Costs and Benefits of On-Farm Beneficial Management Practices that Reduce Net GHG Emissions

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Abstract

In the context of climate change from greenhouse gas emissions, this study examines the abatement costs of adopting a host of agricultural BMPs. These include nitrogen, manure, livestock, soil, tree, and wetland management practices that have program abatement costs from $1.08/t CO_2e to $400/t CO_2e. To achieve approximately 30 million t CO_2e emissions reduction and 18.6 million t CO_2e carbon sequestration over 5 years from March 2023 to March 2028, the outlined program would require just over 2 billion dollars in that span, at an average abatement cost of approximately $42.57/t CO_2e.

The values described in this report are estimates for broad regions across Canada for financial, emissions reduction and carbon sequestration effects (FCS, 2022a). Local conditions could change the benefits described for any individual farm operation or field. Therefore, caution should be used in the application of these results. The monetary values are estimates that, in some cases, attempt to reconcile a lack of adoption of seemingly beneficial practices amongst Canadian farmers. Therefore, these estimates may require further examination and regional specificity. The values generated here are used to budget the approximate equivalent incentive payments required to increase the attractiveness of BMPs to specified percentages of new producers. The actual policy mechanisms that will bring about these changes and deliver these dollars are described in the associated policy report (FCS, 2022b).

A summary of the practices considered, and their estimated per unit spending, abatement and program abatement costs is presented in Table A1.

Table A1: Practice total costs, per unit costs, total CO_2e reduction, unit reduction and program abatement cost, including total and annual averages for programs of 5 year framework.

Practice	**Total Cost ($)**	**Cost per Unit ($/Unit)**	**Total CO_2e Reduction (t CO_2e)**	**Unit CO_2e Reduction (t CO_2e/unit)**	**Program Abatement Cost ($/t Co_2e)**
Nitrogen Management					
Right Rate (ha)	221,659,191	33.69	3,345,000	0.508	66.27
Precision N (ha)	47,522,071	13.38	1,085,143	0.306	43.79
Enhanced Efficiency N (ha)	258,316,960	42.84	5,580,000	0.925	46.29
No Fall Application (ha)	4,831,939	3.50	600,000	0.435	8.05
4R Manure (t)	1,018,496	10.89	247,500	2.647	4.12
Organic N Credit (t)	5,945,472	30.33	555,000	2.832	10.71
Manure Management					
Synthetic Covers (hd)	35,169,461	4.57	2,707,156	0.352	12.99
Acidification (hd)	80,092,650	10.41	4,001,765	0.520	20.01
Conserving Manure N (t)			484,914	2.593	
Livestock Management					
Pasture: Legumes (hd)	3,845,984	1.94	3,384,261	1.709	1.14
Rotational Grazing (hd)	38,215,571	19.30	7,617,436	3.846	5.02
Extended Grazing: Annuals (hd)	69,293,642	34.99	1,900,629	0.960	36.46
Soil Management					
Cover Crops (50% Legume Mix) (ha)	649,356,201	184.55	7,981,804	2.269	81.35
Intercropping (ha)	374,548,156	114.81	4,808,380	1.474	77.89
Agricultural Tree and Wetland Management					
Alley Cropping (ha)	7,775,617	172.62	422,750	9.385	18.39
Silvopasture (ha)	7,775,617	172.62	385,750	8.564	20.16
New Riparian Trees (ha)	9,315,362	2,981	410,500	131.4	22.69
Shelterbelt Conservation (ha)	3,273,750	3,000	88,750	81.42	36.89
Wetland Conservation (ha)	225,000,000	3,000	2,925,000	39.00	76.92

Wetland Restoration (ha)	26,000,000	5,200	65,000	13.00	400.00
Total	**2,068,956,141**		**48,596,738**		
Annual Average	**413,791,228**		**9,719,348**		**42.57**

1. Introduction

Greenhouse gas emissions reductions are important aspects of Canada's policy suite as interim targets in 2030 and net zero targets by 2050 rapidly approach. The Agricultural Policy Framework presents an opportunity to reduce harmful emissions and sequester carbon through initiatives that encourage the adoption of agricultural beneficial (or best) management practices (BMPs). There are a variety of BMPs that affect net carbon balances from nitrogen use, livestock, soils, and wetlands. However, the economic effects of these practices, particularly across space and time, are still uncertain. Some practices have initial investment costs that have longer pay-back period, while some are immediately advantageous. Some may be costly to farmers and require government intervention to be broadly adopted.

Given the relative uncertainty of some of these practices, the first objective of this study aims to quantify the range in net change in farm-level returns expected from the adoption of selected BMPs across two major agricultural zones - the Prairies and the Rest of Canada (ROC). The second objective aims to use these ranges and current adoption rates to estimate the costs of inducing different levels of adoption across the two major agricultural zones. This will also be accompanied by anticipated changes in net carbon equivalents pulling from the associated technical reports (FCS, 2022a), allowing the estimation of abatement costs in terms of dollars per tonne of CO_2e mitigation for practice adoption.

This report employs farm financial analysis and economic modelling. The results presented here depend on average farms in broad regions. The analysis is meant to serve as the basis and justification for budget allocation to different programs and may be further refined in the associated policy report (FCS, 2022b). Some of the results presented here are updated values from an earlier version of this report, following a similar structure (De Laporte et al., 2021a). They results do not necessarily represent any individual farm and careful consideration should be given to the results in a specific context.

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 2.1. 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 outlier cases are also possible. Therefore, careful consideration of site-specific information is required when applying this information to any operation. In general, the analyses in this section are best suited to black soil regions in the '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. Results are presented in 2022 CAD, inflated from previous years using the Bank of Canada's Inflation Calculator (Bank of Canada, 2022) when necessary, also incorporating an exchange rate of 1.25 USD/CAD when appropriate.

Table 2.1: Annual change in net returns per unit for on-farm BMPs by location in Canada, with negative values implying costs to implement.

