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Navigating Climate Change: Alberta's Carbon Program for Sustainable Agriculture

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EXECUTIVE SUMMARY

In order to feed a growing world population, Alberta must continue supporting the province's agricultural industry while also taking substantial steps to reduce the industry's methane and nitrous oxide emissions to meet Canada's climate commitments. Balancing these goals presents challenges, as implementing emission reduction measures may incur costs for producers or necessitate changes in food production practices, potentially impacting industry growth in the short term.

Alberta's agricultural sector emits 21 million metric tonnes of CO_2 equivalent annually, constituting 29.7 per cent of Canada's agricultural emissions and about eight per cent of Alberta's own total greenhouse gas (GHG) emissions. Animal production is responsible for 64 per cent of those emissions in Alberta, while crop production contributes 21.5 per cent.

This paper summarizes and updates the findings from Alberta's carbon program, focusing on how uncertainty is the biggest challenge for producers when trying to reduce emissions. Producers face uncertainty around emission levels, the effectiveness of the proposed best management practices as mitigation strategies, the accuracy of emissions measurement methods, future policy directions and who will bear the financial burden of implementing these strategies. For instance, Alberta producers need more information on the use of enhanced efficiency fertilizers in dryland production systems. However, a significant research gap persists regarding these fertilizers. Other barriers to adoption include costs, uncertainty about yield benefits and concerns about the environmental tradeoffs of polymer-coated fertilizers. Addressing these uncertainties is crucial for advancing the adoption of effective mitigation strategies across the province.

Currently, Alberta's agriculture sector is supported by three active emission offset protocols: Nitrous Oxide Emissions Reduction, Greenhouse Gas Emissions from Fed Cattle and Low Residual Feed Intake Markers in Beef Cattle. However, these protocols have produced less than one per cent of agriculture-based credits. The now-expired Conservation Cropping Protocol was the most successful, accounting for 23 per cent of credits. Key challenges in deriving desired results from these protocols include inadequate revenue for producers, limited protocol coverage, difficulties with establishing baseline emissions, protocol expirations and barriers to adopting best management practices. Additionally, the federal REME protocol, released for public consultation in December 2023, covers only 12 per cent of beef cattle emissions and excludes effective strategies like 3-nitrooxypropanol (3-NOP) and seaweed, limiting its overall effectiveness.

Among the most promising candidates for offset protocols is the feed additive 3-NOP, while seaweed additives have shown the greatest and most consistent results in reducing emissions from cattle. Indeed, the Canadian Food Inspection Agency (CFIA) recently cleared 3-NOP as a feed supplement and recommended it be approved. With Alberta's significant role in Canadian feedlot operations, these protocols can maintain the province's competitive edge in beef production while tackling emission reduction.

Programs that target farm-level actions could make offset protocols more understandable and transparent because they would directly link carbon credits to specific farm activities.

Currently, protocols covering best management practices in Alberta for reducing nitrous oxide emissions fall short in provincial emission reduction at the national level, mainly because these measures are not part of the national methodology. Canadian policy-makers and stakeholders must align current and future programs aimed at emission reduction with the national methodology.

There are several challenges Alberta producers face in implementing emission mitigation strategies, including high cost, uncertainty on yield benefits and concerns about polymer-coated fertilizers and environmental tradeoffs. At the current carbon price of $95/tonne, offsets from polymer-coated fertilizers yield only $7/hectare, resulting in a net revenue drop of $29 per hectare. For 3-NOP adoption, emission reductions translate to potential offsets of $7.66 to $12.97 per head for cattle at finishing stage and $4.62 to $7.13 per head for cattle at backgrounding stage of production. The feasibility for cow-calf producers will depend on the cost of 3-NOP and its inclusion in federal methane reduction offsets.

The Canadian methodology for measuring the impact of these strategies has limitations and does not account for many best management practices, including some recommended in Agriculture and Agri-Food Canada's (AAFC) policy documents. This requires not only consistent and reliable measurement methods but also stronger intergovernmental co-ordination, increased investment and clearer guidance on best management practices. Additionally, aligning carbon offsets with international standards is essential to ensure Alberta's efforts are both effective and globally recognized.

Alberta needs to better understand its producers' willingness to adopt best management practices for emission reduction. Defining these practices depends on many factors, such as varying farm practices and differences among geographic regions in Canada. Consumers' willingness to pay for environmentally produced agricultural products is another part of the equation. It's possible that labelling such products with an emission score would be an attractive incentive for consumers, and thus for producers.

The first order of business is to collect baseline data with which to create effective policies and future targets. Policy-makers need to understand on-farm activities and nitrogen use across varied production systems and regions. Much work remains to be done in the agriculture sector both in Alberta and across Canada to meet international emissions standards while also rising to the challenge of stepping up food production for an increasingly hungry world.

ABSTRACT

In 2021, the Government of Alberta launched the carbon program initiative to evaluate environmental practices and greenhouse gas reduction strategies in the agricultural sector. The program has produced various technical reports, policy briefing papers, industry surveys and roundtables. This policy paper consolidates the findings of the research. It presents an analysis of Alberta's greenhouse gas emission profile, historical trends and the policy framework, as well as an examination of mitigation strategies such as carbon pricing and their effectiveness in Alberta's agricultural system. The key question addressed in this paper is how Alberta can continue to support its thriving agricultural industry while responding to the federal and global calls to significantly reduce its methane and nitrous oxide emissions and fulfil Canada's climate commitments. The paper also outlines the obstacles that producers encounter when implementing these strategies, as well as the limitations of the current emission estimation methodology in measuring the impact. To effectively address the challenges of emission mitigation in Alberta's agriculture sector, a co-ordinated approach at both the federal and provincial levels is crucial. The paper concludes with the following recommendations that outline specific actions to help reduce uncertainties and support producers in implementing best management practices (BMPs) to lower greenhouse gas emissions.

FEDERAL GOVERNMENT:

- Prioritize investment in primary research: Increase funding for foundational research and establish clear reporting guidelines to facilitate the secondary use of data for further analysis.
- Develop a Tier 3 methodology: A detailed methodology that accurately quantifies the impact of best management practice (BMP) adoption on greenhouse gas emissions.
- Streamline the approval process: Simplify the approval process for emerging technologies and practices to accelerate their adoption in the agricultural sector.
- Reconsider fertilizer emission reduction targets: Replace broad fertilizer reduction goals with specific BMP adoption targets that are more achievable and can better address emission concerns.

PROVINCIAL GOVERNMENT:

- Reinvest in extension services: Enhance funding for extension services and research activities to improve knowledge sharing among producers and ensure provincial research objectives are met.
- Address research gaps: Focus on closing the research gap on the effectiveness of enhanced efficiency fertilizers in dryland production systems.
- Increase support for sector-specific research: Prioritize further research on the impact of 3-nitrooxypropanol in the feedlot sector to provide clearer guidance for producers.
- By addressing these targeted federal and provincial actions, we can improve consistency in emissions measurement, enhance the adoption of BMPs and support Alberta's agricultural sector in reducing greenhouse gas emissions.

