Costs and Benefits of Effective and Implementable On-Farm Beneficial Management Practices that Reduce Greenhouse Gases

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Abstract

Greenhouse gas (GHGs) emissions from Canadian agriculture are projected to increase to 2030, which is incongruent with Canada's commitment to reduce emissions significantly by 2030 and achieve net-zero by 2050. Increasing adoption of agricultural beneficial management practices (BMPs) known to reduce GHGs is an important pathway to mitigating emissions in the sector. Farmers face many barriers in adopting new practices, including economic, and government funding may be necessary to encourage the adoption of practices with disproportionately large public compared to private benefits. The next federal budget represents an opportunity to encourage targeted BMP adoption programs, particularly for practices with low abatement costs ($/t of GHG reduced). However, the magnitude of these payments remains uncertain. Therefore, the purpose of this report is to assesses the annual net change in farm returns per hectare from adopting various best management practices that reduce GHG emissions and determine the costs of adoption.

This report finds that many practices could have either a positive or negative effect on farm incomes. External supports would likely be necessary to increase the adoption of costly on-farm GHG mitigating practices. However, the results also indicate that some practices, mutually beneficial to farmers and the environment, still have low levels of adoption. These practices may also need support to become widely adopted where appropriate. To drive adoption, the study found that lower incentives per hectare are necessary to advance 4R (Right Rate, Right Placement, Right Timing, Right Source) N management practices, but that this had lower mitigation potential per hectare. Cover crops, conservation of wetlands and trees and rotational grazing had higher inducement costs per hectare, but also had higher mitigation potential. The abatement costs range from $31 to $77 per tonne CO2e (Table S1).

Overall, the total costs of the 4 programs proposed to improve adoption of nitrogen management, cover crops, rotational grazing, and the conservation of wetlands and trees on agricultural lands are estimated to be $283 million dollars per year. The total GHG emissions reduction in CO_2e is more than 9.5 million tonnes across 17 million hectares. This results in an approximate total average abatement cost of $29.69/t CO_2e, equivalent to a cost share incentive of $16.47/ha (Table S1).

Table S1: Summary of program costs, GHG emissions reductions, covered area and abatement costs for 4R implementation, rotational grazing adoption, cover crop adoption and set-aside trees and wetlands.

BMP	Change	Cost Share Equivalent ($/ha)	Area Affected (ha)	Total Program Cost ($)	Total GHG Mitigation (t CO2e)	Abatement Cost ($/t CO2e)
4R (50% Cost Share)	15% New and Improved Adoption	8.35	13,861,275	115,698,825	2,919,111	39.63
Cover Crops	15% New Adoption in ROC 1% New Adoption in Prairies	47.98	2,360,073	113,244,945	2,216,471	51.09
Rotational Grazing	10% New Adoption	24.22	967,132	23,424,375	302,414	77.46
Set Aside	40% Vulnerable Wetlands and Trees Preserved for 20 Years	2,363.71	13,104	30,973,740	4,105,652	7.54
Total		16.47	17,201,584	283,341,885	9,543,648	29.69

1. Introduction

Greenhouse gas (GHGs) emissions from Canadian agriculture are projected to increase to 2030, which is incongruent with Canada's commitment to reduce emissions significantly by 2030 and achieve net-zero by 2050. Agricultural beneficial (or best) management practices (BMPs) can help mitigate GHG emissions and sequester carbon. However, there are many agricultural BMPs, with unclear economic and environmental effects. To limit the scope of this work, a short-list of BMPs were selected based on their potential to reduce GHGs, their ease of near-future implementation, and their palatability to farmers. The practices selected are improved nitrogen management, cover crops, rotational grazing, and conservation of wetlands and trees most at risk of conversion on agricultural lands. A complementary report, Burton (2021), describes the magnitude of the GHG reduction potential of these practices.

The economic costs and benefits of these practices need to be established to better understand both the cost-effectiveness and impact of practices to mitigate GHGs to maximize the impact of investment by the farmer, the government or non-government entities. This report seeks to address this through two main objectives.

The first objective aims to quantify the range in net change in farm-level returns expected from the adoption of these BMPs across two major agricultural zones - the Prairies and the Rest of Canada (ROC). The second integrates these ranges in net returns to establish the costs of inducing different adoption scenarios for each BMP at the landscape scale, to estimate the total GHG reductions and the cost per tonne CO_2e of government investment in agricultural programs in the near term. This report employs farm financial analysis and economic modelling. The results presented here depend on average farms in broad regions. They do not necessarily represent any individual farm and careful consideration should be given to the results in a specific context.

Section 2 presents a summary of the annual on-farm net return associated with adopting select BMPs This section reveals that there are upfront economic barriers to adoption of some BMPs, even if private benefits of adopting these practices do accrue over time, in many cases. Section 3 examines the integrated economic and GHG analysis to examine the abatement costs and GHG mitigation effects of different kinds of programs that would help to encourage adoption of appropriate BMPs. The GHG analysis used in this report is drawn from the complementary report by Burton et al. (2021).

2. On-Farm Costs and Benefits of BMP Adoption

This section employs farm-level enterprise budgeting techniques to examine the range in net returns from the examined BMPs. This section describes the analysis summarized in the findings presented in Table 1. It establishes ranges for 'average' or 'representative' farms by broad geographic regions. This means that a specific operation could fall anywhere within the range, although cases are possible outside of these ranges. Therefore, careful consideration of site-specific information is required when applying this information to a specific operation. In general, the analyses in this section are best suited to black soil regions in 'Prairies' and humid conditions in the 'ROC'. None of the cost-benefit analyses here integrate environmental benefit values monetarily. As this report ultimately aims to quantify the program costs of GHG reduction from these practices, including the financial value of these benefits was not seen to be appropriate.

Table 1: Annual change in net returns per unit for various on-farm best management practices by location in Canada, with negative values implying costs to implement.

Practice	Location (Type)	Annual Change in Net Revenue			
		Low	Middle	High	Unit
Split Nitrogen Application	ROC	-55.24	-3.63	49.25	$/ha
(Right Timing)	Prairies	-30.52	2.85	39.78	$/ha
Enhanced Fertilizers	ROC	-162.49	-19.35	139.31	$/ha
(Right Source)	Prairies	-125.24	-33.41	80.30	$/ha
Recommended Rate	ROC	-10.39	7.01	24.40	$/ha
(Right Rate)	Prairies	0.90	13.48	22.18	$/ha
Variable Rate Application	ROC	-45.29	27.11	95.54	$/ha
(Right Placement)	Prairies	-31.88	17.51	67.25	$/ha
Cover Crops	Rye	-314.46	-85.91	44.33	$/ha
	Oats	-265.66	-77.76	34.00	$/ha
	Clover	-107.05	66.23	255.04	$/ha
	MS 70% Legume	-202.76	-44.68	142.05	$/ha
	MS 50% Legume	-123.19	7.77	159.63	$/ha
Rotational Grazing	Canada	3.54	22.24	47.95	$/ha
Increased Legumes in Pasture	ROC	-96.40	-29.73	21.89	$/ha
	Prairies	-101.32	-34.65	16.97	$/ha
Maintaining Pasture	ROC	-90.82	113.97	557.83	$/ha
	Prairies	229.35	257.64	331.90	$/ha
Maintaining Wetlands	ROC	-265.80	-205.32	-144.84	$/ha
	Prairies	-29.65	3.28	36.20	$/ha
Maintaining Shelterbelts	ROC	-271.36	-257.79	-244.22	$/ha
	Prairies	-9.69	2.00	3.06	$/ha

2.1 Nitrogen Management

For the purposes of this analysis, nitrogen management BMPs are considered by a suite of 4R practices, including split N application (right time), enhanced efficiency N fertilizer (right source), recommended N rates (right rate) and variable rate N application (right placement).