Practice		**Values**			
Nitrogen Management	**Location**	**Low**	**Middle**	**High**	**Units**
Quantitative Determination of Right Rate	Prairie (Canola)	120.54	131.04	141.54	$/ha
	Prairie (Wheat)	45.44	55.95	66.45	$/ha
	ROC (Corn)	120.54	131.04	141.54	$/ha
Precision Nitrogen Management	Prairie (Canola/Wheat)	6.43	17.47	25.73	$/ha
	ROC (Corn)	17.74	31.01	38.33	$/ha
Enhanced Efficiency Nitrogen Fertilizers	Prairie (Canola/Wheat)	-44.30	-24.30	-4.30	$/ha
	ROC (Corn)	-28.10	-8.10	11.90	$/ha
Elimination of Fall Application	Prairie (Canola)	-18.83	-15.39	-12.50	$/ha
4R Management of Manure	Liquid	0.50	1.25	3.60	$/t
Improved Crediting of Organic N Sources	Liquid	43.50	59.25	75.00	$/t
	Solid	17.40	23.70	30.00	$/t
Manure Management	**Location**				
Synthetic Impermeable Floating Covers	Prairie (Dairy)	-30.52	-19.84	-9.16	$/hd
	ROC (Dairy)	-53.75	-34.94	-16.13	$/hd
	Prairie (Swine)	-1.96	-1.28	-0.59	$/hd
	ROC (Swine)	-3.22	-2.09	-0.96	$/hd
Acidification	Canada (Dairy)	-19.60	-13.10	-6.55	$/hd
	Canada (Swine)	-3.17	-2.84	-2.50	$/hd
Livestock Management	**Location**				
Pasture Quality: Legumes	Prairie (Cow-Calf)	219.10	223.49	227.89	$/hd
	ROC (Cow-Calf)	229.54	232.37	242.57	$/hd
Rotational Grazing	Canada (Cow-Calf)	23.60	55.39	87.18	$/hd
Extended Grazing: Annuals	Canada (Cow-Calf)	74.28	97.36	120.45	$/hd
Soil Management	**Location**				
Cover Crops	Canada (50% Legume)	-66.69	57.25	205.40	$/ha

Intercropping	Prairie	-140.68	-78.70	19.81	$/ha
	ROC	19.81	46.35	72.90	$/ha
Agricultural Tree and Wetland Management	**Location**				
Alley Cropping	ROC		-172.62		$/ha
Silvopasture	Canada		-172.62		$/ha
New Riparian Trees	Canada		-2980.92		$/ha
Avoided Shelterbelt Conversion	Prairie		-3000.00		$/ha
Avoided Conversion of Wetlands	Prairie		-3000.00		$/ha
Wetland Restoration	Prairie		-5200.00		$/ha

2.1 Nitrogen Management

Quantitative Determination of Right Rate

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 established through soil testing, and fully accounting for other sources of N, including from previous legume crops and cover crops, likely results in synthetic N rate reductions without yield losses. Since N is costly to apply this could increase net returns. In general, even large reductions in synthetic N application can have small effects on net returns, but large environmental benefits. Yanni et al. (2021) 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. (2021b; 2021c) 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 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.

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. CropPro Consulting (2022), estimates soil testing costs at $8.65/ha, offering 5 samples on a minimum 56.7 ha field in Saskatchewan.

N rate changes alter input costs according to the price of N. From provincial crop planning and budgeting guides, estimated N prices are $1.74/kg (OMAFRA, 2022) in Ontario, $2.85/kg in Manitoba (MARD, 2022), and $2.93/kg in Saskatchewan and Alberta (SMA, 2022; AFRED, 2022). As N prices have been continually increasing over the last year, recent market reports put the price of N at $3.00/kg (Quinn, 2022).

Assuming no yield loss, efforts to adjust the rate, either by accounting properly for N credits from previous crops, or adjusting the rate based on soil tests, increase net returns by the magnitude of the reduction times the price of N ($3/kg), minus the cost of soil testing ($8.65/ha to $29.65/ha). This combined strategy – soil testing and accounting - results in a range of net returns from $120.54/ha to $141.54/ha (Mean = $131.04/ha) for 50 kg N/ha reductions in the Prairies (on canola) and in the ROC (on corn). In the Prairies (on wheat), assuming a reduction of 25 kg N/ha, the net returns would range from $45.44/ha to $66.45/ha (Mean = $55.95/ha). These values are highly dependent on the price of N fertilizer.

Increased Adoption of Precision Nitrogen Management

Variable rate and precision techniques could increase the efficiency of input use by targeting areas of the field that need that input the most. If implemented correctly, this could increase 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. For example, CropPro Consulting (2022) estimates the ongoing costs of agronomic services including prescription maps at $12.36/ha, although there is a higher initial cost to map the field. Precision application could also reduce N rates by 10% (FCS, 2022a).

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.

Assuming no long-term change in yields from precision application, 10% N rate reductions and agronomic costs to the model farm enterprises, variable rate application has net returns from $6.43/ha to $25.73/ha (Mean=$17.47/ha) in the Prairies on canola and wheat and from $17.74/ha to $38.32/ha (Mean=$31.00/ha) in the ROC on corn. These net return changes consider, decreased N cost, and yearly agronomic services to create prescription maps, and do not include the environmental benefits of less N application.

Increased Use of Enhanced Efficiency 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. 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%. Meta-analysis in Germany shows that nitrification inhibitors cause no statistically significant change in yield with reduced N application (Hu et al., 2014).

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. (2021), 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. Enhanced efficiency fertilizers could reduce N rates by approximately 10% (FCS, 2022a).

Assuming no yield change from the use of enhanced efficiency fertilizers with accompanied reductions in N rate, the change in net returns from inhibitor application on canola and wheat is from −$44.30/ha to −$4.30/ha (Mean=−$24.30/ha) in the Prairies, and on corn is from −$28.10/ha to $11.90/ha (Mean=−$8.10/ha) in the ROC.

Elimination of Fall N Application

Fall N application results in increased fertilizer loss over winter and significant emissions. While relatively rare in synthetic fertilizer application, it is still a practice that does happen, mostly for time saving in the spring. Switching fertilizer application to the spring could have no cost or could result in a need for custom application services in the spring, with an estimated net return on the prairies between −$18.83/ha to −$12.50/ha (Mean=−$15.37/ha) (MARD, 2022; SMA 2022).

