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This chapter is an excerpt from the CCA report *Nature-Based Climate Solutions*. Information about the charge, the expert panel authors, the sponsor, other ecosystems, and references can be found in the full report.

Agriculture and Grasslands

Chapter Findings

- Cropland management and avoided grassland conversion hold the greatest potential for carbon sequestration in agriculture and grasslands. Uncertainties in estimating mitigation potential primarily stem from feasibility considerations, where uptake of NBCSs is affected by costs, policies, and behavioural barriers that can drastically change the area of opportunity for their implementation.
- Realizing the sequestration and emissions reduction potential of agriculture and grasslands requires an ongoing management effort together with long-term planning and policy incentives to prevent regression.
- Nutrient management is important not only for providing farm-level emissions reduction, but also for reducing eutrophication and related GHG emissions in adjacent and downstream aquatic systems.
- Engaging with Indigenous communities and recognizing Indigenous knowledge and management practices are essential for the long-term success of certain NBCSs, including the reintroduction of buffalo to grasslands as a component of grassland restoration and conservation. These NBCSs also foster reconciliation through the promotion of Indigenous self-determination.

Agricultural lands and grasslands contain large stocks of carbon in their soils, and exchange significant amounts of carbon with the atmosphere. There are approximately 47 Mha of cropland in Canada, while managed grasslands, used for pasture or rangeland, occupy approximately 6.2 Mha. The exact extent of natural grasslands in Canada is currently unknown (ECCC, 2022b). In Canadian grasslands, herbaceous species are the dominant form of vegetation. These are found mainly in the prairie regions of southern Alberta and Saskatchewan, as well as in the dry, interior mountain valleys of British Columbia. Grassland systems absorb and release carbon in response to environmental conditions and land management practices, offering a range of opportunities for enhancing carbon sequestration or reducing GHG emissions.

4.1 Opportunities for Enhancing Sequestration and Reducing Emissions in Agricultural and Grassland Systems

Agricultural and grassland NBCSs involve the sequestration of additional carbon or a reduction in GHG emissions: CO_2, CH_4, and N_2O. Most carbon is stored in soil organic matter (SOM), although above- and belowground vegetative biomass also contributes to carbon stocks in the case of agroforestry NBCSs. Carbon in soils is assessed through soil organic carbon (SOC) levels and is released to the atmosphere as either CO_2 or CH_4 (Hristov *et al.*, 2018; Paustian *et al.*, 2019). Carbon is added to soils via manure, crop residues, and root exudates (fluids emitted through the roots of plants) and is removed through erosion (which can also redistribute carbon) as well as microbial decay.

NBCS practices to sequester additional carbon in soils either increase the rate of carbon input or reduce the turnover rates of carbon already present in the soil (Paustian *et al.*, 2019). Beyond carbon sequestration, limiting emissions of other GHGs (N_2O in particular) is also an objective. N_2O has 298 times the global warming potential of CO_2 and is a significant component of agricultural systems, released as a by-product of nitrogen input to soil (IPCC, 2012; Équiterre & Greenbelt Foundation, 2020). In 2020, agricultural soils in Canada were estimated to emit an average of 21 Mt CO_2e of N_2O compared to an estimated net cropland carbon sink of 9.6 Mt CO_2e (ECCC, 2022b).[18] GHG emissions from grasslands also occur but are minor in comparison, accounting for less than 0.05 Mt CO_2e in 2020 (ECCC, 2022b).[19] These emissions are due, in large part, to the occurrence of naturally caused, prescribed, or human-induced fires (ECCC, 2022b).

Tables 4.1 and 4.2 identify agricultural and grassland NBCSs that could be implemented in Canada. Many of these NBCSs (sometimes referred to as agricultural *beneficial management practices*) have been well researched, leading to a number of key recommendations for wide implementation in Canada (Groupe AGÉCO *et al.*, 2020; Équiterre & Greenbelt Foundation, 2020; Drever *et al.*, 2021; Meadowcroft, 2021).

18 To convert non-CO_2 gases into CO_2e, ECCC (2022b) used GWP100 values from IPCC (2012) where CH_4=25 and N_2O=298.

19 Ibid.

Table 4.1 Agricultural NBCSs

Definition of NBCS	Mechanism
Crop Management	
Cover crops are planted in the fallow season or between rows of primary crops to function as protective cover, to maintain living roots, and to increase the carbon input to soils.	Additional biomass input to the soil increases the rate of carbon sequestration, while covering the soil reduces erosion (Équiterre & Greenbelt Foundation, 2020). Cover crops implemented in the shoulder season or over winter maintain living roots in the soil for longer, further increasing carbon. If crops are leguminous, they reduce the need for fertilizer application, thereby reducing N_2O emissions (Yanni *et al.*, 2018; Drever *et al.*, 2021).
Crop diversification includes the use of crop rotations (some of them cover crops), intercropping, and perennial cropping systems (perennialization) to move away from monocultures. Crop rotation involves varying the types of crops grown in the same field over successive growing seasons (or during the shoulder or winter season in the case of cover crops), while intercropping involves growing more than one cash crop simultaneously. Perennial cropping strategies include the replacement of annual crops with perennial ones (e.g., fruits, nuts, hay, perennial cereals).	Diversifying annual crop rotations to include perennial crops and legumes increases the carbon input (perennials) or reduces the need for nitrogen fertilizer (legumes) (McDaniel *et al.*, 2014). Perennial crops have extensive root systems, which increase SOM, add soil cover to reduce erosion, and remove the need for tillage, preserving soil carbon (AAFC, 2008). Perennial crops lower GHG emissions by reducing the need for tillage (thereby also reducing emissions from machinery), decreasing fertilizer application rates, and allowing for more efficiency in nutrient cycling (Yanni *et al.*, 2018). Increasing the percentage of legume crops will reduce the total need for external nitrogen fertilization, thereby avoiding N_2O and CO_2 emissions.
Soil Management	
No-till or **reduced tillage** practices involve completely halting or reducing soil turnover through tilling.	No-till avoids soil disturbance and leaves crop residue on the surface, reducing decomposition by soil microorganisms and thereby increasing carbon sequestration (Équiterre & Greenbelt Foundation, 2020; Drever *et al.*, 2021).
Biochar is produced by converting crop residue or other organic inputs (e.g., bone) to recalcitrant carbon (i.e., charcoal), which is added to soils.	Recalcitrant carbon in biochar is resistant to decomposition and therefore stable over long timescales (Lehmann, 2007; Song *et al.*, 2016); amending agricultural soils with biochar therefore increases the storage of CO_2 (Drever *et al.*, 2021).

Definition of NBCS	Mechanism
Nitrogen Management	
Promising practices for reducing the amount of nitrogen are known as the **4Rs**: limit the rate **(Right Rate)** of nitrogen application to more closely match crop requirements, adjust the timing **(Right Time)** of application relating to when a crop is actively growing and taking up nitrogen, vary the placement of fertilizer **(Right Place)** at depth (injection), and/or choose alternative fertilizer types **(Right Source)** that delay release or use inhibitors that prevent quick transformation (De Laporte *et al.*, 2021a).	Application of 4R practices can reduce the amount of nitrogen available in the soil for loss through (de)nitrification or leaching and volatilization, immediately reducing GHG emissions. Certain practices, such as right source, allow plants to access nitrogen more easily (De Laporte *et al.*, 2021a).
Agroforestry	
Alley cropping (also known as tree intercropping) sequesters additional CO_2 through the planting of trees between row crops and hay lands.	Carbon is stored in above- and belowground biomass, including through increased litter and root exudates (Baah-Acheamfour *et al.*, 2017). Variability in carbon storage estimates depends on the type of tree selected for planting, the density of tree planting, and the variety of cash crop (in the case of alley cropping) (Baah-Acheamfour *et al.*, 2015; Drever *et al.*, 2021).
Shelterbelts are rows of annual or perennial trees and shrubs that have traditionally served as windbreaks, but more recently have been observed to sequester carbon in soils and in both above- and belowground biomass.	
Riparian tree planting increases CO_2e sequestration when trees are planted in 30 m "buffers around all water bodies in agricultural zones where forests are the natural land cover" (Drever *et al.*, 2021).	
Silvopasture involves the integration of trees with pasturelands, simultaneously managed for livestock grazing, forage, and tree crops (Drever *et al.*, 2021).[20]	

20 For the purposes of this report, the Panel chose to focus on the expansion of silvopasture through the planting of trees in existing pastures. Silvopasture can also involve the grazing of understory in existing treed areas (e.g., Baah-Acheamfour *et al.*, 2014), but expansion of silvopasture in these areas was not modelled by Drever *et al.* (2021) and therefore not included in mitigation potential calculations.

Table 4.2 Grassland NBCSs

Definition of NBCS	Mechanism
Maintaining and Restoring Grasslands	
Avoided grassland conversion preserves SOC and above- and belowground biomass.	By reducing the area of grasslands converted into cropland each year, the emissions associated with clearing and tilling the land can be reduced, current soil carbon stocks are maintained, and emissions due to carbon oxidization are avoided.
Grasslands are restored on marginal and less productive agricultural lands.	Carbon storage has been observed to increase over time due to accumulation of root mass, and grasslands with higher root masses tend to accumulate SOC at greater rates (e.g., Jones & Donnelly, 2004; Soussana *et al.*, 2004; Lorenz, 2018; Yang *et al.*, 2019). Soil carbon is also increased by the deposition of material shed by plant roots (Soussana *et al.*, 2004; Lorenz, 2018).
Improved Grassland Management	
Improved grazing includes rotational grazing (described in recent literature as adaptive multipaddock grazing or AMP) and the introduction of bison to grassland systems. AMP employs longer rest periods between grazing and halting grazing during plant recovery, maximizing the active growth time of plants (Prescott *et al.*, 2021).	Improving grazing management (of any grazing animal) may affect carbon cycling in numerous ways, including through plant community alteration (Lyseng *et al.*, 2018), enzyme activity in plant litter (Chuan *et al.*, 2020), improved water infiltration (Döbert *et al.*, 2021), and production of excess carbon through root exudates (Prescott *et al.*, 2021). Introducing bison to grassland systems has the potential to alter carbon uptake by native plant species (Knapp *et al.*, 1999; McMillan *et al.*, 2019).
Producers can **introduce legumes** to pasturelands by including them in species mixes during sowing.	Legumes increase forage production in grasslands, leading to additional belowground carbon inputs and increased soil nitrogen, resulting in greater SOM produced by microbes and higher soil fertility, reducing the need for fertilizer (thereby reducing N_2O emissions) (Conant *et al.*, 2001; Bolinder *et al.*, 2007; Fornara *et al.*, 2016; Drever *et al.*, 2021; Prescott *et al.*, 2021).
Pastures can be sown with seed mixes targeted at **improved grass species selection** to enhance carbon inputs to the soil.	Improved grass species increase SOC by enhancing production via better adaptation to the local climate, increased resiliency to grazing and drought, and increased soil fertility as a result of high biomass production rates and deep rooting systems (Jones & Donnelly, 2004; Conant, 2012).