Split N Application

Split N application aims to provide N during times of N stress and to avoid excess N on the field, which is subject to loss, therefore striving to match N need to crop demand. Split N has potential yield gains and losses, depending on weather, with dryer conditions associated with yield losses and wetter conditions associated with yield gains. From Kabir (2020), the yield changes from split N on Corn, applied at either vegetative stage six or thirteen, with fixed total N application, range from -1.2% to +3.7% in Elora, Ontario. With N rate changes (applying less N in dry weather and more N in wet weather), split N application becomes more profitable. Split N is probably most beneficial on high N application crops like corn. The costs of split N in the ROC can be estimated by custom application rates, with an extra application pass being estimated at $29.65/ha (OMAFRA, 2020). In the Prairies, custom fertilizer spraying is much less common. The cost of an extra pass with an owned self-propelled sprayer is $9.14/ha, based on increased fuel and labour costs (MARD, 2020a). The custom rate cost calculation for a high clearance sprayer in Saskatchewan is $12.50/ha to $15.77/ha depending upon the size of the tank (SMA, 2020b). The extra application pass is the only evaluated cost for this BMP, besides yield loss.

The change in net returns uses corn as an example, as split application would most likely be used for higher N crops, including wheat and canola. Smaller revenue effects would be expected for lower yielding or lower priced crops. Estimated corn yields and prices are 174 bu/ac at $4.96/bu in Ontario (OMAFRA, 2020), 135 bu/ac at $4.50/bu in Manitoba (MARD, 2020a) and 108 bu/ac at $4.70/bu in Saskatchewan (SMA, 2020a). Bringing together yield changes and the cost of the extra fertilizer application pass, in the ROC, the estimated change in net returns is from –$55.24/ha to $49.26/ha (Mean=–$3.63/ha) across all weather conditions. For the Prairies, the range in net returns change is –$30.52/ha to $39.78/ha (Mean=$2.85/ha). Rate switching could increase net returns (Kabir 2020). Late season application, at vegetative stage thirteen, could cost more from a custom rate perspective and could not be done with normal spraying equipment.

Enhanced Efficiency N Fertilizer

The use of nitrification and urease inhibitors along with N fertilizer attempts to slow the release of bioavailable N to better time plant uptake phases, representing a chemical, rather than physical, split application. The yield effects of Agrogtain Plus™, a combined urease and nitrification inhibitor additive, were slightly negative, from –6.4% to 2.5%, with an average of −1.4%, on Ontario wheat in a year with late application (OSCIA, 2015). On Ontario corn, Drury et al. (2017) identified yield increases between 0.3% to 9.3%.
The cost of N efficiency enhancers, like Agrotain Plus™, is difficult to estimate due to varied pricing and relatively uncertain optimal use rates. From Yanni et al. (2020), the costs of N additives are between $40/ha and $80/ha with an average of $60/ha. Either nitrification or urease inhibitors alone are closer to $40/ha, while a combined product is somewhat less than double. There are no additional application costs as the inhibitors are added to the fertilizer mixture before application.

Changes in net returns are computed for both corn and wheat. Using the same corn yields and prices presented in split application, the change in returns from inhibitor application on corn is from –$53.35/ha to $139.31/ha (Mean=–$63.98/ha) in the ROC and from –$55.70/ha to $68.76/ha (Mean=$20.10/ha) in the Prairies. Estimated wheat yields and prices are 87 bu/ac (OMAFRA, 2020) at $7.50/bu (GFO, 2020) in Ontario, 59 bu/ac at $6.75/bu in Manitoba (MARD, 2020a) and 64.7 bu/ac at $6.42/bu in Saskatchewan (SMA, 2020a). The resulting net returns from inhibitor adoption on wheat are from –$162.49/ha to –$20.49/ha (Mean=–$83.04/ha) in the ROC and from –$123.90/ha to –$35.37/ha (Mean=–$74.37/ha) in the Prairies. Inhibitor use on wheat does not seem to make economic sense, but use on corn, especially with high yields, may be economically beneficial.

Recommended N Rates

Economic research has found that the yield (and therefore revenue) responses of grain crops, particularly corn, to N application are relatively flat (Pannell et al., 2019). This means that moving from average, historical, or personal N rates to those recommended by agronomists and provincial agencies, for example, likely result in N rate reductions and small yield losses. However, since N is costly to apply this could increase net returns. Even large reductions in N application could have small effects on net returns, but large environmental benefits. Yanni et al. (2020) assumes that a 20 kg N/ha reduction from (170 to 150 kg N/ha [11.8% decrease]) results in no yield loss on corn. De Laporte et al. (2020)

shows that an average reduction in N rate from 176 kg N/ha to 124 kg N/ha (52 kg N/ha [28.4% decrease]) results in an average corn yield loss of about 1.1% across the province of Ontario over 30 years of weather with some other practice adaptations. The University of Nebraska Lincoln (Wortmann, 2019) estimates that N rate reductions of 40 kg N/ha result in yield losses of 2.8% in a corn-soybean rotation.
N rate reduction to recommended rates reduces input costs according to the price of N. Estimated N prices are $1.22/kg (OMAFRA, 2020) in Ontario, $1.06/kg in Manitoba (MARD, 2020a) and $1.11/kg in Saskatchewan (SMA, 2020a).

Reducing the N rate by 20 kg N/ha (assuming no yield loss) increases net returns by $24.40/ha in the ROC and by $21.73/ha in the Prairies. Reducing the rate by 40 kg N/ha (assuming a yield loss of 2.8% on corn) changes net returns in the ROC by –$10.39/ha and by $5.23/ha in the Prairies. Greater N rate reductions and higher yields result in greater yield loss risks. However, modest reductions in N rate to recommended rates are likely beneficial to net returns.

Variable Rate Application

Variable rate techniques could increase the efficiency of input use by targeting areas of the field that need that input the most. If implemented correctly, this increases yield and likely decreases input use. The costs of variable rate application include the technology; however, in the long run, especially in the ROC, where custom application is common, the costs are unlikely to be that much higher than current levels. Zhang (2020) presents an examination of variable rate N application to corn, showing yield increases between 2.0% and 4.4%, leading to revenue increases of between 7% to 9% (~$80/ha). However, yield losses of 2.1% are also reported, when variable rate is not implemented effectively. Translating these yield increases to the model farm enterprises here, variable rate application has net returns from $–45.28/ha to $95.54/ha (Mean=$27.11/ha) in the ROC and from –$31.88/ha to $67.25/ha (Mean=$17.51/ha) in the Prairies. These net return changes mostly consider increased yield and do not include the environmental benefits of less N application, or the costs of prescription map creation, for example.

2.2 Cover Crops

The cost to the farmer and adoption of cover cropping will be quite heterogeneous across the country. Differences in rotation practices, growing season lengths, regional temperatures and soil conditions will all influence the suitability, profitability, and adoption of cover cropping. This section outlines the costs of cover crops, including multi-species mixtures, generalized to the Prairies and the ROC, along with a review of some cover crop cost-share programs from the United States.

