Brief to the Senate Standing Committee on Agriculture: Soil Health Study

Canadian Organic Growers is pleased to contribute the following comments to the Senate's Soil Health Study. This brief summarizes the scientific literature on the relationship between organic agriculture and soil health. It is part of a larger study we are undertaking (to be completed by summer 2024) aimed at identifying the impacts of organic agriculture on environmental, climate and economic outcomes in Canada.

Organic Agriculture as a Model for Restoring the Health of Canada's Farmland Soils: A Review of the Scientific Literature

Soil health is the foundation of our food system and is paramount to food security and combating climate change. However, decades of intensive agriculture have contributed to the loss of soil fertility, and soil erosion costs Canadians $3.1 billion annually.

Stacking agroecological practices allows farmers to optimize soil health and should be encouraged.

Studies have shown the benefits of beneficial management practices (BMPs) such as diverse crop rotations, conservation tillage, amendments, and cover crops, and their impacts on soil health (see Appendix 2). However, there is less research on how these practices function together as a system, and how utilizing certain practices simultaneously in various combinations (stacking) can result in significant gains. Individual practices are important to improve soil health; however, implementing these practices separately may not result in measurable and lasting systemic improvements.

Organic agriculture provides an ideal system for research and testing of stacked practices to manage trade-offs and improve outcomes.

Organic farming systems place a central focus on maintaining and building soil health through ecological management, necessarily using a systems-based approach of stacking agroecological practices to ensure the resiliency of production. Key recommended practices for managing soil health are routinely utilized in organic cropping systems in varying combinations depending on intensity of management.

This provides an ideal testing ground for practices that can manage trade-offs across the agricultural sector, such as the increasing risk of managing nitrogen at the expense of declining carbon, a key factor for soil health. **Organic farming systems are ideal production systems for testing and refinement of advanced organic carbon and nitrogen management to improve overall agri-environmental outcomes for Canada**. **This point is expanded upon in Appendix 1.** Organic systems spur constant innovation to respond to challenges such as weed and pest management, thus the adoption of organic practices can benefit all producers, helping to address challenges like high input costs, herbicide resistance, and environmental impacts.

Research to date suggests improved soil health and soil organic carbon through organic management; however, more research is needed.

A recent literature review on soil health in organic systems in Canada (found in **Appendix 2**) found that, compared to conventional production, **organic management can maintain soil health and soil organic carbon (SOC)**. This is especially true when best management practices are used and combined in organic systems. These practices include reduced tillage intensity and frequency, cover crops, forages, and integration of livestock into the system. However, farming practices in organic systems vary widely in intensity, with varying impacts on soil health outcomes. As well, research conducted in the Canadian context, particularly for horticultural crops, is lacking when considering soil health. This confirms the need for more research to properly assess the impacts of organic management with a variety of practices in Canada's diverse agricultural system.

Case Study: Upland Organics, Saskatchewan: Combining regenerative practices improves soil health and climate resilience.

Upland Organics, a Regenerative Organic Certified 8,000 acre mixed cattle and grain farm near Wood Mountain, Saskatchewan has **achieved an average 1% increase in soil organic matter (SOM) across the farm** (total SOM ~3%), along with increased soil aggregation and stability. A key measure of soil health, SOM also has a significant impact on the farm's drought resilience, since every 1% increase in SOM results in soils being able to hold an additional 25,000 gallons of water per acre. **Soil health is a key climate resilience strategy** for the farm, which is located in the drought-stricken Palliser Triangle.

Upland Organics places a central focus on managing soil health by combining practices including reduced tillage, diverse and extended crop rotations, intercropping, cover crops, pollinator strips, composting, and rotational grazing in order to build a resilient soil ecosystem that supports soil water conservation, natural fertility, and pest management.

This increase in SOM also corresponds to an annual increase of approximately 1.5 tonnes of soil organic carbon (SOC) per hectare per year, considerably above the rate of about 0.2 tSOC/ha/yr ascribed to Prairie no-till on its own, helping the farm contribute to climate change mitigation. While soil erosion risk has declined through the reduction of tillage and summerfallow, the use of multiple regenerative practices can greatly enhance results.

Summary

Regenerating the health of our soils rests in the hands of our farmers, ranchers, foresters, and land stewards. Delivering research, extension and incentives to producers will improve outcomes along the whole spectrum of management to assist producers in building soil health and long-term resilience. To advance this goal, the organic sector is currently conducting a national soil health benchmarking study.

