience some tillage effects, as fall banding followed by sowing with a disc drill or a precision side-banding hoe drill cause some soil disturbance. She says they try to apply fertilizer in the less busy fall period, as this makes seeding in the spring quicker and easier. Dorian says they are watching one of their neighbors, who uses a

stripper header, ultra-low disturbance including broadcasting the bulk of his fertilizer trying to get a highly functioning healthy soil.

2. Rourke's still employ spot tillage to control weeds on saline or previously wet areas that have become full of weeds and/or ruts. They are working to seed these areas to permanent forages, but it is a work in progress, with good success in certain places and years.
3. Dorian says they have tried to expand the number of plants growing from snow to snow, which has not been easy in the current dry cycle: they had success under-seeding clover in barley in 2018, but drought hampered a couple of under-seeding attempts in 2023. Furthermore, she notes that alsike clover seeded into winter wheat essentially disappeared over the hot, dry (45% of normal precipitation) summer. Similarly, the perennial rye grass that had been overseeded into four-leaf canola also thinned during that summer. Fortunately, they had an excellent five-foot-tall, sixty bushel/acre canola crop this year, and there is still hope the perennial rye grass might recover. Sweet clover seeded into winter wheat stubble in mid-August had a good catch with very minimal soil moisture, but most of the seedlings were desiccated by a very windy 35C day three weeks later; as such, the crop is unlikely to be sufficient to make a good seed crop. Dorian says crop insurance can help cover the loss, but a good forage seed crop would have been much better. They plan to try some of these practices again, hopefully under normal rainfall conditions.
4. The Rourke's have been including more winter cereals over the last couple of years to bolster plant growth through the fall and early spring. Winter wheat is grown as a commodity grain, while fall rye can be used as either a cover for green seeding, a commodity grain, or cover crop seed for other farmers.
5. Dorian notes that her mom, Diane, is not happy about seeding in the fall. Diane thinks David must have "season seeding disorder" if he deems it a good idea to get off the combine to go and seed. Diane says harvest is the only time they get paid, so fall seeding is a big distraction. Dorian mentioned that David is working on a technology called Delayed Germination Seed Tech (DGST), which would allow a cover crop to be coated with a material that would delay germination for about eighty days. This would allow the cover crop to be seeded alongside the cash crop in the spring in a one-pass operation, only the cover crop would emerge as the cash crop enters early senescence (i.e., when it begins dropping its leaves and is no longer using moisture). DGST would make establishing fall cereals and fall seeded cover crops more scalable by providing better logistics, timing, and economics.

Dorian says her dad acknowledges that DGST is a long shot but believes it will be a game changer if it can be made to work.

6. The Rourke's have tried green seeding a couple times. Green seeding was originally developed by Jeff Moyer of Rodale Organic Farm Institute (Pennsylvania) while exploring ways of enabling organic no till. This approach works best in areas with longer growing seasons, milder winters, and high rainfall. The idea is to allow fall rye to grow until anthesis when it can be killed with a roller crimper, with soybeans being sown at or just before roller crimping. During particularly rainy years, herbicide can be applied to terminate the rye much earlier than anthesis, usually at or before seeding the cash crop. Dorian says their best green seeding has been with peas, while they have had less success with soybeans. She says she is unsure whether green seeding would work with faba beans, as they need to be seeded very early, which would limit the growth and advantage of the fall rye cover crop. Their only experience with green seeded faba beans was in a wet year with delayed seeding.
7. Dorian says they have experimented with a wide variety of cover crops, including peas, lentils, hairy vetch, clovers, alfalfa, oats, fall rye, brassicas, flax, buckwheat, millets, ryegrass, and sorghum-Sudan grass. When they were organic, they needed to use full-season cover crops, but Dorian says they have been working on figuring out which combinations work best since switching to Zero-Till Plus. She says they are leaning towards companion crops and have noticed that, lately, the best cover crops are volunteer off-growth, whether the owners of those fields wanted the cover or not. Dorian says that some of their friends are planning to set their combines to throw more seed over the sieve and then to harrow to attain cheap cover. David is also experimenting with planting eighteen small-seeded species using broadcasting and drilling to see which ones do best under each condition. In his experience, broadcasting seed usually does not work on this farm, but volunteer seed from the combine does (somehow).
8. Dorian says they have grown a wide variety of crops—including winter wheat, spring wheat, fall rye, barley, oats, corn, sunflower hemp, canola, flax, peas, lentils, chickpeas, fababeans, native grass seed, alfalfa seed, and hay—but are keeping it simple as they transition back to Zero Till. This decision is partly due to the large weed bank accumulated during the organic years and partly to allow them to learn more about what constitutes an economic cropping system.

Dorian rated minimal disturbance and maintaining soil armor highest among the discussed BMPs, with Zero Till being a key enabler. She also rated these BMPs highest with respect to economic return. Sustainable intensification and diversity were the next-highest ranked BMPs, while agroecology, plants from snow to snow, alternative N, and conservation all rated low, mainly due to a lack of technology or, in the case of conservation, weak prevention laws and enforcement. The lowest ratings were assigned to alternative fuels, P recycling, grazing animals, and Organic; Dorian felt the first two were not practical at present, and the last two were of no interest to her due to prior experiences with them.

Dorians was first introduced to the concept of global warming 15 years earlier through Al Gore's, *An Inconvenient Truth* (2006). Her journey with Net Positive farming began when she took up farming full-time four years ago, which coincided with Rourke Farms' inclusion in the General Mills Regenerative Ag initiative. She attributes this "club" for enhancing her understanding of AGW, and she has attended many tours, events, and conferences focusing on regen ag. She says she also follows Menoken Farms, Young Red Angus, and Stuart Chutter for innovative ideas.

Dorian says that Rourke Farms' excellent financial position (very little debt and ownership over all the land they farm) gives them more flexibility to try new things compared to farms with less financial latitude. Dorian says she does not have a succession plan with her five-year-old daughter, Stella, although Stella has expressed interest in becoming a "Princess Farmer" when she grows up. When asked about profitability, Dorian thought Rourke Farms were competitive with their neighbors, stating that they have no choice but to be profitable, as the existence of the farm depends on it.

Dorian admitted that none of her soils were as good as they need to be. The few long-term Zero-Till fields have produced better yields but are prone to becoming hard and blocky, especially after a year with only 45% of normal precipitation. She notes that the fields used for organic farming had poor soil structure and were more susceptible to erosion, which was a key reason for the transition back to Zero Till. The Rourke's have sampled their soil annually for the last forty-three years. This is mainly done using a traditional chemistry-based soil test, but they have had Haney and PFLA tests done through the General Mills program as well. She says she does not have a specific term for their farming style, but says she prefers Zero Till plus over Net Positive. She said the negative thing about NP or regen farming is that it makes you aware, which can lead to "existential dread".

Dorian says global warming is not her top priority, that spot belongs to remaining financially viable and continuing to improve the soil. Nonetheless, she says she is very aware of AGW and, while it does not keep her awake at night, the thought of inaction can make her feel angry, helpless, and hopeless because there is not a lot individuals can do on their own. She noted that the Monday after the most recent US Thanksgiving set a record for the most passenger air miles in history, observing that "People with money just fly with no apparent appreciation for global warming". She also commented on how rampant consumerism causes lots of textile, plastic, and even food waste.

Table 4.5.9.1. Summary of Dorian's BERT/E ratings of the various BMPs.

Dorian								Max 625
BMP	**Ideal**	**Practical**	**B**	**E**	**R**	**T**	**E**	**Adj. BERT/E**
1 Disturb	100%	80%	4	4	5	3	1	600
2 Snow to Snow	100%	60%	5	3	4	2	5	60
3 Divers	100%	70%	5	3	3	3	2	170
4 Armor	100%	70%	5	4	5	5	2	625
5 Alt N	100%	80%	4	4	5	1	2	100
6 Alt fuel	75%	10%	3	1	5	1	5	8
7 Ag Eco	75%	10%	3	3	5	2	3	75
8 S I	90%	60%	4	4	5	4	3	267
9 Conserv	100%	60%	5	4	2	1	1.5	68
10 Phos	100%	20%	4	1	5	4	5	40
11 Grazers	100%	0%	1	2	5	5	5	25
12 Organic	10%	0%	1	1	5	4	5	10

Table Note: BERT/E stands for (Believe x Economics X Regulations X Technology)/ Energy to change. Max is 5x5x55/1=625. The BERT/E math may not align exactly due to an adjustment made relative to every participant having at least one 625 score and all scores were increased by that factor to put everyone on equal footing.

4.5.10. Michael's Story, December 2023

Michael (34) farms with his wife, Regan (who is also a professional agrologist), their three young children, his dad and mom, an uncle, and a full-time consulting business employee during seeding and harvest. Mike and Regan's farm is located near Melfort, Saskatchewan, covering 3000 acres of clay loam soil in a cooler, wetter part of the black soil region. Favourable conditions over the millennium have resulted in SOM of 7% to 9% and, as such, the area is known for its relatively consistent high yields. Michael holds diplomas in finance and accounting and is the fourth generation of his family to farm this land, taking over from his father in 2009. His family originally settled at Loresburn (south of Saskatoon) but moved in the 1930s due to persistent drought and crop failures in the Palliser triangle.

Mike's original crop rotation in 2009 was conventionally tilled wheat and canola. Mike's farm changes every year, but they are currently growing oats, wheat, barley, and canola along with intercrops of canola/peas and peas/oats. Over the last four years, he has added a two-year forage phase consisting of sweet clover, red clover, alfalfa turnip, radish, two forage grasses, and festolia, and he added faba beans last year. He sells the hay standing and has tried to get ranchers to bring cattle into the mix.

Mike is close to 100% Zero Till. He says excess rain can lead to ruts, which may make some light tillage necessary to relevel the land (he says they tilled six to seven acres in 2023). When asked about the best term to describe his farming style, he said that something like "regenerative Zero Till" would probably be most suitable. Mike says they are playing the "long game" to optimize profit and continue to build the soil for the future generations.

Mike's comments regarding the twelve management areas in this study and his regenerative Zero Till (Zero-Till Plus) or Net Positive Carbon Grain Farming practices are summarized below.

1. Mike says minimal soil disturbance is a major goal on the farm. To this end, Mike tries to minimize tillage and the use of harsh pesticides, and he tries to use alternatives to synthetic fertilizer, although the options here are limited. Current nitrogen and balanced fertility plans are important inputs for crop yield and profitability. Seeding is performed using a 10-inch spacing 5710 Bourgault narrow opener hoe air seeder with mid-row bands and a 7.5-inch spacing JD 1560 single-disc box drill. While the hoe drill does the bulk of the seeding, the box drill is used for site-specific cover-crop seeding, as well as for the forage crops. It is also used to seed areas where the hoe drill will not fit. When asked about his preference

between the two drills, Mike said they are both useful depending on the yearly conditions and cropping plans.

2. Mike gave a very high rating to the idea of growing plants from snow to snow, says he is still trying to figure it out in practice. He says about 25% of the farm may get fall cover crops, mostly from the establishment of forage, and another 15% may get good cover from volunteer grain crop seed. He says he leaves the volunteers to grow, and that this has resulted in an extra 20 lbs of soil N (vs. a sprayed-out check strip) after fall growth from volunteer peas. He did not mention being worried about the cover crop stealing moisture from the next crop, possibly due to his location in a wetter, highly productive region.
3. Plant diversity is another important goal on regenerative farms. Mike says they foster diversity by including a wide range of crops in the rotation, by planting forages, and by precision underseeding intercrops. Mike notes that, while too much trash on the surface can cause the disc drill to hairpin, thus resulting in poor plant establishment, it will go through more trash from a heavy crop than a hoe drill. He points out that he could obtain more immediate profit from growing more canola (less diversified), but that will not do so. As Mike puts it, he is playing the "long game," and wishes to be a great steward of the land and build his soil's resiliency by improving its water holding capacity and health. If a proper rotation is implemented and his soil's health and water holding capacity improve, he believes his profit will increase as well. Mike believes that inadequate crop insurance limits diversity by discouraging intercropping and the establishment multi-species forage-based cover crops. He points out that one part of the government promotes and even pays for farmers to diversify their crops, while crop insurance discourages it. Despite this tension, Mike continues to grow peas/oats and canola/peas as intercrops. He says the intercrops provide self-insurance to some degree: in wet years, the canola or oats do well, and in dry years, the peas thrive. He says being able to afford better cleaning/seed separation equipment would also be a boost.
4. Maintaining soil armor is largely a function of minimal soil disturbance. Mike rates maintaining soil armor highly, both as an idea and as a practice. His use of Zero Till, his choice of crops, and his placement of them in the rotation allow him to balance having too much armor and not enough. Too little armor and the soil is vulnerable; too much armor, and he cannot seed properly. Mike helps to ensure this balance by having good choppers on his combines and managing his stubble height. He says he has seen farmers cultivate three

times in the fall to keep their fields black, which he thinks is "crazy." In contrast, some of these farmers look at Mike like he is the crazy one.

5. Alternative N is another practice that Mike likes in theory, but that lacks practical, available options. Mike practices Zero Till, which counts as an alternative N strategy according to Dr. Franzen (NDSU). Franzen reports that, based on 130 N response trials, wheat grown on Zero-Tilled land for at least six years there accrues a 50 lb/acre N credit. Franzen has found this to be true of other crops as well but cautions that he cannot generalize his results to other contexts (i.e., crops in other locations). Thus, local testing is needed. Mike also includes N-fixing legumes, namely, peas, faba beans, alfalfa, and clover, into his rotation. Another area where more local data would be beneficial is the performance of "Bugs in a Jug" and what it takes to optimize the natural soil biology. Mike is currently investigating "Bugs in a Jug" products. Mike figures he uses about 20% less fossil-fuel-based N than his conventional neighbours. With respect to the 4Rs, Mike soil tests and applies fertilizer at variable rates (the right rate), and he mid-row bands (right place) the fertilizer at the time of seeding (right time). He did discuss sources of N and whether he needed or had a high-efficiency coating. Practically speaking, Mike noted that it would take considerable infrastructure to buy ESN treated urea in July for use the following May (July is often the cheapest month for buying fertilizer).
6. Mike likes the idea of alternative fuels but does not currently use them on his farm, mainly due to the lack of significant options. Nonetheless, Mike says he likes the potential of nuclear and biodiesel, proudly observing that Saskatchewan produces the best uranium in the world. He points out that the use of biodiesel supports Saskatchewan famers, although he is not sure about its advantages and disadvantages.
7. Mike incorporates a number of agroecological practices into his farming practices. For instance, the use of diverse crop rotations helps reduce weeds, disease, and insect damage. Mike and Regan scout for pests and tend to err on the side of not spraying. He says that, while this approach may result in some short-term yield loss, it ultimately benefits the microbes, insects, and birds that suppress crop pests over the long term. Mike says that they nearly spot sprayed for grasshoppers last year, as they were losing crops to them, but that not spraying was ultimately the right decision, as the yield loss was low anyway, they saved the cost of spraying, and they left the beneficial species unharmed. Crop variety

selection is also made erroring on the side of pest resistance vs yield. He suggests that more research into non-synthetic solutions could help.