Direct costs associated with cover cropping are seeds, planting, terminating and, in some cases, fertilization. We chose to focus on annual ryegrass, oats, red clover and two multi-species mixes (~70% Legume; ~50% Legume) as they are readily studied, incorporated in a wide variety of cropping rotations, and can grow in cooler conditions across Canada. The greenhouse gas and nitrogen management capabilities of each are different, particularly between grasses and legume crops. We have simplified our analysis to these representative options; however, there are dozens of additional choices and many multi-species mixtures that are not considered here.

Annual ryegrass can be planted with a grain drill, no-till drill, or a broadcast applicator with light tillage. The suggested seeding rate ranges from 15-90 lbs/ac depending on agronomic and environmental goals (Mayers, 2015; Hoorman, 2015; OMAFRA, 2019), costing $0.67/lb to $0.8/lb. No-till planting directly into the seed bed is typically cheaper at $18.34/ac (Hoorman, 2015) to $26/ac (OMAFRA, 2019) than broadcasting with light tillage. There are other options such as aerial seeding, broadcast seeding with slurry and incorporated seeding; however, we have simplified our analysis to include only the low cost no-till planting. Termination can be done with herbicides or roller-crimping with the former being more common and the later, cheaper. Estimated kill costs range from $20/ac to 22.42/ac for herbicide and $5/ac to $13/ac for roller-crimping (MARD, 2020a; OMAFRA, 2019). A report from Iowa suggests the cost of rye is roughly $88/ac ($68 USD/ac) (Tyndall and Bowman, 2016) while an article from Kansas suggests $50.29/ac to $68.29/ac ($28-$73 USD/ac) if fertilizer costs are omitted (Bergtold et al., 2017).

Oats are one of the most common cover crops grown in the Prairies as well as the ROC. It has similar planting costs to rye, but slightly cheaper seed giving a lower range of $52/ac to $64/ac (MARD, 2020a; Hoorman, 2015). The seed price is marginally lower in the Prairie Provinces with other inputs quite similar.

Red clover seed prices range, with differing quality, from $1.25/lb to $2.6/lb (MARD, 2020a; Hoorman, 2015) typically on the higher end. Seed can be either broadcast or directly drilled ranging from $10/ac to $26/ac (Hoorman, 2015; OMAFRA, 2019). If we assume custom application, it will be closer to$26/ac. Red clover can be terminated mechanically or with herbicides giving a range of prices from $5.35/ac to $16/ac. Red clover costs range from $40.47/ac to $74.42/ac with the lower range of prices more common in the Prairies. The ROC faces a higher price of $5/ac to $10/ac from seed costs and slightly higher termination costs.

Many multi-species mixes exist, but often combine leguminous crops and grasses with varying seed prices. For example, a crop mixture of ~70% legumes (clover/alfalfa) costs $4.93/lb, whereas a mixture with ~50% legumes (forage peas) costs $1.35/lb (Speare Seeds Limited – Personal Communication). The differences in seed cost are apparent and the nutrient benefits are straightforward to assess. However, other aspects, such as differential impacts on soil health, remain difficult to assess.

In addition to soil erosion control and scavenging for nutrients, cover crops have the potential to reduce required nitrogen application in the following cash crop. Cereal cover crops, such as rye and oats, have limited influence on nitrogen levels due to their structure. However, legume cover crops, such as red clover, have great potential for nitrogen reductions ranging from 70 to 140 lbs/ac, lowering costs in the following crop by $28/ac to $56/ac at a nitrogen price of $0.4/lb. Multispecies mixes including legumes would have similar effects weighted by the relative establishment of these species in the mix.

According to SARE (2019), tangible benefits to cover crops include yield increases over time. For example, corn yields increase by 0.52% in year one, but increase to 3% after five years. The effect on soybeans is even more pronounced, with yield increases of 2.12% after one year and 4.96% after five. Furthermore, cover crops lessen the negative effects of compaction ($19.89/acre), provide weed control ($0/acre to $25/acre) and erosion repair ($2/acre to $4/acre). However, some of these associated benefits may be lower in Prairie dryland agriculture, compared to the ROC.

We used studies from across the United States and Canada to estimate tillage, seed, planting and kill costs, along with nitrogen savings, compaction, weed control and erosion repair benefits. The net return of rye cover crop ranges from –$314.46/ha to $44.33/ha (Mean=–$85.91/ha). The net return of oat cover crop ranges from –$265.66/ha to $34.00/ha (Mean=–$77.76/ha). The net return of red clover crop ranges from –$107.05/ha to $255.04/ha (Mean=$66.23/ha). The net return of a multi-species mixture cover crop with ~70% legumes ranges from –$202.76/ha to $142.05/ha (Mean=–$44.68/ha). The net return of a multi-species mixture cover crop with ~50% legumes ranges from –$123.19/ha to

$159.63/ha (Mean=$7.77/ha). Net returns benefit here from leguminous crops due to the nitrogen credit. Large ranges reflect uncertain seeding rates, seed prices, nitrogen credits and weed control benefits that evolve over time.

Evidence from Cost-Share Programs

There are several programs in the U.S. that cost-share cover cropping practices. Maryland Agricultural Water Quality Cost-Share (MACS), Environmental Quality Incentives Program (EQIP), State-level Iowa and Illinois crop insurance, and the Conservation Stewardship Program are some of the largest programs, all with substantially different cost-share rates. While the rates vary substantially between states and programs, few fully cover the cost. Cover crop seed is typically more readily available and cheaper in the Prairie region suggesting a lower overall cost. For instance, North and South Dakota and Minnesota have lower cost-share per acre than the Corn Belt States.

Multi-species mixes are becoming more common as they provide a wider range of benefits. The Environmental Quality Incentives Program, offered through the USDA and NCRS, offers roughly 12% higher rates for multi-species mixtures.

2.3 Rotational Grazing

Rotational grazing aims to maximize the potential of a pasture by allowing the grass to properly rest and regenerate after and between grazing. It allows for higher stocking rates and additional dry matter yield than continuous grazing. The costs of rotational grazing are related to fencing and water installation, along with labour. In Manitoba, these capital costs have been estimated at $97.33/ha, with annual maintenance costs of $10.15/ha (MARD, 2020b). Examining a 30-year pasture project life, the cost is $5.86/ha/year. In South Dakota, pasture capital and maintenance costs range from $2.94/ha/y to $10.17/ha/y (Mean=$5.85/ha/y) (Wang, 2020).

The benefits of rotational grazing relate to increased stocking rates and increased finishing weights. According to Wang et al. (2018) the annual average 30-year benefits of rotational grazing range from $3.54/ha/y to $47.95/ha/y (Mean=$22.24/ha/y) across stocking rates from 15 to 55 steers per 100 ha. This range in net returns likely extends to cattle production across Canada. Lower stocking rates in the range represent a lower intensity of rotational grazing, approximating targeted cattle pressure. Similarly, higher stocking rates represent advanced rotational grazing.

Increased Legumes in Pasture (For Tame vs. Native Pasture)

Adding legumes to pasture can mitigate the need for N application, and it is an integral part of an advanced rotational grazing plan. In this way, it reduces N requirements, at the cost of seed and planting. The potential cattle yield effects are not included here. Using similar values as for cover crops, this section considers red clover and alfalfa as legume additions to pasture, up to 50% of the mix. The N benefits are assumed to be half of 80 kg/ha, the cover crop N benefit (OMAFRA, 2020). The costs include seeding at $4.37/kg for red clover and $13.43/kg for alfalfa. Seeding rates range from 2.7 kg/ha to 6 kg/ha. Planting costs range from $14.83/ha to $64.24/ha. Increasing legumes in pasture changes net returns from –$96.40/ha to $21.89/ha (Mean=–$29.73/ha) in the ROC and from –$101.32/ha to $16.97/ha (Mean=–$34.65/ha) in the Prairies. Differences between the regions of Canada relate to the price of N, with higher N prices resulting in greater benefits.