4.2 Indigenous Agricultural and Grassland Management

Indigenous Peoples have been stewards of grasslands and lands currently being used for agriculture since time immemorial. The diversity of plant and animal communities and their distribution across North America have been impacted by long-term Indigenous management (Turner, 2020). Furthermore, Indigenous Peoples have historically developed and engaged in agricultural practices, including forest gardens in the Pacific Northwest (Armstrong *et al.*, 2021; Fox, 2021) and widespread use of polyculture through the Three Sisters (corn, beans, and squash), the latter of which is still researched and practised today (AAFC, 2021). These traditions are precursors to some of the NBCSs discussed in this chapter. Three Sisters polyculture, for example, is a form of crop diversification and rotation. The inclusion of legumes provides nitrogen to the soil, while corn and squash provide structural support, weed control, and protection from erosion (Mt. Pleasant, 2016; Hill, 2020; Ngapo *et al.*, 2021).

As of 2016, Indigenous farm operators made up 2.6% of the national agricultural population, but the ratio of farmers to leasers is unknown (Gauthier & White, 2019). Data have previously demonstrated that the majority of land owned by First Nations in the Prairies is leased to non-Indigenous farmers (Pratt, 2004); this number may be an underestimate due to the shrinking overall number of family farms across the country (Arcand *et al.*, 2020; Sommerville, 2021).

Reintroduction of buffalo to the plains is an opportunity to foster reconciliation and restore prairie ecosystems

"Management of carbon stocks and fluxes is encompassed within, and not easily separated from, the overall Indigenous perspectives that holistically link human and ecological health" (McCarthy *et al.*, 2018). *Wahkohtowin*, the Cree word for the concept of kinship, describes this relationship; it is a worldview based on the idea that all of existence (including humans, plants, and animals) has spirit and is interconnected (Wildcat, 2018) (Section 2.4). "Elders would say we were in constant consultation with the spiritual realm that resides within the plants, soil, animals, water, and through living that way for millennia our people had opened up that spiritual access code which guided our governance and the way we conducted ourselves" (Philip Brass, personal communication).

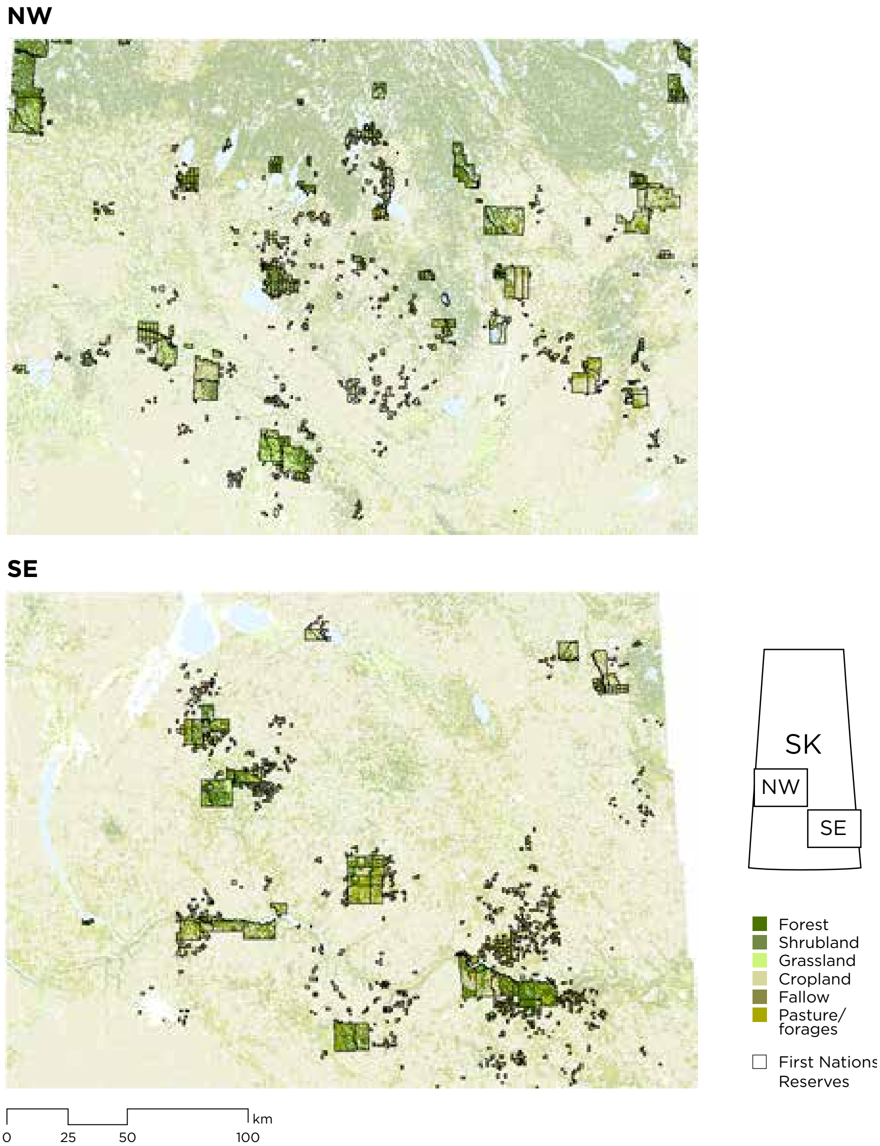
Wahkohtowin encompasses both the natural laws of ecosystems and how Indigenous Peoples understood the consciousness of the ecosystems they inhabited and were part of. For the peoples of the plains, their relationship with buffalo exemplifies this consciousness:

> *We became buffalo chasers on the prairie and took direction from the buffalo spirit. Following the buffalo led us to clean water, medicines, acting as a tour guide to the prairie world. Life, and our survival and ability to thrive here, relied on the buffalo, and we moved them around to graze prairie grass over thousands of years, developing a massive carbon sink in the great plains.*
>
> Philip Brass (personal communication)

Widespread slaughter of buffalo in the nineteenth century and the expansion of agriculture led to deterioration of the prairie ecosystem, and with it the relocation of First Nations to reserves on marginal lands — mere fragments of their traditional territories (Corntassel & Woons, 2019). Efforts to reintroduce buffalo to the Prairies are ongoing and represent a critical opportunity for reconciliation and restoration of the prairie ecosystem, including Indigenous plains Peoples' relationship to the buffalo (Section 4.6.2).

Perennial plant cover is connected to First Nations land across the provinces

The conversion of grassland to cropland has been found to release large quantities of carbon to the atmosphere, significantly reducing natural carbon stocks (Janzen *et al*., 1998). Notably, however, many of the remaining pockets of conserved grasslands and aspen groves are connected to First Nations reserve land across the Prairies. Figure 4.1 highlights the fragmented nature of perennial plant cover across the region and the correlation of those areas to land managed by First Nations across the prairie provinces.



Data Source: GC (2021h, 2022a)

Figure 4.1 Relationship of Perennial Land and First Nations Reserves in Saskatchewan

This figure depicts land cover distribution in the northwest (left panel) and southeast (right panel) of the Grassland and Aspen Parkland regions of Saskatchewan. The two panels cover most home reserve lands of First Nations within the grain-growing region of Saskatchewan. Land-cover data were sourced from GC (2021h) and boundaries of First Nations lands were sourced from GC (2022a).

Although little evidence currently exists on why First Nations reserve land is so closely associated with perennial plant cover, the Panel believes that the ongoing success of prairie-parkland conservation on First Nations land may be potentially attributed to sociopolitical elements. The complex land-use history of these areas may be a key contributing factor to their preservation of perennial vegetation cover. The Numbered Treaties that span the contemporary agricultural regions of Alberta and Saskatchewan featured agricultural provisions and included reserve land that could be used to establish farming (e.g., Treaty No. 4 from 1874, Treaty No. 6 from 1876). Initially, many First Nations took up farming and broke reserve land for agriculture. However, historic barriers to First Nation participation in the agricultural sector (e.g., Buckley, 1992; Carter, 2019), combined with the high proportion of marginal land on reserves, likely contributed to conservation and the reversion of some cropland to perennial cover. Indigenous farmers continue to face institutional and structural barriers that hinder the implementation and growth of agricultural endeavours on First Nations-owned land and that may also contribute to the preservation of these grasslands (Pratt, 2006; Natcher *et al.*, 2011; Arcand *et al.*, 2020); farmers are less able to sustain long-term agricultural production on their own and would thus be incentivized to leave the land as it is. The Panel recognizes, however, that natural grassland ecosystems are integral to many plains First Nations communities, and their conservation may be linked to the protection and perpetuation of culture (e.g., LeBourdais, 2016).

"Recognizing the conservation linked to these communities is crucial in understanding not only how these practices can be implemented on a larger scale, but how many NBCSs are inherently Indigenous — tied to Indigenous knowledge and traditional practices that have been carried out by communities for generations."