4R Management of Manure

Manure timing can be complicated and applying later in fall, or the use of nitrification inhibitors can save as much as 25% of the N present in manure, resulting in lower synthetic N needs. The custom cost to apply manure is approximately $3.63/t ($14/1000 gal) (OMAFRA, 2019). The cost of using nitrification inhibitors is more complicated but may be as low as $0.50/t for liquid swine manure, assuming the inhibitor rate matches the assumptions made regarding enhanced efficiency fertilizers.

Improved Crediting of Organic N Sources

Improved crediting of organic N sources could significantly decrease synthetic fertilizer applications, by as much as 25 kg N/ha in liquid manure systems and by 10 kg N/ha in solid manure systems (FCS, 2022a). To ensure that N content is correct, manure samples at approximately $50 per composite sample would be required. The net return relates directly to N savings vs. the price of N, along with sampling costs. For liquid systems, this ranges from $43.50/ha to $75/ha (Mean=$59.25/ha) and from $17.40/ha to $30/ha (Mean=$23.70/ha) for solid systems.

2.2 Manure Management

Synthetic Impermeable Floating Covers

The cost of a synthetic impermeable cover ranges between $3 to $10 per square yard including rainfall and gas venting systems, with a 10-to-15-year lifespan (Andersen et al., 2014a). This is equal to a cost of $1,484 to $4,945 [2022 CAD] for a 400 m^2 surface liquid manure tank. Assuming an average dairy herd of 162 hd on the prairies, the average cost of covers is $19.84/hd. In the ROC, the average dairy herd size is 92 hd, leading to an average cost of $39.94/hd. For swine, the average cost is $1.28/hd on the prairies (2519 hd) and $2.09/hd in the ROC ($1538 hd). This analysis assumes that manure storage tanks have a constant exposed surface area of 400 m^2 regardless of the capacity of the tank.

Acidification

Acidifying manure reduces ammonia emissions and therefore increases the value of the manure fertilizer, at the cost of sulfuric acid. According to Iowa State Extension, the cost of applying acid to a 1000 swine finishing barn is about $2.50/head [$2 USD to CAD at 1.25], when reduced ammonia losses are considered (Anderson et al., 2014b). For dairy, the costs of acidification range between $6.55/hd to $19.60/hd (Mean=$13.10/hd) (Sokolov et al. 2019).

2.3 Livestock Management

Improving Nutritional Quality of Forage in Pasture Systems via Legumes

Cow-calf production in the East and West is different, requiring separate budgets. Many cow-calf producers in Alberta operate on native and tame pastures (Bao et al., 2019). In the prairie provinces, stocking densities are estimated to be 0.4 hd/ac, following the grassland cow-calf producers identified in an Alberta-based survey by Bao et al., (2019). In Ontario, stocking density is assumed to be 1.54 hd/ac following an OSCIA survey (Yungblut, 2015). Following the increased DM intake on grass-alfalfa mixtures identified by McCaughey et al. (1999), the necessary required grazing land reduces by 20.6 %. Annualized pasture costs are estimated to be $80/ac based on water, fencing, and seeding costs for a Western Canada grass pasture and $24/ac in the prairies.

Estimates place the use of legume-grass mixtures at 25%. The additional cost of the legumes birdsfoot trefoil, sainfoin or alfalfa, at 20-30% of a grass mixture, ranges from $10/ac to $70/ac, depending on initial grass mixture and seeding method, and the selected legume. Our primary focus is on alfalfa, due to its excellent drought tolerance, moderate re-growth rate and nitrogen fixation. While other legumes, such as sainfoin and trefoil do not cause bloat they are less tolerant to low precipitation and may not be well-suited for more the more intensive grazing systems. We allow for a conservative reduction in fertilizer application of 30 lbs/ac.

The financial benefits from legume-grass mixtures occurs at several stages for a cow-calf producer. We make a simplifying assumption that stocking densities would not increase, moving unused land out of livestock production. The ratio of calf-cow pairs increases from 85% to 89.5% and weaning weight at sale increases by 13.3%, both quite drastic changes (FCS, 2022a). In Ontario and Alberta, weaning prices were set to range from $1.9/lb to $2.1/lb for stocker steers under 600 lbs and $1.8/lb to $2.0/lb for larger weaned calves.

Expected net returns from adding alfalfa to pasture range from $219.10/hd to $227.89/hd on a cow-calf farm in the Prairies and from $229.54/hd to $242.57/hd in the ROC, when upfront costs are spread over 5 years. Rotational grazing is more profitable in Eastern Canada, suggesting different necessary policy approaches.

The positive return reflects higher calf revenues, reduced over-wintering costs, and greater calf-cow pairs. The difference between the regions stems mainly from the relative cost change of pastures conversion, assuming similar DM rate changes.

Pasture costs are subject to large differences across Canada. The most common rental rate in Alberta is $30 AUM (AFRED, 2020), in Saskatchewan costs are lower at $14.1 AUM, and higher in Manitoba at $40-70 AUM. Differences can largely be attributed to annual precipitation and land opportunity costs.

Due to considerably higher baseline cost for pasturing cattle in the prairies and ROC, based on provincial budgets and land lease agreements, the benefit to including legumes is more profitable than the baseline. When the upfront costs are considered, it does not present a substantial barrier to farmers in Eastern Canada with higher cost pastures and greater initial stocking densities. On the prairies, the upfront costs are substantial barriers due to the low stocking density, placing a higher cost per head.

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, 2020). Examining a 30-year pasture project life, the cost is $5.86/ha/year. Others find the cost to range from $3 to $70 depending largely on farm size, with costs decreasing for larger operations (Wang, 2018; Undersander, 2002). 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 translates to annual benefits of $23.6/hd to $87.18/hd (Mean = $55.39/hd). 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.

