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ATTITUDES & PERCEPTIONS TOWARDS NITROUS OXIDE REDUCTIONS IN CROP PRODUCTION

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ABSTRACT.

The pressure to change agricultural practices in order to mitigate emissions is high, with persisting environmental, social, and economic dimensions. In December 2020, the Government of Canada released *A Healthy Environment and a Healthy Economy*, a climate plan that proposed Canada's first national emission reduction target for the agricultural sector. This target aimed to reduce fertilizer-based emissions by 30 percent of 2020 levels by 2030. This target relies on the adoption of Best Management Practices for fertilizer use at the on-farm level. Choice to adopt the emission reduction strategies and practices is ultimately decided by the landowner, operator, and/or producer. The proposed target was met with significant resistance opposition from producers and producer groups across Canada's agricultural sector, particularly in western Canada, with claims that the target was the equivalent to a ban on fertilizer.

This research aims to better understand the attitudes and perceptions towards the emission reduction target and more generally around emissions mitigation strategies within the crop sectors. This report takes a qualitative approach by conducting 26 hour-long interviews with stakeholders along the production chain. Interviews with producers, geneticists, actors in crop inputs and manufacturing, and stakeholders in agricultural production policy and advocacy were conducted over July and August 2022. Participants were asked questions about climate change, the role of different levels of government in the development of emission regulations, potential strategies on a short- and long-term horizon basis, and incentives. Interviews were transcribed and categorically defined, highlighting reoccurring themes. These themes provide insight into awareness of different strategies considered by different actors within the agricultural supply chain, and potentially anticipate avenues which the Government of Alberta should prioritize in developing policies. Ensuring future protocols account for benchmarks of current agricultural operations and management is critical for accessible and producer-inclusive policy, that optimizes transition risks and secures the pathway forward, balancing the precarious equilibrium of burden on agricultural producers, food security, and sustainable, resilient agriculture.

HIGHLIGHTS & POLICY RECOMMENDATIONS.

The following generalized policy recommendations are meant to serve as a foundation to be further refined and built upon, so different industries can adapt based on current operational benchmarks and future sector growth across stakeholders in the production and supply chain.

The development of carbon credit protocols should be specific to actions measurable at the on-farm level, facilitating the verification process. Qualification for offsets must be straightforward and simple, with minimal administrative and resource burden assumed by producers. Carbon offsets have demonstrated significant uptake amongst producer groups in the past (i.e., the Conservation Tillage Protocol); therefore, using carbon credits as a tool to drive adoption of BMPs and emission reduction strategies should be integrated into future course of action by the provincial government.

- Framing around emission mitigation strategy adoption should centre on how adoption would drive higher operational and on-farm efficiency, to better engage with primary producers. Emissions are perceived as being inversely associated with efficiency, which is associated with operational longevity.
- Co-operation between Federal, Provincial, and local governments is necessary in development and implementation of nitrous oxide mitigation strategies, however; the disjointed relationship between Federal regulations and targets and practical on-farm operations must be rectified. Reinvestment and reestablishment of Provincial agricultural extension programs may act as a first step in this conciliation.
- Structures to mitigate perceived BMPs adoption risk assumed by producers must be developed. Producers are aware of some BMPs and practices that would potentially reduce N_2O emissions, and many have successfully pursued transition and adoption. However, several barriers, predominantly around cost, must be addressed before anticipating widespread and consistent adoption.

INTRODUCTION.

In Western Canada, cropping production systems can vary drastically depending on geography and environmental factors. Dryland cropping of wheat varieties represent the most common type of farm in Alberta, in addition to similar systems in the production of barley and canola. Irrigation systems are expanding within the province; in Fall 2020, the Federal and Provincial governments announced a major investment in Alberta's irrigation network, with intention to increase agricultural output and profits, increasing employment opportunities and gross domestic product (GDP) (The Government of Alberta, 2021). The majority of Canadian irrigation located in southern Alberta, representing a critical area of for Canadian production with significant benefits compared to dryland cropping, such as increased yields and stability (The Government of Alberta, 2000).

Fertilizer, on a per hectare basis, is the most expensive annual input in 2022 crop production (The Government of Manitoba, 2022). However, as crops and crop varieties advance in yield potential, nitrogen is a limiting factor. Therefore, the nitrogen that crops require to ensure sufficient plant substrates to facilitate optimal growth and output must be met through fertilizer application. Advances in fertilizer management and technology support the Fertilizer Canada 4R [1] Nutrient Stewardship Plan, aligning with the Nitrous Oxide Emission Reduction Protocol (NERP), aiming to designate and recognize producers who voluntarily complete and apply fertilizer according to the responsible and effective management of nutrient resources.

Adoption of these practices varies between different farm types. As of 2021, 54 percent of canola acres, and 58 percent of spring wheat acres in western Canada were following Basic 4R Principals. However, in wheat growers, only 34 percent soil sample annually, 20 percent vary rate on a field-by-field basis, and an additional 15 percent use advanced 4R BMP of variable rate technology. This contrasts with western Canadian canola growers; in 2021, spring application accounted for 75 percent of nitrogen application. Enhanced efficiency fertilizer accounted for 15 percent of nitrogen applied in canola production across Canada (Fertilizer Canada, 2021).

[1] 4R Nutrient Stewardship refers to the "Right Source, Right Rate, Right Time, Right Place®" in fertilizer use (Agriculture and Agri-Food Canada, 2022).

Climate change will have a profound effect on global agriculture, driving adaptation due to variable weather patterns and shifting growing zones(Franke et al., 2022). Currently, the agricultural sector accounts for approximately 10 percent of total Canadian greenhouse gas (GHG) emissions (Environment and Climate Change Canada, 2021). Agricultural emissions differ from emissions from other industries, as methane (CH_4) and nitrous oxide (N_2O) comprise the majority of the sector's total emissions.

Nitrous oxide emissions from the agricultural sector are predominantly a result from the use of fertilizer in crop production systems (Agriculture and Agri-Food Canada, 2022). Increasing intensification of crop production and pressure to increase output while maintaining or reducing land use has resulted in significant increase in nitrogen requirements across agricultural commodities (Bourassa et al., 2022). Fertilizer use in Canada has increased 71 percent from 2005 to 2019, especially in Western Canada (Fertilizer Canada, 2021). In the same timeframe, N_2O emissions related to the application of synthetic fertilizer use increased 54 percent. In the four largest emitting provinces, Alberta, Saskatchewan, Manitoba and Ontario, emissions from crop production increased by 84 percent (Environment and Climate Change Canada, 2021). Although several factors can influence on-farm N_2O emissions resulting from fertilizer use, there is a direct causal relationship between increase in synthetic fertilizer application and N_2O emissions (Bourassa et al., 2022).

In 2020, the Government of Canada's Strengthened Climate Plan, "A Healthy Environment and a Healthy Economy", outlined an ambitious aim to reduce N_2O emissions from fertilizer application by 30 percent of 2020 levels by 2030 (Environment and Climate Change Canada, 2020). The emission reduction target protocol is currently in development through the Federal government and has involved several phases. In March 2021, Agriculture and Agri-Food Canada (AAFC) collected initial feedback from stakeholders in the agricultural sector, generally categorized into the following themes (Agriculture and Agri-Food Canada, 2022):

1. Concern about the impact on yield and exports;
2. How emissions are defined and measured;
3. Adoption barriers of sustainable practices and technologies;
4. Incentivization for producers and funding;
5. Variability in Canadian agricultural landscapes and farming practices;
6. Communication as a key lever to drive farmer acceptance of the target;

7. Challenges surrounding the development and participation in voluntary agreements;
8. Data gaps in accurate measurement of fertilizer emissions.