However, no element is likely to be the sole explanatory factor underpinning the correlative relationship between First Nations land management and perennial plant cover on conserved grasslands. The Panel believes it is more likely the result of a combination of factors — including but not limited to those outlined above — that change and evolve within the cultures and contexts of each Nation and community. Nevertheless, this observed relationship makes clear that there is an ongoing need for recognition and support of First Nations in the implementation of NBCSs. Recognizing the conservation linked to these communities is crucial in understanding not only how these practices can be implemented on a larger scale, but how many NBCSs are inherently Indigenous — tied to Indigenous knowledge and traditional practices that have been carried out by communities for generations (Townsend *et al.*, 2020).

The Panel also notes that there is a need to actively support the conservation efforts of First Nations communities, in order to ensure that adverse economic development is not prioritized. These perennial landscapes represent carbon stocks that are at risk of becoming sources if lands are (re)converted into cropland. Push for further economic development, including increasing government supports for First Nations farmers, can potentially incentivize conversion of native grasslands, thereby releasing carbon to the atmosphere. On the Prairies, land-use change significantly impacts carbon sequestration and emissions reductions, and the potential to "lose carbon for cash" cannot be overlooked. However, any First Nations engagement must comply with the self-determination rights of these communities in land-based decision-making, ensuring that NBCSs do not end up dispossessing First Nations of their lands or knowledge.

4.3 Magnitude of Sequestration and Emissions Reduction Potential

Assessing how much additional carbon can be sequestered through agricultural or grassland NBCSs, or the amount of GHG emissions that can be avoided, requires understanding the impacts of changes in management practices or land use on carbon and other GHG fluxes in a given area. Such impacts have been widely studied in the context of improving agricultural productivity and sustainability, though there is substantial variation depending on environmental conditions and soil characteristics, and thus regional variation across Canada.

4.3.1 GHG Fluxes in Croplands

Variability in regional conditions and crop characteristics determines the potential of some agricultural NBCSs

Determining the national mitigation potential for most NBCSs is difficult due to the considerable variability inherent to agricultural landscapes. Myriad combinations of crop and soil types, climatic conditions, and management practices result in large uncertainties in estimating SOC accumulation and GHG emissions (Hristov *et al.*, 2018; Bradford *et al.*, 2019). Even NBCSs promoted as best management practices, such as cover crops, are subject to uncertainties and limitations relating to their suitability for certain climates. Though global and U.S. estimates of carbon sequestration for cover crop implementation are around 0.3 t C/ha/yr, values for Canada (adjusted for climate and timing of harvest for preceding cash crop) range from 0.025–0.64 t CO_2e/ha/yr, with the lowest in the west and highest in the east (Eagle *et al.*, 2012; Poeplau & Don, 2015; Drever *et al.*, 2021). For example, short growing seasons and water limitations have historically prevented widespread implementation of cover crops in the Prairies, though this trend is slowly starting to change, encouraged by uptake in neighbouring American states and eastern Canada (Morrison & Lawley, 2021).

Similarly, reduced or no-till practices (also known as conservation tillage) have been widely practised in Canada (especially in the Prairies), resulting in measurable increases in carbon inputs to soils (ECCC, 2022b). Land under conservation tillage increased by 18 Mha between 1990 and 2020 (ECCC, 2022b). Despite success elsewhere, there are still significant uncertainties related to the effects of reduced or no-till practices in eastern Canada, where impacts were inconsistent and highly dependent on climate and soil texture (Liang *et al.*, 2020). A synthesis of long-term experiments found that no-till led to an increase of 0.14 t C/ha/yr in western Canada over an average of 23 years, whereas an increase of only 0.06 t C/ha/yr was recorded in eastern Canada over an average of 18 years (VandenBygaart *et al.*, 2008).

Soil carbon and nitrogen mechanisms are linked, and can affect each other and soil biota

The carbon and nitrogen cycles within soils are intricately connected through in a series of complex interactions (Guenet *et al.*, 2021). Therefore, any actions to increase SOC in agricultural systems may also affect the nitrogen cycle and subsequent N_2O emissions. These interactions and effects are numerous: transformations of mineral nitrogen depend on SOC, plant dry matter production is limited by nitrogen availability, and turnover of SOM is determined by nitrogen availability to microorganisms (Guenet *et al.*, 2021). Microbes, which have been found to contribute substantially to SOC, depend on the availability of nitrogen to spur increased microbial biomass and thereby create SOM (Kogel-Knabner, 2017; Liang *et al.*, 2019; Kopittke *et al.*, 2020). The chemical balance of carbon and nitrogen in soils is therefore a critical consideration for the implementation of NBCSs, as high SOC contents have been shown to correlate to higher N_2O emissions (Stehfest & Bouwman, 2006; Henault *et al.*, 2012). This is particularly relevant to nutrient management, where the application rate of nitrogen to soils needs to take this relationship into account.

Crop type can also influence GHG fluxes

The interactions between carbon and nitrogen in soils also depend on the characteristics of the crops themselves. For example, the use of pulses in crop rotations has been touted as a method for reducing N_2O emissions due to their ability to fix nitrogen from the atmosphere, thereby reducing fertilizer requirements. Tests of four pulse types found that only two (pea and faba bean) reduced N_2O emissions when compared to continuous wheat crops, while others (chickpea and lentil) actually increased N_2O emissions (Liu *et al.*, 2021). Choice of cover crop type can also impact N_2O emissions; the magnitude of which relies on several factors, such as carbon to nitrogen ratios, decomposition rates, tillage practices, and additional fertilizer inputs (Guenet *et al.*, 2021). A low carbon to nitrogen ratio in the cover crop variety (like in legumes) increases the availability of nitrogen in the soil to microbial reactions, leading to a surplus of soil nitrogen if all leguminous biomass is incorporated (and any additional nitrogen input is not correctly adjusted). Nonetheless, a meta-analysis by Guenet *et al.* (2021) found that, while, on average, N_2O emissions from cover crops do not completely offset the gains made to SOC, the overall effects may be highly site-specific and are an important consideration when implementing NBCSs that increase SOC.

Uncertainties also stem from technical complexities and limited data

Some interventions, such as crop diversification, are difficult to study due to the number of variables in play during experiments. Perennial species may be introduced as a component of crop rotations; this complicates drawing conclusions on the ability of either one of these strategies to sequester additional carbon, and to attribute changes in flux to individual NBCSs. A review by Yanni *et al.* (2018) concluded that few studies have investigated the effects of crop rotations and crop diversification on carbon sequestration and GHG emissions in Ontario, though — in the Panel's view — this gap extends to other regions in Canada, as well. Experiments that do exist have found that rotating cash crops (e.g., corn) with other crops (e.g., alfalfa, oats) reduced emissions of N_2O, even when scaled to yield (Drury *et al.*, 2014).

Although agroforestry systems are widely employed across Canada, the precise extents of the different types of systems are uncertain. This lack of information contributes to uncertainty around the area of opportunity (i.e., the area over which a practice can feasibly be implemented) for increasing the uptake of these NBCSs (Baah-Acheamfour *et al.*, 2017). Furthermore, there are few studies reporting on the carbon storage capacities of these systems (An *et al.*, 2022); although agroforestry NBCSs have been repeatedly shown to have higher soil carbon content than adjacent croplands (e.g., Baah-Acheamfour *et al.*, 2014; Lim *et al.*, 2018), tree type and the NBCS itself will affect the carbon storage capacity (Baah-Acheamfour *et al.*, 2015). For example, Baah-Acheamfour *et al.* (2015) found that the use of *Populus* tree species resulted in the greatest increase in SOC when used in silvopasture, whereas *Picea* species were best used in shelterbelts. This variability contributes to uncertainties associated with the magnitude of sequestration potential for agroforestry NBCSs in Canada, along with the regional distribution.

4.3.2 GHG Fluxes in Grasslands

The carbon sequestration potential of improved grassland management is uncertain, as are the underlying mechanisms relating to improved grazing

As with agricultural systems, carbon fluxes in grasslands are influenced by land management strategies as well as environmental factors, such as mean temperature and precipitation (Ma *et al.*, 2021). Improved management is the most widely acknowledged soil carbon intervention for grasslands; however, its net effects on carbon sequestration are debated (Liu *et al.*, 2011; Lorenz, 2018; Bengtsson *et al.*, 2019; Iravani *et al.*, 2019; Ma *et al.*, 2021; Wang *et al.*, 2021a). Rotational grazing — identified by the Government of Canada as an agricultural climate solution (GC, 2022b) — has been associated with increased productivity and soil carbon sequestration (Lorenz, 2018), as has moderate grazing in general (Wang *et al.*, 2014; Hewins *et al.*, 2018; Bork *et al.*, 2020). However, recent research investigating all GHG fluxes from Ma *et al.* (2021) found no positive relationship between rotational grazing and reduced overall GHG emissions. Instead, carbon fluxes were found to be influenced by specific conditions, such as "cattle stocking rate, cultivation history, soil moisture content, and bulk density" (Ma *et al.*, 2021). This is supported by similar findings in Iravani *et al.* (2019) and Wang *et al.* (2021a).

Conflicting results may stem from the wide range of choices made by livestock producers when implementing grazing. This includes stocking rates and densities, as well as the pattern of grazing (e.g., timing, intensity, length of recovery period) (Teague *et al.*, 2013; Bork *et al.*, 2021). Furthermore, pastures are also generally grazed unevenly, with patterns dictated by proximity to sought-after resources such as water or minerals (e.g., salts), potentially affecting measurements (Wang et al., 2021a). Ecological limits, such as growing season and climate change, impact the efficacy of grazing NBCSs (e.g., increased or decreased grazing intensity) (Eldridge *et al.*, 2016; Ma *et al.*, 2021). As Wang *et al.* (2021a) highlight, "the plant recovery time [necessary for reducing carbon emissions] under rotational grazing depends on environmental conditions, such as the season of the year."