2.4 Conservation of Wetlands and Trees on Agricultural Land

Maintaining Pasture

Pasture maintenance can be beneficial to the environment but may have opportunity costs to farmers looking to expand grain crop enterprises. The potential financial benefit of converting pasture to cropland is the opportunity to make crop returns, rather than the value of pasture. However, many pasture lands are lower quality lands, with compromised crop yields. This analysis assumes that Class 4 cropland (the lowest class for crop growth) will be converted from pasture to cropland. The yield of Class 4 cropland is approximately 26.5% lower than the average yield of Class 1, 2 and 3 land (Yang and Weersink, 2004). Therefore, the benefit of converting, or cost of preserving, pasture is the return of common crop rotations with 26.5% less yield. The benefit of preserving any cropland can be estimated from the value of the land (FCC, 2020), times the interest rate [1.5% to 2.0%] plus the land tax [0.5%] (MARD, 2020a). The lowest land values in the ranges from Farm Credit Canada (FCC) were used to represent pasture. In this way, the value of pasture in the ROC is from $24.71/ha to $673.36/ha (Mean=$229.50/ha) and, in the Prairies, is from $39.54/ha to $142.09/ha [Mean=$67.83/ha]. Therefore, considering the benefit from lower yielding crop rotations, the net benefit of maintaining pasture in the ROC is from –$90.82/ha to $557.83/ha (Mean=$113.97/ha) and, in the Prairies is from $229.35/ha to $331.90/ha (Mean=$257.64/ha). Pasture maintenance is particularly valuable in the Prairies due to lower yields causing negative returns to row cropping. In the ROC, only lower rental value farmland makes economic sense to convert.

Maintaining Wetlands

Wetland maintenance is costly to farmers as they could otherwise grow productive crops on the land. There are also nuisance costs to consider, including increased fuel and maintenance costs for driving around the wetland and potential input overlap costs. Wetland drainage costs on the Prairies typically consist of draining 'potholes' using surface drainage techniques and ditches, whereas in Ontario and other parts of the ROC, many wetlands are attached to larger bodies of water, somewhat forested and require the installation of drainage tile. Drainage, rehabilitation and 20-year maintenance costs (Discount Rate=5%) in the Prairies range from $692/ha to $2,008/ha (Cortus, 2005; De Laporte, 2014). In the ROC, these costs range from $1,947/ha to $4,366/ha (De Laporte 2007; De Laporte et al., 2010). From the crop budgets mentioned before, the present value of 20-year increased crop revenue is $1,284/ha in the Prairies and $7,263/ha in the ROC. Therefore, the annual average net returns from wetland maintenance (over a 20-year time horizon) in the Prairies is from –$29.65/ha to $36.20/ha (Mean=$3.28/ha) and from –$265.80/ha to –$144.84/ha (Mean=–$205.31/ha) in the ROC. As cropland returns are higher in the ROC, conservation is more costly to farmers.

Maintaining Shelterbelts

Shelterbelts reduce wind erosion to some degree, depending on the design. They also present crop growth opportunity costs, nuisance costs and eventually require replacement at the end of their life cycle. The changes in net returns from shelterbelt maintenance in Saskatchewan are –$9.69/ha in the black, $2.00/ha in the brown and $3.06/ha in the dark brown soil zones based on a representative crop farm, including yield benefits (Kulshreshtha et al., 2018). Older estimates of shelterbelt costs (no benefits) from the Midwestern U.S. (particularly Iowa) estimate net returns at between –$244/ha/y and –$271/ha/y for a 50-year stand life across different tree mixes (Grala, 2004). This estimate includes land rent (opportunity) costs, whereas it is unclear if that is so in the Saskatchewan study. In the ROC, costs would be more similar to the Midwest based on crop type distribution.

3. Program Abatement Costs: Integrated GHG and Economic Analysis for Selected BMPs

This section outlines the potential integrated environmental and economic costs (abatement costs expressed as $/tonne of CO2e) of inducing the adopting of BMPs, either alone or in combination, based on adoption rates. The study integrates the information in Table 1 using GHG values provided in Burton et al. (2021). This section also attempts to examine the costs of inducing different levels of adoption, for each practice, based on changes from the current, or estimated, baseline levels of adoption.

The method generally considers a distribution of prices as outlined in Table 1, with low and high values representing the 5th and 95th percentiles of a normal distribution of net returns around the middle value. This implies that adoption is more expensive per unit initially, then becomes less expensive per unit as the practice is adopted and the practice becomes common, and finally becomes more expensive per unit again as the final adopters (hardest to reach) are incentivized. Moving from a current (baseline) scenario to increased adoption requires inducement of producers who have not yet adopted. This study assumes that the producers with the greatest benefit adopt first and to induce new producers, a payment equivalent to the difference in net returns between the lowest benefit new adopter and the lowest benefit baseline adopter would be necessary. This equalizes the benefit level of new adopters to at least the benefit level of previous adopters, thereby theoretically inducing adoption. When program costs are calculated, they do not include additional implementation costs, such as monitoring and enforcement. The abatement costs estimated here are based on large area averages and ranges, and do not necessarily reflect the abatement costs of any individual farmer or farm operation.

Combined Nitrogen Management Practices

Adopting 4R practices will not likely be done as single practices, but rather as a suite of practices as time goes on. The following levels of 4R adoption are used in this report: Basic (Rate Reductions); Intermediate (Rate Reductions, 1/3 Enhanced Efficiency Fertilizers, 1/3 Split Application and 1/3 Variable Rate Application); and Advanced (Rate Reductions, ½ Enhanced Fertilizers, ½ Split Application, and Variable Rate Application). The net returns of these practices are defined in Table 1, with the net return of basic being equivalent to 4R: N Rate Reduction. Moving from the baseline scenario to each adoption level scenario involves advancing a portion of land towards the next more practice – an incremental approach for producers from basic, to intermediate, to advanced. For example, to get from 20% to 40%

adoption in advanced, 20% of the producers in intermediate are first converted, rather than 20% of those not implementing 4R or implementing basic 4R being converted. The adoption scenarios are defined in Table 4R1, broken down into two levels: 'Strong Foundation' and 'Going for Gold'. Strong Foundation supports higher total 4R adoption, with more focus on entry into basic and intermediate levels of adoption, whereas Going for Gold encourages adoption of advanced 4R practices (see Burton et al. [2021] for more details). Both scenarios include projected levels of adoption in 2025 and 2030. However, for this analysis, these years are treated as adoption level scenarios without temporal considerations. These scenarios reflect an expectation that some producers will never adopt these practices, but those who do adopt will eventually make their way toward advanced over time.

The analysis was done for Corn and Winter Wheat in the ROC and for Spring Wheat and Canola in the Prairies, with the results in Table 4R1. Corn has the cheapest abatement cost per tonne of CO_2e due to larger nitrogen applications. Larger amounts of croplands on the Prairies make program costs correspondingly larger. Lower N application and differences in dryland agriculture also make the emissions reduction effects lower, thus increasing per hectare costs. For canola, the adoption scenario is the most extreme, with few producers currently employing more advanced forms of 4R.