8. Mike uses a lot of technology on his farm, and he is fond of the sustainable intensification options in his toolbox. Unfortunately, he cannot afford everything he would like, but he has amassed a considerable array of useful tools, including GPS, RTK, autosteer, precision ag, variable rate, sectional control, and the 4Rs. He notes that unreliable cell signals are a major limitation in his area, as all these tools are "worthless" without one.
9. Mike says there is significant incentive to clear land and turn it into $5000/acre crop land. He thinks there should be regulations preventing Class 4 and 5 sloughs and water bodies from being cleared and drained, and that the government should consider paying farmers to conserve wildlands. For his part, Mike leaves the wildlands on his farm undisturbed, which accounts for 200 of his 3000 acres. Mike says there should be more technology to measure and show the importance of these wildlands to farmers and the general public.
10. Mike has tried struvite. He says it is more expensive than commercial phosphate but provides a better yield response, making it fairly competitive with regular commercial monoammonium phosphate. Struvite is P recovered from wastewater from cities, but its availability is limited at present. Mike is also interested in identifying which plants and microbes will make the 1000s of lbs/acre of P in the soil available to his crops. He knows that buckwheat is good at solubilizing soil P, but he his ability to sell this crop is limited.
11. Mike is enthusiastic about the prospect of integrating cattle into his cropping system, but he has not been able to sort out the logistics thus far. For example, he has incorporated forages into his rotation but has been unable to find a cattle person who is on the same page. He says he would consider investing in cattle, but he does not have the time, infrastructure, or management to do so. Consequently, he is still looking at options for finding the right partner.
12. Organic farming is not an option for Mike because, "I never want to take a tool out of the toolbox. I need all the tools." Among other things, Mike says widespread tillage is simply not an option. He recognizes that some farmers can make organic work but questions the long-term market demand and price stability.
13. Mike did consider one "other" management area: the ability of biological, eco-tea seed treatments to help build soil biology and healthier plants. Notably, several other participants also mentioned this strategy. One developed his own biological seed

treatment, IMOS, which allowed him to eliminate N, P, fungicides, and insecticides while maintaining area average yields. He suggests his yields will be above average in dry years but may lag a bit in wet years. Overall, he has a respectable bottom line, one of the best in the study.

Mike says that the term, "Net Positive Carbon Grain Farming" does not resonate with him because "it is a hard definition, and you can't measure it. I just want to improve my farm from where I was last year." Establishing baselines for comparison is very difficult, as his farm is subject to different environmental and economic factors each year. Mike is also part of two consulting companies: Exceed Grain and Collective Impact. Mike heads three programs for Collective Impact: the Northern Plains Program, which is an education, idea/practices swapping network, and two other private carbon onset programs for corporations. Collective Impact helps Canada's agriculture, mining, energy, and forestry industries develop carbon programs to meet ESG and carbon offset goals.

While Mike and I may not agree completely on labels, we are both serious about reducing emissions and sequestering carbon while maintaining profitability. Indeed, Mike says his top priority is to ensure he is profitable every year. However, Mike also expressed his desire for long-term viability, noting that he is willing to sacrifice a bit of present yield to ensure continual soil improvement. Mike says he took his first steps in this direction eight years ago when he began VR fertilizing. Mike further pointed out that he has been adding regenerative practices to his farm since getting involved with the General Mills Regenerative Program about five years ago, and that he would like to help other farmers move in this direction. This is evidenced by his founding of the North Plains learning program and the opportunity for farmers to participate in a carbon credit programs through Impact Carbon.

Mike says he is not concerned about global warming; he is concerned about what he can do to become a better steward of the land, while increasing profits and reducing risk. Mike says this has been paying off, as he has increased his SOM by 0.75% by adding forage to his rotation and has seen a steady increase in water infiltration in his faba beans and forage crops. Ultimately, Mike is sequestering carbon and reducing emissions, which makes him a Net Positive farmer in spirit, if not in name.

Table 4.5.10. Summary of Mike's BERT/E ratings of the various BMPs

Mike								Max 625
BMP	**As Idea**	**As Practices**	**B**	**E**	**R**	**T**	**E**	**BERT/E**
1 Disturb	92%	99%	5	4.5	5	3	3	113
2 Snow to Snow	100%	40%	4	2.75	4	3	2	66
3 Diverse	100%	100%	5	3.5	3	3	2	79
4 Armor	90%	90%	5	5	5	5	1	625
5 Alt N	100%	20%	5	3.5	5	4	2	175
6 Alt fuel	100%	0%	5	3	1	4	4	15
7 Ag Eco	100%	75%	4	3	3	3	2.5	43
8 S I	100%	60%	4	4	3.5	4	2	112
9 Conserv	100%	80%	5	4	5	5	3	167
10 Phos	50%	20%	5	3.5	4	4	2	140
11 Grazers	100%	5%	5	4	5	5	1	500
12 Organic	0%	0%	1	2	5	1	5	2

Table Note: BERT/E stands for (Believe x Economics X Regulations X Technology)/ Energy to change. Max is 5x5x5x5/1=625. The BERT/E math may not align exactly due to an adjustment made relative to every participant having at least one 625 score and all scores were increased by that factor to put everyone on equal footing.

4.5.10.1. Mike's Comments on His Story.

Very well-done David,

I made a few minor changes highlighted in green. Thank you for including us in your report. I am not a huge fan of titles, personally. I could be called Michael Ferguson and be happy with that. I think that's one thing I'm seeing in the industry around carbon and ESG is the titling. I'm more a fan of action and trying new things to create changes on the landscape. I think little changes here and there will make a big difference in the long haul.

Talk soon, Michael

4.5.11. Dan's Story December 2023

Dan's farm, which he runs with his dad, Jeff, is situated in the wet, black clay gumbo of the Red River Valley, approximately equidistant from Starbuck, Sanford, Brunkild, Sperling and Fannystelle. Dan is the third generation to farm this very productive but sticky and fickle soil. He shares that he is unsure whether either his two preschool-aged daughters or one of his many nieces and nephews will want to take over the farm someday, but he aspires to keep on improving and expanding it to ensure that they at least have the option in the future (and to keep things fun for himself). In addition to his "small" 2700-acre farm, Dan also owns a thriving agronomy advisory and scouting business.

Dan is a curious person, which has led him to try what few have dared: to employ Zero-Till practices on Red River Valley gumbo. Dan tries to grow 50% cereal crops (e.g., spring wheat, winter wheat, fall rye, oats, corn, and millet) and 50% broadleaf crops (e.g., canola, soybeans, peas, and hairy vetch). Dan says he does not have a label for his type of farm management, as he prefers not to be confined to any one box. He must remain flexible to take advantage of and farm within the limits of the sticky, often spring-water-saturated clay soils. He says he adapts ideas and practices from a wide range of sources, including no till, organic, regenerative, and conventional. We agreed the most apt term to describe Dan's style would be "rotational Zero Till" or "strategic tillage". Of these, Dan says he prefers Zero Till, but he has learned that some fall tillage is sometimes necessary to ensure a crop can be planted in the spring. He says he has the most difficulty Zero Tilling after a corn crop, as it is challenging to warm the soil when it is under a blanket of crop residue. This is particularly important for corn and soybeans that need warn soil for uniform emergence. Nonetheless, Dan says he is working on solving this problem.

Dan credits his dad, Jeff, for giving him the latitude to move to Zero Till about ten years ago. They have enjoyed considerable success using Zero Till in dry years, achieving massive oat yields (110 bushel/ acre) while their tilled fields suffered. Dan acknowledges that there have also been disasters, a fact he takes as part of the learning curve. In general, Dan says Zero Till pays best in dry years and is more difficult in wet years or years with wet, late springs.

The following findings illustrate how Dan's farm differs from most neighboring farms.

1. The most obvious difference is Dan's use of Zero Till wherever possible. Dan says he is still learning but defaults toward Zero Till. He credits their success with Zero Till to good straw management out of the combine, followed by a heavy harrow and the use of a Bourgault disc drill with mid-row banders. He says his ability to practice Zero Till also depends on the

crops in the rotation and the individual fields. While there are some low fields that must be tilled each year, others have been Zero Till for ten years. Dan says the easiest crop stubbles to Zero Till into are soybeans, peas, and canola. He says that cereal stubbles are more challenging and admits that he has yet to figure out corn stubble. Dan is probably one of the only farms using Zero Till in the Red River Valley. This contrasts with other areas of the prairies where nearly all farms use Zero Till.

2. Dan is passionate about maintaining soil armor, and his use of Zero Till and strategic tillage has essentially eliminated wind-driven soil erosion.
3. Dan says that Net Positive (or even Zero Till) is not really his goal. Rather, Dan says his main goal is to build his soil sponge, as this will allow it to hold more water, thus making it more resilient to variations in precipitation and weather. In turn, this will enable higher yields and bolster the farm's financial stability. Armor keeps the soil much cooler than exposed black soil, which can reach well over 60C, and it enables available moisture to transpire through the crop rather than evaporate off the surface. Dan says that Zero Till has increased the sponge, but it has been hard to measure this via SOM. He also notes that switching to Zero Till has allowed them to decrease their diesel fuel use and the number of hours put on the tractor while improving yields (where they have mastered the application). He also credits less tillage to improving the habitat for beneficial insects, noting that he has not had to apply a foliar insecticide on canola in years. For Dan, Net Positive is a co-benefit of his farm-management approach, not a direct goal.
4. Dan firmly believes that growing plants from snow to snow and increasing plant diversity are desirable goals. However, he says logistics and economics relating to these practices have been difficult to sort out. Dan says that, a few years ago, 60% to 70% of their fields had more than one species/year; this number subsequently fell to 30%, and he expects it to be 0% next year. Dan says costs are staying high and grain prices have fallen nearly 50%, so it is not the time to take chances. He was also keen to note that the current crop insurance penalizes farmers who embrace something other than monoculture crops, which are easier, less risky, less work, and insurable at levels close to break even.
5. An affordable way to achieve fall plant cover is with volunteer grain from the combine, followed by heavy harrow. Dan says he just bought a two-year-old combine equipped with an automation system to reduce harvest losses, and better telecommunication and data logging to enable more insightful management decisions. Dan may be getting fewer

volunteer cover plants with his latest purchase, but he may be able to optimize this loss to attain a "just right" seeding rate. Dan says that, while he has found very few opportunities to sow cover crops in the fall, he has sown winter wheat, fall rye, or a diverse multi-species mixture in early harvest years. He also notes that he has had some success with fall rye seeded with hairy vetch and then takes both off for seed.

6. The BERT/E adoption rating scale showed that Dan had a high interest in agroecological solutions and sustainable intensification. He says a lot of "agronomists" do not consider or embrace agroecological solutions for longer-term challenges, but that this a priority for him both on the farm and in his agronomy business.
7. While agroecology is a priority, sustainable intensification is a necessity on the farm. Dan was adamant that the government should subsidize such purchases, as only a few farmers receive these funds. Dan says he would prefer to see money going into research and development and to allow people to use the current accelerated depreciation write off to help with the cost/benefit ratio when deciding what new technology he can afford.
8. Dan is highly interested in alternative fuels or N, but he does not know of any viable alternatives that would be economical to adopt. He opined that fossil-fuel-based N needed to remain available at or above current use rates if we are to maintain, or hopefully increase, yields. He was sure that he would eventually find ways to improve the nitrogen use efficiency (NUE), but this would depend on his ability to increase his "soil sponge" (i.e., the SOM). He thought the next yield increase would come from making the "sponge" bigger and increasing the NUE, rather than simply throwing more N at the crop.
9. Dan is also very interested in recycling phosphorus. He has received manure from neighboring hog barns, and he has used struvite-phosphate derived from city effluent. Dan discussed a study by Dr. Charles Grant, who proposed the construction of a manure pipeline from the intensive livestock areas east of the Red River to areas west of the river where there is much less livestock. Dr. Grant suggests this pipeline would enhance the value of recycling nutrients.
10. Dan has little interest in incorporating cattle/ruminants onto his farm. He says he tried to find a partner to graze their cattle on his fall cover crops but did not have any luck. So, he gave up. One potential reason for Dan's lack of success may be that cattlemen tend to only have interest in short-term grazing if they can walk their herds over to a neighboring field.

11. Dan always is always open to learning from organic farmers about non-synthetic solutions to agronomic problems, but he says that organic does not appeal to him as a cropping system, as tillage wastes moisture and can accelerate soil erosion. Moreover, Dan believes that it is important to provide affordable food for many, rather than expensive food for a few.

When asked about Net Positive farming, Dan reiterated that he was more interested in building his soil sponge and improving his bottom line, noting that, at best, Net Positive would be a co- benefit of achieving these goals. However, he acknowledged that NP is likely comprises a greater part of his outlook, but that its influence is largely subconscious.

Dan's crop scouting experience over the last decade has led him to seek long-term solutions to agronomic problems, rather than applying "band aids". He says he looks into a wide range of sources for solutions, for example, Joe Gardiner from Covers and Co., Kevin Elmey from Imperial Seeds, Allan Savory, and books such as, *Weeds and What Tell Us* (1946).

Dan says it is hard to know exactly how his farm is doing compared to his neighbors but suspects that differences are likely in the 5% to 10% range. He further notes that, despite a string of profitable years, he and his neighbors are preparing to pull back a bit due to higher inputs, much lower crop prices, and higher interest rates. Nonetheless, Dan says that, if they benchmark from their pre-zero-till days, they are doing much better and are more resilient.

Dan conducts regular soil testing (using Haney and Solvita tests) and pays attention to the residual nutrients in the soil. He uses this data and his agronomic background to determine the right rate of fertilizer. He says that it is more difficult to assess SOM, especially since bulk density can vary significantly depending on soil moisture. Dan has also tried to measure water infiltration, but water infiltration varies widely with moisture content of clays. For example, in dry summers, such as the summer of 2023, the ground often cracks as it dries out, sometimes as much as two to three feet deep.