ACRONYMS AND ABBREVIATIONS

AAFC: Agriculture and Agri-Food Canada

BMPs: Best management practices

CH4: Methane

CO_2: Carbon dioxide

CFIA: Canadian Food Inspection Agency

CFIT: Canadian food inspection technology

CRNFs: Crop residue nutrient factors

ECCC: Environment and Climate Change Canada

EENFs: Enhanced emission nutrient factors

IEF: Implied emission factor

IPCC: Intergovernmental Panel on Climate Change

$MtCO_2$: Megatonnes of carbon dioxide

N2O: Nitrous oxide

NI: Nitrification inhibitor

PCF: Pan-Canadian Framework on Clean Growth and Climate Change

REME: Federal offset protocol for reducing enteric methane emissions from beef cattle

SCP: Strengthened climate plan

SIF: Supplementary information form

SGER: Specified Gas Emitters Regulation

UNFCCC: United Nations Framework Convention on Climate Change

VERs: Verified emissions reductions

4R: Right source, right rate, right time, right place

INTRODUCTION

The Government of Canada signed the Paris Agreement in 2016 (GoC 2016), committing to a 30-per-cent reduction in national greenhouse gas (GHG) emissions below 2005 levels by 2030. To achieve this, the government introduced the Pan-Canadian Framework on Clean Growth and Climate Change (PCF) in 2016, outlining emission-cutting policies and plans, including carbon pricing. The "A Healthy Environment and a Healthy Economy" strengthened climate plan (SCP), introduced in 2020, further enhanced emissions reduction to 40-45 per cent below 2005 levels by 2030 (ECCC 2020).

The repercussions of climate change, however, are not uniform across the nation's diverse regions. In Western Canada, the anticipated warmer climate offers a dual narrative, potentially extending growing seasons and broadening the spectrum of cultivable crops. Simultaneously, this shift introduces heightened vulnerabilities to extreme weather occurrences and increased pest and disease risks, affecting both crops and livestock.

Canadian agriculture grapples with the dual challenge of curbing emissions while sustaining increased food production to meet growing global demand (IISD 2021). Accounting for 10 per cent of total emissions, agriculture in Canada makes up a significant proportion of national GHG emissions, up from nine per cent in 2005 (UNFCCC 2015). However, the PCF did not specify a target for the agriculture sector and proposed climate measures focused only on increasing carbon storage in soil, bio-energy and innovation.

This changed with the SCP, which put a greater emphasis on agriculture. It established the first climate target for the agricultural sector: 30 per cent below 2020 levels from fertilizers, working with fertilizer manufacturers, farmers, provinces and territories to reduce emissions. A year later, Agriculture and Agri-Food Canada (AAFC) defined fertilizer emissions as direct and indirect emissions from applying inorganic fertilizer and CO_2 emissions from urea and other carbon-containing fertilizers (AAFC 2022).

ALBERTA'S AGRICULTURAL EMISSIONS

Alberta plays a significant role in the national agricultural sector and is also the top contributor to agricultural GHG emissions in Canada. The province's agricultural sector emits 21 million metric tonnes (Mt) of CO_2 equivalent (CO_2eq), constituting 30 per cent of Canada's agricultural emissions and roughly eight per cent of the province's total greenhouse gas emissions, which amounted to 270 Mt CO_2eq in 2022 (ECCC 2023b).

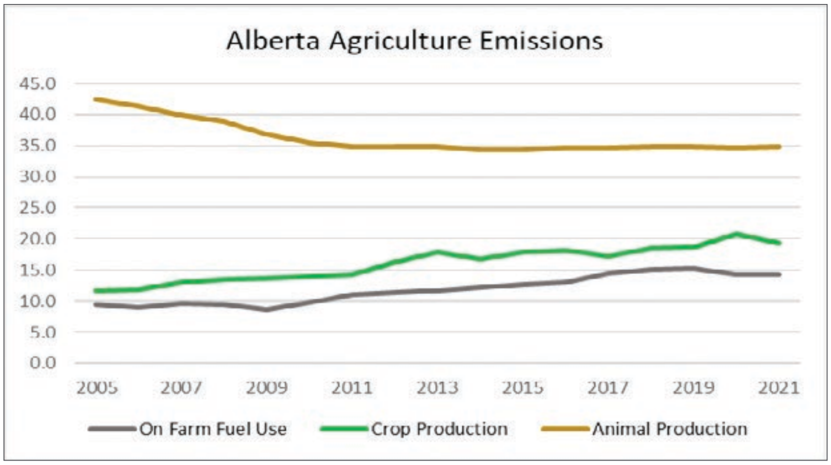
Animal production remains a major GHG emission source in Alberta, responsible for 64 per cent of emissions, while crop production contributes 21.5 per cent of emissions. In the animal production subsector, GHG emissions in Alberta are the highest. Emissions from agricultural soils in Alberta take the second spot after Saskatchewan. Thus, Alberta's share of the country's total agriculture sector emissions means it can substantially contribute to achieving the national emission reduction goal related to synthetic fertilizer and methane emissions.

Alberta's 2021 carbon program was established to enhance the understanding of environmental practices and GHG reduction in agriculture, evaluating and reporting on national and international carbon emissions practices and providing policy recommendations for sustainable agriculture with a specific emphasis on Alberta. The program extends its focus to assessing the effectiveness of globally adopted emission reduction strategies in both crop and animal production in Alberta.

Alberta's agricultural GHG emissions in 2022 remained almost at the same level as 2005 (21 $MtCO_2$ eq). However, the largest subsector of animal production decreased emissions by 16 per cent. This decrease was mainly driven by a fall in the cattle herd following the bovine spongiform encephalopathy (BSE) outbreak in 2003. However, the decrease in animal production emissions was offset by an 82-per-cent increase in emissions from crop production, which directly correlates with an increase in synthetic fertilizer offtake (ECCC 2023b).

The change in emissions over the 2005–2021 period has been driven mainly by variation in production levels rather than emission factors. Considering the anticipated future increase in food demand and the resulting increase in the production of crops and animal products, the role of climate policies will be to delink output growth from agriculture emissions.

Figure 1. Agriculture Sector GHG Emissions in Alberta 2005–2021



Source: ECCC (2023b)

The majority of GHG emissions from the crop sector — roughly 97 per cent — are primarily composed of nitrous oxide (N2O), which emanates from various sources, including the application of synthetic and organic fertilizers, soil cultivation, tillage, mineralization of soil organic matter and manure management, among others. Emissions from animal production mainly result from the enteric fermentation of cattle and biomass decomposition, with approximately 90 per cent being methane (CH4) and 10 per cent N2O.