Organic farming is both an established system to invest in to increase soil health, and a model system that benefits all of agriculture. With research, extension, and incentives, increased and improved organic production can contribute to improved soil health while producing nutritious food without the use of pesticides and synthetic fertilizers, with reduced inputs costs and lower reliance on fossil fuel inputs, and benefits for biodiversity and climate.

Appendix 1: Advanced Organic Carbon and Organic Nitrogen Management to Improve Agri-Environmental Outcomes in Canada's Next Agricultural Policy Framework[1]

Advanced Organic Carbon (C) Management

1. **Soil organic carbon (SOC) levels are continuing to decline particularly across cropping systems in Eastern Canada** (Clearwater et al., 2016; Nyiraneza et al., 2017), leading to declining soil health and soil degradation and loss, due to cropping intensification (less diverse rotations often including low residue crops).

2. **SOC gains must be based on added residue and C input to soil**. Zero-tillage does not reverse SOC declines in humid regions (Angers et al., 2017) and minimum tillage increases N_2O emissions on finer textured soils when growing season precipitation exceeds 600mm (Pelster et al., 2024).

3. **It is not just about cover crop utilization, but proper management of cover crops.** Current federal (On-Farm Climate Action Fund, Living Labs) and provincial programs are increasing on-farm testing and exploration of cover crop utilization. Cover crops have the potential to provide three natural climate solution services; increased SOC, N fertilizer replacement, and reduced N_2O emissions and N leaching (Drever et al, 2021). However, current cover crop adoption and utilization may not significantly enhance SOC levels, as:

    - SOC gains from cover crops alone vary widely with their type and utilization (full-season, intercropped, relay cropped etc.) and region. In the Prairie region black soil zone average cover crop biomass rates ranges from 0.5 to 0.6 Mg C ha^{-1} yr^{-1} (Thiessen-Martens et al. 2015), but is less in drier prairie regions, compared to up to 2 Mg C ha^{-1} yr^{-1} (~4 Mg biomass) in more humid cropping regions, with earlier planting and later termination achieving upper ranges (Blanco-Canqui, H. 2022). As only a fraction of cover crop soil C input contributes to SOC gain (Gregorich et al., 2017), rates of SOC gain, if any, from cover crops are suggested at 0.27–0.39 t C ha^{-1} yr^{-1} or less depending on cover crop biomass production (Poeplau et al., 2024).

    - Generating higher cover crop biomass rates being avoided due to (i) perceived risk of N immobilization challenges for the following cash crop (R. Barrett pers comm.), (ii) evidence of a link between cover crop biomass and N2O emissions in humid regions leading to recommendations to use cover crops primarily as a low-biomass catch crop to utilize excess residual soil mineral N (RSMN) (M. Tenuta pers comm; Thapa et al., 2018). Cover crops of low biomass (<2 Mg ha^{-1}), however, are unlikely to contribute to SOC gains (Blanco-Canqui, 2022).

    - Some studies suggest enhancing SOC levels may not be guaranteed by more diverse rotations which include cover crops unless a period in perennial forages is included (Arcand and Congreves, 2018; Sprunger et al., 2020).

4. **Soil is the fundamental and critical non-renewable resource that must be sustained, and SOC is central to all aspects of soil health**. While Advanced Nitrogen Management (4Rs) has a key role to play in achieving greenhouse gas (GHG) reductions in cropping systems, there is a need for a parallel emphasis on Advanced Carbon Management to sustain SOC, soil health and climate resilience, i.e. programming geared to enhance testing and adoption, optimized by region, namely:

[1] By Dr. Derek Lynch - Professor, Canada Research Chair, Organic Agriculture, 2005-2015

Rotation diversification (including cover crops)
Residue management (residue exports (straw, hay etc.) can negate gains from diversification)
Rate of tillage intensity (based on frequency and level of disturbance/STIR metrics)
Return of manure (or composts)

These [4Rs for Advanced Carbon Management] are key pillars of regenerative agriculture, and these practices are routinely utilized in organic cropping systems in varying combinations depending on intensity of management (Lynch et al., 2022).

Advanced Organic Nitrogen (N) Management

1. **Improvements observed from organic cropping practices.** Frequent use of cover crops, as practiced in organic cropping systems, further enhances the significant yield gains from use of cover crops, yield gains in the range of 13-22% shown for corn and wheat in the meta-analysis of Bourgeois et al. (2022). Cover crop mixtures that include legumes may provide yield gains plus increased soil N and C contents (Lavergne et al., 2020).