We discussed climate distress and how moving towards Net Positive might impact his outlook. Dan says that global warming is generally in the back of his mind. In fact, he shared that, over the past ten years, the warmer climate has actually been advantageous to farmers like himself. Unsurprisingly, then, Dan says that anthropogenic global warming does not keep him awake at night. Instead, he puts his energy into things where he can make a difference, such as building the SOM sponge and developing a farming system that can contribute to supplying affordable food.

Nevertheless, Dan says he is concerned for the welfare of the planet and diligently recycles his plastic and uses a home composter in addition to building the sponge.

Dan is fond of the statement, “If you look after the soil, the soil will look after you,” and shared multiple examples in which building up the SOM resulted in better crops, lower costs, and higher profits. The co-benefits of better SOM are better nitrogen use, less diesel use, more resilient soils, and the ability to produce affordable food with lower emissions. Based on Dan’s comments and practices, he could be classified as a Net Positive farmer, even if he is reluctant to accept that label.

Table 4.5.11. Summary of Dan’s BERT/E Ratings of the various BMPs

Dan								Max 625
BMP	**As Idea**	**As Practice**	**B**	**E**	**R**	**T**	**E**	**BERT/E**
1 Disturb	100%	50%	5	4	5	5	1	500
2 Snow to Snow	100%	90%	5	3	1	5	1	75
3 Diverse	100%	13%	5	1	5	2.5	5	13
4 Armor	100%	70%	5	5	5	5	1	625
5 Alt N	100%	10%	5	1	5	3	1	75
6 Alt fuel	100%	20%	5	1	3	3	5	9
7 Ag Eco	100%	100%	5	5	5	5	1	625
8 S I	100%	100%	5	5	4	5	1	500
9 Conserv	100%	100%	3	3	5	5	3	75
10 Phos	100%	10%	5	3	5	4	1	300
11 Grazers	0%	0%	5	1	5	5	5	25
12 Organic	0%	0%	1	1	5	1	5	1

Table Note: BERT/E stands for (Believe x Economics X Regulations X Technology)/ Energy to change. Max is 5x5x5x/1=625. The BERT/E math may not align exactly due to an adjustment made relative to every participant having at least one 625 score and all scores were increased by that factor to put everyone on equal footing.

4.5.11.1. Dan’s Comments on His Story

David,

I have spent lots of time reflecting since we started this story. I made a couple highlights in green, but I don't think they affect the story so you can decide if you want to change. On the BERT/e Rankings 1-5, I forget if I picked those numbers, or you did? The general findings sound about right. Happy to have a quick chat as need call anytime. Dan

4.5.12. Rick's Story, December 2023

Rick farms at Gross Isle, Manitoba, and is the third generation of his family to run the farm. His grandfather originally bought a quarter section in 1934, and his dad added another quarter section some years later; since taking over, Rick has increased the original farm to 6000 acres and has recently purchased another 6000 acres at Gypsumville, along the east edge of Lake Manitoba. One reason for their success is that they have been involved in the seed business for seventy-five years. While Rick is currently grooming staff to run the farm so he can step back into the role of CEO, he says he loves the farm, including the challenges and opportunities associated with improving its economic, environmental, and social sustainability. Rick has two grown sons: one has allergies, which restricts his involvement in running the farm or working in the seed plant, and the other currently works in the agricultural lending industry (there are plans for him to eventually be the CFO).

The south farm (Gross Isle) is in the Red River Valley and benefits from a series of provincial and municipal ditches and in-field drainage. Without this drainage, the fields would be a bog or wetland. The soil is predominantly heavy, sticky black clay soil, with 6.5% to 8% SOM. The north farm is on black-to-grey wooded glacial till clay loam soil, meaning it has some stones. It also has some old peat soils, so the SOM can vary from 4% to 12%. Both farms are in higher rainfall areas of the prairies, receiving about 21 inches of precipitation each year. However, variations in rainfall can result in years of excess moisture or droughts. Due to the heavy, sticky soil in the valley (south farm), Rick must be strategic in his use of tillage. He says he would like to be Zero Till but has experienced problems with too little and too much tillage. Rick says he would call his method, "responsible tillage." Rick notes that he always seeds his winter wheat directly into standing stubble, and that he can often direct seed his spring wheat as well. He is excited to incorporate "strip till" on the south farm as a possible "best of both worlds" solution. For example, he plans to allow volunteer peas to grow—with a little encouragement from harrowing or shallow tillage—then strip till and apply fertilizer in precise rows with his RTK-guided autosteer tractors. This will allow the planter to be close to the right position to precision seed on the strip till bands, which sit beside the fertilizer bands. To further ensure precise placement, Rick says he has “steering” on his planter to ensure everything lines up exactly. Rick is the first in his area to try this new technology.

Rick attributes his wide range of crops for his success in building the SOM over the last twenty years. Notably, this improvement coincided with the decision to stop burning crop residues. Indeed, the soil quickly improved as residue was returned to the soil and tillage was reduced. Rick is trying to limit soil disturbance to as little as one pass with the seeding equipment. However, having a fall strip till pass maybe be advantageous. He realizes that, after a heavy crop of corn or barley, he may need additional passes to spread excess straw to prevent the spring runoff from carrying it to the leeward end of his fields. He says he need to get the tillage right so he can avoid having to burn his straw residue, something he has not done in twenty years. The south farm grows spring wheat, winter wheat, oats, barley, corn peas, canola, and soybeans. Due to the recent purchase of the north farm, Rick is keeping the cropping simple for now, growing wheat, canola, and some soybeans. However, he says he will be expanding crops as he gains more experience with the farm. Rick says he has increased the SOM from between 3.5% and 4.0% to 7 to 8 % over the last twenty years. This is increase far surpasses the 4 per 1000 (0.4%/year) target set out at the Paris Accord meeting.

Rick’s comment on the twelve management areas discussed in this study are summarized below.

1. Rick cannot consistently use Zero Till on his sticky clay soils, but he tries to minimize tillage passes and leave as much crop residue on the surface as he can without creating seeding problems and jeopardizing crop production. Despite some tillage, Rick has rapidly increased his SOM. He attributes this improvement to no longer burning crop residue, employing a more diverse crop rotation, growing a lot of crop, and adding biomass to the soil, and using fairly deep incorporation when he does till. Rick says optimizing his fertilizer use has contributed to big crops and biomass, and he is looking forward to incorporating more corn into his rotation. However, Rick noted that soybeans tend to reduce soil health and make the land more vulnerable to wind erosion. His single-disc precision air seeder with mid-row banders and a no till equipped planter gives him the flexibility to direct seed when possible. He says he is in the process of finding the right strip till equipment; currently, he uses an air drill to micro till and place the fertilizer, which in turn allows him to precisely place the corn seed with the planter, thus enabling optimal fertilizer/seed placement.

2. Rick likes the idea of growing plants from snow to snow and has taken steps in that direction. He does not plant cover crops, but he is experimenting with winter camelina after canola followed by winter wheat. He has also found that he can get a good catch of volunteer peas following a crop of seed peas. He says they can get a foot tall and should be contributing N to the soil. He says he plans to strip till into these volunteers and plant corn in the tilled strips in the spring. He often leaves volunteer cereals to grow in the fall. In autumns with vigour volunteer growth, he has observed nutrient tie-up of as much as 70-80 lbs of N/acre by volunteers. He believes that this level of nutrient tie up has hurt his pea, or soybean yields the subsequent year. Overall, he says our short growing season makes it difficult to be too aggressive in this area.
3. With the exception of his intercrops, Rick says he is continuously working to diversify his crop rotation. While he did not expressly say it, being a seed grower with a reputation for purity likely makes intercropping difficult. Rick says he has increased pulse crops by 35% and can see corn accounting for 15% of his land as he perfects strip tilling. Rick recently installed a new corn drier, which is a further testament to his dedication to diversity.
4. Rick says he has sufficient armor on about 80% of his fields. He wants as much "trash" as possible on his field surfaces and cites strip tilling as another method for ensuring maximum soil amor. Rick tries to minimize the number of tillage passes each year and tries to use his least disruptive tools to ensure good seeding conditions in the spring. He says he has changed implements three times in a single field to make sure he is using the right tool for the job.
5. With respect to alternative N, Rick says he Pivot Bio's "Bug in a Jug" helped increase his corn yield by about 10 bushels/acre in back-to-back years. Rick has also dedicated about 30% of his land to legume crops, which do not need added nitrogen, as they can generate their own with the help of rhizobia bacteria. Rick further noted that he is monitoring Fuel Positive's promise to build an on-farm NH_3 plant at Sperling Manitoba by the spring of 2024. Rick has been working with university researchers to measure mineralization in his high-organic-matter soils to attain the 50 lbs N credit that comes with continuous Zero Till. Put differently, this means achieving the same wheat yield with 50 lbs/acre less N. Rick says the researchers' findings indicated that his soils are good at supplying N to his crop. Rick samples the soil in every field each year and uses long-term field yield maps to identify zones requiring variable rate fertilizer. He says he does not understand why more farmers do

not take advantage of this technology. Rick has worked hard over the years to ensure he has very high NUE and estimates that his current NUE is around 95%. Rick believes he can further fine-tune his N application by measuring grain protein by mounting an on-the-go, real-time protein monitor to each of his combines. His target is to obtain 13.5% protein (or just a bit lower), as the market does not pay for levels higher than 13.5%, and yield is often optimized at this level. Rick is adamant that N drives the system, and that being short is not good for food production, the bottom line, or building healthy soils.

6. Rick is intrigued at the possibility of growing his own diesel fuel substitute. He is currently trying winter camelina, as it regarded as it is superior for fueling diesel engines, easy to crush, pourable down to -20C, and can be used as an SVO without the gumming problems associated with other vegetable oils. He also likes camelina because it is not a food crop. Rick says the main thing keeping camelina from being classified as a food crop is its generally-regarded-as-safe (GRAS) status. Rick is not as interested in renewable diesel due the food-or-fuel implications. He notes that many of the tractors displayed at Agritechnica (Germany, fall 2023) had H_2 engines but there was little information about how and from where to obtain fuel. Rick says that, at present, his camelina yield was not high enough for it to be economical as an alternative fuel. He has tried double cropping it with soybeans, but grasshoppers differentially ate the soybeans out of the camelina in just two days. Despite this setback, Rick says he is going to give it another try in 2024. He noted that camelina might be a better fit in drier areas of the prairies where canola yields were lower.
7. Rick's main thought on agroecology was that combine weed seed destroyers may need to become the norm as weed resistance becomes more common. He also mentioned the possibility of using the allelopathy associated with rye as a weed suppressant, and that he might be interested in doing so if the hybrid rye companies allowed the free use of carry over seed for cover crops. Finally, Rick discussed the possibility of green seeding into rye but said he has not tried it yet. Overall, Rick is not too interested in agroecology, as he thinks these options are not economical or scalable.
8. Rick indicated high interest in sustainable intensification. At present, he is the main cooperating farmer for a government/industry initiative named EMILE, which promotes digital solutions in agriculture. Rick uses many SI tools, including GPS, precision ag, RTK, implement steering, the 4Rs, variable rate, and yield and protein mapping. While he keeps

an eye on Green-on-Green sprayer tech, he says he found more affordable satellite and drone options when he was at Agritechnica.

9. Since Rick's farm sits on an artificially drained lake bottom, there is very little wildland on or around it. His main interest with respect to conservation and restoration is capturing excess water runoff in holding reservoirs for irrigation purposes. He says these artificial ponds could be managed as wildlife refuges for moose and birds. However, Rick is still working through the details of doing so, including regulations, permits, and costs vs benefits.
10. Rick's only P recycling initiative is the use of biosolids from the nearby city wastewater plant, which provides P for about 5% of his land each year. Rick says he has not tried struvite and has no access to animal manure.
11. While Rick never likes to rule out anything completely, he does not see any opportunity to have grazing animals on the south farm; however, he says it may be possible on the north farm due to some marginal land on it. Rick also views COP 28 and its focus on cows as a producer of methane as another hurdle against cattle.
12. Rick says he saw some very intriguing organic farming implements and strategies at Agritechnica, but he thinks organic is not sustainable and that consumers are losing interest. His north farm manager, who is from France, tells Rick that organic premiums have fallen and some French farmers who have been organic for fifteen to twenty years are calling it quits.
13. Rick had no suggestions for other NP farming practices, simply saying, "I am hoping someone can find the silver bullet—that one thing that would fix everything."

Rick says he has never heard a definition of global warming he can buy into and that the climate is changing all the time. For example, he points out how, in the1980s, his friends in Chile thought they were going to become a desert, but now they are too wet. Like most innovative farmers, Rick is motivated by two things: profits and soil health. Both of these factors are critical, as they ensure that his farm is sustainable and stable, which in turn ensures the safety and well-being of his family. In reality, global warming mitigation is not a goal for most farmers: many do not even believe it is real, and those who do view its attenuation as, at best, a co-benefit of soil-building activities (which remove CO_2 from the atmosphere and sequester it in the soil). Rick acknowledges that his ability to grow corn is mostly genetic, but he adds that avoiding a killing frost until late

October does not hurt either. He says he is not eager for an early frost like the one in 2004 that hit the prairies on August 18, resulting in average corn yields of 7 bushels/acre.

Rick says he does not lose sleep over AGW, but he does worry about climate activists who have no real appreciation of what it takes to feed cities that can be home to up to tens of millions of people. He also wonders whether the federal government, particularly the ECCC, is forgetting where the bulk of the food comes from. Despite not being sold on AGW, Rick thinks that he would exceed government targets if they took 2000 as his base GHG starting date. He says he uses less nitrogen with less emissions (4Rs), has a 95% NUE rate, has upgraded to farm equipment that produces only 3% of the emissions from 2000, and has significantly reduced his total fuel /acre due to significantly less tillage. Rick says he would like to see farmers receive inset carbon credits to reward them for doing the right thing and enable them to continue down this path.

Table 4.5.12. Summary of Rick's BERT/E ratings of the various BMPs.