The discussion paper summarizes the choice to adopt the proposed Best Management Practices (BMPs) listed in Appendix 1, that ultimately depend on the producer. As it stands, the voluntary nature of 4R and NERP do not require operators to reduce on-farm emissions. Previous Fertilizer Canada data collected through a fertilizer use survey conducted from 2014 to 2021 indicated that a lack of proven benefit, incentive, and cost associated barriers were the most critical factors (Fertilizer Canada, 2021).

The choice of adopting BMPs hinges on multiple factors that are variable in different farming practices and different geographic regions in Canada. Understanding the factors that can and will drive adoption of BMP and emission reduction strategies is an important factor in understanding perceptions of practices and may provide insight on potential predictability of adoption within the agricultural sector (OECD Regulatory Policy Outlook, 2021).

Our objective was to identify perceptions and attitudes of the actors in Western Canada's crop producers and adjacent industries towards the adoption of N_2O mitigation and reduction strategies as a proxy for other strategies. Information gathered throughout this report can contribute to the development of inclusive, accessible, and engaging policy, potentially driving increased subsequent adoption throughout the agricultural sector.

METHODOLOGY.

This research was reviewed and approved by the Conjoint Faculties Research Ethics Board (CFREB), University of Calgary (Ethics ID: REB22-0688). Questions asked to participants are listed in Appendix 2.

RESEARCH PARTICIPANTS AND ENGAGEMENT

As this report specifically addresses N_2O emissions from crop production, and the BMPs and strategies specifically target on-farm management and fertilizer use, the crop production supply chain was narrowed to stakeholders that have a role in cropping systems and their inputs. This includes seed geneticists and retailers, primary production farmers, actors in crop policy, producer advocacy groups, and crop input manufacturers and distributors.

Potential participants within these and adjacent categories were recruited through centralized stakeholder lists. Initial contact was made through email and phone calls to potential participants, with an explanation of the research goal. Interested participants were then contacted through email, and invited to complete the consent form through Qualtrics, indicating their consent to the use of recording and transcription through the interview, and included preference for the use of personal information and details in the report. Participants had the option to consent to be referred to by their name, professional role/title, or to remain anonymous in the report. The data collected was completely anonymized and retained according to the University of Calgary's Secure Computing Data Storage requirements and Retention Policy.

RESEARCH SCOPE AND QUESTIONS

The proposed interview questions were divided into several segments:

1. General perceptions on climate change and links to the agricultural sector
2. Role of government in agricultural emission reductions
3. How emissions can be reduced on a short- and long-term horizon
4. Monetization and incentivization of GHG reductions

These themes were the basis of nodes within NVivo software. Working within these themes, answers to questions were compiled to extract reoccurring sub-themes within these categories; this included specific strategies that were proposed by participants.

INTERVIEWS AND ANALYSIS

Individual interviews were conducted throughout July and August 2022. The interviews were conducted through Zoom platform, and recorded and/or transcribed, according to the participant's consent. Additionally, interviewer notes were taken throughout the interview for further context. The transcriptions were checked for accuracy against video, and the transcription text was uploaded to NVivo software. Using the questions (Appendix 2) and scope as a guideline, the transcript for each interview was reviewed to fit within interview segments, which are as follows:

- Climate change and its potential impact on agriculture
- The role of government and industry (Top-down vs. Bottom-up approaches and solutions)
- Mitigation strategies on a short- and long-term horizon
- Incentivization and monetization
    - Longevity and profit
    - Carbon credits and the offset market

Climate Change and Alberta Agriculture

Opening interview questions probed participants' background within the agricultural sector and defined their current role and progression throughout the sector. Participants were then asked about their belief in climate change and to suggest how Alberta agriculture would be impacted by climate change. Analysis of answers was defined as sentiment towards belief of climate change and how it would impact Alberta, as well as reoccurring themes around how climate change would manifest within the Alberta agricultural supply chain.

The role of Government and Industry

The relationship between agriculture and government was divided into three defined sub-structures for participants: the Federal government, the Provincial government, and local/municipal governments and organizations, which includes organizations like producer cooperatives and advocacy groups. Participants were asked what level of government should have the majority of responsibility in implementing emission reduction policies, and define the role each level of government should have in the development and adoption of BMPs, and the potential role of industry.

Mitigation Strategies: Short- and Long-term Horizons, and the Importance of Selection Traits

Participants were asked about if the Federal target of 30 percent N_2O emission reduction target by 2030 was feasible. Following, participants were asked about short term mitigation strategies, considering on-farm management and operation practices, economic considerations, and insights from their own experiences within the sector. Subsequent questions about long-term mitigation strategies that focused less on current economic barriers and restrictions, and rather considered future applications of current fields of research and development, were asked. Lastly, participants were asked about the role of trait selection in crop breeding methodologies and variety selection currently, and how that role would change into the future within the context of emission reduction targets.

Incentives and Monetization: Emissions as Indicators for Prosperity, Longevity, and the Carbon Offset Market

Participants were asked if emissions were linked to current and future prosperity and longevity at the on-farm level, and how these factors are connected. Further, participants were probed about options that would offer the best avenues for emission reductions to be monetized.

If participants had not yet brought up the carbon credit and offset market in the previous question, the interviewer introduced the idea, and asked participants about their existing knowledge of the market and potential current or previous participation in the market. Participants that had engaged in the market and sold credits were asked about their previous experience and overall sentiment, and why they were no longer participating. Participants who had not engaged in the market explored barriers to participation, and what changes would be required in order to start participating in the market. Finally, participants were asked if carbon credits are perceived as a viable future revenue stream to offset transition risks.

This concluded the interviewer questions. Participants were then invited to further contribute and elaborate on previous questions and responses, and discuss any topics related to N_2O emission reduction strategies that were not covered in the questions. This concluded the interview.

RESULTS & DISCUSSION.

A total of 26 participants were interviewed (Table 1). Participants represented a mix of longstanding stakeholders with little change in professional roles or affiliations, while others, more so on the policy and advocacy side within the production chain, had more varied experiences. Researchers identified four themes that encapsulated the key points which were covered in interviews with participants:

1. Climate change
2. The Role of the Government and Industry - Top-down vs. Bottom-up approaches and solutions
    - The Role of the Federal Government,
    - The Role of the Provincial Government,
    - The Role of Producers and Adjacent Industries
    - Increased Producer Involvement in Policy Making

3. Nitrous Oxide Emission Reduction Targets
    - Emission Reduction Strategies: Short-term Horizon
        - 4R Nutrient Stewardship
            - Rate: variable rate technology & soil sampling
            - Place: sectional control
            - Source: enhanced efficiency nitrogen fertilizer
        - Proper Crop Rotation & Pulses
    - Emission Reduction Strategies: Long-term Horizon
        - Genetics & Breeding
        - Re-investment in Provincial agricultural extension
        - Technology
4. Incentives
    - Carbon Credits
    - Longevity and Profit
    - Additionality and Measurement

Table 1

Participant Breakdown

Industry Role	Participant Number	Distribution of Location
Producer	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	Central Alberta, Southern Alberta
Crop Inputs and Genetics	12, 13, 14, 15, 16, 17	Central Alberta, Southern Alberta
Producers Associations	18, 19, 20, 21, 22, 23, 24, 25, 26	Southern Alberta, Saskatchewan, New Brunswick

1. CLIMATE CHANGE: OPPORTUNITY OUTWEIGH RISKS

All participants agreed that climate change is currently, and will continue to, impact agricultural production in Western Canada. There was no apparent link between length of experience or variety of roles and sentiment towards climate change.