Extended Grazing: Annuals

Maintaining beef cattle on pasture for longer periods of time using a range of extended grazing strategies may reduce emissions. While a wide variety of extended grazing strategies exist – our primary focus is grazing of annuals with practices such as swath grazing. Over-wintering cattle outdoors on swaths can be a large cost and labour-saving practice. The benefit depends on the location, additional housing and water access needed in some areas. Some evidence suggests cattle condition may decline if feed is difficult to access and low quality. This may lead to issues of timely breeding, calving and early culling. The risk and additional losses of productivity are difficult to quantify. Further, substantial inter-annual variation on the amount of dry matter available on fields between years make swath grazing a less reliable source of food.

Despite the potential risks, the large costs savings have spurred adoption of roughly 56%. In Minnesota, swath grazing estimates are close to triticale at $0.57 AUD compared to $2.05 AUD for baleage feeding. A study by AAFC in Alberta found feed costs to range across crops with triticale ($0.78 AUD), barley ($1.24 AUD), and corn ($1.05 AUD) cheaper than confined feeding ($1.98 AUD) (Baron et al. 2014). For Alberta, this implies a range of net returns from cost savings of from $74.28/hd to $120.45/hd (Mean=$97.36/hd). Across the prairies, over-wintering costs are quite heterogenous with consistent savings from grazing of annuals. Overall, there are considerable cost savings of roughly $0.35 to $1.27 AUD across the prairies. This indication of a strong private benefit suggests extension services may be beneficial to advise farmers on methods and viability of swath grazing.

2.4 Soil Management

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. The greenhouse gas and nitrogen management capabilities of each are different, particularly between grasses and legume crops. We have simplified our analysis to a generic 50% grass-legume mix; however, there are dozens of specific choices for single or multi-species cover crops.

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, 2022; 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, 2022; 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, 2022; 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 60 to 80 lbs/ac, lowering costs in the following crop depending upon the nitrogen price, assumed to be $1.36/lb (Quinn, 2022). Multispecies mixes including legumes would have similar effects weighted by the relative establishment of these species in the mix. Rye has also been shown to grant an N credit up to 25 lbs/ac (SARE, 2019).

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. Assuming an N price of $3/kg, the net returns of a multi-species mixture cover crop with ~50% legumes range from −$66.69/ha to $205.40/ha (Mean=$57.25/ha) across Canada. Net returns benefit from the nitrogen credit in leguminous crops. The maximum benefits, particularly, consider a full stand of well-established cover crop, which is less likely in the Prairies. Cover crop use becomes particularly important when N prices are high. Large ranges reflect uncertain seeding rates, seed prices, nitrogen credits and weed control benefits that evolve over time.

Intercropping

Intercropping increases the amount of biomass on a field, leading to increased carbon sequestration. It also focuses N delivery to half as much area, significantly lowering N rates. With intercrops seeded and harvested simultaneously, new seeding and harvest techniques may be necessary to separate the harvest properly. In relay cropping (with soybean planted into winter-wheat), seeding and harvest would be conducted at different times of year. Chemical costs would change, depending on the intercrop, as some herbicides, fungicides and pesticides would not be possible to apply to both crops. Intercropping would provide suppression of some crop issues. Four primarily prairie intercropping scenarios were considered including, canola-pea, flax-chickpea, barley-lentil, and canola-lentil. Winter wheat-soybean intercropping was considered for the ROC, along with smaller amounts of canola-pea intercropping. Estimated costs and benefits were adjusted based on provincial crop budgets (MARD, 2022; OMAFRA, 2022; SMA, 2022).

The estimated average change in net returns for prairie intercropping was from −$140.68/ha to $19.81/ha (Mean=−$78.70/ha), with average LER expectations of 1.2 (20% more total grain – 50% legume yield and 70% non-legume yield). For the ROC, the range was from $19.81/ha to $72.90/ha (Mean=$46.35/ha), based on higher LER expectations of at least 1.3 (50% legume yield and 80% non-legume yield). Intercropping returns are greatly affected by yield expectations. Furthermore, when grain and input prices are high, intercropping helps save on some inputs, although with higher total input costs, and increase total grain yields in year.

2.5 Agricultural Tree and Wetland Management

Tree Planting: Alley Cropping, Silvopasture, and New Riparian Trees

Canada has made a large commitment to planting new trees. Farmers should be considered as important partners in 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 $1.02 (USDA, 2004) [converted from 2004 USD], this results in a per seedling net return of −$0.10 to $0.76 (Mean=$0.33) for nurseries.

Alley Cropping and Silvopasture

Additional trees per hectare in crop and pasture would require an equivalent planting of approximately 111 trees per hectare for both alley cropping and silvopasture. Given a price of $1.02 per seedling and planting costs roughly half of the cost of the seedling (USDA, 2004), installing this type of tree planting would cost $172.62/ha. As these trees would be integrated with agriculture, no land value for the set-aside trees is considered.

New Riparian Trees

Buffers on the farm, like a shelterbelt, or riparian buffer, require an equivalent planting of 1600 seedlings per hectare. Given a price of $1.02 per seedling and planting costs roughly half of the cost of the seedling (USDA, 2004), installing this type of tree planting would cost $2,488/ha. Using more mature potted plants could cost as much as $37,180/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 (lower quality land), 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 forgone land rental value, resulting in a net return ranging from −$2,981/ha (saplings) to −$37,676/ha (larger trees) throughout Canada.

Maintaining Shelterbelts and Woodlots

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 closer to the Midwest based on crop type distribution. Alternatively, outright land purchases may cost between $2,500/ha and $20,500/ha on the Prairies (FCC, 2022). Setting a conservation easement, or a set aside program at $3,000/ha may be more attractive to producers.

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.

The costs maintaining wetlands through conservation easements, for example, could be as low as $1,500/ha in the Prairies (FCS, 2022a). Alternatively, outright land purchases may cost between $2,500/ha and $20,500/ha on the Prairies (FCC, 2022). Setting a conservation easement, or a set aside program at $3,000/ha may be more attractive to producers.

Wetland Restoration

Wetland restoration costs are expensive, ranging from around $5,200/ha on the Prairies, up to around $31,000/ha in the ROC (FCS, 2022a). As there are few direct financial benefits to the farmer from restoration, assuming that unprofitable marginal land was not being employed, these represent the full average costs of restoration.