The precise mechanism linking improved grazing practices to increased carbon sequestration (such as rotational or AMP grazing) is yet unknown. Grazing has been shown to convey positive effects on soil carbon through stimulation of plant productivity, especially in roots (Frank *et al.*, 2002). More recent research has shown that grazing alters the composition of plant communities (Lyseng *et al.*, 2018), the activity of enzymes released from roots and microbial cells (Chuan *et al.*, 2020), and increased water infiltration (Döbert *et al.*, 2021). Specifically allowing for adequate recovery time between grazing (a key tenet of rotational and AMP grazing) provides an avenue for increased productivity; longer rest periods between grazes paired with prohibited grazing during recovery time maximizes the time spent in active growth (Prescott *et al*., 2019). The increased soil carbon resulting from this has been hypothesized to result from exudation and excess carbon production during rest periods, but Prescott *et al*. (2019) noted more research is needed to understand this process fully. All of these mechanisms, along with external factors such as moisture availability and temperature, may affect the carbon sequestration capacity of grazed grasslands.

The introduction of bison instead of domestic cattle could also potentially yield carbon sequestration benefits, but this is also subject to significant uncertainty. Although there are notable differences in foraging patterns between cattle and bison, there is a lack of comparative data assessing the long-term effects of grazing while management practices are held constant (Knapp *et al*., 1999).

4.3.3 Estimating National Sequestration and Emissions Reduction Potential

At the global level, Roe *et al*. (2021) produced estimates of the magnitude of sequestration potential in Canada of several agricultural and grassland NBCSs, including technical and cost-effective (available below \$100/t CO_2e) potentials (Table 4.3). However, values are based on global datasets and were derived using assumptions that are unlikely to apply to the Canadian context; some estimates are quite high (e.g., no-till practices, biochar application) or quite low (e.g., nutrient management).

Table 4.3 Annual Sequestration Potential in Canada, 2020–2050

NBCS	Magnitude of Sequestration Potential (Mt CO_2e/yr) to 2050	
	Technical	Cost-Effective
Nutrient management	1.9	1.5
Cover crops + no-till[a]	27.6	24.9
Improved grassland management[b]	12.7	7.6
Agroforestry	44.8	9
Biochar	35.1	27.6

All values were extracted from supplementary information provided by Roe *et al*. (2021).

a No-till labelled as *soil carbon sequestration – croplands* in original document.

b Improved grassland management labelled as *soil carbon sequestration – grasslands* in original document.

In the study by Roe *et al.* (2021), the technical sequestration potential of agroforestry practices involved planting trees alongside crops in the total land area used for cropland. This, however, is an unlikely scenario for parts of Canada due to required use of large machinery and the related difficulties navigating around trees. Furthermore, tree growth is inhibited in most areas of the Prairies. That said, the cost-effective potential reduced cropland area to 20% of the total, and the potential uptake to only 10%, which may be more reasonable for the Canadian context (compare to Table 4.4). Estimates for the magnitude of potential for no-till and cover cropping are also likely overestimates; no-till is already extensively practised in Canada, and further expansion is limited by climate and technical constraints. Implementation of cover cropping is hindered by climatic constraints, and the assumption of 90% uptake in all cropland areas by 2050 is unlikely. These disparities demonstrate that a key determinant of total magnitude of sequestration potential is the area of opportunity, which in turn is influenced by both technical and socioeconomic factors (Section 4.5).

In the view of the Panel, more realistic estimates — ones that take greater environmental and regional detail into account, as well as additional constraints on NBCS implementation — can be found in Drever *et al.* (2021) (Table 4.4). These values were derived from calculating the relevant area of opportunity in Canada, as well as GHG fluxes in various cropland and grassland systems. The estimates are generally much lower than those presented by Roe *et al.* (2021). Mitigation potential was calculated based on various assumptions while accounting for several areas of uncertainty for each NBCS: productivity (scaling to ensure no reduction in crop yields), uptake (linear, and with errors reflecting over- and underestimation), regionality (reflecting climate and soil characteristics), additionality (building from a business as usual scenario), albedo trade-offs (applied to agroforestry NBCSs), logistics (technical constraints), and related emissions (upstream and concurrent effects on emissions).

Table 4.4 Agriculture and Grassland NBCS Sequestration Potential, as Estimated by Drever *et al.* (2021), and Panel Confidence

Magnitude of Sequestration Potential (Mt CO_2e/yr)			Panel Confidence to 2030	
NBCS	**Now to 2030**	**2030 to 2050**	**Flux**	**Area of opportunity**
Cover crops	9.78 (7.6 to 12.1)	9.78 (7.6 to 12.1)	Moderate	Low–Moderate
Crop diversification[a]	2.6 (2.4 to 2.8)	2.6 (2.4 to 2.8)	Moderate	Moderate
Crop management practices TOTAL	**12.38**	**12.38**	**Moderate**	**Moderate**
Reduced/no-till	0.9 (0.7 to 1.1)	0.6 (0.5 to 0.8)	High	High
Biochar application	6.9 (3.2 to 10.6)	6.9 (3.2 to 10.6)	Moderate	Low
Soil management practices TOTAL	**7.8**	**7.5**	**Moderate**	**Low–Moderate**
Nitrogen management (4Rs)	6.3 (5.0 to 7.6)	6.3 (5.0 to 7.6)	High	Moderate–High
Alley cropping	3.9 (0.5 to 14.4)	3.9 (0.5 to 14.4)	Moderate	Low
Silvopasture	2.8 (0.8 to 7.0)	2.8 (0.8 to 7.0)	Low	Low
Riparian tree planting	0.7 (-0.9 to 2.3)	1.6 (0.6 to 3.5)	Low	Low
Avoided conversion of shelterbelts	0.2 (0.0 to 0.4)	–	Moderate	Moderate
Agroforestry TOTAL	**7.6**	**8.3**	**Low**	**Low**
Avoided grassland conversion	12.7 (2.2 to 41.3)	4.1 (0.2 to 20.2)	Low	Moderate
Grassland restoration	0.7 (-0.1 to 1.5)	0.4 (0.0 to 1.8)	Low	Low
Improved grassland management[b]	0.22 (0.19 to 0.25)	0.22 (0.19 to 0.25)	Low	Moderate
Grasslands TOTAL	**13.62**	**4.72**	**Low**	**Low**

Data source: Drever *et al.* (2021)

This table presents the annual sequestration potential of agricultural and grassland NBCSs in Canada to 2030 and over the 2030–2050 period. The Panel has indicated its level of confidence in these estimates by providing ratings for both the GHG flux and area of opportunity used by Drever *et al.* (2021) to calculate the mitigation potential. See the Appendix for Panel confidence scale.

a Although this category includes crop rotations, perennial crop strategies, and legume crops, the value represented here only uses the magnitude of sequestration potential for legume crops, as estimates for crop rotation and perennial crop strategies were not considered by Drever *et al.* (2021).

b Several strategies are encompassed within this NBCS, but the values provided only represent avoided N_2O emissions from increasing legumes in pastures derived from Drever *et al.* (2021). Not enough information on area of opportunity exists for the other strategies.

Overall, the estimates of emissions and sequestration rates in Drever *et al.* (2021) represent current knowledge on the state of these NBCSs, though uncertainties associated with the area of opportunity used to calculate total mitigation potential in Canada are underrepresented. The extent of cropland and pastureland is relatively well known due to the managed nature of these regions, so the area of opportunity for implementing most agricultural NBCSs is based on feasibility considerations (both technical and economic, taking into account policy and behavioural barriers). Uncertainty relating to the area of opportunity for avoided grassland conversion is especially high; some reports indicate continued conversion of native grasslands in both Canada and the United States, while others indicate that, at least in some regions, grasslands are not being converted at a rapid rate (WWF, 2021; CAPI, 2022; Raven *et al.*, 2022). This uncertainty is compounded further when future market pressures related to global food shortages are considered, as these will likely increase grassland conversion to cropland (Section 4.4). Furthermore, Panel confidence in flux estimates for grassland NBCSs is low, reflecting relatively few data on GHG fluxes and high uncertainty when compared to cropland NBCSs.

One limitation to the above data is the assumption that uptake of these practices is linear instead of the more realistic S-shaped curve shown to generally characterize the uptake of innovations (Rogers, 1962; Pratt *et al.*, 2021). Drever *et al.* (2021) assume that, so long as an NBCS is proven to be economical, no further incentives are needed to promote implementation. When determining costs for cover crops, Drever *et al.* (2021) found that maximum adoption is profitable regardless of carbon price; if this is the case, additional barriers must be considered (Section 4.5.2) to understand why uptake has not already occurred. Similarly, there is limited detail on which incentives motivate the adoption of various levels of 4R management, making it difficult to assess the validity of the magnitude of emissions reduction.

In the view of the Panel, the estimates in Drever *et al.* (2021) provide a useful baseline to inform future policy decisions on agricultural NBCSs in Canada. Large uncertainties remain, however, and more research is needed to understand the longevity of these activities (Section 4.4) and how best to overcome social, economic, and technical barriers for implementation (Section 4.5).

4.4 Stability and Permanence

Terrestrial soils have a carbon storage limit

The conversion of natural forests and grasslands to agricultural lands resulted in historical soil carbon loss in Canada, making these areas amenable to carbon addition through improved management practices. Once such practices are implemented, stocks and fluxes will reach an equilibrium state after a few decades, however, and no more SOC will accumulate (Paustian, 2014; NASEM, 2019; Groupe AGÉCO *et al.*, 2020), as demonstrated by declining rates of accumulation in reduced and no-till cropland systems. Liang *et al.* (2020) found that no-till systems in western Canada sequestered 0.74 t C/ha/yr 3–10 years after implementation, 0.26 t C/ha/yr 11–20 years after implementation, and 0.1 t C/ha/yr in the very long term (>20 years after implementation). This limitation extends to grassland ecosystems, which cannot remain sinks in perpetuity (Smith, 2014).

> "While soil carbon stocks can remain stable (barring natural or anthropogenic disturbance), the sink function of grasslands cannot be considered indefinitely sustainable."