Changes in growing season and arable land were linked to a potentially more prosperous agricultural sector in Alberta, increasing output and opportunities for the agricultural sector (Motha & Baier, 2005). "*Our growing season is almost 2 weeks longer than what it used to be in terms of frost-free days*" (Participant 25). Opportunities that producers associate with an extended growing season are the ability to grow crops that they currently are unable to and an increase in yield. Although risks associated with severe weather events, especially increased drought risk and flood incidences, were recognized, overall, these risks do not outweigh the benefits of milder winters and longer growing seasons. Several participants mentioned the increasingly important role of crop insurance as risk of adverse weather continues to increase, and the continuing expansion of crop insurance to further include other agricultural lands (i.e., forages and grazing pasture) (Keller & Saitone, 2022; Wang et al., 2021). From a regulatory lens, producers are concerned about the policy that may be introduced as governments become more concerned about climate change. Participants from all backgrounds wanted discussions around climate change to focus on creating a win-win solution that will effectively reduce greenhouse gas emissions, increase food production, and ensure crop producers have a profitable business model.

2. THE ROLE OF GOVERNMENT AND INDUSTRY (TOP-DOWN VS. BOTTOM-UP APPOACHES AND SOLUTIONS)

The Role of the Federal Government

Participants envisioned the Federal government's role in regulating emissions as goal setting and the promotion of BMPs, without mandating how goals will be met. Producers expressed feeling that the Federal government effectively lacks understanding in the affordability and practicality of emission reduction and mitigation strategies, and is therefore not in a position to mandate practices on producers. *"It is not their role to dictate what practices are used on farm, it is their job to set the ultimate goals of what needs to be done"* (Participant 13). Participant groups seconded these sentiments and indicated feeling that Federal and provincial governments are not qualified to be making decisions on behalf of producers as they lack practical, hands-on information and experience that is central to crop producers. Participants suggested that it is the Federal government's role to consult with both the Provincial government and industry leaders to provide producers with a framework and guidelines to meet emission targets. As new policy is developed, participants stressed the importance of harmonization between the Federal and Provincial governments to ensure equitably distributed responsibility and reduce risk of provinces being in a completive disadvantage. Ultimately, participants felt it is up to the Federal government to facilitate the operational aspects needed to bring the voices of all stakeholders to the table when creating policy and regulations. Analysis of participant interviews confirmed that producers are looking for modern technologies that will enhance production while reducing N_2O emissions from fertilizer. This highlights an increasing need for the Federal government to continue to expand research funding and projects at the Provincial levels that will progress the technology and information required to reach 2030 emission reduction targets.

The Role of the Provincial Government

The Government of Alberta introduced the Conservation Cropping protocol in 2012, replacing the Tillage System Management Protocol, as a pathway for farm operators to participate in the Carbon Credit/Offset market. This protocol saw major uptake by crop producers; however, participation was mainly driven by economic benefits resulting from BMP adoption, rather than the opportunity for sale of credits/offsets (Davidson et al., 2019; van Wyngaarden, 2022). With the retirement of the Conversation Cropping Protocol in December 2021, opportunities for crop producers to participate in the carbon markets are limited.

Producers expressed a need for comprehensive solutions that are tailored to climatic and agricultural regions in Alberta, as well as different crop types and farm management and operational styles, throughout interviews. *"In Alberta there are four different soil types, so all these practices really need to be adapted to what is possible on farm"* (Participant 26). Producers indicated wanting to see more protocols designed for specific areas and operations. Producers felt that the Provincial government can better encapsulate variability in how operations are managed more granularly compared to the Federal government. An opportunity for the Provincial government to refine and adapt Federal frameworks down to strategies that are implementable on a local level was highlighted by participants across categories. Participants expressed that involvement in the development of policies to ensure that producers are provided with a range of provincial and potentially local polices to implement on farm depending on specific operation and management is the responsibility of the

Provincial government. Additionally, producers expressed the importance for the Provincial government to work with producer groups in the advocacy for agricultural stakeholders and producers.

Several participants expressed an overwhelming need for more educational programs and conferences throughout the province to drive adoption of new practices. Discussions with participants suggested that producers felt more confident adopting practices after observation and interactions in person and in a hands-on environment or educational setting. The adoption of innovative technology and BMPs associated with emission reductions often requires significant capital investment on behalf of the producer or holdings; therefore, producers want to see what they are going to be investing in on an operational level (Liu et al., 2018; Soma & Nuckchady, 2021). *"You need to have some kind of demonstration or proof to sell it to farmers"* (Participant 23). Participants across categories voiced concern regarding an overwhelming lack of clarity surrounding new practices and products on the market. Producers felt that they were required to go to extensive measures to access information surrounding new technologies and products. An Albertan farmer shared that they drove all the way to a conference in Saskatchewan to see a product, feeling as though they *"came away with a wealth of information...that can go a long way in convincing somebody to change"* (Participant 1). Producers believe that increased funding and accessibility of extension programs are needed in Alberta to effectively communicate the benefits and trade-offs of BMPs to producers. Participants felt that extension work will help bridge the gap between the government and agriculture industry, as Participant 4 stated *"we need people in the province who have a relationship with their stakeholders who are invested"* (Participant 4).

Producer's Role and Support from Adjacent Industries

Participants agreed that stakeholders involved directly in production of commodities carry the role of adopting and implementing BMPs at the farm level. This role is supported by adjacent industries involved in research and development of innovative technology, including tools and practices, to facilitate and support implementation at the on-farm level. Producer participants indicated feeling that a lot of opportunities to reduce emissions, and the most direct and impactful changes in reducing N_2O emissions, will be made at the farm-level. Participants across categories indicated interest in being involved in the policy development process to ensure that new protocols and programs consider the industry's perspective and are accessible to producers. *"We need a combination of collaboration between public and private entities in order to support the kind of changes that producers are being asked to make"* (Participant 15).

Discussions with participants exposed an underlying resistance to change within the agriculture industry, also reported in previous studies (Barnes & Toma, 2012; Davidson et al., 2019; Haden et al., 2012; Niles et al., 2016). Many producers accredited this reluctance to change throughout interviews being associated with a lack of communication and understanding the complete implications and trade-offs of changes. Participants felt current communication and marketing strategies of emerging emission reduction technologies and strategies are not effectively conveying the information that producers require to make informed decisions, especially related to long term effects and impact on management and labour resources (Gardezi & Arbuckle, 2018). Producers expressed wanting emission reduction solutions that are sustainable from an economic and environmental standpoint and requiring extension programs in place to educate producers on what practices will help them achieve this goal.