2. **Beyond manure management.** Current programs and recommendations with respect to improved crediting of organic N sources focus primarily on manure management, with minimal or no emphasis on replacement of N fertilizer use through targeted use of perennial or cover crop legumes in rotation.

3. **Provincial suggested N credits for preceding legume cover crops vary widely and need refinement to enhance fertilizer N replacement and adoption.** Outside of organic farming systems, farmer inexperience, and perceived agronomic risks, limit the potential of expanding testing and use of common and novel leguminous cover crops as predominant source of N supply for the following cash crop. Biological nitrogen fixation (BNF) capacity and soil N supply from some novel leguminous cover crops have been shown in eastern Canada to largely replace N fertilizer needs for corn (Yang et al., 2024), wheat (Alam et al., 2018) and potatoes (Lynch et al., 2012).

   As with fertilizer N, N from legumes can also lead to N_2O emissions (Rochette et al., 2008), but this is offset by cover crop co-benefits to soil health and resiliency, biodiversity, and potential for SOC gain (Lynch, D. H. 2022).

   Estimates of relative N_2O emissions rates from cover crops are also under ongoing revision (Liang et al., 2020). D'Amours et al (2023) in Quebec found that a chisel ploughed green manure minimized per hectare N_2O emissions without increasing crop (barley, corn, soybean) yield-scaled N_2O emissions.

4. **N balances in organic systems are typically low compared to non-organic systems**. The intensity of N fertilizer use has continued to increase across cropping systems in Canada with attendant increases in field scale N balances (N input-outputs). The emission rates of N_2O are considered to be non-linear in relation to N inputs and have increased accordingly.

   Organic farming systems, even within specific sectors, vary in terms of management and farm nutrient intensity (Roberts et al., 2008), but are **generally significantly less intensive** with respect to N flows than conventional cropping systems. As a result, field scale N balances and residual soil mineral N levels post-harvest are typically low in organic cropping systems, with attendant **reduced risk of N losses via leaching and direct or indirect N_2O losses** (Lynch et al., 2012).

5. **A leguminous, or legumes-in-mixture, perennial or cover crop rotation phase acts as an 'N-buffer' that allows application of diverse carbon-rich soil amendments** (composts etc.). Legume BNF ability avoids a loss of biomass productivity due to N immobilization following amendment application (Lynch et al., 2004).

Summary

The GHG benefits of advanced organic carbon and organic nitrogen management practices, used alone or in-combination, remain understudied and are not currently covered in the National Inventory Report (NIR). **The increasing risk of managing nitrogen in conventional systems at the expense of declining C must be addressed.** Organic systems are ideal production systems for testing and refinement of Advanced Organic Carbon and Nitrogen Management to Improve Agri-Environmental Outcomes for Canada.

Appendix 2: A Literature Review of Soil Health in Organic Systems in Canada – Organic Task Force Report[2]

Context

Healthy soils are the foundation of productive systems. In agriculture, soil health is defined as the ability of the soil to produce high-quality food with minimal inputs. Soil health is the result of multiple interactions between physical, chemical, and biological soil functions (Bünemann et al., 2018). Therefore, soil health indicators need to reflect soil functions. For example, because soil organic carbon (SOC) is the key element that influences multiple soil functions, SOC and labile SOC fractions [particulate (POM-C), permanganate oxidizable (POXc), mineralizable C] are essential components and measures of soil health (Hurisso et al., 2016; Norris et al., 2020). Therefore, relative to other soil properties, more studies on SOC and SOC fractions are included in this review of soil health.

Soil health is important to organic producers. Cranfield et al. (2010) found that health and environmental concerns were a greater motivation than economic considerations for conversion to organic production in Canada. Interviews with 34 producers in Atlantic Canada found that organic producers had a more holistic definition of soil health than conventional producers (Mann et al., 2021). They also tended to be more open to more comprehensive soil health assessments that include chemical, physical, and biological soil properties, such as the Cornell Soil Health Assessment (CSHA). In a study conducted on three organic farms in southwestern Ontario, Hargreaves et al. (2019) found that organic producers' perceptions of productivity and soil health were associated with physical, biological and chemical soil properties.

This review draws on reviews and meta-analyses to compare organic and conventional agriculture in a Canadian context. It is organized as follows:

- Comparisons of soil health under organic and conventional cropping systems.
- Comparisons of soil health under organic and conventional horticultural systems.
- Best management practices to improve soil health.