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 reduction) 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 and estimated adoption rates provided in the associated technical report (FCS, 2022a). This section examines 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. This method is particularly appropriate when a practice has positive expected net returns, as it attempts to explain a lack of adoption of seemingly beneficial practices, when abatement costs would otherwise be negative or zero. In situations where the practices are mostly costly, direct costs of adoption may be used instead to calculate abatement costs.

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. The results in this section are initially presented as spending and GHG changes to ramp up in a single year (2028). However, all the programs are designed to ramp up to the 2028 values over the expected 5-year agricultural policy framework from March of 2023 to March of 2028, in Section 3.6. This section also considers differences in the permanence of some of the changes (capital vs. reversible investments), as there are some temporal issues that arise in presenting the total program effects. Therefore, we also present total and annual breakdowns of program spending in Section 3.6.

3.1 Nitrogen Management

Quantitative Determination of Right Rate

The range of net returns for the Prairies and the ROC are assumed to be those in Table 1. For canola in the prairies, the base adoption of some form of right rate is high, with only 23% of canola producers seriously overapplying N. However, as many as 54% of corn in the ROC and prairie wheat producers may be overapplying N. This leaves more opportunity to reduce N application on corn than on canola, for example. Rate reductions may be more effective from an area-based emissions reduction standpoint on corn in the ROC. The results of the right rate analysis are in Table 3.1.1.

Table 3.1.1: Estimates of costs of adopting quantitative determination of right rate among Canadian farmers by adoption rate, quantity effected, total incentive cost, unit-based costs, emissions reductions, emissions reductions per unit and abatement costs.

	Quantitative Determination of Right Rate		
Location	Prairie (Canola)	Prairie (Wheat)	ROC (Corn)
Increased Adoption	25%	50%	50%
Increased Area (ha)	2,300,000	3,580,000	700,000
Total Incentive Cost ($)	23,298,511	42,317,461	8,270,426
Area Cost ($/ha)	10.13	11.82	11.81
Emissions Reduction (t CO2e)	415,000	340,000	360,000
Area Emissions Reduction (t CO2e/ha)	0.180	0.095	0.514
Abatement Cost ($/t Co2e)	56.14	124.46	22.97

Precision Nitrogen Management

The range of net returns for the Prairies and the ROC are assumed to be those in Table 1. Precision management adoption is relatively rare on both the Prairies (~15%) and the ROC (~13%). Precision N management may also be more effective from an area-based emissions reduction standpoint on corn in the ROC. The results of the precision nitrogen management analysis are in Table 3.1.2.

Table 3.1.2: Estimates of costs of adopting precision nitrogen management among Canadian farmers by adoption rate, quantity effected, total incentive cost, unit-based costs, emissions reductions, emissions reductions per unit and abatement costs.

	Precision Nitrogen Management		
Location	Prairie (Canola)	Prairie (Wheat)	ROC (Corn)
Increased Adoption	20%	20%	20%
Increased Area (ha)	1,840,000	1,432,000	280,000
Total Incentive Cost ($)	8,037,057	6,254,927	1,548,706
Area Cost ($/ha)	4.37	4.37	5.53
Emissions Reduction (t CO2e)	200,000	76,714	85,000
Area Emissions Reduction (t CO2e/ha)	0.109	0.054	0.304
Abatement Cost ($/t Co2e)	40.19	81.54	18.22

Enhanced Efficiency Fertilizers

The range of net returns for the Prairies and the ROC are assumed to be those in Table 1. Enhanced efficiency fertilizer adoption is relatively rare on both the Prairies (~10%) and the ROC (~8%). Enhanced efficiency fertilizer may also be more effective from an area-based emissions reduction standpoint on corn in the ROC. The results of analysis are in Table 3.1.3.

Table 3.1.3: Estimates of costs of adopting enhanced efficiency fertilizers among Canadian farmers by adoption rate, quantity effected, total incentive cost, unit-based costs, emissions reductions, emissions reductions per unit and abatement costs.

	Enhanced Efficiency Nitrogen Fertilizers		
Location	Prairie (Canola)	Prairie (Wheat)	ROC (Corn)
Increased Adoption	40%	25%	40%
Increased Area (ha)	3,680,000	1,790,000	560,000
Total Incentive Cost ($)	57,358,784	19,521,337	9,225,532
Area Cost ($/ha)	15.59	10.91	16.47
Emissions Reduction (t CO2e)	1,120,000	300,000	440,000
Area Emissions Reduction (t CO2e/ha)	0.304	0.168	0.786
Abatement Cost ($/t Co2e)	51.21	65.07	20.97

Elimination of Fall Application

The range of net returns for the elimination of fall application are in Table 1. This practice is relatively common on the Prairies (~77%), leaving little space for improvement. The results of analysis are in Table 3.1.4.

Table 3.1.4: Estimates of costs of eliminating fall application among Canadian farmers by adoption rate, quantity effected, total incentive cost, unit-based costs, emissions reductions, emissions reductions per unit and abatement costs.

	Elimination of Fall Application
Location	Prairie (Canola)
Increased Adoption	15%
Increased Area (ha)	1,380,000
Total Incentive Cost ($)	1,610,646
Area Cost ($/ha)	1.17
Emissions Reduction (t CO2e)	200,000
Area Emissions Reduction (t CO2e/ha)	0.145
Abatement Cost ($/t Co2e)	8.05

4R Management of Manure

The range of net returns for 4R management of manure are in Table 1. This practice is relatively rare in the ROC with ~75% of producers applying manure, applying in the fall. The unit costs in this case, of paying for custom application to save time in the spring, were constant at $3.63/t manure. The results of analysis are in Table 3.1.5.

Table 3.1.5: Estimates of costs of adopting 4R management of manure among Canadian farmers by adoption rate, quantity effected, total incentive cost, unit-based costs, emissions reductions, emissions reductions per unit and abatement costs.