Increased Producer Involvement in Policy Making

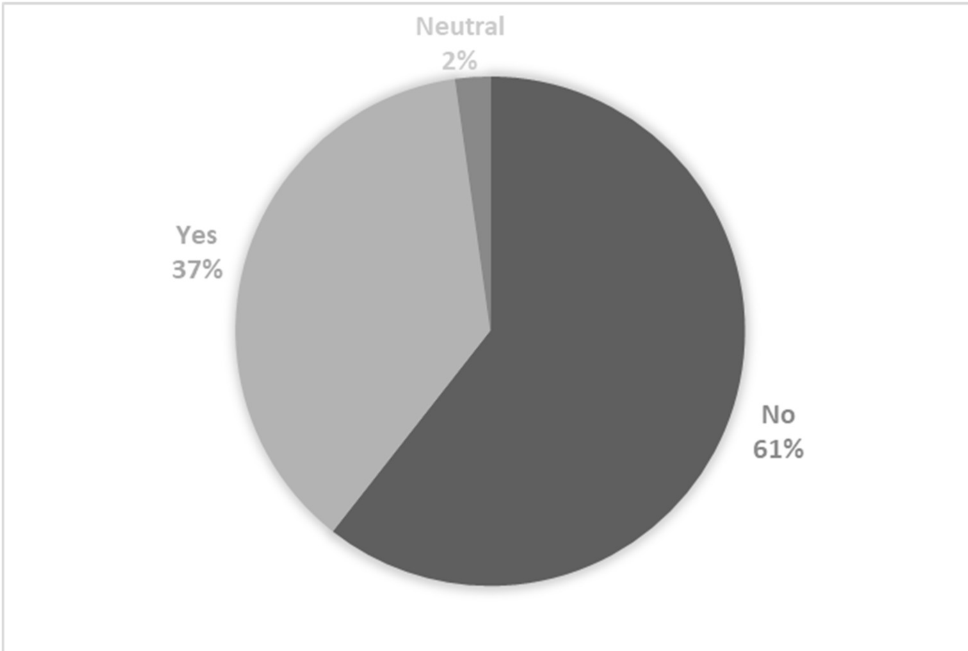
Producers preferred N_2O emission reduction efforts to be approached with a bottom-up framework. Producer participants expressed disfavour for policy developed with a top-down approach, associating the process with the Federal government's lack of understanding of feasibility of strategies on-farm. To achieve emission reduction targets, participants called for the implementation of a bottom-up approach that includes the voice of all relevant stakeholders, creating policy that the industry feels they have been a part of. *"We can't have policy coming down from the Federal Government that's contradicted by a provincial policy and that is not implementable on farm"* (Participant 21). Many participants suggested that the industry is striving to advance and develop, however, there is a disconnect in understanding what needs to change. Participants conclude that if the government wants to reduce emissions by 30 percent, they must be consulting with the industry to build an effective framework to achieve those goals. This will require effective communication and consultation between each level. Producers demand that the government recognizes that they are *"part of the solution, not a part of the problem*" (Participant 24). Participants felt a need for collaboration between the government and the agriculture industry to ensure that new policy and protocols promote BMPs in a way that will not harm the livelihoods of producer's operations. The goal is to *"reach a consensus from the bottom-up, rather from the top-down"* (Participant 26). Producers acknowledged that they rely on the support of the public and private sector, highlighting the need for consultation between all stakeholders.

3. NITROUS OXIDE EMISSION REDUCTION TARGETS

The majority of participants did not consider the 2030 target to reduce N_2O emissions from fertilizer by 30 percent to be feasible (Figure 1). Discussions uncovered a degree of frustration amongst participants, as they would like to see the government set goals and targets that they consider to be realistically attainable. *"If you are going to design goals, make sure that those goals can be attained on farm"* (Participant 10). Producers do not see how the required changes can realistically be made within seven growing seasons. Participants referenced the Conservation Tillage protocol development, stating *"it took about ten to fifteen years to adopt conservation tillage, when it was a no brainer"* (Participant 23). The benefits of conservation tillage were clearly defined, and the risk of changing practices was clearly understood by producers. A full industry change occurring within ten to fifteen years is considered to be a rapid change, this implying that it is likely to take a long time for producers to adopt technology where the benefits are not clearly defined. Producers who are early adopters of new technologies felt as though it would be harder for them to reduce emissions beyond what they have already achieved on their operations. There is concern amongst participants that the targets may penalize early adopters while providing a win-win opportunity to producers that have yet to adopt BMPs. *"They're punishing the guys that are ahead, adopted the best management practice, versus the guy that is using 150 tons, if you force them to use 30 percent less, then they would just adopt some of these best management"* (Participant 1).

Producer participants that expressed optimistic sentiment about the feasibility of the Federal government's 2030 goal demonstrated hesitancy about the long-term sustainability of the goal. Conversations highlighted the importance of sustainability from an environmental lens, as well as an economic lens. Producers were concerned that a 30 percent reduction in N_2O emissions from fertilizer will compromise the financial viability of their operations. Many producers correlated a reduction in N_2O emissions with reduced yields, which would have consequences on their operation as well as the countries net food production.

Figure 1



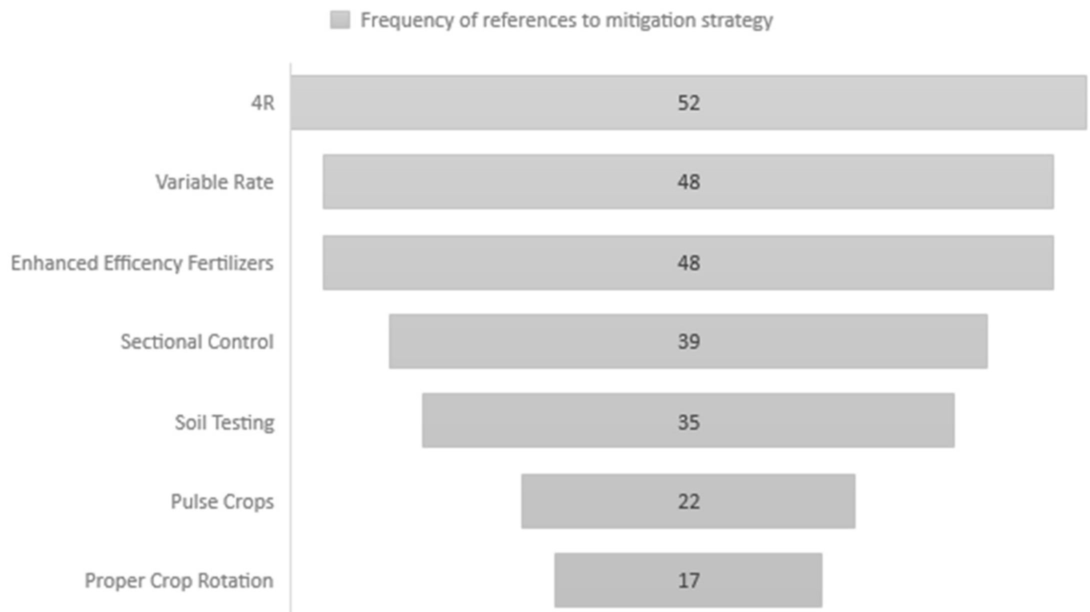
Perception of Feasibility of 2030 N_2O Emission Targets, by percentage of participants

4. NITROUS OXIDE EMISSION REDUCTION STRATEGIES & BMP ADOPTION: SHORT-TERM HORIZON

Prompted with a short-term horizon, with considerations towards economic feasibilities and current on-farm management and operational practices, four mitigation strategies were mainly highlighted by participants (Figure 2). These strategies were perceived as being the most accessible practices for crop producers to adopt to reduce N_2O emissions:

- 4R Nutrient Stewardship
    - Rate – variable rate technology & soil sampling
    - Place- sectional control
    - Source – enhanced efficiency nitrogen fertilizers
- Proper crop rotation & pulses

Figure 2



Frequency of references to mitigation strategies throughout interviews with participants.