Analysis by Smith (2014) determined that, following land-use conversion or changes to land management regimes, grasslands will take up soil carbon but then reach equilibrium after a certain period of time, after which further increases in carbon stocks cannot be sustained. This equilibrium is the result of a steady decline in soil carbon absorption following rapid sequestration in the years immediately after the recorded change (Smith, 2014). While soil carbon stocks can remain stable (barring natural or anthropogenic disturbance), the sink function of grasslands cannot be considered indefinitely sustainable.

Adding biochar to soil can overcome this limitation, since biochar is resistant to microbial decay and, on average, remains in soils for hundreds of years or more, making it a long-lasting carbon storage vehicle (Santos *et al.*, 2012; Wang *et al.*, 2016). However, although SOC equilibrium may be achieved in agricultural systems, actions to reduce emissions of non-CO_2 gases such as N_2O can continue to accrue GHG mitigation benefits indefinitely (Paustian *et al.*, 2016).

Changes to Canada's climate can both help and hinder NBCS effectiveness

Future climate changes, especially in warming and precipitation, will affect SOC in both agricultural systems and grasslands. Significant uncertainties remain about the specific characteristics of soil carbon pools in grasslands, as well as the extent to which future warming will impact carbon sequestration trends in grassland soils (Jones & Donnelly, 2004). Temperature and precipitation rates play a significant role in soil processes and, as the climate changes, these variables will affect the rate and amount of carbon sequestered. Warming could prompt increased microbial respiration, causing loss of soil carbon in the short term. However, warming could also boost primary productivity, increasing soil carbon in the long term (Jones & Donnelly, 2004).

Future climate change scenarios could also exacerbate soil carbon destabilization, for example, where drought-induced soil drying coupled with extreme precipitation events can lead to disturbance of soil aggregates and fluctuations in soil redox (chemical reactions involving both oxidation and reduction) (Bailey *et al.*, 2019). Warming may extend the growing season of some crops and is expected to increase ecosystem respiration (Hristov *et al.*, 2018), while CO_2 fertilization will potentially enhance the growth of certain crops, leading to increased carbon input to soils. Warming will affect microbial metabolism, further enhancing soil destabilization and elevated CO_2 emissions (Bailey *et al.*, 2019). Increased precipitation could lead to increased sequestration of carbon in soils, but reduced precipitation could limit plant productivity and lead to drought.

As of 2019, there were no Canada-wide studies of future drought predictions, but models generally indicate that there is a higher likelihood of drought in the southern Canadian prairies and interior of British Columbia (Bonsal *et al.*, 2019). Dry conditions have already hindered adoption of cover crops in the Prairies, with 27% of farmers polled in a recent survey reporting establishment problems caused by a lack of moisture in the fall (Morrison & Lawley, 2021). Increased warming and drying in grassland regions can also contribute to greater probability of extreme fire conditions and wildfire occurrence (Cohen *et al.*, 2019). Although the emissions associated with the burning of grassland biomass in Canada are low (<0.05 Mt CO_2e/yr),[21] there is uncertainty associated with the estimated area burned per year, as well as the average fuel load per hectare and combustion efficiency of the areas (ECCC, 2022b).

NBCSs must rely on sustained efforts by landowners and producers if sequestration and emissions benefits are to last over the long term

NBCSs involving management practices require ongoing efforts to maintain both carbon sequestration and emissions reduction. Achieving these benefits requires sustained, repeated, and often seasonal implementation of NBCSs, such as planting of cover crops and legumes, maintaining no-till, applying 4R nitrogen fertilizer practices, and grazing management. Should management practices resulting in carbon accumulation revert to business as usual (e.g., resumption of intensive tillage), stored carbon will be lost, effectively undoing previous efforts. In contrast, reduced N_2O emissions due to 4R implementation are not erased; rather, those emissions increase only in the year when practices are

21 To convert non-CO_2 gases into CO_2e, ECCC (2022b) used GWP100 values from IPCC (2012), where CH_4=25 and N_2O=298.

reverted — even so, maintaining a trend of emissions reduction requires sustained application of the 4R method. Policies or funds to encourage uptake of NBCSs would consequently need to be maintained and enforced over the long term (Paustian *et al.*, 2019).

In the Panel's view, threats to the continued use of NBCSs include rising maintenance costs, the completion of landowner contracts, and changing market pressures — all of which are difficult to predict and therefore apply to mitigation potential calculations for the future. Market uncertainties are further tied to future pressures on food security; demands for land to grow crops can be directly at odds with efforts to mitigate climate change and may drive further demand for conversion of marginal lands, including grasslands and wetlands (Hasegawa *et al.*, 2018; Ma *et al.*, 2022).

4.5 Feasibility

Many agriculture NBCSs, such as no-till and cover cropping, are already widely practised in some regions of Canada. Barriers associated with their implementation are well documented, and the industry has considerable experience and knowledge about approaches to overcome them. Knowledge bases for other NBCSs are continually being developed; for example, the adoption of the 4R strategy across Canada is a significant topic of research and policy, and there is widespread awareness of benefits beyond emissions reduction (such as reduced pollution of waterways, discussed in Section 4.6.1). Expanding these NBCSs further will likely be easier than those less well studied. When considering the feasibility of implementing these NBCSs, it is important to note that most agricultural lands are privately owned, and therefore both costs and policies associated with implementing them need to balance private costs to landowners with primarily public benefits. As discussed in Section 2.3.2., not all policy options will be appropriate in all situations, and careful consideration of incentives and regulations will be critical for maintaining a balance.

4.5.1 Agricultural and Grassland NBCS Costs

Costs for the implementation of agricultural NBCSs vary depending on climate, soil characteristics, and crop types

Due to the inherent variability in climate, crop type, soil characteristics, and choice of farming methodologies, the range of costs for implementing agricultural NBCSs can vary widely across Canada. For example, individual cover crop types differ in their capacity to sequester carbon, in turn affecting the costs per tonne of carbon sequestered, with specific differences between grasses and legumes (De Laporte *et al.*, 2021b). Based on a survey of cover-crop studies in the United States and Canada, De Laporte *et al.* (2021b) found that — when tillage, seeds, planting, and termination are considered alongside fertilizer savings, compaction, and weed and erosion control benefits — costs outweighed the benefits in non-legume crops (i.e., a mean value of -\$86/ha, ranging from -\$314/ha to \$44/ha for rye cover crops), whereas nitrogen credit conveyed a net benefit in legume crops (i.e., a mean value of \$66/ha, ranging from -\$107/ha to \$255/ha). These ranges reflect uncertainties surrounding seed prices, nitrogen credits, and the value of weed control over time (De Laporte *et al.*, 2021b); along with limited timeframes for establishment, they also potentially deter producers from implementing cover cropping (Schipanski *et al.*, 2014; CTIC, 2020).

Furthermore, higher economic gains achieved through monoculture disincentivize farmers from using certain crop rotations — for example, replacing annual cash crops with perennial grass or legume hay on a short-term basis (NASEM, 2019). Although inclusion of winter wheat in corn and soybean rotations has been proven to be profitable over time, high initial costs and lower initial returns can deter implementation (De Laporte *et al.*, 2022). Based on calculations by Drever *et al.* (2021), Cook-Patton *et al.* (2021) estimated the mean marginal abatement cost (MAC) for adopting cover crops to be \$63.01/t CO_2e. This estimate relies on 2011 data from the Statistics Canada *Census of Agriculture* and will therefore be affected by shifting costs for seeds, fertilizer, and weed control, both regionally and in the future.

Vegetation type also affects the costs for using biochar as a soil additive to enhance soil carbon. Drever *et al.* (2021) found that not all crop residues used in creating biochar were economically feasible. Wheat and oat/barley (which collectively comprise ~70% of available residue) were estimated to cost \$88 and \$92 per t CO_2e in 2050, respectively, which is below the commonly used threshold for cost-effective mitigation of \$100/t CO_2e. However, the mean MAC calculated by Cook-Patton *et al.* (2021) is \$150/t CO_2e in 2030, highlighting the variability in crop type and the temporal considerations for relatively novel NBCSs such as biochar.

While no-till agriculture is relatively prominent in areas of Canada already, Drever *et al.* (2021) assumed that market signals would be important for adopting reduced tillage, increasing no-till from the already high level of adoption, and for maintaining that high level. This is reflected in the relatively high average MAC of \$74.44/t CO_2e (Cook-Patton *et al.*, 2021). Due to the uneven uptake of no-till across the country, regionality will be a key determinant of the costs for encouraging and implementing no-till or maintaining the current levels of uptake.

Costs for implementing nitrogen reduction depend on the intensity of adoption

Annual nitrogen monitoring costs have been estimated to range from $3–18/ha for basic to advanced scenarios, whereby monitoring moves from simple to detailed, from field level to sub-field, and from simply matching nutrient supply to manipulation of the timing and type of fertilizer (Drever *et al.*, 2021). Advanced nutrient management implemented at a level beyond standard practices has a MAC of $55.79/t CO_2e (Cook-Patton *et al.*, 2021). Assumptions about the level of adoption of 4R practices can have significant implications for cost. A study comparing two scenarios — one with 90% of fertilizer managed under 4R by 2030 (but with a lower percentage of advanced uptake) and another with only 70% managed under 4R by 2030 (with a higher percentage of advanced uptake) — found that costs for the latter were nearly three times greater on a cost-per-tonne basis than the former for nearly identical outcomes; the variation stems from the high costs for enhanced efficiency fertilizers used in the advanced scenario (Burton *et al.*, 2021).

Despite being shown to be mutually beneficial to farmers and the environment, farmers are still not widely adopting the 4Rs (De Laporte *et al.*, 2021a). Overapplication of fertilizer, for example, continues to occur, possibly due to the desire to maximize yields in good years and ensure there is always enough nitrogen available to crops (Rajsic & Weersink, 2008; De Laporte *et al.*, 2021a). In the Panel's view, this demonstrates that costs are likely higher than the direct financial calculations; even in cases where practices are profitable, there is hesitancy to engage in them because of perceptions of risk reductions with higher applications, perceived benefits of higher rates of use beyond cost-effectiveness, and cultural factors (Section 4.5.2).