Rick								Max 625
BMP	**As Idea**	**As Practice**	**B**	**E**	**R**	**T**	**E**	**BERT/E**
1 Disturb	100%	75%	4	4	5	4.5	1	360
2 Snow to Snow	100%	21%	4.75	3.75	5	5	1.5	297
3 Diverse	100%	100%	5	4	5	4.5	1	450
4 Armor	100%	80%	5	5	5	5	1	625
5 Alt N	100%	35%	5	5	3	2.5	1	187.5
6 Alt fuel	100%	5%	5	1	5	5	1	125
7 Ag Eco	100%	0%	3.5	2	5	2	2.5	28
8 S I	100%	100%	5	5	5	5	1	625
9 Conserv	100%	0%	3.5	4.5	3	5	1	236
10 Phos	100%	5%	3	2	5	2	4	15
11 Grazer	0%	0%	5	4	5	5	2.5	200
12 Organic	1%	0%	1	1	5	5	4.5	6

Table Note: BERT/E stands for (Believe x Economics X Regulations X Technology)/ Energy to change. Max is 5x5x5x5/1=625. The BERT/E math may not align exactly due to an adjustment made relative to every participant having at least one 625 score and all scores were increased by that factor to put everyone on equal footing.

4.5.12.1 Rick's Comments on His Story

Hi Dave, Very impressive synopsis of our operations. One small change. I have 2 sons: the one with alleges is not involved in the farm. And present doesn't think he will be coming back to the farm. My second son is the ag lender. At present is doing the books for the north farm. And plans in the future to take a more active role. Become the CFO of both farms. The rest is well done and hits the points of our operation and my vision of our operations. Your question on being a Net Positive operation. I think of that a fair bit. I wish government/ Agri policy/ the world in general, could agree on a definition of Net Positive grain farmer. More importantly the calculations that go into the statement. Thanks David, I look forward to your report. Rick

4.6. Research Agronomists

4.6.1. Sam's Story, December 2023

Sam (26) has recently taken over management of the Dakota Lakes Research Farm from Dr. Dwayne Beck who, along with a group of committed local farmers, founded the farm in 1990. The farm, which is owned by 400 farmers, has utilized Zero Till since its founding and has recently expanded to 1100 acres. The farm is located 17 miles east of Pierre, South Dakota, on fragile, low-organic-matter short grass prairie soil. While the area receives about 18 inches of precipitation per year, this moisture is more prone to loss via evaporation due to its more southern latitude (relative to the Canadian Prairies). Thus, one of the farm's original purposes was to find more efficient moisture-management strategies. The farm's primary focus is still finding method to maximize the use of natural rainfall. This led to the development of numerous tools that are dependent on no till, which requires the optimization of diverse rotations, livestock integration, and nutrient management for maximum benefit. Most recently, the farm's directorate set the goal of becoming fossil fuel neutral. The range of cropping systems compared on the farm include continuous corn, corn/soybeans, stacked rotations, and diversified rotations with warm/cool season broadleaf and grasses, with and without a perennial forage phase in both dryland and irrigated systems. Dakota Lakes was included in this study because it is the most focused, practical applied research facility in the Northern Great Plains and a leader in Net Positive farming.

Sam's comments regarding the twelve management areas of the study and their potential contribution to Net Positive Carbon Grain Farming are detailed below.

1. As expected, Sam felt minimal disturbance was of paramount importance, as no till has been the foundation of the work at Dakota Lakes for the past 33 years. Sam says they use disc drills and stripper headers and leave all the crop residue on the land. They have found that, properly managed, no till costs less, and improves the SOM, soil aggregation, and water infiltration, resulting in more stored water and higher yields. However, he notes that herbicide-resistant kochia has recently emerged as a serious concern.
2. Sam says they view growing plants from snow to snow as a good idea and implement this practice in a number of ways. The easiest method is to add a perennial phase to the annual crop rotation and to use the resulting forage for pasture or hay. They have also grown some perennial switch grass for seed. Here, the hay is fed back onto the land and does not leave the farm. Sam acknowledges that crops are worth more than beef, and that economics may not make this a widely adopted practice. Finally, Sam says they also establish fall cover crops, which is easy to do with irrigation and can be done on dry land when there is good rain.
3. Sam also assigned a high rating to plant diversity, noting that she primarily practices it through the use of diverse crop rotations. He says they have used up to eight to ten species but four to six is more common. He further says that they sometimes only use one species in their full season cover crops or cover crops seeded after early harvested winter wheat. He says they are less excited about intercropping due to their moisture deficit region, and that they have found yield drags from alfalfa under seeded with corn. Sam is also not a proponent of growing two or more cash crops together, saying that the work often outweighs the reward.
4. Soil armor is another area to which Sam gave the maximum endorsement. Sam says they use a stripper header to leave high stubble to trap snow and slow down crop residue degradation, which occurs faster when the residue is pushed into the soil. Better snow catch can increase the soil moisture available for the next crop and further increase the potential for more biomass for soil armor. The one area where they exercise extra care is trying to minimize damage to the armor from grazers during wet weather. To do so, they move the cattle to perennial pastures to prevent compaction and excess hoof punching on the less resilient annual crop pastures.
5. Sam says they are very interested in alternative sources of N, with legumes, particularly alfalfa, being their main source so far. However, he says that, even with long-term Zero Till,

they are often forced to use the traditional amount of nitrogen fertilizer, or about 1 lb. /acre for corn and 2.5 lbs./acre for wheat. They have not found any good “Bugs in a Jug” products, but Sam says they are interested in Green NH_3 and have purchased some solar panels, which will supply some of the green electricity needed to make green N.

6. One of the goals of Dakota Lakes is to become fossil fuel neutral. As such, they are very interested in alternative fuel sources. At present, they have a cold press oilseed press and a filtering system, and they have installed solar panels, bought an all-electric pickup truck, and converted a utility vehicle to electric. Sam says that they have not discussed renewable diesel.
7. Agroecological solutions were rated highly by Sam, particularly diversified rotations, and NT as main mechanisms of keeping pests at bay. Diversified rotations, which have a high degree of crop inconsistency, were favored, and Sam observed that the lack of disturbance with Zero Till plus, and the greater resultant soil biology/nutrient cycling, seemed to decrease weeds.
8. Sam says many sustainable intensification tools are good, and he acknowledges the high number of VR applications going on around them. Some work was done with Green-on-Green spraying, but it may have been too early in the evolution of the technology for it to be useful. These tools are a little less applicable on the research farm, but the staff certainly finds autosteer and its resulting ease of operation to be very “nice”.
9. Sam says they have restored the more fragile land on the farm to grasslands, but conversion is still ongoing in the wider area. The economics of corn and soybeans and the high price of land make it an easy decision for some to farm those sensitive areas. He suggests that grazing should be encouraged on conversation reserve program land, as cattle would help build the soil health more quickly, provided they practiced good grazing management.
10. Sam assigned the maximum score to P recycling, as his PhD work focuses on phosphorus, particularly preserving it for as long as possible on the farm. For instance, when they press oilseeds for oil, the meal is fed to the cattle and eventually deposited back onto the land. Similarly, any hay they bale is used on the farm. He further notes that including cattle in the perennial phase of the annual crop rotation or for grazing cover crops is another way to recycle the P on the farm before it is finally sold in the form of grain. They also are looking at the interaction between AMF, arbuscular mycorrhizal fungi, fertilizer P, and available soil P

to determine whether keeping the soil P at about 5 ppm helps the AMF function better, thereby making the otherwise unavailable P available. Finally, Sam says they have not worked with products like struvite.

11. Cattle are an integral part of the research at Dakota Lakes; however, Sam rates the economics associated with cattle as a deterrent. He says it takes careful management to ensure they do not harm the soil when wet weather prevails, but that cattle are essential to the nutrient cycle on the farm.
12. Sam says they have no interest in organic farming because they are not interested in systems that require tillage. Their soil is just too fragile.

Sam says the farm has been on the path towards Net Positive ever since it was founded in 1990. Improved economics decreased the need for fossil fuel, and increased SOC and soil health continue to motivate them to find further improvements. Sam says they have observed a substantial change in their SOM over their thirty-three-year history. Indeed, when they commenced operations, the SOM was 2%; now, it is 3 to 3.5 %. Dr. Beck, the original manager, says he has increased Dakota Lake's SOM by about 1.2%/year, which is three times the UN's target of 0.4%/year. He says the number of large new grain bins around the country is evidence that no till with a diversified rotation not only improves the soil and water use efficiency, but it also has a remarkable effect on the bottom line.

Table 4.6.1. Sam's BERT/E ratings of the various BMPs.

Sam								Max 625
BMP	As Idea	As Practice	B	E	R	T	E	BERT/E
1 Disturb	100%	100%	5	5	5	5	2.5	250
2 Snow to Snow	100%	100%	5	3	5	5	3	125
3 Diversity	100%	100%	5	5	5	5	2	313
4 Armor	100%	100%	5	5	5	5	2	313
5 Alt N	100%	15%	3	2	5	1	3.5	9
6 Alt fuel	100%	25%	5	3	2	2	2	30
7 Agroeco	100%	100%	5	5	3	5	1	375
8 S I	100%	100%	4	3	5	5	3	100
9 Conserve	100%	22%	5	3	5	5	1	375
10 Phos	100%	100%	5	5	5	5	1	625
11 Grazers	100%	100%	5	2.5	5	4	1	250
12 Organic	0%	0%	1	1.5	5	2	5	3

Table Note: BERT/E stands for (Believe x Economics X Regulations X Technology)/ Energy to change. Max is 5x5x5x5/1=625. The BERT/E math may not align exactly due to an adjustment made relative to every participant having at least one 625 score and all scores were increased by that factor to put everyone on equal footing.

4.6.1.1 Sam's Comments about His Story

David:

Here are my edits.

Thanks, Sam

4.6.2. Richard's Story, December 2023

Richard grew up in Rhode Island, where the main crops were turf and Christmas trees (according to him). Consequently, he had no early appreciation for the notion that food can come from somewhere other than the grocery store. Richard has a BSc. in resources development from University of Rhode Island and an MSc and PhD in soil chemistry from Iowa State University. He is currently an Associate Professor at the University of Saskatchewan and is the Ministry of Agriculture

Strategic Research Program (SRP) Chair in Soil Biological Processes. For the past twenty-five years, Richard's research has focused on understanding GHGs in ag systems and developing innovative solutions for enhancing food security and improving environmental benefits, such as increasing carbon sequestration and lowering nitrous oxide emissions. He calls himself a "net zero nerd."

Richard's comments regarding the twelve management areas of this study and their potential contribution to Net Positive Carbon Grain Farming are summarized below.

1. Richard says it is hard to fit one system to all geographies, and that there is no one best BMP for all situations. For example, Zero Till can increase N_2O content in wet areas, such as Ontario, and can reduce it in dryer areas, like Saskatchewan. Conversely, planting cover crops has been shown to reduce N_2O emissions in Ontario but has had little effect in Saskatchewan. Generally, for Saskatchewan, it is necessary to continue to improve Zero Till and to find better ways to incorporate cover crops into the crop rotation. Richard says his major concern with Zero Till is herbicide-resistant weeds.
2. Richard says it is an ongoing challenge to find the right cover crop species and strategies for Saskatchewan. He notes that different solutions will be more effective for different soil zones and even within the soil types in each one. Richard says that the accumulation of more field data will eventually allow them to use AI-based modelling to help build recommendations.
3. Richard says that the adoption of Zero Till and the accompanying switch to diverse rotations has dramatically improved soil health. In particular, soil health and profits benefitted greatly from the decision to abandon continuous wheat production. Richard notes that the use of intercropping has improved soil health in many places around the world. For instance, in Hawaii, farmers have improved their soil health by adding leguminous shrubs to planation crops. In Saskatchewan, Richard says that intercropping canola (or mustard) with various pulse crops has yielded good results, but they are still exploring other options.
4. When Richard arrived at the University of Saskatchewan in 1997, Saskatoon had been covered in precious prairie topsoil by a series of dust storms. Richard says he has not seen anything like it over the past twenty years, as the adoption of Zero Till and the resultant deposition of soil armor has proven effective at preventing soil loss due to wind erosion. Richard further notes that dry, exposed soils degrade faster than covered soil during rain events, and that they are home to less biological activity and, therefore, less soil particle aggregation. When rains do come, a proportionally greater volume of water infiltrates the

healthy armored soil than the exposed soil. Richard has found that the summer sun can raise the temperature of the bare soil to as high as 60C, which can result in the collapse of the soil structure (especially if tilled), as soil organisms die at these extreme temperatures.

5. Richard discussed various alternative N strategies that could replace fossil-fuel-based N. While Zero Till is well-established in Saskatchewan, there has been little research expanding upon Dave Franzen's findings that fields that have been Zero Till for at least six years have an N credit of 50 lbs/acre for wheat (Franzen 2009). Richard says that such work is important. In Saskatchewan, legumes are an important and extensively employed N replacement strategy, with semi-arid-loving legumes such as peas, lentils, chickpeas, and fenugreek, being ideally suited to the area. However, market conditions (i.e., demand) and root diseases (e.g., Aphanomyces) can restrict the number of legumes included in the rotation. Richards says there is hope for "Bugs in a Jug" products, but the first generation of these products work best in more humid climates and on high sugar crops like corn. He expects genetic engineering will be needed to make such products viable for prairie crops, observing that a lot of factors go into getting these products to work, including competition with indigenous microbes and abiotic stresses, such as dry weather. He sees a fit for Green N, but notes that cost and the availability of Green electricity to make the Green-base NH_3 will be major limitations. Richard has worked a lot with 4Rs. Here again there are many interactions. He says that ESN emission reductions respond best with modest fertilizer rates, but that it is hard to convince farmers to pay more for low-emission fertilizer or to use less. Fortunately, researchers are working to develop new products to reduce emissions and increase NUE. For example, AAFC-Ottawa and researchers from the University of Waterloo have been working on a SMART N fertilizer that is based on a drug-delivery technology wherein N is released to the plant based on a DNA signal. Richard notes that increasing NUE to 70% (up from 50% to 60%) could yield strong financial and environmental benefits. Overall, Richard says we will need fossil-fuel-based N fertilizer for the foreseeable future.
6. Richard is curious but sceptical about our ability to replace fossil fuels, at least in the short term. He says electrifying everything also poses problems, particularly being able to get enough electricity and where it will be coming from. These concerns also apply to Green N, which requires Green electricity as well. Finally, Richard questioned how the switch to

biofuels would impact food availability (i.e., whether they would compete for the same land).