This paper consolidates the findings from carbon program research. It delves into an analysis of the GHG emission profile, historical trends, policy framework, mitigation strategies and their effectiveness in Alberta's agricultural system. The paper also provides recommendations regarding the roles that various levels of government and research institutions can play in mitigating agricultural GHG emissions and enhancing estimation methodologies to meet emission reduction targets.

THE CHALLENGES IN EFFECTIVE EMISSION OFFSET IMPLEMENTATION

Alberta pioneered carbon trading in North America back in 2007, courtesy of the Specific Gas Emitters Regulation (SGER). This system allowed emitters to buy emission offsets generated in Alberta under government-approved protocols, including the one designed for the agriculture industry (Goddard 2021). In 2016, the PCF mandated provinces and territories to establish carbon-pricing systems, either through an explicit price-based system or a cap-and-trade system, to meet federal benchmarks. The current output-based pricing system, along with the carbon offset mechanism, falls under the jurisdiction of the Technology Innovation and Emission Reduction (TIER) Regulation, which covers about 60 per cent of Alberta's emissions (GoA 2021a). Any emissions offset projects must adhere to the TIER Regulation's criteria, comply with offset standards and use a quantification protocol approved by the Alberta government.

Alberta currently has three active protocols for the agriculture industry, covering nitrous oxide emissions reduction, reducing greenhouse gas emissions from fed cattle and selection for low residual feed intake markers in beef cattle. These protocols have only produced less than one per cent of issued agriculture-based credits so far (GoA 2021a). Another protocol covering conservation cropping and tillage management systems expired in 2021 and was the most prolific, accounting for 23 per cent of all issued carbon offset credits. These four protocols have achieved emissions reductions of 70.4 Mt CO_2eq in carbon offsets to date (Van Wyngaarden 2022). However, there are challenges in effective implementation. It's reasonable to assume that barriers to adopting BMPs are similar to those hindering participation in carbon offset markets. Apart from the barriers such as costs, lack of information and complexity of implementation, to qualify for emission offsets, projects are required to establish a baseline scenario, where emission reductions beyond that are considered additional. Additionality refers to the need for a carbon offset project to result in emission reductions that wouldn't have occurred without the project. It measures whether the outcome is different due to a policy by comparing it to what would have happened without the policy (Gillenwater 2012). For carbon offsets to be effective and meaningful, they should be used in situations where agricultural producers adopt new sustainable practices specifically because of the offset program. The role of offsets is to compensate for emissions that are otherwise difficult to reduce. To address challenging emissions, the primary strategy should focus on reducing emissions at the source, with offsets as one of the tools serving to complement other emission reduction efforts instead of substituting them (Van Kootan and Zanello 2023). Administering the projects that reward additionality presents challenges as accuracy in measuring baselines and estimating the effect of BMPs cannot always be ensured. The effectiveness of carbon offset programs also varies based on project quality, monitoring and verification mechanisms.

Some of the challenges highlighted in effective implementation of carbon offsets may be summarized thus:

- Insufficient revenue for the producers to cover the costs of implementing best management practices;
- Limited coverage of existing emission reduction protocols due to varying crop-specific eligibility;
- Requirement of establishing a baseline emission scenario, where emission reductions beyond that are considered additional, which does not incentivize early adopters;
- Expiration of the Conservation Cropping Protocol (2021) could lead to a stagnant market for agricultural carbon credits;
- Emissions from synthetic fertilizer use are likely to increase unless such use is reduced with BMPs which might adversely impact crop production;
- BMP adoption faces barriers such as risk perception, financial constraints and a lack of reliable information (Pannell et al. 2006; Liu et al. 2018; Prokopy et al. 2019);

- Effective carbon-offset program design depends on project quality, monitoring and verification mechanisms;
- More consistent and user-friendly accounting schemes are necessary to incentivize adoption; and
- The federal offset protocol for reducing enteric methane emissions from beef cattle (REME) released by ECCC (2022b) for public consultation in December 2023 has coverage limited to around 12 per cent of the beef cattle. The protocol does not apply to any strategies used outside feedlots, though the majority of emissions occur on pastures (Vinco, Bourassa, Arman et al. 2022). The eligible strategies also do not include the top two globally recognized strategies to reduce emissions: 3-nitrooxypropanol (3-NOP) and seaweed. REME also has an additionality requirement which would further limit the coverage, compromising its effectiveness even more.

STRATEGIES FOR REDUCING AGRICULTURAL EMISSIONS

Several options are available for reducing agricultural GHG emissions depending on the type of farm operation. Carbon program research focused on analyzing the effectiveness of N2O and enteric methane emission mitigation strategies and BMPs in Canada.

MITIGATING ENTERIC METHANE EMISSIONS: OPTIONS AND STRATEGIES

Methane (CH4) is a highly potent greenhouse gas compared to CO_2, with no capacity for photosynthetic uptake and a shorter atmospheric half-life (Badr et al. 1991). Therefore, reducing methane emissions from agriculture is particularly crucial for short-term impact on climate change.

Most beef production in Canada is linked to Alberta production systems, typically starting in cow-calf operations and finishing in feedlots. Mitigating methane emissions from Alberta's livestock sector can significantly contribute to Canada's national emissions reduction efforts. Although emission targets have not been set for the beef production sector, increasing social, political and environmental pressures will require the beef industry to continue adapting to increasing sustainability measures (Arman et al. 2022).

A 2011–2022 scoping review of 189 cattle production research studies conducted by Kowk and Vinco (2022) suggested a number of mitigation strategies regarding enteric methane production. These included seaweeds and algae, tannins, forage, grains and other components, dietary lipids, nitrate, essential oils, natural and synthetic additives and yeast.

Marine macroalgae feed additives show substantial potential for reducing enteric methane emissions. However, their labour-intensive cultivation and substantial spatial requirements, coupled with variability in quality and efficacy, make them less practical. Also, their growth in warmer climates could result in increased transportation costs and might render their use in Canada impractical. Efforts are underway to commercialize natural algae-based feed supplement through land-based cultivation system in Canada (Synergraze 2023).[1]

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1 Synergraze Inc. has been awarded $1.3 million in funding from Sustainable Development Technology Canada (SDTC) to develop and commercialize a livestock feed additive that is capable of drastically reducing methane emissions from cattle and other ruminants.