Agroforestry NBCSs can be deployed at relatively low cost beyond riparian areas

Mean MAC estimates for adding or maintaining trees in agricultural lands vary, depending on the species of tree selected, density of planting, and management strategies: $11.15 for alley cropping, $6.36 for avoided loss of shelterbelts, and $3.58 for silvopasture (Cook-Patton *et al.*, 2021; Drever *et al.*, 2021). However, in the view of the Panel the MAC for silvopasture may be an underestimate; Drever *et al.* (2021) assumed adoption at zero cost for the first third of the estimated area of opportunity, and only the cost of trees for the second third. Drever *et al.* (2021) also assumed that costs for establishing silviculture depend primarily on the price of trees and associated establishment expenses, and that uptake can be encouraged through partial or full compensation. Since most costs for agroforestry are low, the lack of current uptake indicates that considerations beyond costs must be contributing to the relative lack of establishment (Section 4.5.2).

Estimates for planting trees in riparian areas — in wetlands, or along the banks of streams or rivers — are considerably higher, with no opportunity at less than \$100/t CO_2e (Drever *et al.*, 2021) and a mean MAC of \$3,873.90 (Cook-Patton *et al.*, 2021). This includes costs for purchasing and planting trees, site preparation, herbicide application (estimated at \$3,920/ha), and maintenance costs (\$451/ha/yr), as well as long-term opportunity costs associated with land retirement from agricultural production. Opportunity costs contribute significantly to the total cost, particularly when high-value crops are removed and direct financial compensation to landowners is required (Drever *et al.*, 2021).

Grassland restoration and conservation costs are difficult to estimate

For avoided grassland conversion, Drever *et al.* (2021) estimated that the majority of mitigation potential would only be available at more than \$100/t CO_2e, with a MAC of \$144.31 calculated by Cook-Patton *et al.* (2021). In the Panel's view, using land values from Drever *et al.* (2021) may overestimate the costs, as they should reflect the difference in returns among land-use types. In contrast, an economic study by De Laporte *et al.* (2021b) found that avoiding the conversion of pasturelands to croplands would actually yield positive returns in comparison to converting them to row cropping, especially in the Prairies. This study assumed that any pastureland would be of lower quality, and that any converted land would therefore have a lower yield. After considering land costs, the authors found that the net benefit of maintaining pasture in the Prairies ranges from \$229.35–331.90/ha (De Laporte *et al.*, 2021b). These contrasting findings highlight issues around additionality and determining the true area of opportunity for avoided grassland conversion. If the costs derived by Drever *et al.* (2021) are overestimated, then avoided grassland conversion may be a more cost-effective option. However, if conversion to cropland, as proposed by De Laporte *et al.* (2021b), is of limited value, then this option may not actually be additional.

Similarly, Drever *et al.* (2021) analyzed the costs associated with grassland restoration in Canadian riparian areas and ultimately determined that 60% of the overall mitigation potential of this NBCS (0.4 Mt CO_2e/yr out of the total 0.7 Mt CO_2e/yr) will be available at a cost of less than \$100/t CO_2e. The mean MAC calculated by Cook-Patton *et al.* (2021) is just over that threshold at \$102. This estimate is limited, however, to the restoration of grasslands in riparian areas; the costs of grassland restoration in other areas were not estimated.

Grassland management strategies can have both negative and positive effects on profits, depending on strategy and region

Given that there are many options for managing grasslands and the potential for implementing multiple strategies at once, it is difficult to determine how upfront implementation costs will interact with potential long-term profits. For example, De Laporte *et al.* (2021b) determined that, despite initial costs for installing fencing and water sources, rotational grazing conveyed a net benefit, with an annual change in net return ranging from \$3.54–47.95/ha. This variation reflects the level of adoption and its relationship to number of animals per unit — the more rotational grazing, the higher the number of animals on each hectare of land and therefore the higher the profit (Burton *et al.*, 2021).

Cook-Patton *et al.* (2021) estimated that adding legumes to pastures would have an average MAC of \$40, which is relatively cost-effective when compared to some other agricultural NBCSs. However, other studies disagree that the use of legumes in pastures to fix nitrogen and reduce dependence on fertilizers can convey either a net benefit or cost. De Laporte *et al.* (2021b) found that increasing legumes in pastures resulted in net average returns — a mean of \$34.65/ha in the Prairies — and a mean of -\$29.73/ha in the rest of Canada. Whether a return is positive or negative depends on regional variation in fertilizer costs; a positive return correlates to high fertilizer costs since more money is saved by not buying and applying fertilizer.

Maintaining crop yields or compensating for crop-yield losses are important considerations when implementing NBCSs

Incorporating additional rotations of crops such as winter wheat into continuous cropping systems, such as the corn and corn-soybean rotations common in Ontario, can result in higher crop yields and reduction in yield variability (Yanni *et al.*, 2018). Incorporating rotations has further been found to produce higher yearly net returns in corn systems (Deen *et al.*, 2006a, 2006b). Once established, no-till systems without reductions in crop yield can have lower economic costs than intensively tilled areas, reducing the costs of labour and equipment relative to other tilling practices (Sørensen & Nielsen, 2005; Derpsch *et al.*, 2010). Reduced tillage does not generally result in higher yields and may produce higher yield variability in certain soils (Beyaert *et al.*, 2002; Dam *et al.*, 2005; Vetsch *et al.*, 2007; Munkholm *et al.*, 2013; Vanhie *et al.*, 2015). Similarly, decisions to reduce the use of nitrogen fertilizer warrant careful consideration so as not to reduce crop yields; while managing nitrogen inputs into soils helps to reduce N_2O emissions, it may also lead to a reduction of carbon sequestration in soils (Groupe AGÉCO *et al.*, 2020) (Section 4.3.1).

The impacts of NBCSs on profitability can be uncertain, and vary with changes in climate, soil conditions, and market demands. It can be difficult to determine in advance whether certain NBCSs will affect profits at all. In a recent survey on the use of cover crops in the Prairies, approximately 47% of respondents were unable to determine the impacts of cover crops on farm profit (Morrison & Lawley, 2021). However, 24% of farmers saw an increase in profit, 24% saw no change, and only 4% experienced a decline (Morrison & Lawley, 2021). Such variability highlights the difficulty in prescribing a one-size-fits-all approach when calculating the feasibility of NBCSs at the farm level.

Marginal lands with low crop yields are most attractive for planting perennial vegetation or trees. Once trees have matured, they can be harvested and used in a variety of ways, including as bioenergy to replace fossil fuels, or for more traditional products such as pulp, paper, and construction materials (Drever *et al.*, 2021) (Section 3.3.2). Species composition depends on climate, topography, and soil type, selected to provide a variety of other co-benefits, such as fruit or nut production. If these areas are agriculturally productive and occupied by high-value crops, then replacing this land with tree buffers will result in economic losses to landowners. Provision of financial compensation for tree establishment would then be critical to promoting adoption (Drever *et al.*, 2021). However, strategies such as alley cropping can still provide benefits, and will additionally reduce erosion in croplands (Yanni *et al.*, 2018).

4.5.2 Policy and Regulatory Challenges

Policies for encouraging uptake of agricultural NBCSs can involve "carrots" (e.g., subsidies or payments to those implementing NBCSs) or "sticks" (e.g., penalties or regulations). Canada has primarily used voluntary agri-environmental programs that provide monetary incentives to further environmental goals, while the use of regulations has been viewed as "a politically unattractive last resort" (Baylis *et al.*, 2022). A review of policies available for encouraging or mandating NBCS uptake is out of scope, but the Panel highlights some considerable uncertainties and barriers to implementation below.

Instability and inadequate compensation can stymy participation in agricultural carbon credit systems

Canada's only operational agricultural carbon credit system is in Alberta. It contains 19 offset protocols, such as 4R nutrient stewardship, and has previously included reduced tillage as part of conservation cropping (Gov. of AB, 2022b; Lokuge & Anders, 2022). Farmers have been reluctant to participate in this program, however, due to inadequate compensation through incentives and instability in the carbon market (Lokuge & Anders, 2022). A literature review on carbon credit systems in agriculture found that, "due to a history of regulatory risk the agriculture sector has seen the revocation of carbon credit eligibility for certain practices, and invalidated credits can lead to significant financial losses for farmers" (Lokuge & Anders, 2022). Research has indicated that reduced-till and no-till projects have the highest risk of being invalidated through changes to the Alberta offset system, which bore out with the closing of the conservation tillage credit stream in December 2021 (Tarnoczi, 2017; Gov. of AB, 2022b). To strengthen the carbon credit system in Alberta, Lokuge and Anders (2022) suggested emphasizing other efficiencies associated with carbon credit-accumulating activities (e.g., co-benefits associated with 4Rs), and not focusing solely on potential financial gains associated with participation in carbon credit programs. Increased stability and more significant rewards may potentially prompt higher farmer participation in carbon credit systems.

Effective implementation of agricultural NBCSs often relies on farmers' awareness of the potential benefits, and relevant policy incentives and supports

Implementing agriculture and grassland NBCSs can be slowed by a lack of awareness about specific NBCSs and relevant environmental relationships (Dessart *et al.*, 2019; Prokopy *et al.*, 2019; Groupe AGÉCO *et al.*, 2020). For example, a survey of producers in Saskatchewan found that many were unaware of the financial benefit of retaining shelterbelts; if any benefits were recognized, they were perceived to be non-economic and therefore not included in management decisions (Rempel *et al.*, 2017). This emphasizes the importance of improving farmers' understanding of the real costs and benefits of shelterbelts. Agroforestry NBCSs are also subject to considerations around reversibility; farmers may be reluctant to invest in actions that are permanent, or cost money to reverse, such as any NBCSs that involve planting trees (Yemshanov *et al.*, 2015). The costs associated with reversal are seldom included in cost calculations based on net present value (e.g., Drever *et al.*, 2021), resulting in further underestimation.