Table 4R1: Estimates for adopting different levels of 4R practices, including adoption inducement costs, emissions changes and total costs and abatement costs.

	Base	Steady		Gold Standard	
		2025	2030	2025	2030
		Corn (ROC)			
Area (ha)	1,444,389				
Adoption Inducement Cost ($/ha)		7.33	16.97	28.98	62.39
Total Emissions Reduction (t CO2e)		570,443	647,751	610,545	662,035
Total Cost ($)		7,936,414	22,064,769	27,211,176	63,078,378
Abatement Cost ($/t CO2e)		13.91	34.06	44.57	95.28
Adoption Rate (B/I/A/T)	27/22/11/60	35/25/15/75	40/30/20/90	15/15/35/65	10/10/50/70
		Winter Wheat (ROC)			
Area (ha)	393,577				
Adoption Inducement Cost ($/ha)		9.38	17.82	32.89	67.56
Total Emissions Reduction (t CO2e)		100,243	109,148	104,421	112,638
Total Cost ($)		2,769,326	6,310,613	8,412,864	18,613,994
Abatement Cost ($/t CO2e)		27.63	57.82	80.57	165.26
Adoption Rate (B/I/A/T)	30/20/10/60	35/25/15/75	40/30/20/90	15/15/35/65	10/10/50/70
		Spring Wheat (Prairies)			
Area (ha)	8,126,399				
Adoption Inducement Cost ($/ha)		6.31	11.95	21.82	44.76
Total Emissions Reduction (t CO2e)		1,040,056	1,240,004	1,130,368	1,347,562
Total Cost ($)		38,438,442	87,417,082	115,249,651	254,621,803
Abatement Cost ($/t CO2e)		36.96	70.50	101.96	188.95
Adoption Rate (B/I/A/T)	30/20/10/60	35/25/15/75	40/30/20/90	15/15/35/65	10/10/50/70
		Canola (Prairies)			
Area (ha)	9,125,716				
Adoption Inducement Cost ($/ha)		8.71	18.91	33.93	60.93
Total Emissions Reduction (t CO2e)		1,208,369	1,517,041	1,379,031	1,639,713
Total Cost ($)		55,612,151	155,331,927	201,290,576	389,232,281
Abatement Cost ($/t CO2e)		46.02	102.39	145.97	237.38
Adoption Rate (B/I/A/T)	45/12/6/63	35/25/10/70	40/30/20/90	15/15/35/65	10/10/50/70

Table 4R1 details costs in $/ha representing cost-share equivalents, or the value of incentives needed to induce different levels of adoption of 4R. Barriers to adoption are not just economic; therefore, direct payments equivalent to the adoption inducement cost may not best support producers to transition. Supporting adoption through a cost-share of the agronomic services required to effectively implement 4R may be a superior tactic. This is because expert agronomic services increase the chance of successful implementation, while minimizing risks, allowing 4R practices to be evaluated and adjusted through residual nitrogen soil tests. This rationale is further described in Burton et al. (2021). Providing agronomic services to farmers implementing 4R practices at 50% cost share results in Table 4R2. Specifically, the Strong Foundation 2025 scenario costs about $105 million dollars per year, providing 2.9 million t CO_2e per year ($35.89/t CO_2e/y) across the four crops of interest (corn, winter wheat, spring wheat and canola). OMAFRA (2019) estimates the cost of soil sampling services at $29.65/ha, recommending that a single soil test not represent more than 10 hectares. However, the 'intensity' of this soil sampling estimate is unclear. SWAT MAPS (2021), estimates soil testing costs at $8.35/ha, offering 5 samples on a minimum 56.7 ha field. The cost of agronomic services is approximately $3.09/ha, while the 1-time cost of prescription map creation is $18.21/ha (SWAT MAPS, 2021). The price of agronomic services lowers considerably once fields have been mapped. Part of this effort encourages the production of prescription maps to allow the pursuit of advanced 4R adoption in the future.

Table 4R2: Agronomic service costs for implementing 4R across different levels and crop types.

	Basic	Intermediate	Advanced	All
	Corn - 1,444,389 ha			
% in 4R Level	35	25	15	75
Area (ha)	505,536	361,097	216,658	1,083,292
Agronomic Costs ($/ha)	11.44	17.51	29.65	17.11
Total Costs ($)	5,783,820	6,323,358	6,424,484	18,531,661
GHG Reduction (t CO2e)	60,935	205,858	303,650	570,443
Abatement Cost ($/t CO2e)	94.92	30.72	21.16	32.49
	Winter Wheat - 393,577 ha			
% in 4R Level	35	25	15	75
Area (ha)	137,752	98,394	59,037	295,183
Agronomic Costs ($/ha)	11.44	17.51	29.65	17.11
Total Costs ($)	1,576,015	1,723,032	1,750,587	5,049,634
GHG Reduction (t CO2e)	10,244	34,168	55,830	100,243
Abatement Cost ($/t CO2e)	153.84	50.43	31.36	50.37
	Spring Wheat - 8,126,399			
% in 4R Level	35	25	15	75
Area (ha)	2,844,240	2,031,600	1,218,960	6,094,799
Agronomic Costs ($/ha)	11.44	17.51	29.65	17.11
Total Costs ($)	32,540,835	35,576,373	36,145,327	104,262,536
GHG Reduction (t CO2e)	103,324	377,032	559,699	1,040,056
Abatement Cost ($/t CO2e)	314.94	94.36	64.58	100.25
	Canola - 9,125,716 ha			
% in 4R Level	35	25	10	70
Area (ha)	3,194,001	2,281,429	912,572	6,388,001
Agronomic Costs ($/ha)	11.44	17.51	29.65	16.21
Total Costs ($)	36,542,438	39,951,261	27,060,121	103,553,820
GHG Reduction (t CO2e)	127,941	460,788	619,639	1,208,369
Abatement Cost ($/t CO2e)	285.62	86.70	43.67	85.70
	Totals			
Total Cost ($)	76,443,108	83,574,024	71,380,519	231,397,650
Total GHG Reduction (t CO2e)	302,445	1,077,847	1,538,819	2,919,111
Total Area (ha)	6,681,528	4,772,520	2,407,226	13,861,275
Total Program Cost ($) - 50% Cost Share	38,221,554	41,787,012	35,690,259	115,698,825
Program Cost ($/ha) - 50% Cost Share	5.72	8.76	14.83	8.35
Program Abatement Cost ($/t CO2e)	126.38	38.77	23.19	39.63

Cover Crops

The cost of inducing cover crop adoption depends on the existing level of adoption and the distribution of cover cropping costs in a location, including the amount of cropland. Cover crops are potentially applicable to every cropland in Canada, although shorter growing season locations make traditional winter cover cropping impractical in many years (See Burton et al. [2021] for more information). Intercropping (interseeding) may be necessary for successful cover establishment in dryer and cooler climates. Cover crop adoption in the Prairies is low, around 0.4%, while in the ROC, it is higher, at approximately 14.5%. Based on these values, this report analysed six increased adoption levels (1%; 5%; 10%; 15%; 20%; 30%).