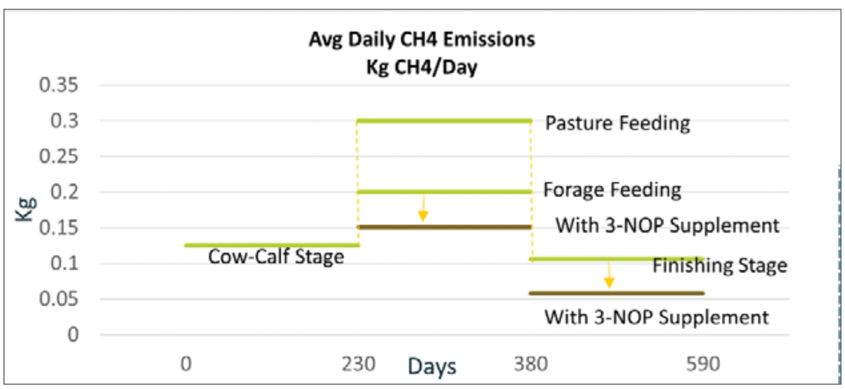
Kowk and Vinco (2022) discovered that incorporating 3-nitrooxypropanol (3-NOP), an enteric CH4 inhibitor developed by DSM Nutrition Products Ltd. (DSM 2019) and seaweeds into cattle diets showed the greatest and most consistent results in reducing enteric CH4. This feed additive is highly soluble and rapidly metabolized in the rumen, showing consistent effects across studies regardless of animal species and diet composition, offering an average reduction in CH4 emissions of 33 per cent (Dijkstra et al. 2018).

CARBON OFFSETS AND 3-NOP SUPPLEMENTATION FOR METHANE REDUCTION

The potential use of 3-NOP in backgrounding and feedlot settings is especially relevant to Alberta, as most Canadian beef is finished in the province (Alberta Cattle Feeders' Association 2018). Research into 3-NOP supplementation in such settings conducted in Lethbridge, Alberta, indicates a dose-dependent response in methane reductions, demonstrating reductions between 20 and 60 per cent, depending on supplementation and diet (Alemu et al. 2021; Vyas et al. 2016).

Vinco, Bourassa, Arman et al. (2022) used a Monte Carlo simulation to investigate the effects of 3-NOP on total lifetime methane emissions in steers through different production systems and different 3-NOP dosage levels. The model was developed using a modified version of the Intergovernmental Panel on Climate Change (IPCC) Tier 2 gross energy approach methodology and parameters specific to Canadian beef production. The potential value of emission reductions with various doses and differing stages of production was subsequently estimated using a hypothetical provincial offset protocol for 3-NOP supplementation.

Figure 2. Daily Emission Estimated Using Treatment Group Average Input Variables



Average daily emissions at each stage of production vary with the quantity and quality of feed. At the time of weaning, the daily emissions are 0.125 kg CH4/day. After weaning, steers that stay on pasture emit more methane emissions (averaging 0.3 kg CH4/day). Methane emissions are much higher when beef steers are left on pasture. Steers that are fed a high-energy forage diet (backgrounding) emit less methane (0.2 kg CH4/day). Average daily emissions are the lowest at the finishing stage because of a high-energy diet. The CH4 emissions are lowered at the backgrounding stage when steers are fed a forage-based diet in a feedlot. Emissions are further reduced when 3-NOP is added at the finishing stage in the feedlot.

The results indicate that lifetime emissions were reduced by between 6.1 and 10.4 kg CH4/head when 3-NOP was supplemented at the finishing stage of production. An additional 3.7 to 5.7 kg/head estimated lifetime emission reductions were observed when supplementation at the backgrounding stage of production occurred. These reductions translate to potential offset values between $7.66 and $12.97 per head in the finishing stage and between $4.62 and $7.13 per head at the backgrounding stage.

Incentives for the adoption of 3-NOP remain uncertain, however, as supplementation is not concretely associated with added production value. Carbon offsets may offer a potential incentivization strategy and programs such as carbon offset protocols in Alberta's TIER framework should be developed, potentially offering values of $7.62 to $20.12 per head at a $50/tonne CO_2eq rate. By 2030, this value could reach up to $68.42 per head with carbon prices at $170/tonne.

There are two major barriers to adoption. First, the Canadian Food Inspection Agency (CFIA) classes 3-NOP as a veterinary supplement which requires a lengthy approval process. Thus, 3-NOP has been unavailable in Canada as of June 2024. Since it is already approved for use in over 40 other countries, CFIA's Animal Feed Program finally evaluated and supported the approval of 3-NOP as a feed ingredient that reduces rumen methane emissions in cattle (GoC 2023b). Based on the scientific data, the CFIA recommends adding 3-NOP to the Canadian Feed Ingredients Table (CFIT) as a new, safe and effective single-ingredient feed (SIF). Second, it is unclear how consumers view synthetic feed additives for emission reduction in livestock production. Consumers might associate them with antibiotics and hormones, which calls for further research and outreach to address consumer concerns. A startup, Volta-Greentech, produces LOME (low on methane) beef using naturally grown seaweed and has met with success at small scale but some barriers to adoption remain (Askew 2022). Large-scale production of seaweed and development costs add a premium to the cost of beef and consumer willingness to pay (WTP) might be one of the barriers. Several studies on WTP for low-emission food have shown that consumers are willing to pay more for environmentally friendly products, but the premium they are willing to pay often depends on the perceived benefits and the trustworthiness of environmental claims. For example, Van Loo et al. (2014) show that environmental labelling, transparency and awareness significantly influence consumer choices.

To drive adoption of methane reduction strategies, the introduction of mitigation technologies and strategies must align with federal and provincial policy development and implementation. It must also ensure sufficient profit to producers, potentially through the sale of carbon offsets as the market develops, to cover additional costs of adoption and incentivize use (Kowk and Vinco 2022).

MITIGATING DIRECT FERTILIZER-BASED EMISSIONS: OPTIONS AND STRATEGIES

AAFC (2022) defined fertilizer emissions as direct and indirect emissions from applying inorganic fertilizer including CO_2 emissions from urea and other carbon-containing fertilizers. The discussion paper outlined various short-term mitigation strategies to achieve the fertilizer-based emission target, primarily regarding the adoption of 4R BMPs (right source, right rate, right place and right time) nutrient stewardship and sustainable fertilizer use in crop production, along with implementing conservation tillage, enhancing field drainage and increasing the use of legumes in crop rotation.

Bourassa et al. (2022) synthesized multiple meta-analytical studies to assess the impact of BMPs on N2O emission reductions and compared their findings with the results of the AAFC discussion paper. They found that the effects of different practices varied significantly and appeared to be highly dependent on environmental factors outside the producer's control. The reviewed studies addressed nitrogen source, application rate, timing, placement, conservation tillage, biochar use, irrigation, cover cropping and rotation. Contrary to AAFC's claims, organic fertilizers showed limited N2O reduction, while biochar, a charcoal form of biomass waste, reduced emissions by 38 per cent and increased yields by 14 per cent, despite adoption challenges in the Canadian Prairies. Conservation tillage was found to increase emissions by seven per cent on average. In the case of other 4R BMPs (rate, place and time), limited research exists on their impact on N2O emissions and yield. This scarcity is likely due to the challenges in finding suitable comparisons for a generalized meta-analysis, compounded by variations in management practices, environmental conditions and crop types. Subsurface fertilizer application could reduce N2O emissions by five to 15 per cent, but Canada's emission estimation methodology doesn't account for fertilizer placement. Conflicting results were found for spring fertilization, split application and fertigation, complicating the understanding of 4R BMPs. The AAFC document under-emphasizes cover crops and rotation, which are noted for their ecological benefits. Bourassa et al. (2022) found that both legume and non-legume crops contributed to N2O emissions, with non-legumes increasing emissions less (eight per cent). However, including legumes in Canadian methodology for N2O reductions requires proper accounting for nitrogen credits.