7. Richard declined to discuss agroecological solutions, saying that it is more of an organic tool with which he has little experience.
8. Richard thinks the term, “sustainable intensification,” is oxymoronic and suggests I change it to, “sustainable optimization.” He says his main interest is to make fertilizer more efficient with less emissions. He says he uses 4R and variable rate for fertilizer optimization but notes that it is hard to demonstrate the effectiveness of these practices, as it is currently not possible to equip a tractor or drone with an N_2O senser to measure fertilizer-based emissions on a real-time, whole-farm basis. Richard is currently developing networks to capture data, which can then be used to build models that identify which practices should be applied when and where. He says that more data is needed to account for more scenarios, crops, soils, and to increase accuracy. While Richard notes that AI can help them make sense of the acquired data, he says he is concerned about the level of complexity of new research equipment: whereas he used to be able to fix something if it stopped working, this is no longer the case. Richard also expressed concern about data ownership (farmer or manufacturer) and who will profit from it.
9. With regards to conservation and restoration, Richard’s mainly focused on public benefits of leaving some wildland on private farmland. He says more funds should be available for ecosystem services to help preserve these areas.
10. Richard says he is not a “P guy,” and that there are larger issues regarding global warming. Furthermore, Richard points out that there is lots of P and K in his soils.
11. Richard questions why one would use good land for beef production when there is more money in crops.
12. Richard does not conduct any research in organic farming. He says that, while the organic section at Sobey’s has been increasing, nonorganic wheat is just a good as organic wheat. He also questions the merits of using organic techniques when food and land are in short supply throughout the world, especially considering the difficulties of scaling up organic practices. Ultimately, Richard thinks organic is more suited to small mixed farms.
13. Richard says more attention needs to be paid to roots, as plants release 30% to 35% of their photosynthates into the soil through their roots. Thus, optimizing this process would help release more carbon into the soil. The exudates feed the soil microbes, which helps provide

nutrition to the plants and build soil health (e.g., improve SOM, soil aggregation, and water infiltration).

Richard says he has been interested in Net Positive Carbon Grain Garming since the University of Saskatchewan as an environmental agronomist in 1997. Since then, he has focused on finding the optimal balance between production and environmental stewardship. He says that applying zero fertilizer still results in N_2O emissions, and that the land can be a small sink for methane. Currently, he is exploring synergies and how to bundle management practises to help ensure Western Canadian farmers have a low carbon footprint, thus giving them an advantage in the world market.

Richard says he was first exposed to the science and concerns relating to global warming about thirty years ago while attending Iowa State. In general, he says he is deeply frustrated with politicians for using populist rhetoric wile largely ignoring the potential disaster that awaits us. Nonetheless, Richard says he is still hopeful and is trying to do his part by continuing to work on solutions to the problem.

Table 4.6.2. Summary of Richard's BERT/E Ratings of the various BMPs.

Richard								Max 625
BMP	**As Idea**	**As Practice**	**B**	**E**	**R**	**T**	**E**	**BERT/E**
1 Disturb	100%	50%	5	4	4	5	3	266
2 Snow to	100%	8%	5	2	5	3	4	76
3 Diverse	100%	80%	5	5	5	5	2	625
4 Armor	100%	80%	3.5	3.5	5	5	4	144
5 Alt N	100%	20%	2	3	3	2	4	18
6 Alt fuel	100%	40%	5	3	3	3	4	68
7 Ag Eco	0%	50%	0	0	0	0	0	0
8 S I	100%	0%	5	4	5	4.5	2	450
9 Conserv	100%	0%	5	1	2	5	5	20
10 Phos	100%	0%	3	0	0	0	0	0
11 Grazer	100%	0%	4	3	3	5	2	180
12Organic	70%	50%	2	3	5	5	4	76

Table Note: BERT/E stands for (Believe x Economics X Regulations X Technology)/ Energy to change. Max is 5x5x5x51=625. The BERT/E math may not align exactly due to an adjustment made relative to every participant having at least one 625 score and all scores were increased by that factor to put everyone on equal footing.

4.6.2.1 Richard's Comments on His Story

Hi David, I apologize for not responding sooner but it has been an especially hectic semester for me. Anyway, attached is a copy of what you wrote with my edits and comments. You will note that the comments are labeled as from "TE," which just means Technical Editor (a position I hold with a journal). I hope your thesis defence goes well. Rich

4.6.3. William's Story, December 2023

William (Bill) has been a research scientist at AAFC, Indian Head, since 1997. His main area of focus is finding pragmatic solutions to farmers' problems. Bill works at two main sites: the north site, which sits on thin, black, 60% heavy clay soil that has good uniformity and gets about 300 mm (12 inches) of rain in the growing season; and the south site, which sits on thin, black oxbow loam that tends toward being rolling and droughty and receives between 207 to 567mm (8 to 22 inches) of precipitation each year.

Bill maintains the long-term Indian Head plots and works on a wide range of crops including all cereals, canary seed, pulse crops, oilseed crops, hemp, various spices, annual and perennial forages, camelina, and self-seeding cover crops like Black Medic. Bill has worked with virtually all plants that grow on the prairies, with nearly all (99%) of his work utilizing Zero Till. Zero Till is well-understood in the area, as it has become the dominant agronomic cropping system due to its ability to save moisture, which enables higher yields with less variation.

Bill's comments regarding the twelve management areas of this study and their potential benefits in relation to Net Positive Carbon Grain Farming are summarized below.

1. Bill fully supports Zero Till as the dominant crop-production system for the area. He says he hates seeing farmers bring up "light tillage" tools from the USA to fix nonexistent problems, particularly since some of this equipment is erroneously marketed as "low disturbance". He says part of his job is to find ways to effectively convert the extra moisture from Zero Till into farm profits.
2. Bill is not a big supporter of growing plants from snow to snow. He says it could be a good idea in wet years, but, in dry years, the extra plant growth would steal yield from the cash crop. However, he is still exploring which techniques and species work best over the range

of conditions. He points out that fitting crops like fenugreek or lentils into a cropping sequence with hairy vetch might enable more continuous plant growth, as fenugreek is a shallow-rooted, semi-arid-adapted legume spice. Bill says some cover crop practices that have proven successful in Ontario are now being promoted in Western Canada, but that they are unlikely to succeed in the prairies due to differences in moisture availability and length of growing season. Bill believes prairie farmers need to find solutions for their own unique conditions.

3. Bill says it is possible to go overboard on diversity and that four crops (e.g., cereal, oilseed, cereal, and a pulse) in a rotation are often enough. In terms of adding diversity via intercropping, Bill says he has had success with flax/chickpeas and camelina/chickpeas, finding that two rows of flax to one row of chickpeas is optimal for stressing the chickpeas to set seed. Bill says there must be a significant yield advantage to compensate for the added complexity and work involved with intercropping.
4. While Zero Till is critical to maintaining soil armor, Bill says that some of the straw can be baled without decreasing SOM. However, a rotation of canola, peas, and soybeans would drastically reduce soil armor and leave the soil open to erosion. According to Bill, the weakness in the Zero Till system is herbicide resistant weeds, particularly kochia, which is a highly prolific annual summer weed that has proven to be resistant to multiple herbicides, including glyphosate, the foundational herbicide that allows Zero Till to work so well.
5. Bill assigned a low rating to alternative N. He says he recognizes the power of N but knows it will be difficult to find an effective alternative. He says some crops like canary seed respond well after a legume crop, but there is little N advantage in growing legumes prior to wheat and canola. Bill further says that he has not seen the N savings reported by Dave Franzen following at least six years of continuous Zero Till. He thinks Zero Till saves moisture and increases yield potential and, therefore, requires more nitrogen. Indeed, depriving crops of N will decrease yield, and the biomass returned to the soil, which may reduce SOM and, consequently, profit.
6. Although Bill is interested in alternative fuels, they have yet to have a significant effect on his research. His attitude towards alternatives fuels can best be summed up as, “I’ll believe it when I see it”.
7. Bill believes in agroecological solutions, despite not being a factor in his research. He says that, while a full toolbox is critical because one never knows which tool will be part of the

solution, agroecological solutions are not the answer to the questions he is asking. Like many others, Bill tends to associate agroecological solutions with organic farming and sometimes forgets the effectiveness of diverse crop rotations, planting geometry, and fertilizer placement—all agroecological solutions—in reducing the need for herbicide or variety selection for pest control.

8. Bill thinks sustainable intensification tools are great resources and is excited by the constant innovation in this area. However, these tools do not play a significant role in his research work, and he says he has some reservations to the cost of "rented tech," either due to the actual rental agreement or more likely, annual subscriptions or planned/unplanned obsolescence. Bill thinks these tools can make some jobs much easier but points out that they can also introduce an array of complexity and dependability issues.
9. Bill supports wildland conservation. However, aside from his work on prairie fruit and nut trees (he is currently working on intercropping sea buckthorn with hazel nuts), conservation does not play a role in Bill's research. Nonetheless, Bill points out that tree crops provide great habitat for birds and insects.
10. Bill is concerned with P management. He has not worked with struvite or tried integrating cattle or manure into his research work, largely due to the lack of animals on the commercial farms in the surrounding area. He says every system loses P, whether from the export of grains, straw, or hay; through soil erosion from tillage-based systems; via the loss of water-soluble P from water runoff through riparian areas; or through surface crop residues on Zero-Till fields. Bill suggests more P will be needed in the future and that it will need to be better managed. He says there is still lots to learn about subjects like the interaction between P and NUE.
11. Bill does not believe cattle should be integrated on good cropland, as the economics are not viable and cattle can damage annual crop land unless carefully managed. He says cattle should be on land where they can be profitable and a tool for improving degraded land associated with perennial pastures.
12. Bill is not fond of organic farming because he is strongly opposed to tillage. He grew up in Ontario operating a tractor with a twelve-foot cultivator and observing the soil erosion it caused. He says organic grain farming on the prairies feeds less people, depletes soil P and SOM, and promotes weed growth. He says organic farming takes more energy, requires two to three times more management, and is simply too much work. He admits that he has seen

a few good organic farms but notes that most degrade the soil. Bill might be interested in having organic cattle on pastureland or if it was possible to practice organic no till with a source of P.

Bill says that, in some ways, his journey to Net Positive farming began with his early exposure to soil conservation programs back on the home farm in Ontario. Bill says they used to add red clover to winter wheat and planted no till soybeans. Bill says he has been aware of the problem of pollution and its effect on global warming for the last ten to fifteen years, and he acknowledges that it gives him cause for concern. He says he copes with this concern by doing the best research he can, although he cautions against living by the ocean. Bill says he is uncertain how fast the climate will change; he knows it will be worse in the future, but he does not know when that change will occur.

Table 4.6.3. Summary of Bill's BERT/E ratings of the various BMPs.

Bill								Max 625
BMP	**As Idea**	**As Practice**	**B**	**E**	**R**	**T**	**E**	**BERT/E**
1 Disturb	100%	99%	5	5	5	5	1	625
2 Snow to Snow	50%	20%	5	3	5	3.5	1.5	175
3 Diversity	50%	60%	5	5	5	1.5	1	188
4 Armor	100%	100%	5	5	5	5	1	625
5 Alt N	20%	25%	5	5	3	2	3	50
6 Alt Fuel	100%	3%	5	3	3	2	5	18
7 Agroeco	100%	0%	5	5	5	1	3.5	36
8 S I	100%	0%	5	5	3	5	4	94
9 Conserve	100%	5%	5	3	5	5	3	125
10 Phos	100%	20%	5	5	5	2	1	250
11 Grazers	50%	0%	3	1	5	5	3	25
12 Organic	0%	0%	1	3	5	3	1	45

Table Note: BERT/E stands for (Believe x Economics X Regulations X Technology)/ Energy to change. Max is 5x5x5x5/1=625. The BERT/E math may not align exactly due to an adjustment made relative to every participant having at least one 625 score and all scores were increased by that factor to put everyone on equal footing.

4.6.3.1. Bill's Comments on His Story.

Hi David. This is as close as anyone could get. Good luck with your thesis! Bill

4.6.4. Joanne's Story December 2023

Joanne (48) has been an assistant professor in soil chemistry and fertility since 2022, when she completed her PhD. As a student, Joanne worked as a research technician in Dr. Martin Entz's Natural Systems Agriculture Lab, which placed heavy emphasis on organic grain production. To this end, they conducted research trials on black (sticky) clay soil at Glenlea, Manitoba, on Almissippi fine sandy loam at Carman, Manitoba, and at various satellite sites, including a long-term organic farm at Oxbow, Saskatchewan. The Manitoba sites receive between twenty to twenty-one inches of precipitation per year. Joanne has worked with a great range of crops and compared long-term cropping rotations with and without the integration of forages and livestock. She has conducted a range of cover crop trials in conventional, organic, and integrated crop-livestock systems, and she has done work on nutrient management, especially N and P in organic systems. Joanne's current research largely focuses on P and organic production, including extensive experimentation with struvite, a recycled P derived from city wastewater.

Joanne grew up on a mixed grain and beef farm near Austin, Manitoba, where her family continues to farm. Joanne says her dad has a low tolerance for "messiness" in the fields, which means he does not always appreciate organic farming and things like intercropping and covering crops. However, he does appreciate landscape diversity and maintains natural features like tree bluffs within and alongside his fields.

Joanne's comments regarding the twelve management areas of this study and their potential contribution to Net Positive farming are summarized below.

1. Joanne rated minimal disturbance lower than most of the other participants, as she has seen some excellent organic production. She says that annual crops need some disturbance to prevent Aspen-woody brush and prairie grasses from taking over the landscape. She agrees there is a tradeoff between disturbance from tillage and herbicides,

noting that both have a role. She acknowledges that, to encourage more organic farming, people will need to change their mindsets from seeing fields as “messy” to seeing them as sources of “biodiversity and resilience”.

2. Joanne feels that it is difficult to scale planting crops from snow to snow unless there are perennials and cattle. She suggests that the technology and economics of using cover crops for more continuous plant growth are limited for grain farmers.
3. Joanne believes that plant diversity is important. Notably, she says that, while it is easy to incorporate diversity via crop rotations, she is more cautious about the use of intercropping, citing the lack of region-specific knowledge for intercropping-species synergies, seeding geometry, and harvest optimization. Joanne also acknowledges the difficulties and extra resources needed to separate the intercrops into saleable stocks.
4. Joanne says the use of soil armor is a good idea, but that it is difficult to implement on the heavy sticky clay soils of the Red River Valley, where Zero Till is more challenging. In addition, it is also difficult to maintain soil armor in organic systems, as the required tillage tends to disperse it.
5. Like many of the participants, Joanne is unaware of any immediately available N alternatives, apart from using more legumes. She thinks that higher fossil-fuel-based fertilizer prices, possibly through carbon taxes, and continued research will be necessary to motivate the development of alternatives. In the meantime, Joanne says she will rely on 4R fertilizer management to help reduce her emissions.
6. Joanne thinks that economic, logistical, and infrastructure challenges will prevent a quick change to alternative fuels such as hydrogen, NH_3, or biogas for on-farm solutions.
7. Agroecological solutions are an area of keen interest for Joanne, as the organic systems she has worked on in the past rely on these practices. Although primarily knowledge-based solutions, agroecological solutions also represent a mindset change and overlap with many other BMPs on this list. Joanne says that these solutions are largely preventative and are based on understanding the available management options. Because tolerance levels may need to be adjusted from conventional high-input farming, it is important to develop a peer group with a similar level of understanding and appreciation for the practices.
8. Joanne noted that the value of sustainable intensification tools for commercial farmers varied depending on their specific landscape. However, she says she does not rely on any of

these tools in her research. Joanne's work more directly contributes to the knowledge required for tools like 4R to work.