As mentioned in Section 1, and also detailed in Burton et al. (2021), cover cropping costs farmers upfront, and private economic benefits are only accrued over multiple years of cover cropping. Given this, this analysis assumes that increasing adoption requires a direct incentive payment. More specifically, it assumes that to increase adoption by 10%, for example, in the ROC, requires an incentive payment of the difference between the net return of the 85% percentile (14.5% adoption), which has already begun cover cropping, and the 75% percentile (which had not). This basically allows the producer at the 75% percentile to have the same level of benefit as the 85%, therefore inducing adoption for this producer and all the producers in between. This adoption can be considered in terms of producers, or total area. In the Prairies, since adoption is so low, we assumed that a 10% adoption rate would require the price difference between the 98th percentile and the 88th percentile. We considered the prices beyond the 95th percentile to be less certain, so we could be underestimating the payment required to induce adoption, particularly in the early stages on the Prairies where adoption remains close to zero (0.4%).

Inducing more adoption becomes more expensive, but at a decreasing rate from 1% to 30% (Table CC1; Table CC2). This affects both the cost per hectare and the cost per tonne CO_2e. It should be noted that cover cropping is considered a reversible decision, which means that a producer who is doing the practice this year does not inherently adopt it next year. However, GHG benefits and private benefits accrue only when the practice is implemented reliably over time. Therefore, the total program cost recognizes that all farmers that have adopted cover crops in past seasons (existing cover croppers) or will adopt cover crops for the first time this seasons (new cover croppers) will be eligible for the cost share level, recognizing the fact that cover cropping is a reversible decision at least in the first 3 years (until private benefits accrue) and a program that disqualified existing cover croppers may perversely incent them to stop the practice only to renew again in the following season to qualify for funding. Furthermore, the carbon benefits of existing cover croppers (14% in ROC; 0.4% in Prairies) must count toward the total emissions reduction, again reflecting the fact that cover cropping is a reversible decision and acknowledging that the payment ensures that existing cover croppers maintain their cover crop in the following season. Overall, the costs are more disparate in the ROC than the Prairies. Total program costs on the Prairies are very high due to the large number of hectares of croplands and the higher abatement costs due to lower C sequestration in drylands. For example, a program that targeted 15% new adoption in the ROC and 1% new in the Prairies would annually cost $113 million, provide 2.2 million t CO_2e and cost about $51/t CO_2e.

Table CC1: Estimates for average cover crop (of rye, oat, clover, 50% legume mix and 70% legume mix), rye and oat costs per hectare, abatement costs, total program costs and total GHG emissions reduction by region.

		Average		Rye		Oats	
		ROC	Prairies	ROC	Prairies	ROC	Prairies
Crop Area (ha)	**Total**	6,516,030	31,274,578	6,516,030	31,274,578	6,516,030	31,274,578
Average Cost ($/ha)	**1%**	4.49	18.48	5.84	24.04	4.80	19.76
	5%	20.73	61.75	26.95	80.30	22.16	66.02
	10%	38.68	93.91	50.29	122.12	41.35	100.41
	15%	54.70	117.53	71.13	152.83	58.49	125.65
	20%	69.55	136.97	90.45	178.12	74.36	146.44
	30%	97.23	169.45	126.43	220.35	103.95	181.17
Average Abatement Cost ($/t CO2e)	**1%**	4.27	55.89	4.41	61.67	3.62	50.70
	5%	19.74	186.72	20.36	206.04	16.74	169.40
	10%	36.83	283.96	37.99	313.34	31.24	257.62
	15%	52.10	355.35	53.74	392.12	44.18	322.39
	20%	66.24	414.14	68.33	457.00	56.18	375.73
	30%	92.59	512.35	95.51	565.37	78.53	464.83
Average Total Program Cost ($)	**1%**	4,532,173	8,092,971	5,893,553	10,523,949	4,845,504	8,652,477
	5%	26,336,727	104,293,066	34,247,791	135,620,770	28,157,513	111,503,354
	10%	61,744,760	305,461,198	80,291,742	397,216,081	66,013,476	326,579,219
	15%	105,151,974	566,040,156	136,737,678	736,068,129	112,421,642	605,173,270
	20%	156,359,955	873,880,460	203,327,588	1,136,377,956	167,169,880	934,296,074
	30%	281,920,629	1,611,055,874	366,604,362	2,094,987,202	301,411,176	1,722,436,015
Average Total Emissions Reduction (t/CO2e)	**1%**	1,087,829	146,087	1,336,967	170,650	1,336,967	170,650
	5%	1,368,559	563,477	1,681,991	658,220	1,681,991	658,220
	10%	1,719,472	1,085,215	2,113,271	1,267,684	2,113,271	1,267,684
	15%	2,070,385	1,606,953	2,544,550	1,877,147	2,544,550	1,877,147
	20%	2,421,297	2,128,692	2,975,830	2,486,610	2,975,830	2,486,610
	30%	3,123,123	3,172,168	3,838,390	3,705,537	3,838,390	3,705,537

Table CC2: Estimates for average cover crop (of rye, oat, clover, 50% legume mix and 70% legume mix), clover and legume mix costs per hectare, emissions reduction costs, total program costs and total GHG emissions reduction by region.

		Clover		70% Legume		50% Legume	
		ROC	Prairies	ROC	Prairies	ROC	Prairies
Crop Area (ha)	Total	6,516,030	31,274,578	6,516,030	31,274,578	6,516,030	31,274,578
Average Cost ($/ha)	1%	4.42	18.22	4.04	16.62	3.34	13.77
	5%	20.44	60.88	18.64	55.54	15.45	46.02
	10%	38.13	92.59	34.79	84.47	28.82	69.98
	15%	53.93	115.87	49.20	105.71	40.76	87.58
	20%	68.57	135.04	62.56	123.20	51.83	102.07
	30%	95.86	167.06	87.45	152.41	72.45	126.27
Average Abatement Cost ($/t CO2e)	1%	5.80	69.49	4.33	55.32	3.20	42.25
	5%	26.78	232.16	20.02	184.84	14.80	141.16
	10%	49.97	353.06	37.35	281.09	27.62	214.67
	15%	70.67	441.83	52.83	351.77	39.07	268.64
	20%	89.86	514.93	67.17	409.97	49.67	313.08
	30%	125.61	637.03	93.90	507.18	69.43	387.33
Average Total Program Cost ($)	1%	4,468,265	7,978,852	4,076,352	7,279,025	3,377,189	6,030,550
	5%	25,965,354	102,822,435	23,687,926	93,803,854	19,625,049	77,714,917
	10%	60,874,101	301,153,906	55,534,818	274,739,622	46,009,664	227,617,161
	15%	103,669,232	558,058,455	94,576,378	509,111,009	78,354,940	421,789,917
	20%	154,155,132	861,557,920	140,634,147	785,990,461	116,513,028	651,179,891
	30%	277,945,282	1,588,338,465	253,566,632	1,449,024,903	210,075,695	1,200,492,786
Average Total Emissions Reduction (t/CO2e)	1%	770,745	114,825	940,611	131,572	1,053,856	142,737
	5%	969,646	442,895	1,183,350	507,493	1,325,819	550,558
	10%	1,218,274	852,983	1,486,773	977,393	1,665,772	1,060,333
	15%	1,466,901	1,263,071	1,790,196	1,447,294	2,005,726	1,570,109
	20%	1,715,528	1,673,159	2,093,619	1,917,194	2,345,679	2,079,885
	30%	2,212,783	2,493,334	2,700,465	2,856,995	3,025,586	3,099,436

Rotational Grazing and Pasture

The cost of inducing adoption for improved rotational grazing depends on the initial amount of rotational grazing already occurring (current adoption) and the desired level of adoption. The baseline adoption of continuous and rotational grazing is shown in Table RG1, based on Burton et al. (2021). As rotational grazing builds carbon stocks and has generally positive on-farm economic effects, the cost of inducing new adoption could be relatively low. As identified in Burton et al. (2021) and here, the upfront capital costs of implementing improved rotational grazing are high, with the purchase of fencing, water, and other equipment to allow for rotation of animals. Additionally, rotational grazing requires a strong plan, and farmers require support to build this into their agronomic and business model. Therefore, there are both upfront capital cost barriers as well as technical barriers that can be addressed through public programming. Agronomic services are a key gateway to influencing adoption. Therefore, a cost-share that supports the development of an appropriate rotational grazing plan, by a trained agronomist, the price of which is around $3000 (MacLeod Agronomics - Personal Communication), as well infrastructure costs can help to induce new adoption of rotational grazing. This analysis considered here applies to only new rotational grazing practice adoption.