4R Nutrient Stewardship

The 4R nutrient stewardship principles were frequently referred to by participants as effective management practices to reduce N_2O emissions. Many participants agreed that the 4R principles are accessible and achievable practices that will reduce N_2O emissions. In western Canada, 54percent of canola acres and 58% of spring wheat acres were following basic 4R principles in 2021 (Fertilizer Canada, 2021). Discussions called attention to the trade-offs associated with the adoption of 4R practices. *"The economic considerations are important, because not all emission reduction tactics are also providing an economic benefit, yet they come with an additional cost"* (Participant 14). Additional cost associated with the purchasing of new equipment, and increased farm management to adopt these BMPs continue to restrain uptake of 4R practices (Liu et al., 2018).

In 2021, the United States Department of Agriculture opened applications to producers for a state legislated grant (USDA, 2022). Producers, ranchers, and private forest landowners were eligible for participation in the Partnerships for Climate-Smart Commodities program. This effort will provide direct benefits to agricultural stakeholders along production supply chains, including small-scale producers. Participant 18 advocated for a protocol similar to the USDAs Partnership for Climate Smart Commodities program in Canada in order to offset high capital investment costs for adoption of equipment required for emission reduction strategies to be implemented.

Right rate- variable rate technology and soil sampling

The 4R principles recommend soil sampling accompanied with the subsequent application of variable rate technology to develop optimal application rates to support yield-based profits while minimizing N_2O emissions through reduction of wastage and redundant application (Agriculture and Agri-Food Canada, 2022). Soil sampling is an essential component of variable rate technology as it is what provides producers with a representation of field variability and recommended fertilizer application rates to achieve yield goals. Numerous producers that were interviewed have adopted soil sampling on their operations to facilitate implementation of efficient and targeted nitrogen fertilizer usage; however, the AAFC discussion paper states that soil nitrogen testing for annual spring fertilizer application has a low level of adoption in Canada (Agriculture and Agri-Food Canada, 2022). The labour requirements of soil testing are a barrier for many participants, as the costs associated with the skilled labour required to carry out soil testing, including the hiring of agronomists, and potential length turnaround times to receive analysis and adjust prescription accordingly in a timely manner, can be challenging. A standard package in soil testing that provides an overview of nutrient profile has an average cost of approximately four to five dollars per acre. Many crop producers associated an increase in efficiency with the adoption of soil testing and variable rate throughout interviews, as these practices effectively reduce potential over-application of fertilizer and costly inputs. This aligns with previous data on drivers and barriers of adoption demonstrated by Fertilizer Canada (2021) and Davidson et al. (2019).

Variable rate technology employs global positioning system (GPS) technology with variable input technology to allow the producers to fertilize crops at different rates in different parts of a field (Bullock & Lowenberg-DeBoer, 2007). Additionally, variable rate technology can record the spatial distribution of yields at harvest (Bullock & Lowenberg-DeBoer, 2007). Participants expressed a hesitancy to adopt variable rate technology due to a lack of knowledge surrounding yield response. The 2021 Fertilizer Use Survey reported that only 13 percent of producers across Canada use variable rate technology on their farms (Fertilizer Canada, 2021). Increased information availability and accessibility on the impact of adoption on yield and return of investment, especially from sources that producers trust, such as cooperatives and advocacy groups, was indicated as a potential lever by producers to increase uptake by directly linking adoption with profitability. Producer participants felt discouraged when considering the adoption of variable rate technology due to expensive equipment costs and additional levels of farm management. *"I'm a small farm, so my fear is that we are going to have all the variable rate equipment and we are going to have to hire an agronomist to create this map and soil and fertilizer recommendations, so that's all going to cost me money to invest in my equipment and will I see a return on all of them coming back my way?"* (Participant 5). Hesitancy to adopt and implement a system that relies on what is perceived as advanced technology, especially since the technology would require additional time to learn and understand, threatens self-sufficiency and reliability, highlights how producers grapple as increasingly advanced applications are introduced into precision agriculture.

Right place- sectional control technology

Producer participants that adopted sectional control technology emphasized the value it added to their operations. *"It's something that paid for itself in one season"* (Participant 1). Sectional control technology utilizes a global positioning system (GPS) to locate, track, and record the position of machinery in the field to limit over application of inputs or application of inputs in undesirable areas (Shockley et al., 2012). Sectional control technology automatically responds to turn the appropriate section, nozzle, or row off if the machine passes over an area that has already been covered, reducing overlap of inputs and potentially increasing profits (Shockley et al., 2012). Interview discussions with participants highlighted that sectional control technology is potentially well adopted because the savings in fertilizer costs are easily recognized by producers. *"You're talking about a one-time fee and a very quick payback, and then after that it is putting money in your pocket, and you can calculate that yourself pretty easily"* (Participant 1). Producers highlighted that sectional control technology is relatively easy to add to existing drills. Although sectional control has relatively high adoption rate, some producers remain hesitant to adopt complex technology and view the initial investment in equipment costs as a barrier (Chavas & Nauges, 2020; Soma & Nuckchady, 2021).

Right source - enhanced efficiency nitrogen fertilizers

Many participants viewed enhanced efficiency nitrogen fertilizer (EENF) as a potential emission reduction tool. EENF reduce nitrogen losses using a coating or inhibitor to slow the rate of nitrogen release and effectively align nitrogen release and crop uptake (Li et al., 2017). Although EENFs are readily available to producers, based on interview analysis of participant responses, few have adopted this technology. Across Canada, only 15 percent of nitrogen volume applied is utilizing an EENF product (Fertilizer Canada, 2021). Barriers to adoption of EENFs highlighted by participants included cost, lack of clarity in relation to yield benefit, and concern over plastic coatings on polymer coated fertilizers. Participants were concerned about the environmental trade-offs associated with EENFs highlighting that *"we are starting to get really worried about putting plastic in everything, if we are going to get rid of straws you don't want to start applying fertilizer with plastic around it"* (Participant 25). Additionally, participants explained that *"there's a bit of research data that's confusing in the sense that [is] EENF technology better or worse? I've seen some data saying EENF gasses off worse for nitrous oxide"* (Participant 23). Conversations with participants highlighted that *"it's primarily the cost of these products that holds producers back"* (Participant 15). Participants felt that these products are *"too expensive and you also have a lack of return on your investment"* (Participant 25). Several participants expressed some level of confusion surrounding the benefit of EENF technology in terms of productivity or yield, concluding that EENFs are prohibitively expensive with unclear relationship in yield and uncertain return on investment. Producers felt as though they are *"being asked to adopt a more expensive product for nitrous oxide emission reduction, that's not necessarily contributing to a yield benefit"* (Participant 15).

Proper crop rotation & pulses

Several participants directly involved in crop production expressed value in the addition of pulse crops such as peas, soybeans, and fava beans into their rotations. Discussions with participants indicated the potential N_2O emission reduction benefits of proper crop rotation and the inclusion of pulse crops into crop rotation. The

AAFC discussion paper identified a 15-20 percent potential emission reduction associated with increasing legumes in rotations, although there is currently a low level of adoption (Appendix 1) (Agriculture and Agri-Food Canada, 2022).

Ross et al. (2015) demonstrated the benefits of incorporating pulse crops into rotations and the positive effects of diverse cropping systems on soil nitrogen and health. Diverse cropping systems improved resiliency by increasing soil organic matter accumulation, water holding capacity, nitrogen nutrition, and providing disease cycle breaks. Repeating crops in a crop sequence can potentially jeopardize the sustainability of a crop systems due to buildup of pathogens that may lower yield and quality. This risk can be mitigated through the inclusion of pulse crops to fix atmospheric nitrogen, requiring little to no synthetic fertilizer and enrich soil nitrogen fur future utilisation by the successive crop, reducing synthetic fertilizer inputs. Crops grown on pulse stubble are shown to have improved yield and quality as a result of improved nitrogen availability.