	4R Management of Manure
Type	Liquid
Increased Adoption	50%
Manure (t)	93,500
Total Incentive Cost ($)	339,499
Unit Cost ($/t)	3.63
Emissions Reduction (t CO2e)	82,500
Area Emissions Reduction (t CO2e/ha)	0.882
Abatement Cost ($/t Co2e)	4.12

Improved Crediting of Organic N Sources

The range of net returns for improved crediting of organic N sources are in Table 1. This practice is relatively more common for liquid manure (~40%) and for solid (~24%). The results of analysis are in Table 3.1.6.

Table 3.1.6: Estimates of costs of improved crediting of organic N sources among Canadian farmers by adoption rate, quantity effected, total incentive cost, unit-based costs, emissions reductions, emissions reductions per unit and abatement costs.

	Improved Crediting of Organic N Sources	
Type	Liquid	Solid
Increased Adoption	50%	50%
Manure (t)	93,500	102,500
Total Incentive Cost ($)	1,374,152	607,672
Unit Cost ($/t)	14.70	5.93
Emissions Reduction (t CO2e)	105,000	80,000
Area Emissions Reduction (t CO2e/ha)	1.123	0.780
Abatement Cost ($/t Co2e)	13.09	7.60

3.2 Manure Management

Synthetic Impermeable Floating Covers

The range of net returns for synthetic impermeable floating covers are in Table 1. This practice is relatively uncommon, virtually negligible, for dairy and swine producers in Canada. As this practice is mostly costly to the producer, this analysis used the average cover costs per head for dairy and swine in the Prairies and ROC. The results of analysis are in Table 3.2.1.

Table 3.2.1: Estimates of costs of synthetic impermeable floating covers among Canadian farmers by adoption rate, quantity effected, total incentive cost, unit-based costs, emissions reductions, emissions reductions per unit and abatement costs.

	Synthetic Impermeable Floating Covers			
Location	Prairie (Dairy)	ROC (Dairy)	Prairie (Swine)	ROC (Swine)
Increased Adoption	50%	50%	50%	50%
Increased Animals (hd)	110,300	593,950	2,922,500	4,066,250
Total Incentive Cost ($)	2,188,638	20,752,742	3,729,407	8,498,674
Unit Cost ($/hd)	19.84	34.94	1.28	2.09
Emissions Reduction (t CO2e)	50,010	292,639	214,512	345,225
Unit Emissions Reduction (t CO2e/hd)	0.453	0.493	0.073	0.085
Abatement Cost ($/t Co2e)	43.76	70.92	17.39	24.62

Acidification

The range of net returns for acidification are in Table 1. This practice is relatively uncommon, virtually negligible, for dairy and swine producers in Canada. As this practice is mostly costly to the producer, this analysis used the average acidification costs per head for dairy and swine in the Prairies and ROC. The results of analysis are in Table 3.2.1.

Table 3.2.2: Estimates of costs of acidification among Canadian farmers by adoption rate, quantity effected, total incentive cost, unit-based costs, emissions reductions, emissions reductions per unit and abatement costs.

	Acidification			
Location	Prairie (Dairy)	ROC (Dairy)	Prairie (Swine)	ROC (Swine)
Increased Adoption	50%	50%	50%	50%
Increased Animals (hd)	110,300	593,950	2,922,500	4,066,250
Total Incentive Cost ($)	1,444,930	7,780,745	7,306,250	10,165,625
Unit Cost ($/hd)	13.10	13.10	2.50	2.50
Emissions Reduction (t CO2e)	73,802	425,268	318,845	516,007
Unit Emissions Reduction (t CO2e/hd)	0.669	0.716	0.109	0.127
Abatement Cost ($/t Co2e)	19.58	18.30	22.91	19.70

Conserving Manure N Content

Conserving manure N content had no additional cost associated with it, other than the costs of acidification and covers. However, the environmental benefit of preserved N in the manure (of displacing additional synthetic N application) was not included in the analysis for acidification and covers. This added emissions reduction is added here.

Table 3.2.3: Estimates of costs of conserving manure N content among Canadian farmers by adoption rate, quantity effected, total incentive cost, unit-based costs, emissions reductions, emissions reductions per unit and abatement costs.

	Conserving Manure N Content
Type	Liquid
Increased Adoption	100%
Effected Manure (t)	187,000
Total Incentive Cost ($)	
Unit Cost ($/t)	
Emissions Reduction (t CO2e)	161,638
Unit Emissions Reduction (t CO2e/t)	0.864
Abatement Cost ($/t Co2e)	

3.3 Livestock Management

Pasture Quality: Legumes

The range of net returns for adding legumes to pasture are in Table 1. This practice is relatively common in the prairies (~34%) and the ROC (~20%) for tame pasture. This highly beneficial practice does carry the risk of bloat with poor management but should be attractive for adoption by producers. The results are in Table 3.3.1.

Table 3.3.1: Estimates of costs of improving pasture quality with legumes among Canadian farmers by adoption rate, quantity effected, total incentive cost, unit-based costs, emissions reductions, emissions reductions per unit and abatement costs.

	Pasture Quality: Legumes	
Location	Prairie (Cow-Calf)	ROC (Cow-Calf)
Increased Adoption	30%	30%
Increased Animals (hd)	1,611,420	369,120
Total Incentive Cost ($)	3,311,297	534,688
Unit Cost ($/hd)	2.05	1.45
Emissions Reduction (t CO2e)	963,308	164,779
Unit Emissions Reduction (t CO2e/hd)	0.598	0.446
Abatement Cost ($/t Co2e)	3.44	3.24

Rotational Grazing

The range of net returns for rotational grazing are in Table 1. For sufficient levels of intensity (more than 8 paddocks), this practice is relatively uncommon in the prairies (~10%) and the ROC (~18%). The practice is much more widely adopted in a more basic form (with 4 or fewer paddocks). The results of the analysis are in Table 3.3.2.

Table 3.3.2: Estimates of costs of rotational grazing among Canadian farmers by adoption rate, quantity effected, total incentive cost, unit-based costs, emissions reductions, emissions reductions per unit and abatement costs.