1. Field crops

[2] By Stéphanie Lavergne, PhD Candidate, Dalhousie University, Faculty of Agriculture

No meta-analysis specific to soil health in organic field crops was found. However, many meta-analyses compared SOC content and concentration. These meta-analyses show that **organic farms have higher soil organic carbon (SOC) concentrations and soil C stocks than conventional farms** (Mondelaers et al., 2009; Gomiero et al., 2011; Gattinger et al., 2012; Tuomisto et al., 2012; García-Palacios et al., 2018). However, in a recent meta-analysis, Alvarez and Cayuela (2022) reviewed 83 head-to-head comparisons of organic and conventional systems. They found that organic systems increased SOC compared to conventional systems, but mostly because of external sources of C (manure from animal production or residue retention). They concluded that organic farming itself does not increase SOC. García-Palacios et al. (2018) found that organic systems had higher soil respiration, SOC stocks, and SOC sequestration rates than conventional systems. Their main explanation was the source of fertilization in organic systems, an external source of carbon inputs. They also hypothesize that crop traits (e.g., leaf N and fine-root C and N) play an important role in the effects of organic systems on SOC stocks and sequestration rates.

Long-term agroecosystem research experiments around the world have compared organic field cropping systems with conventional ones. Most of these studies have collected soil health data over many years. In the majority of these studies, organic systems generally have higher SOC content or concentration than conventional systems when an external C source is used (Teasdale et al., 2007; Delate et al., 2013; Omondi et al., 2022; Mayer et al., 2022). This is reflected in other soil health indicators such as SOM, POM-C, MBC (microbial carbon biomass), POXc (Spargo et al., 2011; Wortman et al., 2011; Delate et al., 2013; Braman et al., 2016; Krauss et al., 2022; Mayer et al. 2022; Lori et al., 2023; Rodale Institute, 2021). However, in P and N deficient systems, organic systems do not outperform conventional systems (Malhi et al., 2009; Bell et al., 2012). Furthermore, soil health in organic systems tended to be similar to conventional ones when organic systems are compared to conventional systems using best management practices such as no-till, cover crops, or manure amendments (Green et al., 2005; Spargo et al., 2011).

Organically managed soils tended to have higher aggregate stability (Lotter et al., 2003; Green et al., 2005; Gomiro et al., 2011; Stainsby et al., 2022). Bulk density has also been reported to be lower in organically managed soils than in conventional soils after 40 years in the USA (Rodale Institute, 2021). Organically managed soils also tended to have higher pH, K, P and N availability (Birkhofer et al., 2008; Wortman et al., 2011; Delate et al., 2013), although in some cases P depletion has been observed in organically managed soils (Malhi et al., 2009; Welsh et al., 2009; Fraser et al., 2019).

2. Horticulture

2.1 Fruits and vegetables

Soil health literature in organic horticultural crops is especially scarce in Canada. A long-term study in Italy (Campanilli and Capi, 2012) reported that over a nine-year period, the SOC and TN content of the organic management system increased over time following the conversion period, while the SOC and TN content of the conventionally managed soils tended to remain unchanged. In California, USA, Reganold et al. (2010) measured soil health in 13 paired organic and conventional strawberry fields. They reported that organic soils had higher SOC, TN, MBC, and mineralizable C than conventional soils. In an on-farm survey conducted in Quebec, preliminary results suggest that organic commercial farms had higher topsoil SOM content and lower soil bulk density compared to conventional farms (Bélanger et al., 2024). In a study conducted on mixed commercial farms in southwestern British Columbia, Norgaard et al. (2022) found no difference in POXc and soil N-NO3 between management strategies. Residual P was eight times higher with high compost than with low compost. In their study, 80% of the farms were organic. In a study conducted on thirty organic mixed vegetable farms in Michigan, USA, Kaufman et al. (2020) reported that BMPs such as tillage depth, cover crop use, and types of soil amendments could increase SOM levels on organic farms. Looking at different management strategies in organic vegetable systems in the US, Prichett et al. (2011) reported that organic amendments had the greatest short-term effect on SOC and bulk density compared to reduced tillage and cover crops.