Producers expressed that a lack of markets for protein crops and legumes is a substantial barrier to adoption throughout interviews. More producers would utilize pulse crops on their operations if there was an increased demand for plant protein derivatives within the market, facilitated by accessible pulse processing infrastructure. The Provincial government should stimulate demand for protein crops though funding the development of protein processing plants in western Canada and specifically Alberta. This is a critical consideration for future investment potential, as the market size and consumer demand for alternative protein sources and plant protein derivatives is projected to grow (Poulson et al., 2020). Other challenges discussed by participants about pulse crops was a high risk of diseases such as root rot. Some crop producers indicated being deterred from including pulse crops such as peas in their rotation due to lodging, increasing difficulty at harvest and requiring additional investment into specific combine headers.

NITROUS OXIDE EMISSION REDUCTION STRATEGIES & BMP ADOPTION: LONG-TERM HORIZONS AND FUTURE POTENTIAL

Considering a long-term horizon, many participants emphasized the potential of the following three fields to reduce fertilizer based on-farm nitrous oxide emissions:

- Crop genetics & breeding

- Re-investment in Provincial agricultural extension
- Technology

Crop genetics & breeding

Discussions emphasized the major opportunities that in the field of genetics in strategies to reduce on farm N_2O emissions. The majority of participants stated that genetic selection and/or seed breeding technologies have influenced their choice of varieties. Many producers recognized the significant advances of selective seed breeding applications in yield and disease resistance, and largely attributed current increases in yield and grain quality in crop production to selectively bred seed varieties. Producers indicated that traits that were associated with improved efficiency such as yield, water usage, nutrient requirements, standability, disease resistance, weather resistance, and synthetic input usage were the main drivers in their choice of variety. This is an especially promising strategy for emission reduction potential for producers and overall, favourably perceived. This is potentially due to genetic technology implementation requiring little to no additional costs, changes in management, or additional farm equipment (Subbarao et al., 2017).

There was a consensus among participants that the development of nitrogen fixing crops would be a revolutionary development for crop production. Participants would enthusiastically adopt the use of nitrogen fixing crops such as wheat and canola, assuming yield would not be sacrificed despite decreased fertilizer inputs. The Federal government will need to continue to fund agricultural research to support the implementation of new climate smart crop varieties.

Many participants across categories voiced concerns associated with the public perception of genetics and seed breeding technologies. Industry further downstream in the supply chain and government have a role in marketing the benefits of transgenic crops to the public. Effective marketing and education will be essential with increasing adoption of crop genetic and seed breeding technologies to ensure accurate and accessible information is available to consumers, maintaining and further cultivating public’s trust in producers and Canadian farms. The Federal government will need to ensure genetic and seed breeding technologies are being approved and regulated in a manner that does not delay the implementation of this technology while simultaneously maintaining consumer confidence. Emission reduction benefits, climate and adverse weather resiliency, and reduced input requirements of genetic and seed breeding technologies were recognized as an accumulative result according to geneticist participants, who additionally re-enforced the importance of these technologies being implemented as soon as possible, so benefits can begin to aggregate.

RE-INVESTMENT IN EXTENSION WORK - AGRICULTURAL EXTENSION AND ACCESS TO AGRICULTURAL RESEARCH

Agricultural extension

The majority of participants across categories voiced a need for further publicly funded extension work throughout the province. Extension work was consistently perceived as a lever to directly assist producers in tangibly understanding the benefits and impacts of BMPs adoption and implementation, and strategies to ensure on-farm profitability. Discussions with producers exposed a knowledge gap between research and industry/on-farm applications. Participants felt that it is essential to educate and *"provide those resources to let producers' know what's happening in the research world and genomics, so that they can understand the value of it in their practices"* (Participant 12). Producers expressed feeling more confident with adopting new practices and implementing strategies if hands-on, educational opportunities that demonstrate the efficiencies of new practices in combination with specific adoption pathways were provided. A willingness to learn was consistent among producer participants, with many associating with producer groups at the local and provincial level, and attending educational conferences where new farming practices and ideas are presented. Participants stated that *"a lot of it is [about] educating farmers, and probably the most effective way in mind is when [farmers] can get out into the field and see a demonstration, rather than just sitting through a meeting*" (Participant 1).

Research demonstrates value in BMP adoption; the next barrier is effectively communicating those benefits to producers to increase adoption. With the start of the COVID-19 pandemic and lockdowns, the way producers accessed information changed, with increased dependency on online and virtual resources (Lai & Widmar, 2021). Interviews demonstrated that producers were unhappy with this shift; being able to palpably understand the implications of adopting new technology and practices, in combination with interactions with trusted information and data sources, is critical to introducing and re-enforcing strategies to be implemented on farm. The gap in extension activities was partially filled by private industry offering and organizing demonstrations and field trials. These demonstrations were mentioned by interview participants; however, were associated with bias in favour of private industry, and a method for recruiting customers and increasing sales, rather than a neutral avenue for producer education and information. Re-investment, specifically from the provincial government, in agricultural research and extension programs is a critical opportunity across multiple dimensions. Extension programs provide potential pathway to increase adoption of BMPs and emission reduction strategies on-farm, delivering information through an informative, hands-on communication resources and channels that resonate with producers to increase impact. This also may offer an important opportunity to re-establish and strengthen relationships between producers and governments.

Early-stage Agricultural research

In order to have successful extension programs, the research and data available to back up new BMPs, products, and technologies must be accessible. Analysis of interviews with participants highlighted a need for continued neutral funding of research to ensure that unbiased data and information is available to properly target and answer producers' questions about the trade-offs with adoption of products, practices, and technologies. Producers expressed that they "*need more proof that this is actually going to make a significant gain, that's where I go back to the data"* (Participant 23). Participants voiced that this role should be for government bodies to invest in research to continue to improve the efficiency of the agriculture industry. Stating that the government needs to "*keep on investing because whatever we reap the benefits of today is because we invested 5 to 10 years ago"* (Participant 22).

Technology

Several producers saw opportunities in incorporating smart technologies into farming practices. Smart agriculture and precision agriculture utilize technology to ensure that the crops and soil receive optimal inputs for health and productivity, with the goal of increased profitability and sustainability (Khanna & Kaur, 2019). Information technologies, satellite technologies, and artificial intelligence have major potential within the agriculture industry, and were identified throughout interviews as technologies producers especially expressed interest in.

The adoption of precision and smart agriculture does not come without challenges and barriers. Producers feared that technologies which require intricate hardware and software frameworks can increase the risk of a system failure, threatening the self-reliability of an operation. *"You start adding electronics and computers, that's when you have problems"* (Participant 9). Most producers in western Canada belong to an older demographic and relatively unfamiliar with smart technology. *"There is an educational factor that is a barrier for some people. I think the younger generation is certainly more inclined to get over that than maybe the older generation"* (Participant 23). Older generations of producers are more reluctant to adopt and invest in unfamiliar smart technologies associated with a steep learning curve, accentuating the need for re-investment in producer inclusive extension work (Rodriguez et al., 2009). *"People like simplicity on the farm. If it doesn't work, who do I get to fix this? And we are seeing that more right now than we've ever seen because of labour and part shortages"* (Participant 23). Many smart technologies rely on a dependable mobile internet connection, which is not always reliably accessible in remote farming areas. Producers additionally recognized that precision agriculture adds an additional level of data management to an operation, requiring further resource allocation participants were not willing to assume.