9. Joanne assigned high ratings to the concepts of conservation and restoration, but she acknowledged the poor economics of leaving farmable land wild. Nonetheless, she says she supports wildland conservation programs, such as ALUS.
10. P recycling is Joanne's current area of research. She believes that P must be recycled, as it is a finite resource and is integral to sustainable agriculture. Joanne has conducted numerous field trials with struvite, a major source of P recycled from city waste waters, and she has promoted its use on organic farms. Getting sufficient P is a major limitation for large organic grain farms that have little or no access to animal manure. Joanne also discussed the importance of keeping P out of rivers, lakes, and oceans, noting that the environmental costs of not sequestering P from wastewater far exceed the logistical costs of doing so.
11. Integrating animals onto the farm is a key element of Joanne's holistic approach, but she conceded that the associated economics were not very good. However, she pointed out that cattle had been successfully integrated onto grain farms whose owners had managed to develop meaningful relationships with nearby cowboys/cow people/ranchers.
12. Joanne said organic farming is an excellent idea for some farmers but is not a solution for Western Canada in general. She said the major hurdles to organic farming are tillage, a good source of P, education and training, and the cost of transitioning one's operations.

Joanne says she likes the term, "Net Positive," because it challenges us to move beyond net zero. Joanne became aware of global warming in the early 2000s, prior to the publication of Al Gore's, *An Inconvenient Truth* (2006). She says that part of her interest was inspired by her early work with Dr. Entz, which partly focused on energy conservation and, later, GHG emission mitigation strategies. Joanne is glad to see interest in regen ag but recognizes that the majority of farmers remain unconvinced.

Ultimately, Joanne says climate change mitigation is a motivating factor for her research program, but she does not lose sleep over AGW. However, she admits that she is worried and can become anxious or angry when thinking about the threat posed by AGW and the government's "unwillingness" to act on it. To assuage these feelings, Joanne focuses on her research and connecting with others who are trying to make a difference.

Table 4.6.4. Summary of Joanne's BERT/E ratings of the various BMPs.

Joanne								Max 625
BMP	**As Idea**	**As Practice**	**B**	**E**	**R**	**T**	**E**	**BERT/E**
1 Disturb	70%	50%	4	3	5	3	2	140
2 Snow to Snow	100%	60%	5	2	5	3	1	234
3 Diversity	90%	60%	5	4	5	4	1	625
4 Armor	100%	50%	5	4.5	5	4	3	234
5 Alt N	100%	60%	5	2	5	3	1	234
6 Alt Fuel	100%	20%	5	1	5	1.5	3	20
7 Ag Eco	100%	80%	5	3	5	3	1	352
8 S I	50%	10%	3	3	5	3	4	53
9 Conserve	100%	60%	5	1	5	5	1	195
10 Phos	100%	90%	5	4	5	4	1	625
11 Grazer	100%	80%	5	2	4	4	2	125
12 Organic	100%	50%	4	4	5	5	1	625

Table Note: BERT/E stands for (Believe x Economics X Regulations X Technology)/ Energy to change. Max is 5x5x5x5/1=625. The BERT/E math may not align exactly due to an adjustment made relative to every participant having at least one 625 score and all scores were increased by that factor to put everyone on equal footing.

4.6.4.1. Joanne's Comments about Her Story

Hi David,

Just a few minor tweaks to the write-up – see attached. Thanks for sharing. Joanne

Chapter 6 Appendices:

6.6.1. Calculations for On-Farm Biofuel and Land Required

Assumptions and calculations:

1. 10 l/acre is sufficient to satisfy farm-motive needs on modern Zero-Till grain farms.
2. This does not include grain drying, which is often a choice of crops grown and varieties selected.
3. Canola yields an average of 50 bushels/acre with an average oil content of 37% and 63% meal.
4. 37% x 50 bushels/acre x 50 lbs./bushel = 925 lbs. of oil/acre.
5. 925 lbs. are roughly 92.5 gallons, which is equal (x 4.54 liter/gallon) to 420 liters/acre.
6. 1 acre needs 10 liters of fuel.
7. 10/420 x 100 = 2.3% of land to produce the oil to power the farm.
8. Minus the meal that is produced.
9. Since this figure is 63%, we can reduce the net land needed by 2.3 – (2.3% x .63) = **0.8% net land.**
10. Soybean calculation would be similar with different % oil and meal but similar net.

6.12.3. Recommendations for Improving BMPs

Lack of disturbance and armor on the soil:

1. Develop strategies to ensure Zero Till is not made obsolete due to lack of weed control.
2. Find a way to extend the use of Zero Till to more acres in Western Canada—green seed, benefits of mature Zero Till, micro till for soybeans and corn, strip till.

Greater plant diversity and plants from snow to snow:

3. More research and extension on intercrops—species, seed rate, seeding configurations, weed control, disease, and insect implications, and optimizing harvest and marketing.
4. Provide crop insurance to encourage vs. discourage plant diversity and the use of cover crops (snow to snow).
5. Develop better cover crop establishment systems that are economical and scalable.
6. Support the development of delayed germination seed technology.

7. Reward farmers for sequestering carbon. It is a public good and a benefit to their farms, but it is also a long-term investment.
8. Volunteer crops have become cheap cover crops. Learn how to manage them, and how to measure their benefits and impact on subsequent crops.
9. Screen species for the ability to establish when broadcast. Farmers in the USA have broadcast cover crop seeds with aircraft, from high-clearance applicators, and from broadcasters mounted behind the headers on combines. Having healthy friable soil with lots of soil aggregation would be an advantage compared to a hard-to-penetrate smooth soil.
10. Screen species for synergies in multispecies mixtures.
11. Screen species and varieties of cover crops for their suitability in the various regions of Western Canada.
12. Screen species for drought tolerance.
13. Search for hardy winter annuals to be used as cover and the base for green seeding. Fall rye works ahead of broadleaf crops. A winter annual broadleaf crop, especially a legume, would be helpful.
14. Breed for cover crop varieties suitable to Western Canada (there are USA breeding programs for fall rye and hairy vetch to make them more suitable as cover crops).
15. Look at new technology to shoot/spray the seed into the soil (e.g., the QuadApplicator by R. A. West from Vulcan AB).
16. Evaluate species for their ability to sequester carbon.

<u>Alternative nitrogen</u>:

Recommendations to increase annual legumes as an alternate N strategy:

17. Improve disease and insect resistance.
18. Work to develop more biologically active soils that can help regulate/control disease and insect vectors, as well as help reduce soil weed seed banks.
19. Continue breeding for improved agronomic and market traits.
20. Continue to develop markets for these crops, particularly for their valuable protein isolates.

Recommendations for Zero Till as an alternative N strategy:

21. Conduct N response trials with long-term Zero Till.

22. Examine whether adding biology such as Kelly's IMOS to short-term Zero Till can speed up the N credit process.
23. Develop extension material supporting continuous Zero Till and tackle the myth of tillage needed for soybeans.
24. Develop a Zero-Till Plus approach that incorporates regenerative practices to further strengthen soil building with Zero Till.
25. Develop strategies to allow clover, alfalfa, and perennial grasses to be used with Zero Till, biologically break up hard pans and redistribute nutrients in the soil.

Recommendations for Bugs in a Jug as an alternative N strategy:

26. Develop policy and support to encourage effective biological N fixation for non-legume crops.

Recommendations for Green NH_3 as an alternative N strategy:

27. Develop policy and support to encourage cost effective Green NH_3 production, whether it be world-scale or farm-scale.

Recommendations for 4R N management:

28. The principles of 4R need to be continued and research emphasis changed to solutions that can minimize N emissions and, ultimately, eliminate fossil-fuel-based N by 2050.

Recommendation for rhizophagy nutrition:

29. Research scientists and farmers should take a serious look at the IMOS system, making sure to use appropriate checks and replication where possible. An IMOS club may already be underway.
30. Look for ways to ensure that it is suitable for a wide range of crops and any yield gaps are minimized.

<u>Alternative fuels</u>:

31. Farmers and farm groups should lobby governments to ensure that any incentives for using renewable diesel should prioritize agriculture. Agriculture also must be prioritized with respect to access to renewable diesel.
32. Develop a strategy to support biodiesel production unless renewable diesel is a clear winner.

33. Develop a strategy to give farmers carbon offset or inset credits for using renewable fuel on their farms, particularly if they grow Net Positive oilseed crops.
34. Do not waste time investigating the use of H_2 or electrifying large continuous-duty farm equipment.
35. Develop emissions-reduction kits for older farm equipment that will allow them to comply with more current standards. With Zero Till, tractors are used much less and remain very functional, even after 30 years. However, old tractors have high emissions. Cummins offers retrofits for emission reductions, but not for popular engines such as the 855 and N14 engines used in many large tractors. Currently, there is no demand. Certainly, some farmers have had trouble with the latest emission equipment, making new equipment unreliable. Therefore, they have bypassed those systems, resulting in higher emissions. Many of our large ag tractors run only 200 hr/year. We need to find a sweet spot where older tractors emit much less, new tractor are dependable, we need to consider the potential use of renewable diesel, the low hours of use plus reducing the need to replace the older tractors with new steel.
36. Embrace renewable electricity, as costs are continually falling. Airloom was discussed as a newer cheap alternative to making electricity from wind. There continues to be opportunity for innovation and cost reduction. Renewables have already made coal obsolete in many regions.

<u>Agroecology:</u>

37. Research to ensure healthy biological active soils.
38. Continue research to reduce or eliminate the need for agrochemicals, including fossil-fuel-based nitrogen through the regeneration of health soils.

<u>Sustainable intensification</u>:

39. These sophisticated and high-capital-cost items come with a need for intensive IT. This may require specialized staff on-farm to determine what pays, how to get the most from it, and how to keep it running. This places smaller farms without specialist staff at a disadvantage. The average age of farmers may also be a factor in the lack of enthusiasm for learning and using some of this technology.
40. Companies should not be able to collect data from farmers for free and then charge them back for the information unless there is a guaranteed ROI for the farmer.

41. This technology is far beyond two highly skilled farm boys putting steel and hydraulics together to make the first precision banding hoe drill, as was the case with the talented Beaujot brothers, which resulted in the two rival Zero Till drill manufactures, Seed Hawk and Seed Master. Farmers could easily be held hostage, as companies have annual subscriptions fees, service fees, and either planned or unplanned obsolescence based on what the majority can pay. The major farm machinery companies may decide to include some of this technology in their fleet discounts to win over a mega farm account, leaving the smaller, independent, non-fleet farms further behind. It is not difficult to see why some are reluctant to buy into all the elements of SI.
42. Policies are needed to ensure that we do not decimate the farm and rural population in the quest for high-input autonomous farming models. Please look carefully at the SFI results in Chapter 6.

<u>Conservation and restoration of wildlands</u>:

43. Any conversions would have to have special and detailed government approval. Those conversions would have to be viewed through something like the SFI, wherein applicants would have to show realistic contribution margins, Kcal/acre, emissions, and +/- changes in SOM. These data would have to be based on real-life experience or numbers generated from "model" farms with similar soil and climatic conditions. Some of this data would be available through crop insurance records. This would also help ensure conversion of unsuitable lands become a burden on the public due to high crop insurance pay out on this type of land or that fragile lands are further degraded.
44. Ban all conversion projects. Learn to live with what we have.

<u>Phosphorus management</u>:

45. Phosphorus is a non-renewable resource and needs to be recycled.
    a. Future food production is dependent on our ability to capture and recycle phosphorus.
    b. The environmental cost of P in rivers, lakes, and oceans is enormous and is the cause of dead-zones in many water bodies around the world.
46. The ability to replace P on Western Candain organic grain farms is difficult, and certification of struvite from human sources would be beneficial to that sector.

Integrating grazers:

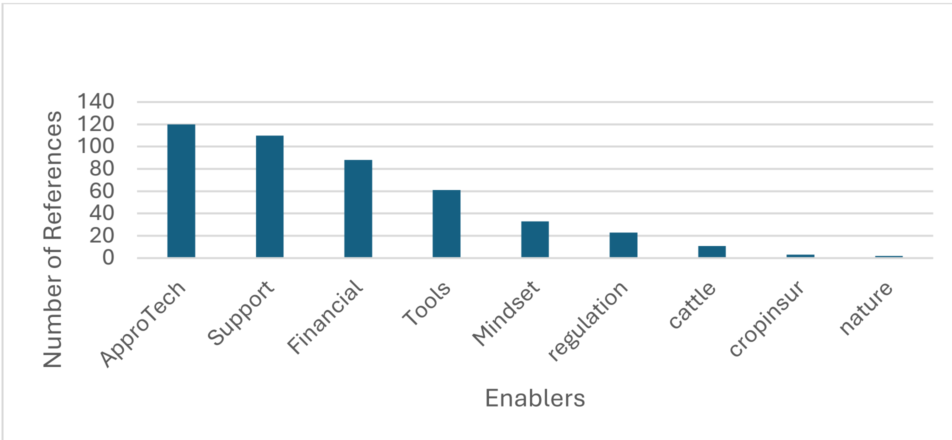
47. Be careful not to oversell the integration of cattle on to cropland. Most grain farmers are not interested and, unless there is a wholesale change in the way cattle are raised, the way science construes cattle on grasslands as high-emission emitters, and the public's negative perception of cattle's role in the food chain, a return to a system that more closely bio mimic the roaming herds of pre-settlement grazers does not seem feasible.
48. The majority of the good quality land in Western Canada is used for grain production. Rather than trying to integrate cattle onto grain farms, let’s focus on what researchers and grain farmers can to reduce emissions and enhance carbon sequestration without the complexity of cattle.