ENHANCED EFFICIENCY NITROGEN FERTILIZERS (EENFs)

EENFs use technologies such as controlled-release coatings, inhibitors or stabilizers to slow the release of nitrogen, providing a more consistent and prolonged nutrient supply to crops. EENFs help extend nitrogen availability by minimizing nitrogen loss. They fall into two main categories: stabilized nitrogen fertilizers (SNFs), which employ urease or nitrification inhibitors, and controlled-release nitrogen fertilizers (CRNF) that use a polymer or resin coating to gradually release nitrogen.

Bourassa et al. (2022) found EENFs to be effective at reducing N2O emissions with an estimated average reduction of 29 per cent, similar to estimates provided by AAFC (2022). Both types of EENFs — SNFs and CRNFs — were effective, with an average reduction estimated to be 37 and 19 per cent. EENFs significantly increased yield compared to conventional inorganic fertilizers, creating a potential win-win scenario where the cost of adoption can be fully or partially offset by increased yields.

CARBON OFFSETS AND EENF ADOPTION IN ALBERTA

Alberta's TIER Regulation offers offset protocols for agriculture, such as the Nitrous Oxide Emission Reduction Protocol (NERP), aimed at reducing fertilizer emissions —including EENFs — through BMP adoption. However, NERP has seen minimal participation since its inception (Van Wyngaarden 2022).

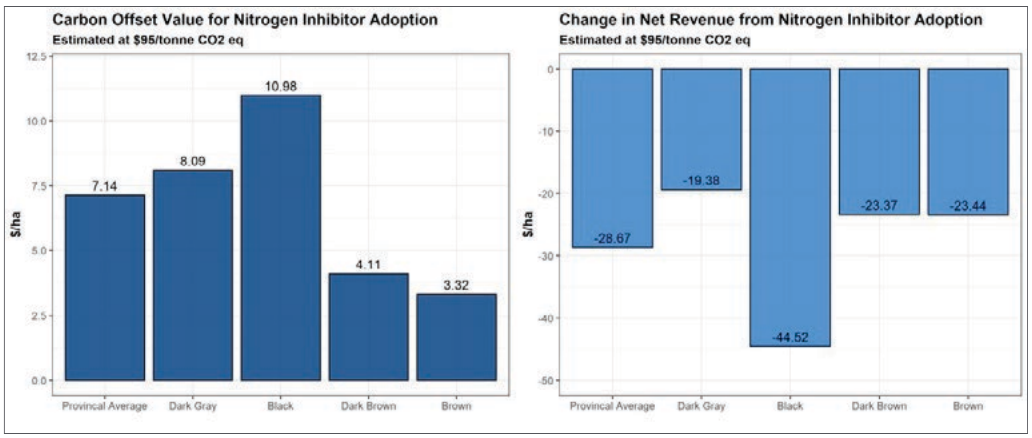
To promote EENF adoption, it's crucial to understand the cost and benefits for producers, an aspect notably lacking in the AAF's N2O emission discussion. Meeting emission reduction targets necessitates widespread EENF adoption, especially in the Canadian Prairies. If BMP adoption remains voluntary, it's crucial to carefully assess its financial implications for farmers (Arman et al. 2022).

Arman et al. (2022) conducted a study to assess the cost and benefits of EENF adoption in dryland wheat production in Alberta. It employs a modified version of Canada's *National Inventory Report* methodology for N2O emissions estimation, using Monte Carlo simulations based on weather and production data. Producer costs and benefits are evaluated concerning potential revenue changes, both without incentives and with carbon offsets valued at $50 and $170 per tonne of CO_2eq.

The study identifies substantial provincial variation in N2O emissions, driven by factors such as rainfall, soil texture and crop productivity. The current average emissions stand at 210 kgCO_2/ha, potentially reducing to about 130 kgCO_2/ha with nitrification inhibitor (NI)/EENF adoption, equating to a relative reduction of about 36 per cent.

However, these reductions are modest per unit, posing challenges for emission-based incentivization. Potential strategies encompass subsidies (with an average cost of $475 per tonne reduced), emission pricing or transferring adoption expenses to producers or consumers. Even at a carbon price of $95/tonne of CO_2eq., emission pricing generates a mere $7/ha from NI adoption, resulting in a substantial net revenue drop of $29 per hectare (Figure 3).

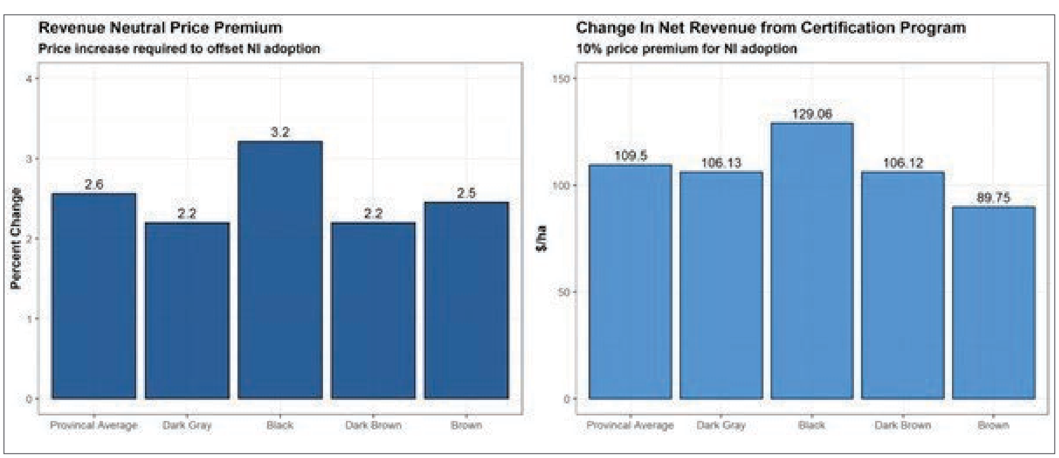
Figure 3. EENF Use, Net Revenue Changes and Value of Carbon Offset



Source: Arman et al. (2022)

To fully offset the cost of NI adoption and remain revenue neutral, wheat prices would need to increase by approximately two to three per cent. A 10-per-cent price premium for NI-produced wheat results in a significant net revenue boost of $110 per hectare across the province.