INCENTIVES

The majority of participants indicated preferring as little government intervention in agriculture as possible. Analysis of interviews demonstrated consistently the sentiment that *"farmers respond well to monetary incentives as long as they are not constricted by long-term legalities or potential penalties"* (Participant 4). To meet the 2030 emission reduction targets, monetary incentives that motivate producers to adopt N_2O emission reduction strategies and practices must be in place. Effective incentive programs should "*help to change mindset and practice"* through specific adoption pathways relevant to current production practices to mitigate emissions and successfully reach Federal goals (Participant 22). For incentivization programs to be meaningful, participants must feel the programs goals are achievable and that reward for participation is relative to contribution. Participants voiced a need for an incentive program that is simple and easy to adopt, with minimal additional burdens (i.e., data collection, management, and storage; administrative burdens) and barriers associated with adoption.

Discussions uncovered a major disconnect between the government and the agriculture industry. Interview analysis demonstrated that the relationship between producers and governments is fraught with discontentedness. To maximize benefits and increase producers' willingness to reliably adopt and implement BMPs, incentivization programs and protocols should include producers in the development process. Open communication between the agricultural industries and governments is critical to ensure that both parties can identify synergies and gaps and provide the necessary support to ensure equitable benefits. The push for reductions in GHG emissions is an opportunity for producers to adjust management practices in more environmentally sustainable manner, and potentially optimize risks associated with climate resilient agriculture, while improving productivity and profitability through enhanced efficiency and nutrient management.

Participants indicated apprehension towards the voluntary protocol proposed by the Federal government, and the possibility of transition to a mandatory protocol, penalizing producers in order to meet emission targets. Many participants were uneasy about the potential that the 2030 N_2O emission targets will result in protocols that ultimately damage producers, for example requiring producers to reduce fertilizer usage without considering the implication on yields and on-farm economics. Crop producers operate within thin margins, particularly in recent years with cost increases for crop and on-farm inputs, and many expressed concerns that penalties would severely impact operations long-term, threatening future livelihood.

Contrary to the opinion of most participants, some participants, notably not directly involved in crop production, but rather policy and advocacy, felt that penalties are the best option to incentivize the adoption of BMPs, stating *"carrots only work if there is a sick that comes behind it"* (Participant 22). *"The early adopters we've already done it, the middle adopters are the only guys who are going to change, they call them late adopter, but some people call them laggers, they are never going to change, so that is where you've got to have a stick"* (Participant 22). Similar to themes mentioned in the development of N_2O reduction and mitigation strategies, on-farm variability is difficult to account for, meaning penalties cannot be unanimous across Alberta. Ultimately, participants suggested that an effective incentivization program will prioritize leveraging producers who choose to adopt sustainable practices, demonstrating the benefits of adoption, rather than penalizing those who do not.

Carbon Credits

Current incentivization programs, such as carbon credit protocols, are not achieving the desired outcome. Current protocols have very little uptake, linked to impracticality for the majority of producers and operators, as indicated throughout interviews and across participants. Many producers indicated not participating in the carbon credit market with goals of changing practices to reduce emissions; this is consistent with research indicating that uptake is associated with economic benefit (Davidson et al., 2019). Current protocols were viewed as an opportunity to *"fill out paperwork and get a couple thousand dollars, having no effect on anybody's practices or operation"* (Participant 9). In speaking about the current opportunities to participate in the carbon credit market, producers felt there are currently more challenges than opportunities. Producers that participated in previous Conservation Tillage protocol received approximately $1732 for every 1000 acres of Parkland area, and approximately $847 for every 1000 acres of Dry Prairie area in 2021 (Government of Alberta, 2021). Considering the data requirements and extensive administrative and record keeping burden associated with the carbon offset protocols and involvement in the market, producers did not feel there is a significant economic benefit; a sentiment further re-enforced as participants who engaged previously in the sale of offsets within the market indicated that only a relatively small portion of each carbon credit payment actually ends up in producers' hands, as they are required to give a significant percentage of each payment to the aggregator, and often, the landowner, depending on the operation dynamics.

A carbon credit program that includes options to contribute partial packages, increasing accessibility to producers and cutting out the role of an aggregator, would create greater financial pay-off for producers. In addition to minimal monetary benefit, the carbon credit program currently has binding regulations that deter many producers; the Conservation Tillage protocol bound producers to maintain untilled land for 100 years as a preventative measure against the reversal of sequestration (van Wyngaarden, 2022). This was perceived as a risk by producers; unexpected weather events and extremes might require tillage in crop fields. Due to increasingly unpredictable variations in climate, the carbon credit protocol should be developed as a short-term contract that limits the burden on producers with complicated legalities, and directly accounts for specific actions on-farm, with offsets allocated after emission removal, to strengthen the verification process. The benefits of the protocols were not currently perceived to out-weigh the faults by participants; however, as carbon credits are a relatively new program, only launching in the 2000s, and the carbon market continues to develop, there is potential for the Government of Alberta to better establish improvements into the future. Producers discussed wanting to see the government improve the current program to eventually become an additional revenue stream for their operations.

Longevity & Profit

The majority of participants believed operations that produce less emissions will have a higher chance of continued longevity. Generally, participants felt that operations choosing to adopt BMPs and new practices would be more efficient overall, allowing them to expand and grow into the future. Many producers recognized a heightened consumer awareness for environmentally conscious and sustainable products, suggesting producers that adopt emission reduction strategies will become increasingly more competitive in the market. Participants acknowledged that climate change and climate resiliency are important factors in agricultural sectors, and implied operations that are willing to adapt and proactively change their practices will be the most successful in the long term. Some participants did not correlate operations that reduce emissions with a higher chance of continued longevity. These participants drew attention to the environmental dimension as only one aspect of on-farm systems and dynamics. An effective production operation strategy must also account for social and economic aspects to effectively support viability and longevity. Participants expressed that *"there are a lot of factors that influence the longevity of an operation, but emissions are not one of them"* (Participant 18).

Generally, participants did not feel as though operations that reduce emissions will have increased profit. Most emission reduction strategies were currently not considered as profitable by participants. *"Regenerative agriculture is great, but I believe so far it does not necessarily help to get the yields that we see maximizing profits"* (Participant 7). Until practices can consistently minimize inputs while simultaneously maximizing yields, participants do not foresee an increase in profit for operations that reduce emissions. Some participants were optimistic that future operations that reduce emissions will have higher profits as a result of increased efficiency and market demand; however, that was not seen as a reality at this point in time.

Additionality & Measurement

The consideration of additionality is critical to the development of establishing emission baselines and subsequent eligibility of carbon credit protocols. Additionality is defined as the creation of additional emission reductions through practice adoption and implementation; it is crucial that these reductions would not have occurred in the absence of emission credit and trading protocols to ensure environmental effectiveness and economic efficiency (Climate Change Authority, 2014).

Additionality is a large point of contention amongst Albertan producers. Early adopters expressed a desire to be recognized for what they have previously accomplished in terms of sustainability practices and BMP adoption on their operations, and do not want to feel penalized or left out of opportunity as policy is developed. One Albertan grain producer raised the question *"if the government goes to incentive people to buy sectional control, I've been using sectional control for 7 years, so why should the government pay for those people to switch?"* (Participant 1). Producers felt there is *"a gap in discussion regarding what producers have already done"* (Participant 14). Producers have been improving their practices for generations and *"take pride in taking care of the land they own as it results in increased production"* (Participant 9). Currently, participants felt framework in place to reward the environmental and sustainable contributions that producers have made up to this point is insufficient.