Adoption of organic farming:

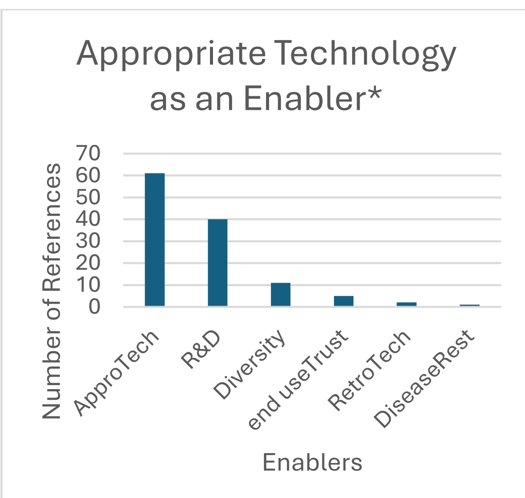
49. Do not promote organic grain farming. It is a costly food alternative and difficult to make sustainable and scalable for Western Canada. Some people, including farmers, may be sensitive to some pesticides. Organic farming is a way for them to farm and supply product to similarly sensitive individuals.
50. Organic should be able to sustain itself for the few that might need it.

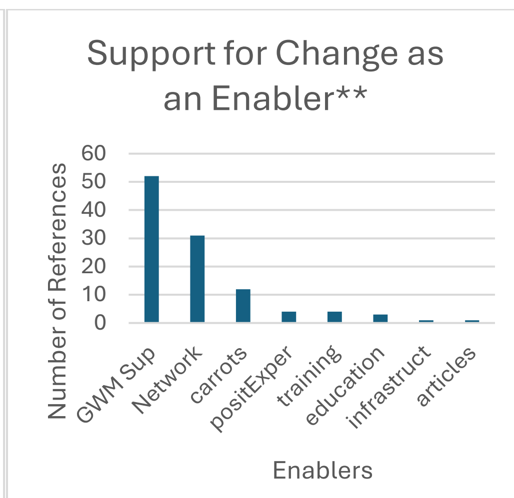
6.14. Enablers and Barriers References: Categories, Breakdown, and Frequency

6.14.1. Enablers



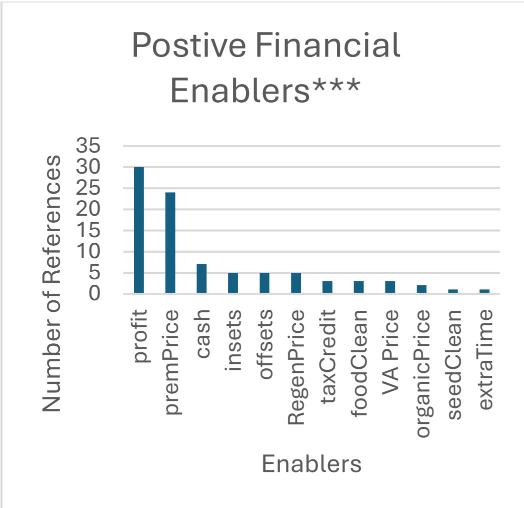
Enablers Legend: Appropriate Technology, Technical Support, Financial Support , Tools, Mindset, Supportive Regulations, Favourabe Cattle Situation, Favourable Crop Insurance, Favorable Situation with Nature.

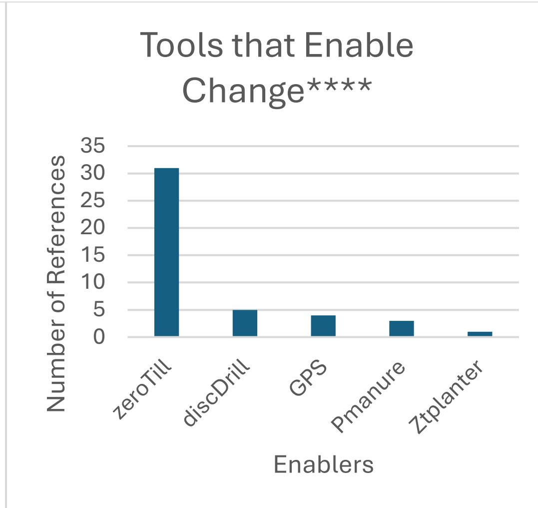




*Appropriate Technology, Favorable Research and Development, Good Diversity Opportunities, Favorable End-Use Trust, Technology to Retrofit, Disease Resistant Plants.

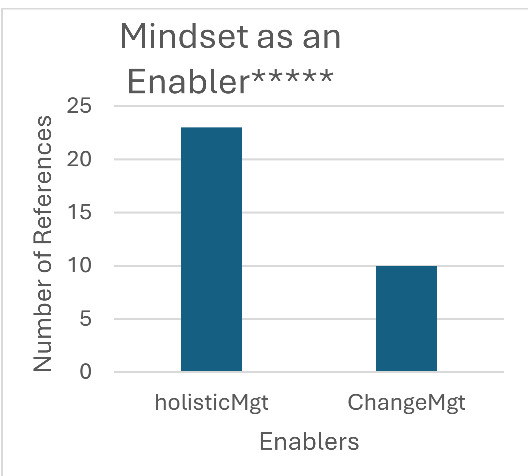
**Global Warming Mitigation Support, Networks, Carrot-Incentives, Positive Experience, Good Training, Good Education, Available Infrastructure, Helpful Articles to Read.

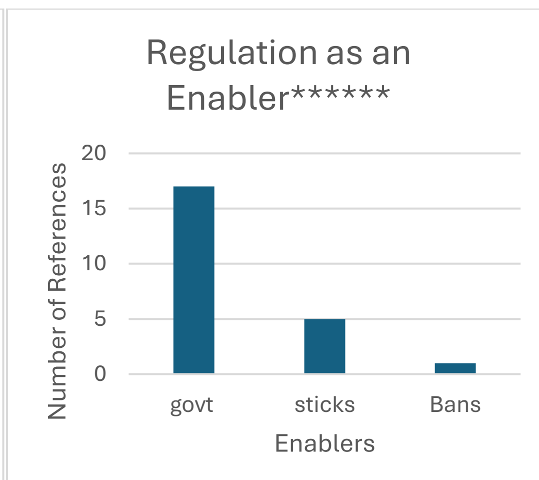




*** Profitable, Premium Price, Good Cash Flow, Inset Credits, Offset Credits, Premium for Regenerative Product, Tax Credits, Value Added Grain Cleaning and Food Processing, Value Added Price, Organic Price, Value Added Seed Cleaning, Extra Time.

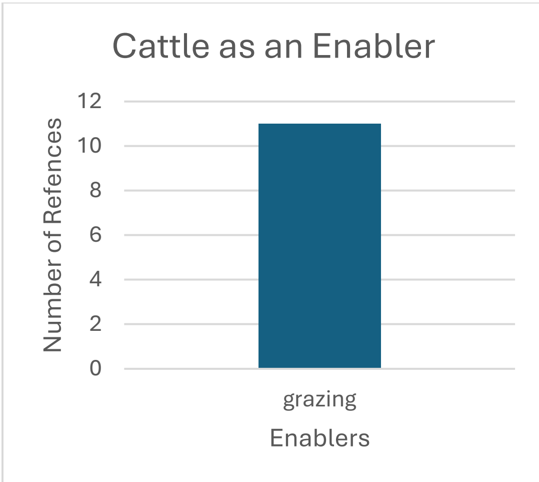
****Zero-Till Technology, Disc Drills, Global Positioning Technology, Pig Manure, Zero-Till Planter.





***** Holistic Management, Change Management.

****** Favorable Government Regulation, Stick Type Regulation, Bans on Certain Practices.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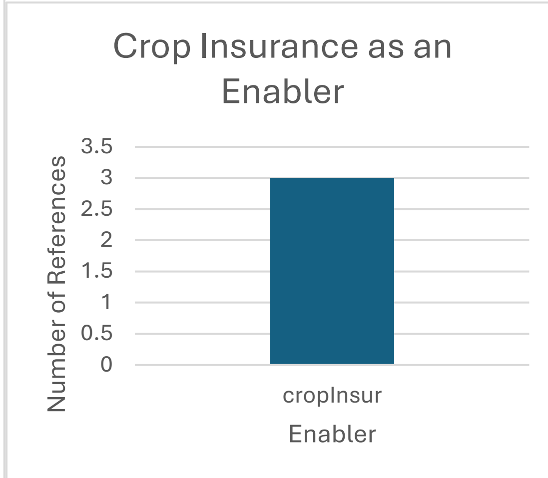
Crop Insurance as an Enabler
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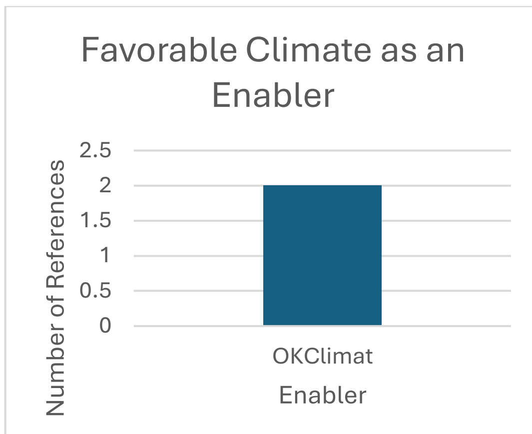
Favorable Climate as an Enabler
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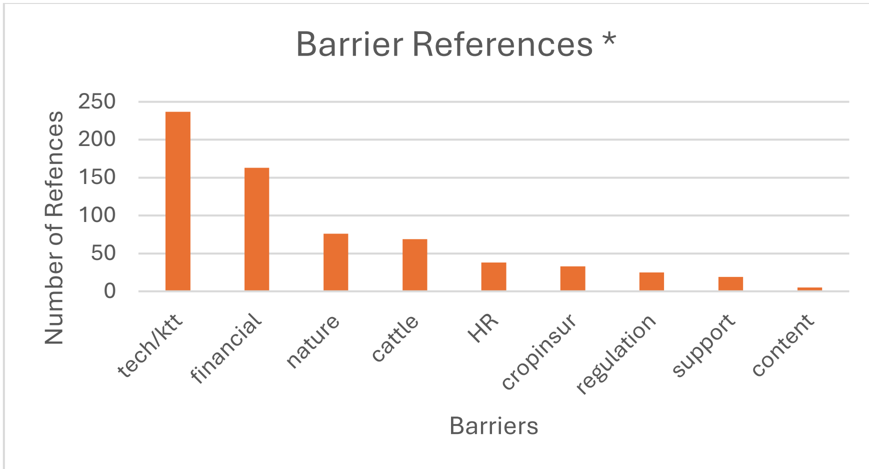
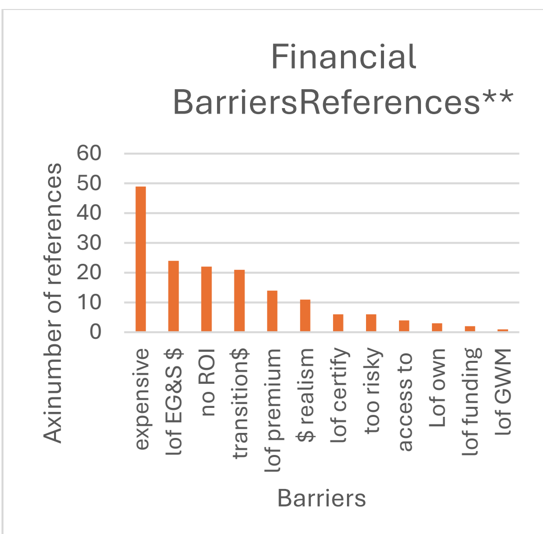
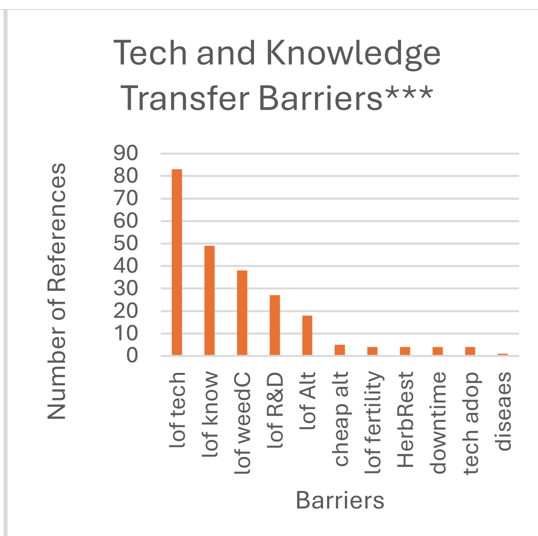
6.14.2. Barriers



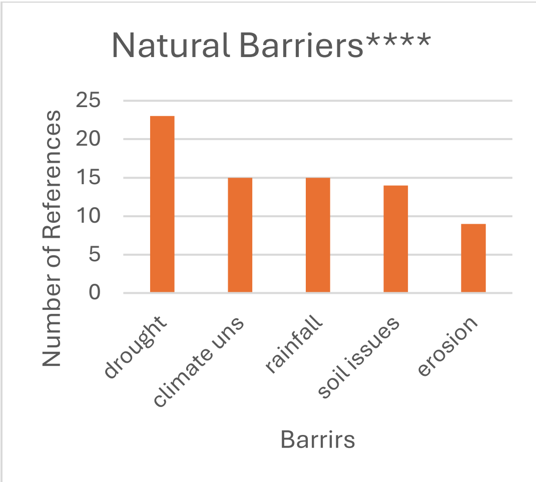
*__Barrier Legend__: Poor Technology and KTT, Poor Financial Conditions or Support, Unfavorable Natural Conditions, Poor Situation for Cattle, Human Resources—Labor and Management Shortages, Inadequate Crop Insurance, Unfavorable Regulations, Inadequate Support, Too Content to Change.

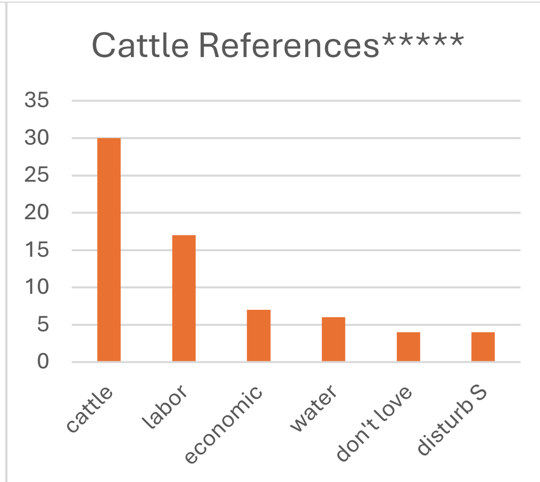




** Too Expensive, Lack of Money for EG&S Projects, No Return on Investment, High Transition Costs, Lack of Premium for Practice, Incentives Too Small, Lack of Funds for Certification, Too Risky, Limited Access to Funding, Lack of Opportunity for Ownership—Related to Long-Term Investments, Lack of Money, Lack of Funds for AGWM-BMPs.