In Eastern Canada, two soil health assessments were conducted on commercial potato farms. Potato rotations in Eastern Canada typically include cereals and are therefore discussed separately from other vegetable studies. In New Brunswick, Nesbit et al. (2014) found that the mean abundance of nematodes, mite suborders and Collembola families did not differ significantly between organic and conventional fields. However, in the same study, organically managed fields had MBC, pH, soil moisture, litter light fraction, and lower C:N ratio and bulk density than the conventional fields. Boiteau et al. (2014) also evaluated soil health in four systems in New Brunswick. They found that conventional production systems had the lowest levels of biological parameters (i.e., earthworm abundance, biomass, soil respiration, Acari, and Collembola abundance) compared to organic potato fields, an abandoned potato field, and pasture. They also reported that conventional systems had the highest P content and P saturation, while organic systems had the highest soil TN and calcium content. In Prince Edward Island and New Brunswick, Nelson et al. (2009) evaluated soil health in extensive potato rotations (i.e., potato phases followed by 4 years of forage) and found a recovery in earthworm abundance and biomass two years after the potato phase, while other soil health parameters remained unchanged.

2.2 Vineyards

Vineyard studies comparing organic to conventional management were mostly conducted in Europe. In a long-term study of organic, biodynamic, and integrated vineyard management in Italy, Simona et al. (2024) found that the sustainability level of organic vineyards was higher than that of integrated vineyards. However, when looking specifically at soil health, bacterial species richness and diversity and SOC storage in integrated management production were similar to those in organic production systems. These results are similar to those reported by Meissner et al. (2019) and Gutiérrez-Gamboa et al. (2019) in studies conducted on research farms. Both reported similar soil health parameters in organic vineyards compared to integrated vineyards. Other studies conducted on commercial vineyards reported similar soil health between conventional and organic vineyards (Vavoulidou et al., 2006; Wheeler and Crips, 2011; Van Geel et al., 2017; Unc et al., 2021). Nevertheless, other studies conducted in commercial vineyards reported higher soil health in organically managed vineyards compared to conventional vineyards (Coll et al., 2014; Brunori et al., 2016; Orkur et al., 2016; Amaral et al., 2022). Interestingly, Coll et al. (2014) reported that most soil health parameters (e.g., SOC, available P and K, and microbial biomass) were higher than in conventional vineyards after 11 years of organic management, but not after only 7 years.

However, organic vineyards appear to be detrimental to earthworms in some cases (Coll et al., 2014; Beaumelle et al., 2023). The use of copper in organic orchards may explain lower earthworm abundance (Steinmetz et al., 2017).

On-farm studies assume that conventional and organic vineyards have identical soil characteristics at the time of conversion, which limits the conclusions that can be drawn from on-farm studies and emphasizes the importance of long-term studies to assess soil health (Probst et al., 2008).

2.3 Orchards

Most of the soil health data available for orchards comes from commercial farm comparisons. **These on-farm studies suggest that organic orchards support soil health parameters compared to conventional orchards.**

A study of mixed fruit orchards in Cyprus found that soils in organic orchards had higher SOM mean weight diameter and respiration than conventional mixed fruit orchards (Ioannidou et al., 2022).

In Spain, Herencia et al. (2019) reported higher SOM, TN, available P, Mg, earthworm abundance and microorganisms in organic plum orchards than in conventional plum orchards.

However, another study conducted in commercial orchards in Belgium showed that SOC, SOM, TN, and bulk density did not differ between integrated and organic orchards (Dealemans et al., 2022). Similar results were reported by Orpet et al. (2020) as soil health parameters did not differ between transition, organic, and conventional apple orchards in the USA.

In a study conducted at a research farm in Washington, Glover et al. (2000) reported that the integrated apple orchard had a higher soil health score than the conventional orchard. The organic production system did not result in a significantly different soil health score than the other two management systems. In this study, both the integrated and organic orchards had lower bulk density and higher MBC than the conventional apple orchard.

3. Best management practices to improve soil health

In a systematic review, Tully and McAskill (2020) reported 17 studies where reduced tillage in organic systems resulted in higher topsoil SOC and microbial biomass compared to conventional tillage. Reduced tillage was also associated with greater soil stratification compared to conventional tillage in most of these studies. They also reported increased soil aggregate stability in four studies, increased water content in one study, and reduced soil erosion in three studies. However, most of the comparisons do not account for variability in tillage intensity and frequency (Tully and McAskill, 2020).

In an on-farm survey in the Midwestern organic corn system, Sprunger et al. (2021) reported that tillage intensity was associated with increased crop diversity and decreased soil health.

Research on organic no-till has been conducted in Canada. In a review of no-till research projects conducted in Eastern Canada, Halde et al. (2017) reported that the fact that soil health was not measured was a research gap.