Unlike the case of 4R, the costs described in Table RG2 do not take an incremental approach. The costs reflect moving from continuous grazing to basic or advanced rotational grazing, not from basic to advanced. However, while it is possible to create a plan to turn basic into advanced, these costs are not listed here. An appropriate grazing plan will put the producer in the correct level for their situation; however, due to average benefits it is likely that the adoption of more advanced practices will be relatively preferred, although labour availability may be a limiting factor in advanced management adoption. The carbon benefits of adoption on tame pasture are larger, as are the costs, generally, due to seed and management, minus nitrogen credits for increased legume content. The net returns for natural pasture are the ones highlighted in Table 1, whereas the net returns for tame pasture include the net returns of including legumes in pasture at 1/5 of the rate to recognize that reseeding will likely occur once every 5 years, on average.

Table RG1: Baseline adoption rates of continuous, and basic and intensive rotational grazing on native and tame pasture.

		Adoption		
		Continuous	Basic	Intensive
Native	ROC	35	50	15
	Prairies	35	55	10
Tame	ROC	25	55	20
	Prairies	25	65	10

Table RG2: Estimates for basic and intensive rotational grazing on natural and tame pastures emissions changes and costs.

	Increased Adoption Rate	Natural				Tame			
		Basic		Intensive		Basic		Intensive	
		ROC	Prairies	ROC	Prairies	ROC	Prairies	ROC	Prairies
Area (ha)		1,915,223	12,346,110	1,915,223	12,346,110	564,410	4,516,898	564,410	4,516,898
Producers (Count)		29,339	42,736	29,339	42,736	24,327	29,765	24,327	29,765
Emissions Reduction (t CO2e/ha)		0.33	0.12	0.92	0.28	0.65	0.21	1.84	0.55
Adoption Inducement Cost ($/ha)	5%	1.58	1.58	2.21	2.80	1.91	1.91	1.91	2.80
	10%	3.29	3.29	4.12	5.00	4.12	4.12	3.62	5.00
	15%	5.20	5.20	5.82	6.91	6.91	6.91	5.20	6.91
Abatement Costs ($/t CO2e)	5%	146.27	104.04	52.35	47.08	203.43	103.24	71.31	41.03
	10%	151.52	118.88	54.43	54.96	206.85	113.74	72.24	45.04
	15%	157.39	135.49	56.28	61.78	211.19	127.06	73.10	48.51
Total Cost ($)	5%	4,552,210	7,386,115	4,612,101	8,137,206	3,702,962	4,896,197	3,702,962	5,096,512
	10%	9,431,098	16,878,092	9,590,081	18,997,992	7,530,433	10,788,833	7,502,194	11,189,462
	15%	14,695,465	28,854,984	14,875,137	32,034,834	11,532,476	18,078,536	11,387,107	18,078,536
Emissions Reduction (t CO2e)	5%	31,122	70,990	88,100	172,846	18,202	47,427	51,926	124,215
	10%	62,245	141,980	176,201	345,691	36,404	94,855	103,851	248,429
	15%	93,367	212,970	264,301	518,537	54,607	142,282	155,777	372,644

The rotational grazing inducement costs in Table RG2 may be low for short-term considerations, as upfront capital costs are steep. Therefore, focusing more on the costs than the benefits may be most appropriate to induce new adoption. Installation costs vary by farm size, as in Table RG3. Providing a cost share of 50% on the agronomic services and up to 50% of $10,000 ($5,000) on the fencing installation was deemed to be a more appropriate level of compensation. This results in the costs and benefits detailed in Table RG3. The rest of Canada is more expensive due to lower average farm size, which increases the per area costs of installation.

Table RG3: Costs of installing rotational grazing fencing in the Prairies and the rest of Canada on Tame and Native pasture, including total program costs, carbon storage and abatement costs.

	Total		Tame		Native	
	Prairies	ROC	Prairies	ROC	Prairies	ROC
Area (ha)	16,863,008	2,479,633	4,516,898	564,410	12,346,110	1,915,223
Farms	42,736	29,339	29,765	24,327	42,736	29,339
Average Size (ha)	395	85				
Installation Cost ($/farm)	39,987	21,169				
Installation Cost ($/ha)	98.82	209.25				
Planning Cost ($)	3000	3000				
Adoption Rate	0.05	0.05				
Total Install Cost ($)	85,443,538	31,054,363				
Install Costs to $10,000 ($)	21,368,000	14,669,500				
Total Planning Cost ($)	6,410,400	4,400,850				
Total Shared Cost ($)	27,778,400	19,070,350				
50% Cost Share ($)	13,889,200	9,535,175				
Cost Share ($/farm)	6,500	6,500				
Carbon Storage (t CO2e)	207,739	94,675	85,821	35,064	121,918	59,611
Abatement Cost ($/t CO2e)	66.86	100.71				

Set-Asides for Trees and Wetlands

Preventing the conversion of sensitive lands, including treed areas and wetlands, into cropland allows the avoidance of significant amounts of stored carbon release. This analysis assumes that the land will be 'set aside' for a minimum of 20-years. The avoided conversion environmental benefit is 17.1 t CO2e/ha/y for wetlands in the ROC, 16.2 t CO2e/ha/y for Prairie wetlands, 14.3 t CO2e/ha/y for woodlands in the ROC and 13.4 t CO2e/ha/y for Prairie woodlands, over the 20-year time horizon, as reported in Burton et al. (2021). As described in Section 1, farmers are often motivated to convert these sensitive areas into crop land for economic reasons. A program that helps to conserve them by paying the farmer a fair price through a 'reverse action' to protect the land from conversion is a cost-effective option to minimize the economic penalty to the farmer of not converting the land. The 'reverse auction' program asks for farmers to bid on a single payment that would set aside the land for 20-years. The net present value of the 20-year returns to that land (minus conversion costs) were assumed to be the bid that a farmer would give to set that land aside. However, a certain number of wetlands are too expensive to drain, and a certain amount of woodlands are beneficial to farmers. Therefore, the minimum bid price was assumed to be the net present value of a stream of payments equal to the rental rate of lower quality (pasture) land, in this case, $492.72/ha (NPV of $39.54/ha/y for 20 years). In this way, the farmer would be assumed to 'rent' the land to the government (with contractual commitment to conserve it as a wetland or treed area) for 20 years in this reservation price scenario. The size of the program depends upon the total area in wetlands and trees on agricultural lands that are potentially at risk of being converted. Annual conversion of wetlands in Southern Ontario is estimated at 5,336 ha/y and at 3,219 ha/y in Quebec (Poulton and Bell, 2017), while 11,736 ha/y are lost in the Prairie Pothole Region (Ducks Unlimited Canada, 2020). Wooded area loss in the ROC is estimated at 12,000 ha/y and shelterbelt loss is estimated at 469 ha/y (2500 km of 3 row (15 m) shelterbelts over 8 years).