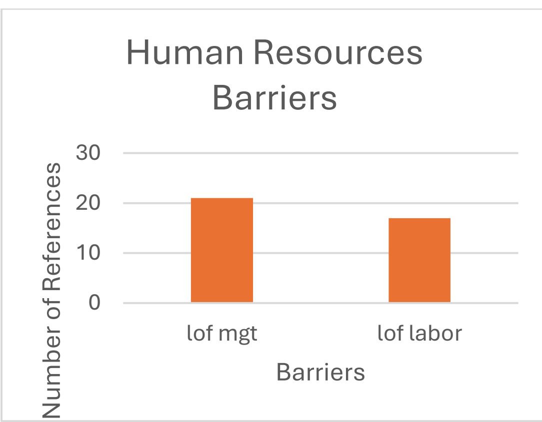
*** Lack of Money to Invest in Technology, Lack of Knowledge, Lack of Weed Control Options, Lack of Money for R&D, Lack of Alternatives, Lack of Cheap Alternatives, Lack of Fertility Options, Problems with Herbicide Resistance, Too Much Potential for Downtime, Hard to Adopt Some New Technology, Uncontrolled Plant Disease.

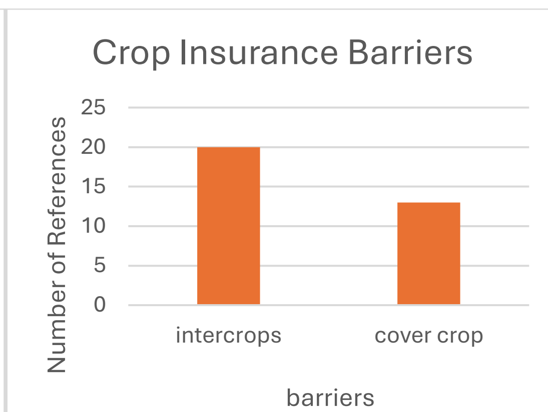


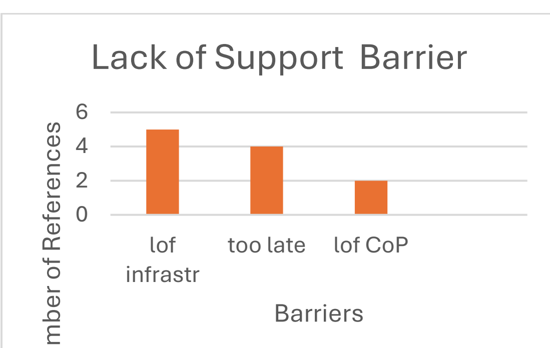


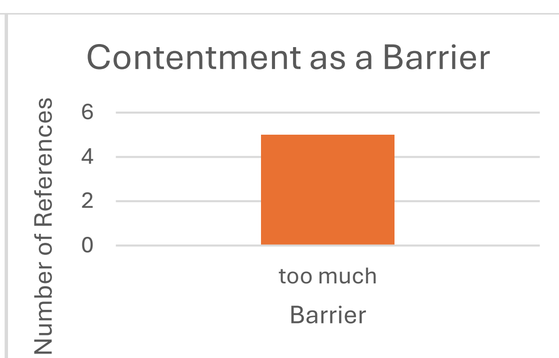
**** Too Much Drought, Climate Unstable, Rainfall Issues, Soil Issues, Uncontrolled Soil Erosion.

***** Cattle Issues, Need for More Labor, Poor Economics, No Water, Don't Love Cattle, Disturb Sleep and Safety.









Chapter 7: Appendices

7.2. Participant Post-Interview Survey: What is Next?

7.2.1 Survey Introduction

Global warming has been caused by using fossil-fuel-based products and the conversion of land to agriculture, roads, and cities. Everyone contributes, but the highly industrialized Global North contribute the most. Canada is tenth in terms of global emissions per capita based on fossil-fuel usage but first when land and use changes are accounted for (Climate Watch 2022).

I asked the participants to tell me what, in their opinions, are the next step(s). One farm can be perfectly Net Positive, but it will all be for naught if it is the only one. The following sections detail the survey material that was sent out to the participants and summarizes their responses.

7.2.2. Survey: What is Next?

The survey was sent to all sixteen the participants, along with a little background information from the thesis findings. The survey background is shown below in Italics.

Net Positive Carbon Grain Farming Participants

One more request

Net Positive Carbon Grain Farming is a Forward-Looking Project. It is a response to the international recognition that the Earth is warming, and it is largely due to the burning of fossil fuels and cultivation of lands--- releasing unprecedented amounts of GHG into the atmosphere. I am searching for ways to convert this problem into an opportunity for Western Canadian Grain Farmers

I have included a brief table of descriptors for each of the participants- (in case you are interested).

I would like to have you complete a quick survey and return it to me. Now that this work is nearly completed the next step is to ask your opinion on - What is Next?

My assumptions shared with the participants were:

1. *The Net Positive needs to be a Triple Win – Support the Farm, feed the Cities, and Heal the Planet.*
2. *Rural life and community are important.*

3. *While this project has identified Net Positive farmers much more work is required for this to be a general practice. The key will be biological N fixation and Green N with optimized carbon sequestration.*
4. *Regardless of the government of the day the combination of international recognition of global warming and corporate action will result in a change at the farm. We are better to recognize the opportunity and be part of the solution. Small and Medium sized farm may need to band together, or investment will go to mega farms who are Net Positive. They will be able to afford the research, MRV, the latest low emission equipment and specialists in-house to respond to the Scope 3 emission reduction targets.*
5. *I have tried to paint each farm as a valuable member of our farming mosaic, each contributing in their own way. Dorian one of the participants is my daughter who is well on her way to becoming the farmer of our farm.*

Table 4.1 Who participated---Key descriptor of participants (borrowed from Chapter 4).

Farm	***Soil Zone***	***Location***	***Major Farm Feature***	***Input Level***	***Cattle***	***Belief in AGW****	***Need for Change***	***SFI - Par** Score***
Josh	*Brown*	*Claresholm, AB*	*Regen ZT Disc Drill*	*Medium*	*Always*	*High*	*High*	*1.4*
Derek	*Brown*	*Minto, SK*	*Regen ZT Disc Drill*	*Very low*	*Custom*	*High*	*High*	*5.8*
Kelly	*Brown*	*Max, ND South of Minot*	*ZT & IMOS- Disc Drill*	*Ultra low*	*Never*	*High*	*High*	*14.3*
Cliff	*Dark Br*	*Hardisty AB*	*ZT - 25%full CC- Disc Drill*	*Medium*	*Always*	*High*	*High*	*1.8*
Brandon	*Thin Blk*	*N of Minot, ND*	*Regen ZT- Disc Drill*	*Low*	*Seldom*	*High*	*High*	*2.4*
Darren	*Thin Blk*	*Deloraine, MB*	*Regen ZT- Disc Drill*	*High*	*Seldom*	*M-H*	*High*	*1.3*
Kristjan	*Thin Blk*	*Moosomin, SK*	*Zero Till Prec Hoe Drill*	*Very high*	*Fall*	*Low*	*High*	*1.3*

Ian	*Thin Blk*	*Oxbow, SK*	*Organic*	*Ultra low*	*Never*	*High*	*High*	*3.2*
Dorian	*Black*	*Minto, MB*	*ZT Plus Disc+HoeDrill*	*Medium*	*Never*	*High*	*High*	*1.9*
Mike	*Moist Blk*	*Melfort, SK*	*Regen ZT Disc+HoeDrill*	*Medium*	*Maybe*	*M-H*	*High*	*1.9*
Dan	*Moist Black*	*Starbuck, MB*	*Flex-ZT-Disc Drill*	*Highest*	*Unlikely*	*High*	*High*	*1.5*
Rick	*Moist Black*	*Gross Isle, MB*	*Flex-ZT, strip till, Disc Drill*	*Very high*	*Never*	*low*	*High*	*1.8*
Research	*Agronomist*							
Sam	*Brown*	*Pierre, SD*	*Diversified ZT-Disc Drill*	*medium*	*Always*	*High*	*High*	
Richard	*Dark Brown*	*Saskatoon, SK*	*Mostly ZT*	*Variable*	*No*	*High*	*High*	
Bill	*Thin Black*	*Indian Head, SK*	*Zero Till PrecHoe Drill*	*Variable*	*Never*	*High*	*High*	
Joanne	*Moist Blackl*	*Winnipeg, MB*	*CT/Organic/ ZT*	*Variable*	*Maybe*	*High*	*High*	

The table is set up based on soil zones. With the driest zone, Brown- short grass prairie, at the top of the table and Moist Black- tall grass prairie, at the bottom. Not everyone is total convinced that the climate is changing or that it is anthropogenic. Everyone believes in improving soil health, but for the majority profitability comes first.

AGW—anthropogenic (human caused) global warming. We collectively burn the equivalent of 100,000,000 barrels of oil/day or 4.9B tonnes/year. Contrast this to the 230 million tonnes of vegetable oil produced each year.*

*SFI**—Sustainable Farm Index = Contribution margin ($/ha) x food energy output (Kcal/ ha) divided by Net Emissions (Kg CO2eq/ Ha)*

A few highlights

Not all BMPs are Created Equal according to BERT/E = Believe+ Economics +Regulation+ Technology/ Energy to change

I included responses as measured by BERT/E to your experience to 2 "Beneficial Management Practices". Armor on the soil is essentially Zero Till; it was well accepted. The next chart is Plants from Snow to Snow and in an annual crop scenario is cover crops. It is not well adopted. The third chart identifies farms that are Net Positive. The two farms below the line are Net Positive. The fourth chart highlights the value that was placed on Zero Till.

These illustrate some of the findings from our work together. If you have any questions, please let me know.

7.2.3. Survey: Analysis and Findings

		ALL	*farmers*	*Res Agronomist*
1.1	Is Net Positive Carbon Grain Farming an important goal?	3.9	4	3.8
1.2	Is it better to call it Net Zero Carbon Grain farming?	2.1	2.4	1.5
1.3	Is it better if we call it Farmers for Soil Health	2.6	2.5	2.8
1.4	Your suggestion			

What are the next steps? 1=personal interested, 2=someone should do it, 3=maybe it should happen someday, 4=probably not necessary, 5=no way I would support that.

	The term Net Positive can be replaced with your preference above	All	Farmers	Res Agronomist
2.1	Are you interested in participating in a Net Positive participant meeting	1.6	1.4	2.3
2.2	Are you interested in participating in a Net Positive workshop	1.7	1.5	2.3
2.3	Are you interested in being a member of a grass roots farmer led Net Positive Network	1.8	1.5	2.8
2.4	Should an NP Network focus only on agronomic solutions	2.9	2.9	3
2.5	Should an NP network negotiate value for Net Positive supply chain or value chain	2.1	1.7	3.3
2.6	Should an NP Network form an alliance with food companies to develop a strategy and plan to reduce Scope 3	2.3	2.1	3

	emissions. Scope 3 emissions are the emissions coming from the supply chain including all aspects of growing, storing, and transporting the crop to the food companies. Over 7900 companies including the largest food companies have made pledges to be net zero by 2050 or sooner.			
2.7	Should an NP Network negotiate carbon inset value for research funds to fill gaps. Develop a mutual partnership to develop BMPs which are economically and logistically possible on a scalable basis.	2.2	2.1	2.5
2.8	Should an NP Network negotiate policy voids with governments and food companies to ensure net zero or Net Positive goals are met.	2.4	2.3	2.3

7.2.4. Conclusion: What is Next for Net Positive?

The short survey affirmed that the participants connected to the term, "Net Positive.” Since it is a unique term compared to "net zero" or "soil health," this result was somewhat surprising ("Net Positive" was rated 3.9/5 compared to 2.1/5 for "net zero" and 2.6/5 for "soil health"). One of the farmers, Mike, gave all the terms a rating of 1/5, stating he thought labels caused division and we should not dwell on them.

There was good farmer support for a follow up meeting to discuss Net Positive (1.5/5 with 1 being full support). This is a reversed scale compared to questions 1.1-1.3. The research agronomists were also supportive, but only at a 2.3/5 level. There was similar support from the farm participants for a Net Positive Workshop (1.5/5) and a Net Positive Network (1.5/5), with research agronomists being a little less enthusiastic (Workshop: 2.3/5, Network: 2.8/5).

The next questions focused on trying to determine the scope of activities that a grass roots farmer-led Net Positive Carbon Farming Network might tackle. There was support for the Network to be more than just an agronomy/production-orientated organization. It is difficult to know if there was more support for the expanded role due to the poor wording of question 2.4, as this question had the greatest variability in answers. The subsequent responses to questions 2.5–2.8 indicate that there is support for an expanded role for a Net Positive Network over and above a production focus. There was support for the involvement of a Net Positive Network in negotiating value for a

Net Positive supply chain by helping food companies understand and invest in Scope 3 emission reductions. The network could also help innovate and prioritize research that aims to advance Net Positive practices through contributions by food companies and governments. Lastly a Net Positive Network could help governments and food companies invest in policies that are pragmatic, equitable, economic, and logistically feasible within a Western Canadian context. While all the above-mentioned activities are legitimate next steps, they are also outside of the scope of this thesis.

7.12.1. Deficiencies of Monoculture Zero Till

While Zero Till has been a drastic improvement over a tilled summerfallow-based system, some unsolved problems remain. These have been observed on Rourke Farms (Rourke 2021) and include:

6. Not using rain where it falls.
7. Increased loss of productive land from saline seepage, perhaps aggravated by monoculture Zero Till.
8. Depletion of over 50% of the native SOC.
9. Excessive runoff—downstream flooding.
10. Nutrient loss: atmospheric, downstream, and into groundwater.
11. Heavy reliance on fossil-fuel-based fertilizers, motive fuels, and the release of GHGs.
12. Relatively low efficiency of commercial fertilizer.
13. Increased resistance to pesticides, including herbicides.
14. Increasing non-target, negative effects of pesticide applications.
15. Traces of pesticides in food.
16. Continued, albeit lower, amounts of soil erosion.
17. Lack of integration of livestock for soil building.
18. Continued loss of habitat for natural biodiversity.
19. Low margins and little leftover to support the local community.
20. Continued depopulation of our rural landscape.