	Rotational Grazing	
Location	Prairie (Cow-Calf)	ROC (Cow-Calf)
Increased Adoption	30%	30%
Increased Animals (hd)	1,611,420	369,120
Total Incentive Cost ($)	32,045,066	6,170,505
Unit Cost ($/hd)	19.89	16.72
Emissions Reduction (t CO2e)	214,778	49,198
Carbon Sequestration (t CO2e)	1,850,349	424,820
Unit Emissions Reduction (t CO2e/hd)	1.282	1.284
Abatement Cost ($/t Co2e)	15.52	13.02

Extended Grazing: Annuals

The range of net returns for extended grazing of annuals are in Table 1. This is a common practice in both the prairies and the ROC (~49%) and seems largely beneficial. The results of the analysis are in Table 3.3.3.

Table 3.3.3: Estimates of costs of extended grazing of annuals among Canadian farmers by adoption rate, quantity effected, total incentive cost, unit-based costs, emissions reductions, emissions reductions per unit and abatement costs.

	Extended Grazing: Annuals	
Location	Prairie (Cow-Calf)	ROC (Cow-Calf)
Increased Adoption	30%	30%
Increased Animals (hd)	1,611,420	369,120
Total Incentive Cost ($)	18,793,050	4,304,831
Unit Cost ($/hd)	11.66	11.66
Emissions Reduction (t CO2e)	515,467	118,076
Unit Emissions Reduction (t CO2e/hd)	0.320	0.320
Abatement Cost ($/t Co2e)	36.46	36.46

3.4 Soil Management

The range of net returns for cover cropping and intercropping are in Table 1. Cover cropping is a negligible practice on the Prairies (<1%) and relatively rare in the ROC (~19%). Cover cropping has many potential benefits, some of which are poorly understood monetarily, leading to increased uncertainty. The Prairie benefits are particularly unclear. Intercropping is also negligible in both the Prairies and the ROC. However, interesting crop combinations show some financial promise, particularly when crop prices are high. The results of these analyses are in Table 3.4.1.

Table 3.4.1: Estimates of costs of cover crops and intercropping among Canadian farmers by adoption rate, quantity effected, total incentive cost, unit-based costs, emissions reductions, emissions reductions per unit and abatement costs.

	Cover Crops (50% Legume Mix)		**Intercropping**	
Location	Prairie	ROC	Prairie	ROC
Increased Adoption	5%	30%	10%	10%
Increased Area (ha)	1,563,729	1,954,809	2,829,685	432,625
Total Incentive Cost ($)	90,829,891	125,622,176	117,177,657	7,671,728
Area Cost ($/ha)	58.09	64.26	41.41	17.73
Emissions Reduction (t CO2e)	62,236	699,292		
Carbon Sequestration (t CO2e)	550,193	1,348,880	1,300,266	302,527
Area Emissions Reduction (t CO2e/ha)	0.392	1.048	0.460	0.699
Abatement Cost ($/t Co2e)	148.31	61.33	90.12	25.36

3.5 Agricultural Tree and Wetland Management

New Trees and Wetlands

The estimated net returns for new trees and wetlands are in Table 1. All these practices were assigned annual capacity limits defined below with the results in Table 3.5.1. They are all relatively rare across the Canadian landscape.

Table 3.5.1: Annual estimates of costs of cover crops and intercropping among Canadian farmers by adoption rate, quantity effected, total incentive cost, unit-based costs, emissions reductions, emissions reductions per unit and abatement costs.

	Alley Cropping	Silvopastu re	New Riparian Trees	Wetland Restoration
Location	ROC	Canada	Canada	Prairie
Increased Area (ha)	9,009	9,009	625	1,000
Total Incentive Cost ($)	1,555,123	1,555,123	1,863,072	5,200,000
Area Cost ($/ha)	172.62	172.62	2,980.92	5,200.00
Carbon Sequestration (t CO2e)	169,100	154,300	12,000	26,000
Area Emissions Reduction (t CO2e/ha)	18.8	17.1	19.2	26.0
Abatement Cost ($/t Co2e)	9.20	10.08	11.35	200.00

Avoided Loss of Trees and Wetlands

The estimated net returns for avoided loss of trees and wetlands are in Table 1. All these practices were assigned annual capacity limits based on annual loss estimates, defined below with the results in Table 3.5.2. Conservation efforts are important to prevent large emissions releases upon their removal.

Table 3.5.2: Annual estimates of costs of cover crops and intercropping among Canadian farmers by adoption rate, quantity effected, total incentive cost, unit-based costs, emissions reductions, emissions reductions per unit and abatement costs.

	Avoided Shelterbelt Conversion	Avoided Conversion of Wetlands
Location	Prairie	Prairie
Preserved Area Area (ha)	218	15,000
Total Incentive Cost ($)	654,750	45,000,000
Area Cost ($/ha)	3,000.00	3,000.00
Emissions Reduction (t CO2e)	35,500	1,170,000
Area Emissions Reduction (t CO2e/ha)	162.8	78.0
Abatement Cost ($/t Co2e)	18.44	38.46

3.6 Total and Temporal Breakdown of Program Costs

Most of the programs have annual spending that must be maintained throughout the life of the program to achieve the GHG benefits due to the reversible nature of the decisions. For example, nitrogen management and cropping decisions in one year can easily be reversed in the next. However, some decisions, specifically fencing for rotational grazing, legumes established in pasture and synthetic impermeable floating covers, would only need to be supported once in the life of the APF, but would continue to accrue GHG benefits every subsequent year for no additional cost. Similarly, new trees and wetlands would continue to sequester carbon throughout their life cycle, well beyond the scope of the APF. Conservation of trees and wetlands prevents large emissions.

The total effect of each of the categories of practices has been summarized in Table 3.6.1. The average annual effects are in Table 3.6.2. The five annual breakdowns for 2023 to 2028 are in Tables 3.6.3 to 3.6.7.

Table 3.6.1: Total program spending, emissions reduction, carbon sequestration, and program abatement cost for the life of the 5-year APF.