The program related costs of preserving from 10% to 90% of the area is given in Table SA1. The marginal bid is the bid of the farmer at the 10% percentile, for example. The bids of other farmers before would be lower. The advantage of a reverse auction is that it allows government to reduce program costs by revealing farmers' near-actual costs in the presence of many bids. However, it intrinsically results in the least vulnerable wetlands and woodlands being preserved first (as they have the lowest cost to preserve). Higher likelihood conversion areas are more expensive to preserve. Potholes and shelterbelts in the Prairies are somewhat inexpensive to convert to cropland, both because of the scale of projects and the lower agricultural return potential of the land. This meant that their preservation bid was exclusively estimated at the reservation rate. While the conversion projects are more expensive in the ROC, the forgone agricultural returns are larger, therefore making these bids more expensive, all above the reservation rate.

Table SA1: Approximate program costs for payments to set aside existing wetland and tree areas for 20 years, including area, emissions avoidance, and abatement costs.

Preservation (%)	Marginal Bid ($)	Area Preserved (ha)	Total Cost ($)	Total Emissions Avoided (t CO2e)	Abatement Cost ($/t CO2e)
Wetlands (ROC) - 8,555 ha					
10	3,164	856	2,461,409	291,982	8.43
20	3,487	1,711	5,331,024	583,964	9.13
30	3,721	2,567	8,427,986	875,946	9.62
40	3,920	3,422	11,706,436	1,167,929	10.02
50	4,106	4,278	15,148,130	1,459,911	10.38
60	4,292	5,133	18,748,288	1,751,893	10.70
70	4,492	5,989	22,512,824	2,043,875	11.01
80	4,725	6,844	26,461,803	2,335,857	11.33
90	5,049	7,700	30,645,805	2,627,839	11.66
Wetlands (Prairies) - 11,736 ha					
10	493	1,174	578,251	379,656	1.52
20	493	2,347	1,156,503	759,313	1.52
30	493	3,521	1,734,754	1,138,969	1.52
40	493	4,694	2,313,005	1,518,626	1.52
50	493	5,868	2,891,257	1,898,282	1.52
60	493	7,042	3,469,508	2,277,939	1.52
70	493	8,215	4,047,759	2,657,595	1.52
80	493	9,389	4,626,011	3,037,251	1.52
90	493	10,562	5,204,262	3,416,908	1.52
Trees (ROC) - 12,000 ha					
10	3,194	1,200	3,406,299	342,240	9.95
20	3,595	2,400	7,522,641	684,480	10.99
30	3,885	3,600	12,034,435	1,026,720	11.72
40	4,132	4,800	16,861,914	1,368,960	12.32
50	4,363	6,000	21,973,344	1,711,200	12.84
60	4,594	7,200	27,360,409	2,053,440	13.32
70	4,841	8,400	33,033,395	2,395,680	13.79
80	5,131	9,600	39,027,208	2,737,920	14.25
90	5,532	10,800	45,429,823	3,080,160	14.75
Trees (Prairies) - 469 ha					
10	493	47	23,096	12,534	1.84
20	493	94	46,193	25,069	1.84
30	493	141	69,289	37,603	1.84
40	493	188	92,385	50,138	1.84
50	493	234	115,481	62,672	1.84
60	493	281	138,578	75,206	1.84
70	493	328	161,674	87,741	1.84
80	493	375	184,770	100,275	1.84
90	493	422	207,866	112,809	1.84

New Tree Plantings – Nursery and Farm

Canada has made a large commitment to planting new trees. Farmers should be considered as important beneficiaries of this commitment, because strategic planting of linear trees can be beneficial to farmers. There are important economic considerations for this, described briefly below. To allow wide-scale new tree plantings, nurseries may need support. Across three methods and three varieties, Dickerson et al. (1983) found that the cost of production per 6-inch tree seedling ranged from $0.26 to $1.12 (Mean=$0.72) [converted from 1980 USD] in Tennessee. With a tree seedling selling for $0.97 (USDA, 2004) [converted from 2004 USD], this results in a per seedling net return of –$0.15 to $0.71 (Mean=$0.26) for nurseries.

On the farm, a 2.5 m spaced, 3-row tree planting (like a shelterbelt, or riparian buffer) requires an equivalent planting of 400 seedlings per hectare. Given a price of $0.97 per seedling and planting costs roughly half of the cost of the seedling (USDA, 2004), installing this type of tree planting would cost $389.48/ha. Using more mature potted plants could cost as much as $5,466/ha (USDA, 2004). Assuming that these targeted plantings were previously farmed, the loss of revenue would be roughly equivalent to the rental value of pasture, with the NPV of a 20-year set-aside being $492.72/ha. In this case, the farmer would need to be compensated for both the tree planting and the set-aside, resulting in a net return of approximately –$882.19/ha. This would result in an abatement cost of $3.09/t CO_2e in the ROC and $3.30/t CO_2e on the Prairies.

Summary of Findings

This report estimates the total costs of the four programs examined for nitrogen management, cover crops, rotational grazing, and the conservation of wetlands and trees on agricultural lands to be $283 million dollars per year. The total GHG emissions reduction in CO_2e is more than 9.5 million tonnes across 17 million hectares. This results in an approximate average total abatement cost of $29.69/t CO_2e, equivalent to a cost-share incentive of $16.47/ha (Table S1).

Table S1: Summary of program costs, GHG emissions reductions, covered area and abatement costs for 4R implementation, rotational grazing adoption, cover crop adoption and set-aside trees and wetlands.

BMP	Change	Cost Share Equivalent ($/ha)	Area Affected (ha)	Total Program Cost ($)	Total GHG Mitigation (t CO2e)	Abatement Cost ($/t CO2e)
4R (50% Cost Share)	15% New and Improved Adoption	8.35	13,861,275	115,698,825	2,919,111	39.63
Cover Crops	15% New Adoption in ROC 1% New Adoption in Prairies	47.98	2,360,073	113,244,945	2,216,471	51.09
Rotational Grazing	10% New Adoption	24.22	967,132	23,424,375	302,414	77.46
Set Aside	40% Vulnerable Wetlands and Trees Preserved for 20 Years	2,363.71	13,104	30,973,740	4,105,652	7.54
Total		16.47	17,201,584	283,341,885	9,543,648	29.69

4. Conclusion

This report assesses the annual net change in farm returns per unit from adopting various best management practices to reduce harmful GHG emissions. This analysis finds that many practices could have either a positive or negative effect on farm incomes (Table 1), and external supports may be necessary in many cases to encourage additional adoption of GHG mitigating practices. While this analysis shows that some practices may be mutually beneficial to the environment and to farmers over time, their lack of adoption shows that there may still be a need for support so that practices become normalized.

To drive adoption, the study found that lower incentives per hectare are needed for 4R, which had lower mitigation per hectare. Cover crops, conservation of wetlands and trees at risk of conversion on agricultural lands, and rotational grazing had higher inducement costs per hectare, but higher mitigation potential as well. This trade-off resulted in the practices having similar abatement costs, ranging from \$31 to \$77 per tonne CO_2e (Table S1). Overall, this analysis shows that this kind of government investment is very cost-effective from a dollars per tonne perspective.

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