> "Increased stability and more significant rewards may potentially prompt higher farmer participation in carbon credit systems."

A focus on farm-level networks can be crucial for supporting the uptake of these NBCSs, as interaction among farmers (both informally in social settings and formally within industry organizations) is correlated with an increased acceptance rate of altered management practices (Prokopy *et al.*, 2019; Groupe AGÉCO *et al.*, 2020). Outreach initiatives to inform farmers and landowners about practices such as agroforestry, as well as the provision of expertise or maintenance equipment (Drever *et al*., 2021), can foster increased awareness and knowledge within the sector, influencing the likelihood of long-term acceptance and implementation of NBCSs. Increased awareness of NBCSs does not always result in optimization, however. In the case of 4R nitrogen management, a survey cited in Burton *et al.* (2021) found that Ontario corn farmers who were familiar with the 4Rs applied 28% more fertilizer on average than those who were not aware. The Panel notes that, in these types of situations, investment in technical assistance and training may help achieve the intended benefits.

Improving nitrogen management and increasing the uptake of cover crops are priorities for the federal government, which included them as target projects for the Agricultural Climate Solutions program (AAFC, 2022). The value of conserving existing trees on farms (including shelterbelts and riparian buffers) has also been recognized by the federal government and supported with $60 million through the Nature Smart Climate Solutions Fund (GC, 2021d). These initiatives indicate the willingness of governments to support NBCS interventions where they are known to have environmental or economic co-benefits. Additional policy measures for reducing grassland conversion could include actions such as a moratorium on future conversion of native grasslands for agricultural purposes, the creation of incentives for avoided conversion of grasslands to cropland, and the expansion of protected areas in grassland zones (Nature Canada, n.d.).

Current programs and policies to reduce agricultural business risk may be incompatible with NBCSs

Risks linked to crop production (including yield and selling price) have been associated with suboptimal nitrogen application rates (Pannell, 2017). In short, policies intended to reduce risk for farmers (such as crop insurance) are "likely to result in increased use of nitrogen fertilizer overall, as they allow farmers to adopt more risky nitrogen application strategies without bearing the full consequences of those increased risks" (Pannell, 2017). In some cases, this strategy bears out; applying excess fertilizer to boost gains in good years is relatively cost-effective compared to the cost of under-application (Rajsic & Weersink, 2008). However, crop insurance programs may also incentivize conversion of intact ecosystems such as grasslands and wetlands, further increasing emissions (FCS, 2022).

NBCSs associated with land-use change on agricultural lands (e.g., agroforestry and mineral wetland restoration/conservation; see Chapter 5) have been disincentivized by existing agricultural business risk management (BRM) programs. A study by Jeffrey *et al.* (2017) demonstrated that net gains or losses associated with implementing certain NBCSs were amplified by participation in BRM programs. For example, benefits associated with the use of legumes or cover crops increased when paired with BRM participation, while, conversely, the net cost for implementation (i.e., disincentive to adopt) for buffer strips and wetland restoration increased. Consequently, "participation in public BRM programs may result in reduced uptake of many environmentally friendly production practices or land-use changes (e.g., buffer strips or shelterbelts) if they are costly for producers to adopt" (Jeffrey *et al.*, 2017). Participation in BRM programs has also been found to increase the use of fertilizer and pesticides, negatively impacting ecosystems and environmental goals (Eagle *et al.*, 2016).

> "In the absence of legal mandates, a landowner's decision to implement NBCSs is an individual one, in large part influenced by their personal beliefs and behavioural characteristics."

One way of dealing with this issue is *cross-compliance*, or "the linking of environmental conditions to agricultural support payments" (Rude & Weersink, 2018). Essentially, to receive income support, farmers must ensure an environmental target is met; success is dependent on combining income support and environmental programs, increasing effectiveness. However, cross compliance is unlikely to be applicable to Canada's current suite of BRM programs — the benefits available to farmers are fewer than compliance costs, leading to limited voluntary participation (Rude & Weersink, 2018).

Behavioural factors are a key uncertainty in assessing uptake of NBCSs

Even if NBCSs have demonstrated net benefits or relatively low costs, they are not uniformly accepted and implemented by farmers across the country. In the absence of legal mandates, a landowner's decision to implement NBCSs is an individual one, in large part influenced by their personal beliefs and behavioural characteristics (Groupe AGÉCO *et al.*, 2020). For example, Dessart *et al.* (2019) found that cognitive factors, including farmers' knowledge of NBCSs and perceptions of the possible outcomes associated with these practices, were most directly related to the adoption and implementation of improved land management practices. Most economic modelling for adopting best management practices (including some NBCSs) assumes that maximizing profit is the primary driver for farmers. It is, however, not the only objective; social influences and awareness of environmental effects can also influence adoption (Weersink & Fulton, 2020).

To better understand the influence of behavioural characteristics on agricultural practices, Huber-Stearns *et al.* (2017) undertook an analysis of enabling conditions — "factors that increase the likelihood of an intended change in… management regime" — in the successful implementation of payment for ecosystem services programs. They found that, alongside biophysical, economic, and governance-related conditions, sociocultural conditions (e.g., trust and transparency, stakeholder communication, proximity of a community to other like-minded actors) were required for the success of the policy and avoiding the development of additional policy barriers (Huber-Stearns *et al.*, 2017). Every decision about agricultural NBCSs is made in relation to a variety of external influences, such as the age, experience, and expertise of a farmer; the farmer's attitudinal orientation toward environmental considerations and risk tolerance/aversion; and characteristics of the farm itself, including size, tenure, and vulnerability of the land (Groupe AGÉCO *et al.*, 2020). The context-dependent nature of individual decision-making results in considerable uncertainty; while many NBCSs may have high technical and economic potential, there is no guarantee of high adoption rates due to these social-behavioural elements. The design of effective policy mechanisms would benefit from consideration of these behavioural factors.

Uptake of certain NBCSs has also been found to be affected by whether or not the land is owned or rented, and how long rentals are expected to last. A study of the implementation of conservation tillage and cover crops in southern Ontario found that activities with short-term benefits, such as conservation tillage, were equally likely to be implemented on both owned and rented lands (Deaton *et al.*, 2018). Cover crops, where positive net benefits take longer to accrue, were 9.9% less likely to be implemented on rented land than on owned land, presumably because farmers are more reluctant to invest up front if there is a possibility that they will not be in a position to reap medium-term benefits. This applies to the time horizon of rented land, as well; farmers with long-term rental arrangements were equally likely to plant cover crops on both rented and owned land, whereas farmers with short-term rentals were not (Deaton *et al.*, 2018). Thus, the ease of implementing certain NBCSs will depend on land ownership when benefits are estimated to arise.

4.5.3 Monitoring and Accounting

Determining optimal strategies for NBCS implementation requires local and regional information

Though some agricultural NBCSs are well established, identifying optimal strategies on a farm-by-farm basis requires detailed knowledge of environmental conditions, soil composition, topography, and land-use history (Groupe AGÉCO *et al.*, 2020). There is no one size fits all strategy that can be universally applied; investment in research that monitors and tracks changes in stocks and emissions can help target actions in a variety of different regions (Meadowcroft, 2021). This need was identified in interviews conducted by Groupe AGÉCO *et al.* (2020), who noted,

> *Regional and farm level soil information is complementary and necessary to manage soil health effectively. Yet…there is a lack of such information on the current status of soil health. This data gap is problematic for researchers (as well as policymakers and producers) as it limits the ability to understand, identify, manage, and track improvements over time.*

Similar challenges apply to pasturelands. As a result of uncertainties around grazing practices and grassland management, many researchers call for site-specific grazing metrics (as opposed to larger-scale spatial data) to accurately track the complexities and variance across management practices (Bork *et al.*, 2021). Although they have merit in terms of accuracy (Smith *et al.*, 2012; Bork *et al.*, 2021), site-specific data often lead to issues of interoperability. For example, Maillard *et al.* (2017) noted that "the sampling depth recommended for SOC measurement varies according to project purposes, institutional preferences, [and] land uses" and, as a result, are often incomparable. Annual changes to grassland SOC are small, and cumulative result is only statistically detectable after several years (Maillard *et al.*, 2017). Measuring such changes can be difficult, however, due to the short-term nature of research projects, which may not capture the full extent of changes in an ecosystem over the required timescales.

Canada does not track or account for changes in soil carbon or GHG emissions associated with some NBCSs

Though monitoring is key to understanding the effectiveness of NBCSs, there are critical knowledge gaps related to tracking changes to carbon stocks around certain NBCSs in agricultural systems and grasslands. For example, there is no Canada-specific breakdown of total carbon sequestration rates and impacts for improved grassland management strategies. As Viresco Solutions Inc. (2020) pointed out, this lack of data results in the potentially inaccurate assumption in Canada's *National Inventory Report* that "grassland management has not significantly altered since 1990 and therefore does not account for any SOC stock changes on grasslands as a result of management or a changing climate." The Government of Canada is now required to address this omission, but the data needed to do so do not currently exist (Viresco Solutions Inc., 2020). As a result, significant uncertainty remains about the regionally specific benefits of different modes of land management across Canada's grasslands. Similarly, the *National Inventory Report* does not track adherence to (and thus the results of) the 4R method of nitrogen management. Although it assesses emissions related to nitrogen input (synthetic and organic), the lack of data on other spatially explicit management practices and their change over time (e.g., timing of fertilizer application) means the potential of these practices to affect emissions is overlooked (ECCC, 2022b). In the Panel's view, this is critical to incentivizing the uptake of NBCSs and evaluating their effectiveness.