Figure 4. Price Premium Required to Offset EENF Costs and Effect of 10-Per-Cent Price Premium



In summary, although subsidies present a rapid path for fostering adoption due to their expediency, their high costs and sustainability concerns remain noteworthy. Theoretically, carbon pricing stands as an efficient mechanism but would require a considerably higher carbon price, ranging from approximately $300-$400 per tonne, to fully counterbalance adoption costs.

While low-emission production certification could reduce offset costs, contingent on consumer willingness to pay a premium, it introduces the risk of encountering low demand and logistical complexities. The exploration and refinement of incentivization methods warrant ongoing discussion to discern the most effective and sustainable approach.

STAKEHOLDER PERCEPTIONS AND ATTITUDES TOWARDS BMP ADOPTION

The adoption of sustainable agricultural practices varies across crops. In 2021, approximately 54 per cent of canola acres and 58 per cent of spring wheat acres in Western Canada adhered to the basic 4R BMPs. However, only 34 per cent of wheat growers conducted annual soil sampling, 20 per cent applied varying rates on a field-specific basis and an additional 15 per cent used advanced 4R BMPs such as variable rate technology (Vinco et al. 2023). In contrast, most nitrogen application in Canadian canola production in 2021 occurred during spring, accounting for 75 per cent of nitrogen applied, with enhanced efficiency fertilizers making up 15 per cent of the total nitrogen applied (Fertilizer Canada 2021).

Vinco et al. (2023) conducted semi-structured interviews to assess perceptions and attitudes towards N2O emissions mitigation strategies in crop production and related industries. Participants universally expressed concerns about climate change's impact on Western Canada's agriculture. They criticized top-down federal policy development, advocating for a bottom-up approach to create inclusive, industry-aligned policies.

Producers feared a 30-per-cent N2O emissions reduction might harm their financial viability due to yield concerns. While endorsing 4R BMPs, they highlighted barriers such as labour shortages and equipment costs. Sectional control technology saw higher adoption due to cost savings. EENFs are under-used, with only 15 per cent of nitrogen volume using EENF products.

Adoption barriers included cost, unclear yield benefits and concerns about polymer-coated fertilizers and environmental tradeoffs. Participants also cited challenges in accessing information about emerging technologies, identifying a lack of internet infrastructure and resource allocation as barriers to precision agriculture adoption.

These concerns could be addressed through risk mitigation measures and simplified carbon credit processes. Producers stressed the need for practical demonstrations of adoption benefits, enhancing on-farm efficiency and soil health through agricultural extension programs to promote BMP adoption for emission mitigation.

ADOPTION OF ENTERIC METHANE REDUCTION STRATEGIES

Canada's National Beef Strategy, as outlined by the Canadian Beef Advisors (2022), aims to reduce greenhouse gas emissions in beef production by 33 per cent by 2030, with a specific emphasis on the role of beef cattle in carbon sequestration and pasture management. The success of this strategy relies on the choices individual cattle producers make at the farm level (Vinco, Bourassa, Arman et al. 2022). In their study, Vinco, Morrison et al. (2022) conducted interviews with 24 stakeholders, including producers, producer associations and a livestock genetics researcher, to assess attitudes toward future methane emission reduction strategies.

Producers highlighted the importance of regulatory approvals for 3-NOP but expressed concerns about the limited timeline and potential approval barriers. Challenges related to accurately administering feed additives, reluctance to change established feed rations due to perceived risks and barriers associated with eligibility and administrative burdens were also noted.

To drive adoption, the study recommended that protocols be expanded across the beef production supply chain. Incentives should focus on enhancing cattle and on-farm efficiency to address cost concerns. Participants expressed frustration with current provincial extension services and recommended strengthening communication channels with the government.

To boost uptake, it is essential to address current limitations on eligibility for the carbon offset market and ease adoption burdens. Protocols should concentrate on on-farm measurable actions to facilitate verification. Involving stakeholders directly in beef production can lead to more inclusive policies and improved emissions data collection. Reinvesting in and expanding agricultural extension programs is vital to inform Alberta's beef production stakeholders about emission reduction strategies.

ASSESSMENT OF GHG EMISSION ESTIMATION METHODOLOGY AND ITS CONSTRAINTS

With increasing environmental, social and political demands to reduce greenhouse gas emissions, the need for precise emission measurements is evident. Carbon footprints vary for every subsector of agriculture and assessing them is a complex effort that involves accounting for every process that occurs throughout production (Fouli et al. 2021).

Canada has established a robust methodology for accurately estimating direct N2O emissions from agricultural soils and CH4 from enteric fermentation and manure management (Bourassa and Vinco 2022). In simple terms, emissions result from multiplying activity data by an emission factor, representing emissions per unit of activity (ECCC 2022c). To lower emissions, activity can be reduced, or emission factors improved. While reducing activity can help lower emissions, it contradicts the goal of increasing production to meet growing local and global demand. Therefore, policies should prioritize enhancing methods to lower the emission factor, preserving Canada's status as a major agricultural exporter. For animal production, emissions are estimated by multiplying livestock population data by specific emission factors for various sources and gases. While many factors are set at international benchmarks, some, such as enteric fermentation with cattle and swine manure management, use more precise Tier 2 estimates. Implied emission factors (IEF), which represent average emission factors, are calculated by dividing total emissions by activity data and can be found in annual common reporting format tables submitted to the United Nations Framework Convention on Climate Change (UNFCCC 2015; Rypdal et al. 2006).

Soil emissions are estimated at the eco-district level, then combined for provincial and national totals. The base emission factor depends on climate and topography, varying across Canada. Soil texture is considered especially in Eastern Canada, where fine textures correlate with higher N2O emissions (ECCC 2023a). Various sources of emissions, such as organic and inorganic fertilizers, are estimated using specific equations and activity data. No-till and irrigation practices are also accounted for, with effects varying by province. Emissions associated with dung on fields are reallocated from crop to animal production in the Canadian economic sector methodology. The last source of emissions comes from cultivating organic soils, using a Tier 1 estimate.

In Canada, estimated soil emissions per hectare vary between provinces due to factors such as precipitation ratios, crop mix, management practices and environmental conditions. Alberta and Saskatchewan, while similar in many ways, still have variations in emissions, largely due to differences in irrigated land. Alberta has more land under irrigation and the methodology accounts for the fraction of land under irrigation, leading to higher emissions on a per-hectare basis in Alberta (Bourassa et al. 2021).

The complexity of the methodology increases significantly in the case of the United States (Tier 3), Canada (Tier 2) and the United Kingdom (Tier 2) as they use dynamic models to estimate emissions tied to specific geographical areas and account for both environmental conditions and management practices (Brown et al. 2022; ECCC 2022c; EPA 2022).