In addition to expressing that producers' previous contributions were not being accounted for, participants felt there is currently no feasible or accurate way to measure changes in on farm emissions. In particular, there were concerns surrounding what N_2O emissions measures and metrics were being used as the baseline. Albertan farmers are *"wondering where we currently are and where we will be"* in regard to emission targets (Participant 8). A 30 percent reduction in nitrous oxide emissions does not seem attainable to producers if there is not an effective method in place to measure emission reductions. Many producers feared the measurement of N_2O emission reductions will be directly accounted for as reductions in fertilizer usage. Producers clearly stated that a 30 percent reduction in fertilizer usage will not be feasible on most operations, as one producer stated *"a straight 30 percent reduction in fertilizer use, I don't think that is feasible. Even though that's not what the policy says they want to achieve, that's what I feel like they want to achieve"* (Participant 3). Discussion throughout interviews highlighted that government investment into the development of stronger protocol regarding the measurement of N_2O and overall GHG emissions to support improved understanding of benchmarks and specific pathways for adoption of BMPs should be prioritized.

CONCLUSION.

The Canadian government's target to reduce N_2O emissions by 30 percent by 2030 is ambitious and has faced significant criticism from agricultural stakeholders across Canada. Although there are several strategies associated with reduced emissions from fertilizer use, the adoption of these strategies is contingent on producers choice at the on-farm level. Interviews with crop producers, and stakeholders in adjacent industries, demonstrated that there is a significant disconnect between government objectives and on-farm operations. Participants agreed that the role of government in on-farm decisions should be minimal, and agricultural policy should be representative of producers at the policy development level, supporting the maintenance of commodity output and security. Re-investment in agricultural extension through the provincial government will be a critical step forward, re-establishing the relationship between producers and government, and facilitating communication and outreach, ensuring accurate information is accessible to producers. This is especially crucial in driving adoption of short- and long-term emission reduction strategies, as producers discussed their hesitancy to implement BMPs due to a perceived association with economic risk and increased resource allocation. Demonstrating the benefits of adoption practically, associated with increases in on-farm efficiency and soil health, through agricultural extension programs can potentially alleviate some of these hesitations.

However, the feasibility of the 2030 goal is still convoluted. The attenuated timeline, with only seven growing seasons between now and 2030, was linked to limitations in reaching the target. The widespread adoption required for the projected reduction in N_2O emissions outlined by AAFC will take time, and ensuring producers are able to implement emission reductions strategies in a sustainable manner for long term success will require further efforts. This is especially prevalent as the goal has face significant backlash and criticism since its announcement. A recently published study from Fertilizer Canada and Canola Council suggests that increased 4R adoption could reduce fertilizer emissions by 14 percent; this may be a more feasible target, given the difficult path ahead (Gamble & Heaney, 2022).

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APPENDIX.

Appendix 1:

	BMP	Regional applicability	Current adoption level	Feasibility of adoption
Rate	Soil N test annual for spring fertilizer application	All regions	low	medium/ high
	Accounting for N in previous legume crop	All regions	medium/ high	high
Time	Applying N in the spring compared to the fall	Mainly west	high	high
	Fertigation (injection of fertilizers with irrigation)	Mainly west	low	medium
	Split application/ sidedress with rate adjustment based on sensors	Mainly east	medium	medium
Placement	Apply in bands/injection accompanied by reduced rate	All regions	high-west medium-east	medium/ high
Source	Enhanced efficiency fertilizers, inhibitors or slow release	All regions	very low	medium
	Replace inorganic fertilizer with manures, compost, or digestate	All regions	low	high
Conservation management	Conservation tillage	All regions	high-west medium-east	high
	Improved drainage design	Mainly east	medium / high - east	medium
Other	Increasing legumes in rotations	Mainly west	low	low/ medium

Overview of BMPs proposed in the AAFC discussion paper, with current and predicted adoption rates. Adapted from Discussion Document: Reducing Emissions Arising from the Application of Fertilizer in Canada's Agriculture Sector, (2022).

Appendix 2: Interview questions

General Questions
How long have you been working in your industry?
Can you provide an overview of your role/profession? Can you provide an approximate location?
Do you think that climate change will impact agricultural production?
How do you think it will specifically impact your business/operation?
Do you feel that addressing agricultural emissions and reductions should be a federal task/a provincial task/a local or farm level task?
What should be the role of the federal government in regulating emissions and promotions in the development of Best Management Practices? (Top-down)
What role should industry have in the promotion or development in the adoption of Best Management Practices? (Bottom-up)

Crop Production Questions:
Canada's current climate plan outlined a target to reduce emissions from fertilizer 30% by 2030.

- Do you feel this target can be met?
- If No, Is this too much/too little and why?

If cost adoption was not a factor, what do you believe to be the most effective way at reducing fertilizer based on farm emissions that is currently available/in the near term?

- What are the challenges associated with adopting those practices?
- Will the adoption of this practice require changes to human capital? (I.e., more trained technicians, increased tech literacy, more workers)
- Will the adoption of this practice require changes to physical capital? (I.e., infrastructure and equipment)

Considering economic considerations, what do you believe to be the most cost-effective way of reducing fertilizer-based on farm emissions that is currently available/in the near term?

- What are the challenges associated with adopting those practices?
- Will the adoption of this practice require changes to human capital? (I.e., more trained technicians, increased tech literacy, more workers)
- Will the adoption of this practice require changes to physical capital? (I.e., infrastructure and equipment)

Has crop genetic selection/seed breeding methodologies influenced your choices to seed on your operation?

- Has this contributed to reducing input?
- Has this contributed to reduced emissions from on-farm operations/production?
- Do you see increased/decreased use of genetic selection with increasing pressure to reduce emissions?
- Are genetic interventions combined with different uses of fertilizers?

Looking into the future, are there any emerging technologies or practices that have the potential to significantly reduce emissions that you are aware of?

- What are the challenges associated with adopting those practices?

- Will the adoption of this practice require changes to human capital? (I.e., more trained technicians, increased tech literacy, more workers)
- Will the adoption of this practice require changes to physical capital? (I.e., infrastructure and equipment)
- Do you foresee any barriers for bringing this product/technology to market?

Monetization and Incentive

Do agricultural emissions influence the longevity of an operation? Do you feel that operations that produce less emissions have a higher chance of continued longevity?

Do you feel that operations that reduce emissions have higher profits?

How can strategies to reduce emissions be monetized? What options do you believe would create the best opportunities in this market?

Were you aware of the Carbon Credit/Offset market? Have you participated in the market? What are some of the challenges you have experiences/foresee in participating in the market?

Where do you see the developing Carbon Credit system/sale of carbon offsets becoming more significant in reductions of on-farm emissions?

Do you foresee the sale of Carbon Credits as a viable way to offset costs and provide an additional revenue stream based on your operation?

I do not have any more questions. Would you like to add anything else, or highlight any themes or responses to any of the questions?

The Simpson Centre mobilizes research for better policymaking and decision-making to realize a more sustainable agricultural industry. Strengthening the sustainability of agri-food and agri-business means increasing food production to feed a growing global population, while attending to social and health impacts and the natural environment.

We connect researchers, everyday people, industry stakeholders and government actors to scientific issues critical to the future of Canada's agricultural and food industry.

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