4.6 Co-Benefits and Trade-Offs

Agricultural and grassland NBCSs have distinct co-benefits and trade-offs; they can all vary through time and often depend on the regional climate, local topography, crop species, soil characteristics, and market conditions, which can all vary through time. Some interventions proposed to sequester carbon in soils have been extensively studied and deployed in Canada (e.g., reduced or no-till), and others were originally employed to primarily offer other benefits, such as shelterbelts to protect soil from wind erosion (Mayrinck *et al.*, 2019; ECCC, 2022b). Most trade-offs in implementing these NBCSs are associated with costs and changes in land use; as such, they are largely discussed above in Section 4.5, while the following discussion mostly concerns co-benefits. Co-benefits can also be split to apply either privately (to the landowner or manager) or publicly; the discussion in this section encompasses both however, ideally, private benefits would be captured in MAC calculations.

4.6.1 Soil and Ecosystem Health

Higher levels of carbon in soils offer benefits to overall soil health

Cover crops confer other benefits beyond carbon storage and reduction of emissions, including drought resistance, reduction of erosion and leaching (leading to retention of soil nutrients), cheaper management of weeds and pests, and better soil structure (Morton *et al.*, 2006; Roesch-McNally *et al.*, 2018; Bergtold *et al.*, 2019). Soil health is also enhanced through an increase in microbial diversity and biomass, as well as improved water retention and nutrient cycling (Hristov *et al.*, 2018). Cover crops can reduce indirect N_2O losses as well, by capturing excess nitrogen after the harvest of the cash crop and reducing the required rate of nitrogen application; however, further research on the applicability of this co-benefit is needed (Yanni *et al.*, 2018). These benefits can offset initial costs of implementation (Roth *et al.*, 2018).

Soil health can also benefit from changes in tillage intensity. No-till practices lessen the effects of erosion, increase water retention, and improve soil health in general (Meadowcroft, 2021). The related practice of one-time deep inversion tillage could also act to bury surface soil layers high in carbon 60–80 cm deep, slowing decomposition (Paustian *et al.*, 2019). This practice is most effective in humid and sub-humid regions with poorly drained soils. However, the expansion of no-till practices, with associated rises in crop residue, has been found to increase phosphorus runoff (which contributes to eutrophication), particularly in the Prairies, where freeze-thaw cycles are a contributor. Incorporating occasional till cycles to break up topsoil has been found to reduce runoff; however, it reverses the positive gains of no-till for both carbon and nitrogen retention (Messiga *et al.*, 2010).

Adding biochar to soils can boost plant productivity and, in turn, enhance carbon input to the soil through plant residues, though this effect is highly dependent on soil and plant varieties, as well as management practices (Crane-Droesch *et al.*, 2013; Subedi *et al.*, 2017). One potential drawback to adding biochar to soil is the risk that toxic compounds (including heavy metals) might also be added (Subedi *et al.*, 2017). In general, agricultural NBCSs that increase SOC stocks also act to enhance the drought resilience of crops, which may become increasingly beneficial as Canada's climate changes (Banwart *et al.*, 2014; Bush & Lemmen, 2019; Oldfield *et al.*, 2019).

Trees in agricultural lands trap snow and promote biodiversity and animal health

In certain scenarios, agroforestry strategies can boost crop yields, enhance the quality of soils, and contribute to the conservation of biodiversity (Kort, 1988; Jose, 2009; Schoeneberger *et al.*, 2012). Adding trees to riparian areas can stabilize streambanks and limit nutrient runoff into water bodies (Schoeneberger, 2009). Beyond sequestering carbon, shelterbelts act to protect crops and livestock from wind and snow and can promote biodiversity in certain regions (Schoeneberger, 2009; Mayrinck *et al.*, 2019). Shelterbelts alongside roads can trap blowing snow, making for safer driving conditions and reducing the need for road maintenance (AAFC, 2009). Moisture from trapped snow is then redistributed to the soil in the spring, contributing to soil moisture retention (AAFC, 2009). Silvopasture has been used to provide habitat for wildlife and provide shelter for livestock (Baah-Acheamfour *et al.*, 2017). However, replacing pastures or croplands with trees can reduce albedo (Drever *et al.*, 2021), which needs to be taken into consideration when evaluating the benefits derived from carbon sequestration.

Intact grasslands reduce erosion, maintain water quality, and support biodiversity

Grassland vegetation conveys multiple benefits beyond carbon sequestration, including prevention of runoff and soil erosion through soil stabilization (Duran Zuazo & Rodriguez Pleguezuelo, 2008; Bengtsson *et al.*, 2019) and water filtration of pollutants ((DUC, 2006). Improved water quality can also benefit livestock production, as both the quality and quantity of plant biomass serving as fodder are important for meat and dairy production (Bengtsson *et al.*, 2019). Furthermore, intact grassland ecosystems support biodiversity by regulating services such as pollination (Bengtsson *et al.*, 2019; Viresco Solutions Inc., 2020). Nature Canada (n.d.) reported that, since 1970, populations of species dependent on native grasslands have fallen by 87%. In Alberta, the majority of identified species at risk are found in grassland regions (CPAWS, n.d.). Moreover, grassland cover offers pollinator species a place to live undisturbed, providing benefit to nearby agricultural fields (CPAWS, 2011).

Reducing nitrogen inputs to agricultural soils has positive downstream impacts

Fertilizer runoff from croplands has led to eutrophication of water bodies (Schindler, 2006). Increased availability of nutrients leads to greater algal productivity, consuming oxygen in the water column and creating anoxic (oxygen-poor) conditions in deep waters and sediments. Under anoxic conditions, the switch from aerobic (oxygen-consuming) to anaerobic (not oxygen-consuming) respiration leads to the production of CH_4, which in turn increases the warming potential of these ecosystems (Beaulieu *et al.*, 2019; Deemer & Holgerson, 2021). Wetlands in agricultural regions, such as the Prairie Pothole Region, are also observed to emit elevated levels of N_2O due to runoff from croplands (Bedard-Haughn *et al.*, 2006; Pennock *et al.*, 2010; Tangen *et al.*, 2015). These emissions have been linked to periods of inundation, prompted largely by spring snowmelt and runoff (Pennock *et al.*, 2010).

These impacts are further reflected in proximal real estate prices and losses in recreational profits; toxic algal bloom presence was found to convey 11–17% capitalization losses in near-lake homes in Ohio, with a loss of 22% in lake-adjacent properties (Wolf & Klaiber, 2017). Recreational damage estimates based on monthly fishing permits for Lake Erie demonstrated a 10–13% drop associated with harmful algal concentrations (Wolf *et al.*, 2017). Thus, addressing surface water eutrophication through reduced nutrient input can have demonstrable economic benefits in addition to reducing CH_4 emissions.

Reducing the use of fertilizers through 4R management could help to stymy, and possibly reverse, the eutrophication of water bodies by limiting the amount of reactive nitrogen available for removal by runoff and groundwater seepage (Beaulieu *et al.*, 2019; Groupe AGÉCO *et al.*, 2020). This is associated with the wider concept of *watershed management*, where decisions around land use take into account all downstream effects for rivers, lakes, and wetlands. Although watershed management is not considered an NBCS in this report, it is a crucial co-benefit of nutrient management.

4.6.2 Cultural Impacts

Maintenance of grasslands is associated with cultural benefits

The sociocultural services that grasslands provide centre mainly on tourism, recreation, and cultural heritage (Bengtsson *et al.*, 2019). Work done by CPAWS (2011) highlighted how, "for decades, the prairies have provided local residents [of Alberta] their livelihood while allowing them to enjoy nature through various recreational activities." Those activities, combined with the aesthetic value of the sprawling grassland ecosystem, are also a draw for tourists, providing economic benefit to local communities (CPAWS, 2011).

Recognizing the role of First Nations in the care and conservation of grassland systems is a form of decolonial justice

Maintaining grasslands is associated with reconciliation, decolonial justice, and the well-being of Indigenous individuals and communities — all vital cultural benefits. For example, bison are slowly being reintroduced to the Prairies after being hunted to near extinction in the late 1800s (Cecco, 2020; Tait, 2021). This effort has been undertaken not just as a means of increasing the ecological stability of the plains, but also as an "effort to heal relationships...between animals and the land" and between Indigenous communities and the state (Mamers, 2021). Bison are, for many plains Indigenous Peoples, central to ways of being and knowing, and "intimately bound to threads of reciprocity, morality, kinship relations, and sovereignty" (Hisey, 2021). They embody "all my relations" (Section 2.4), a fundamental tenet in which the interrelationship of all things is respected, conserved, and perpetuated (Buffalo Treaty, 2014). As such, their reintroduction also represents an ontological shift toward the "human-Creation" relationship (Hisey, 2021); the Buffalo Treaty, which explicitly focuses on returning bison to the land through collaboration with federal and provincial/territorial governments, is at the centre of this shift (Buffalo Treaty, 2014). Signed by 11 Indigenous nations, the treaty represents a vision of the future — one in which reconciliation is not merely an acknowledgement of the past but motivation for a better future (Mamers, 2021).

4.7 Conclusion

Many of the NBCSs discussed in this chapter are well studied and have either been implemented in the past or are currently being encouraged, lending an advantage to their more widespread use across Canada. Although uncertainties around the rates of SOC sequestration or emissions reduction for certain NBCSs remain, the more critical issue of estimating the magnitude of sequestration potential at any scale is linked to determining the area of opportunity — which is likely to vary regionally. Costs, policies, behavioural barriers, and technical impediments can all affect the implementation of NBCSs and require careful analysis and consideration to improve predictions about which NBCSs are the most promising for widespread use in Canada. There are opportunities to foster reconciliation by advancing self-determination and sovereignty over lands, while simultaneously conserving or restoring native grassland ecosystems by engaging Indigenous experts and recognizing Traditional Knowledge. Beyond the implementation of NBCSs, it is crucial to consider how to maintain their ongoing use, especially for those requiring sustained efforts to continue to reap benefits (e.g., nitrogen management, no-till practices). Long-term initiatives, policies, and funding programs, as well as extensive monitoring networks, will be important decision-making components for maximizing the potential of these NBCSs in agricultural areas and grasslands across Canada.