While advanced emission estimation models such as Tier 2 and Tier 3 offer advantages, they come with limitations that affect the options for reducing emissions. In Canada, emission factors are primarily influenced by eco-district level environmental variables, including precipitation, potential evapotranspiration, topography and soil texture. Emission levels are calculated through a two-step process in which applied nitrogen is multiplied by the emission factor and then modified to account for tillage (conservation or conventional) and irrigation (yes or no). Producers' decisions directly influence only five model inputs: crop type, nitrogen source, application rate, tillage and irrigation. This approach restricts the scope for producers to reduce emissions, making it challenging to achieve emission reduction targets without substantial cuts in fertilizer use (ECCC 2022a; EPA 2022).

The current emission estimation methodology, while suitable for large-scale assessments, has limited applicability in identifying and formulating policies to reduce soil-based emissions and an even narrower scope in the Canadian production system. A comparison with BMPs in the AAFC discussion document reveals that only three out of 11 identified BMPs are directly integrated into the methodology (Table 1). The reasons for exclusion of some of the BMPs from emissions estimation methodology include insufficient data or recognition in national assessments. Also, discrepancies could arise from the lag in incorporating new research findings into official emission estimation frameworks. While four BMPs might influence emissions if total nitrogen sales decrease, their full impact is uncertain. Notably, the model excludes key practices like enhanced efficiency fertilizer use, spring nitrogen application, fertigation and improved field drainage, which represent 55 per cent of the potential for mitigation.

Not including BMPs such as EENFs as a model input makes the proposed emissions reduction target unattainable without significant reductions in nitrogen fertilizer use. While achieving the target by 2030 is unrealistic, prioritizing data collection and improving understanding of on-farm activities and nitrogen use are feasible short-term steps. Regarding non-point source emissions, precise modelling is essential because direct monitoring across vast areas is often impractical or unfeasible. It is important to note that the choice of methodology, even with consistent data, can have a substantial influence on estimated emission levels and the feasibility of emission targets (Bourassa et al. 2023). Another challenge is improving the robustness of fertilizer-induced N2O emission factors in Canada estimated by Rochette et al. (2018), which are based on a meta-analysis of 54 studies. However, a lack of standardized data reporting rendered many studies unusable. Furthermore, these studies have been heavily concentrated in Quebec, despite that province accounting for only five per cent of total farmland and six per cent of inorganic nitrogen use (Statistics Canada 2022, 2023). Efforts must also be made to conduct research outside traditional research clusters such as Agassiz, Lethbridge, Guelph and Quebec City to increase the variation in soil and environmental conditions.

Table 1: Information on the Beneficial Management Practices Identified in the AAFC Discussion Document

Beneficial Management Practices	Regional Applicability	Current Adoption Level	Mitigation Potential (%)	Mitigation Potential (Mt CO_2e /yr)	Included in Methodology
Annual Soil Testing + Spring Application	All Regions	Low	5-15%	0.23	Indirectly Included
Nitrogen Credit (legume crop)	All Regions	Medium/High	10-20%	0.63	Indirectly Included
Spring Application	Mainly West	High	5-15%	0.12	Not Included
Fertigation	Mainly West	Low	15-25%	0.02	Not Included
Split Application + Sensor Adjusted Rate	Mainly East	Medium	15-35%	0.65	Indirectly Included
Bands/Injection + Reduced Rate	All Regions	High (W) Medium (E)	5-15%	0.24	Indirectly Included
EENF USE	All Regions	Very Low	15-35%	2.35	Not Included
Organic Fertilizer Use	All Regions	Low	10-20%	0.15	Included
Conservation Tillage	All Regions	High (W) Medium (E)	5-15%	0.15	Included
Improved Drainage Design	Mainly East	Medium/High (E)	10-30%	0.13	Not Included
Increasing legumes in Rotations	Mainly West	Low	15-25%	0.1	Included

Source: Bourassa et al. (2023)
Discussion Document: AAFC (2022)

CONCLUSION AND POLICY RECOMMENDATIONS

This paper consolidates the findings from Alberta's carbon program and provides recommendations regarding the roles that various levels of government and research institutions can play in enhancing emission reduction measures and estimation methodologies and to meet the national targets.

Some of these recommendations are:

CONSISTENCY IN THE MEASUREMENT OF GHG EMISSIONS

Under the current methodology, production decisions influence fertilizer quantity, but there is no specific emission factor assigned to different types of fertilizer use. The quantification protocols covering 4R BMPs in Alberta for reducing nitrous oxide emissions in agriculture fall short in effectively reducing provincial emissions at the national level, primarily because these measures are not integrated into the national methodology. Canadian policy-makers and stakeholders must align current and future programs aimed at emission reduction with the national methodology.

To reach the goal of net zero emissions by 2050, Canada must develop emission-based targets, requiring a Tier 3 emission methodology like the U.S. (GoC 2023a; ECCC 2022a). For this purpose, GHG emission data collection needs to be prioritized and research efforts must be dispersed more evenly across the country for success. AAFC is well suited to lead these efforts due to its involvement in funding and conducting agricultural research in Canada.

INTERGOVERNMENTAL CO-ORDINATION

Improved intergovernmental co-ordination is strongly recommended for alignment of policies with national objectives and to enhance the implementation and impact of emission reduction efforts. For example, establishing a new Tier 3 emission methodology necessitates substantial investment and co-ordination among federal and provincial entities, universities and colleges. Research efforts must be dispersed more evenly across the country for more evidence and improving the accuracy of emission factors in diverse agro-climatic conditions. This will also help augment the methodology with BMPs that are unaccounted for in the current methodology. While developing a national methodology will inevitably be a federal responsibility, provincial organizations should be heavily involved in encouraging and funding research in their respective provinces.

Federal funding should be aligned with provincial and farmer-level initiatives, facilitating seamless implementation and ensuring that federal support directly contributes to achieving local and national goals. Federal and provincial carbon protocols should be designed to ensure that the practices and standards for carbon management are consistent with what farmers are implementing on the ground.

Establishing a system for regular communication and oversight between provincial and federal agencies to monitor the integration of protocols and funding is recommended. Better planning and co-ordination across governments and research institutions can also improve standardized reporting and integration of emission mitigation efforts in tracking progress, identifying gaps and adjusting strategies as needed.

OFFSET PROTOCOLS FOR FEED ADDITIVES

To better incorporate carbon offsets into Alberta's Technology Innovation and Emissions Reduction (TIER) system, a framework specifically designed for carbon offset protocols would provide much-needed clarity and adaptability. This framework could streamline the inclusion of carbon reduction measures such as feed supplementation (e.g., 3-NOP) and feed additives, reflecting Alberta's critical role in the beef and feedlot industries.

However, it is important to acknowledge that offsets are not a one-size-fits-all solution. The policy landscape around offsets must recognize that different sectors, technologies and practices will require tailored incentives and adoption pathways. Widespread adoption may not occur uniformly and certain practices may be less effective or harder to implement across various production systems. Moreover, the development of offset protocols for 3-NOP and similar innovations should consider not only emission reductions but also their broader impacts on production efficiency, profitability and market dynamics.