Management Practice	Total Incentive Cost ($)	Total Emissions Reduction (t CO2e)	Total Carbon Sequestration (t CO2e)	Total Program Abatement Cost ($/t Co2e)
Nitrogen	539,294,129	11,412,643	0	47.25
Manure	115,262,111	7,193,835	0	16.02
Livestock	111,355,198	6,076,819	6,825,507	8.63
Soil	1,023,904,357	2,284,585	10,505,598	80.05
Trees/Wetlands	279,140,347	3,013,750	1,284,000	64.95
Total	**2,068,956,141**	**29,981,632**	**18,615,106**	**42.57**

Table 3.6.2: Annual average program spending, emissions reduction, carbon sequestration, and program abatement cost for the life of the 5-year APF.

Management Practice	Average Incentive Cost 2023-2028 ($/yr)	Average Emissions Reduction 2023-2028 (t CO2e/yr)	Average Carbon Sequestration 2023-2028 (t CO2e/yr)	Average Abatement Cost 2023-2028 ($/t Co2e/yr)
Nitrogen	107,858,826	2,282,529	0	47.25

Manure	23,052,422	1,438,767	0	16.02
Livestock	22,271,040	1,215,364	1,365,101	8.63
Soil	204,780,871	456,917	2,101,120	80.05
Trees/Wetlands	55,828,069	602,750	256,800	64.95
Total	**413,791,228**	**5,996,326**	**3,723,021**	**42.57**

Table 3.6.3: Program spending, emissions reduction, carbon sequestration, and program abatement cost for 2023-2024.

Management Practice	Incentive Cost in 2023 ($)	Emissions Reduction in 2023 (t CO2e)	Carbon Sequestration in 2023 (t CO2e)	Abatement Cost in 2023 ($/t Co2e)
Nitrogen	35,952,942	760,843	0	47.25
Manure	12,373,402	479,589	0	25.80
Livestock	13,031,887	405,121	455,034	15.15
Soil	68,260,290	152,306	700,373	80.05
Trees/Wetlands	55,828,069	200,917	85,600	194.85
Total	**185,446,591**	**1,998,775**	**1,241,007**	**57.24**

Table 3.6.4: Program spending, emissions reduction, carbon sequestration, and program abatement cost for 2024-2025.

Management Practice	Incentive Cost in 2024 ($)	Emissions Reduction in 2024 (t CO2e)	Carbon Sequestration in 2024 (t CO2e)	Abatement Cost in 2024 ($/t Co2e)
Nitrogen	71,905,884	1,521,686	0	47.25
Manure	17,712,912	959,178	0	18.47
Livestock	17,651,463	810,243	910,068	10.26
Soil	136,520,581	304,611	1,400,746	80.05
Trees/Wetlands	55,828,069	401,833	171,200	97.43
Total	**299,618,910**	**3,997,551**	**2,482,014**	**46.24**

Table 3.6.5: Program spending, emissions reduction, carbon sequestration, and program abatement cost for 2025-2026.

Management Practice	Incentive Cost in 2025 ($)	Emissions Reduction in 2025 (t CO2e)	Carbon Sequestration in 2025 (t CO2e)	Abatement Cost in 2025 ($/t Co2e)
Nitrogen	107,858,826	2,282,529	0	47.25
Manure	23,052,422	1,438,767	0	16.02
Livestock	22,271,040	1,215,364	1,365,101	8.63
Soil	204,780,871	456,917	2,101,120	80.05
Trees/Wetlands	55,828,069	602,750	256,800	64.95
Total	**413,791,228**	**5,996,326**	**3,723,021**	**42.57**

Table 3.6.6: Program spending, emissions reduction, carbon sequestration, and program abatement cost for 2026-2027.

Management Practice	Incentive Cost in 2026 ($)	Emissions Reduction in 2026 (t CO2e)	Carbon Sequestration in 2026 (t CO2e)	Cost in 2026 ($/t Co2e)
Nitrogen	143,811,768	3,043,371	0	47.25
Manure	28,391,932	1,918,356	0	14.80
Livestock	26,890,616	1,620,485	1,820,135	7.82
Soil	273,041,162	609,223	2,801,493	80.05
Trees/Wetlands	55,828,069	803,667	342,400	48.71
Total	**527,963,547**	**7,995,102**	**4,964,028**	**40.74**

Table 3.6.7: Program spending, emissions reduction, carbon sequestration, and program abatement cost for 2027-2028.

Management Practice	Incentive Cost in 2027 ($)	Emissions Reduction in 2027 (t CO2e)	Carbon Sequestration in 2027 (t CO2e)	Cost in 2027 ($/t Co2e)
Nitrogen	179,764,710	3,804,214	0	47.25
Manure	33,731,442	2,397,945	0	14.07
Livestock	31,510,192	2,025,606	2,275,169	7.33
Soil	341,301,452	761,528	3,501,866	80.05
Trees/Wetlands	55,828,069	1,004,583	428,000	38.97

Total	**642,135,865**	**9,993,877**	**6,205,035**	**39.64**

The abatement cost of the programs drop over time (Tables 3.6.3 to 3.6.7) as practices that require a single investment continue to accrue additional benefits over time, while practices that require continual spending remain the same.

4. Conclusion

In the context of climate change from greenhouse gas emissions, this study examines the abatement costs of adopting a host of agricultural BMPs. These include nitrogen, manure, livestock, soil, tree, and wetland management practices that have program abatement costs from \$1.08/t CO_2e to \$400/t CO_2e. To achieve approximately 30 million t CO_2e emissions reduction and 18.6 million t CO_2e carbon sequestration over 5 years from March 2023 to March 2028, the outlined program would require just over 2 billion dollars in that span, at an average abatement cost of approximately \$42.57/t CO_2e.

The values described in this report are estimates for broad regions across Canada for financial, emissions reduction and carbon sequestration effects (FCS, 2022a). Local conditions could change the benefits described for any individual farm operation or field. Therefore, caution should be used in the application of these results. The monetary values are estimates that, in some cases, attempt to reconcile a lack of adoption of seemingly beneficial practices amongst Canadian farmers. Therefore, these estimates may require further examination and regional specificity. The values generated here are used to budget the approximate equivalent incentive payments required to increase the attractiveness of BMPs to specified percentages of new producers. The actual policy mechanisms that will bring about these changes and deliver these dollars are described in the associated policy report (FCS, 2022b).

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