CARBON OFFSETS AND BMP ADOPTION

To enhance transparency and clarity, the Alberta government can design carbon credit protocols and programs that focus on farm-level actions, with payments contingent on verified emissions offset. This approach simplifies the process, making it more understandable and transparent by linking specific activities and measures to carbon credits in the revision and development of offset protocols.

To compensate farmers' costs for EENF adoption, Alberta may issue low-emission production certification which can offset costs if consumers are willing to pay more, but it carries a risk of low demand and logistical complexities. To increase coverage of the offset protocols in Alberta, establishing a rebate program tied to EENF sales through crop input retailers can be an option. Retailers should apply for rebates based on their EENF sales, with the goal of reducing consumer prices and promoting greater EENF adoption.

Further deliberation is needed on incentivization methods to determine the most effective approach. A potential pathway for Alberta involves updating its emission offset system to align with internationally recognized standards for low-emission production certification, thereby encouraging the adoption of BMPs in crop and beef production.

Cargill has recently developed a Gold Standard-approved methodology that establishes a framework for measuring methane emission reduction through the use of feed supplements (Cargill 2023). This methodology is accessible to global beef producers, enabling them to quantify, audit and validate methane reductions. Consequently, they can register for Gold Standard certification and trade verified emissions reductions (VERs) in carbon markets. Recognition in corporate value chains allows beef producers and food companies to incorporate reduced supply chain greenhouse gas emissions into their accounting, contributing to the fulfillment of their Scope 3 targets.

The approval and availability of 3-NOP is not a distant reality after CFIA recently cleared it as a feed supplement and recommended it for approval. Further research on the impact of 3-NOP in the feedlot sector is needed to clarify its effects on production markers, aiding operators in understanding the implications of adoption and potential benefits or risks linked to supplementation. Clear communication of benefits and potential trade-offs would support producers in understanding the full implications of these new technologies.

The Alberta government can enhance research on the effectiveness of EENFs in dryland production systems, addressing a current research gap. Most studies focus on other regions, so prioritizing Alberta-specific trials can provide a better understanding of EENF impacts and financial benefits. The intrinsic efficiency benefits to farmers of implementing these protocols should be emphasized for their own sake.

One way to encourage adoption is by bundling the environmentally friendly traits of EENF adoption in crops or feed supplement and genomic selection in livestock with their efficiency benefits. Worden et al. (2023) show that producers' willingness to adopt environmentally friendly substitute technologies or management practices primarily depends on the resulting economic benefits rather than the environmental benefits.

COMMUNICATING THE BENEFITS OF BMP ADOPTION

Enhancing producer buy-in involves integrating both private and societal benefits into a unified entity, as opposed to singularly emphasizing a specific aspect of the technology or management practice. This bundling approach results in a super-additive willingness to pay the cost premium, underscoring the significant role of combining private and public goods in agricultural production. This would require minimal policy intervention.

AGRICULTURE EXTENSION SERVICES

Prioritizing reinvestment in Alberta's agricultural extension is crucial to improve knowledge and adoption. These programs, tailored to crop and beef producers and stakeholders, provide unbiased, accessible information on emission reduction strategies and research results. They also foster stronger government-producer relationships and better communication. This would help to convince Alberta farmers to invest in emission-reducing technologies for nutrient management and adopt BMPs for the purpose of making money in the current Alberta carbon credit market.

To develop effective policies and set future targets requires a comprehensive understanding of on-farm activities and nitrogen use across diverse production systems and Canadian regions.

Once baseline data are established, clear, measurable and attainable adoption-based targets should be implemented to ensure policy objectives are achieved. Table 2 provides a summary matrix of the recommendations, detailing the associated stakeholders for each.

Table 2. Summary of Recommendations for Enhancing Agricultural Emission Reduction and Management

Recommendation	Description	Stakeholders Involved	Approach
Develop a new Tier-3 emission methodology	Create a comprehensive emission methodology to track and report greenhouse gas emissions, similar to advanced approaches used in other countries.	Federal and provincial governments, research institutions	Top-down
Create carbon offset protocols encompassing feed supplementation and additives, especially 3-NOP	Establish protocols for carbon offsets that include specific feed additives like 3-NOP to reduce emissions from cattle.	Government, agricultural organizations, feed producers	Top-down
Implement low-emission production certification to offset EENF adoption costs	Develop certification programs for low-emission production that help offset the costs of adopting enhanced efficiency nitrogen fertilizers (EENFs).	Provincial governments, certification bodies, farmers, agricultural organizations	Bottom-up and top-down
Enhance research on the effectiveness of EENFs in dryland production systems	Increase research efforts to understand how EENFs perform in dryland conditions and their impact on crop yields and emissions.	Research institutions, farmers, agricultural organizations	Bottom-up
Conduct Alberta-specific trials to better understand EENF impacts and financial benefits	Perform localized trials in Alberta to gain insights into the effectiveness and financial implications of using EENFs.	Researchers, provincial government, farmers	Bottom-up
Prioritize reinvestment in Alberta's agricultural extension	Focus on reinvesting in agricultural extension services to improve knowledge dissemination and adoption of best practices.	Provincial government, industry, farmers	Bottom-up
Standardize reporting and integrate emission mitigation efforts	Develop consistent reporting standards and integrate efforts across various emission mitigation programs.	Federal and provincial governments, industry stakeholders	Top-down
Ensure consistency and alignment in federal and provincial carbon protocols	Align carbon protocols across federal and provincial levels to streamline implementation and effectiveness.	Federal and provincial governments	Top-down
Design carbon credit protocols and programs focusing on farm-level actions, with payments contingent on verified emissions offset	Create farm-level carbon credit programs that provide payments based on verified emissions reductions.	Government, farmers, carbon credit agencies	Top-down
Develop sustainability benchmarking and labelling products with an emission score	Introduce sustainability benchmarks and labelling to provide consumers with information on the emission footprint of products.	Industry, consumers, regulatory bodies	Bottom-up and top-down

NEXT STEPS IN POLICY RESEARCH

A substantial body of knowledge exists regarding agricultural land management practices that can transform land from a source to a sink for greenhouse gases. However, there is a lack of evidence regarding the efficiency and effectiveness of specific policy instruments that will encourage the uptake of these practices.

Alberta needs a better understanding of its producers' willingness to adopt BMPs. The choice of adopting BMPs hinges on multiple factors that vary in different farming practices and geographic regions in Canada. Understanding the factors that can and will drive the adoption of BMPs in Alberta may provide insight into the potential predictability of adoption in the agricultural sector (Vinco et al. 2023).

Similarly, Alberta needs a better understanding of its consumers' willingness to pay for environmentally produced agricultural products. Labelling products with an emission score could be an incentive for producers and an attractive feature for consumers.

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