In a study conducted in Nova Scotia comparing different green manure termination strategies, Marshall and Lynch (2018) found that three years after green manure termination, topsoil SOC was higher in the no-tilled green manure compared to the tilled green manure. In the same experiment, they also found lower earthworm abundance in the tilled treatment compared to no-till; however, the earthworm population recovered three years after tilling (Marshall and Lynch, 2018).

In Western Canada, Halde et al. (2014) investigated the adaptation of no-till practices to include cover crop mulch. They found a similar yield under the organic no-till system as the organic tilled system (Halde et al., 2014).

Halde et al. (2015) compared different types of cover crop mulch and reported that hairy vetch mulch was the best option for N supply and weed control. Soil organic carbon, P, and pH did not vary between treatments. No other soil health parameters were measured in these systems.

Future organic no-till trials in Canada should be conducted over a longer period of time and include soil health measurements.

In a meta-analysis of different BMPs in organic systems, Crystal-Ornelas et al. (2021) found that cover crops increased SOC by 10% compared to no cover crops. They also found a temporal trend where the effects of cover crops were significant 5 years after adoption.

Incorporating cover crops into the rotation may be more beneficial when combined with organic amendments. Studies have found that the combination of cover crop use with animal manure application can improve N use efficiency (Torstensson et al., 2006), soil N availability (Chirinda et al., 2010; Kauer et al., 2015; Spargo et al., 2016), and soil respiration (Chirinda et al., 2010). The combination of cover crop use and organic amendments can reduce animal manure application rates and improve nitrogen use efficiency.

The benefits of cover crops on cash crop yields have been demonstrated in eastern Canada. Lavergne et al. (2021) found that cover crops seeded after grain harvest increased soil nitrates in the following spring, contributing to corn yield. Similar results have been reported for organic wheat (Alam et al., 2018) and organic potatoes (Alam et al., 2016). The use of cover crops in organic systems does not always result in higher soil health (McNeil et al., 2023) or higher cash crop yields (Evans et al., 2016), leaving room for optimization of cover crops depending on both region and system (Thiessen Martens, 2019).

Adding forages to organic crop rotations can improve soil health (Sprunger et al., 2021). A meta-analysis showed that organic farms tend to have longer crop rotations, resulting in higher diversity than conventional farms (Barbieri et al., 2017). Including alfalfa in organic cereal rotations increases SOC (Wander et al., 2007; Welsh et al., 2009) and soil biological activity (Wander et al., 2007; Braman et al., 2016). Over a 5-year rotation, Wachter et al. (2019) found that SOC remained unchanged after two organic rotations with alfalfa, but decreased under conventional management. There are some exceptions (Bell et al., 2012; Wortman et al., 2011; Blanco-Canqui et al., 2017; Spargo et al., 2011). Including alfalfa in grain rotations can also increase soil nitrogen (Welsh et al., 2009; Spargo et al., 2011). Integrating livestock into organic cropping systems could improve soil health and SOC status.

Integrated livestock is a great opportunity for grazing crop residues (Rakkar and Blanco-Canqui, 2018). Livestock can be integrated in different ways into cropping systems (e.g., lambs and goats in vineyards and orchards, cattle on mixed crop farms, or chickens on vegetable farms). Long-term studies and global systematic comparisons of soil health in organic and conventional field crop systems suggest that efficient stockless organic systems rely on external sources of manure (e.g., Omondi et al., 2022; Mayer et al., 2022). Smith et al. (2000) studied the effect of organic manure application in annual crop and perennial pasture systems and reported that manure application improved SOC in annual crop fields compared to perennial pastures.

The use of perennial crops in the rotation could improve soil health and SOC levels (Spargo et al., 2011; Delate et al., 2013). However, studies have suggested that harvesting or removal of crop residues may limit the ability of perennial crops to increase SOC (Bell et al., 2012). In the US, Rui et al. (2022) reported that perennial pasture managed with rotational grazing was the only treatment that supported MAOM-C and SOC accumulation compared to annual grain systems.

The literature directly addressing the effects of organic management on pastures is sparse. Schulz et al. (2014) observed a negative effect of no-till organic crop production on SOM levels after 11 years, compared to mixed cropping. They also concluded that perennial legume leys should be included in organic crop rotations to maintain SOM.

In northern England, Zani et al. (2021) investigated the effects of organic and non-organic (conventional) farming systems on soil quality indicators on a mixed commercial farm and found that when grazing was included, both conventional and organic systems benefited from significantly improved soil quality. The length of pasture leys in the rotation was positively related to SQ regardless of the type of farming system, and a grass-clover ley length equivalent to 30-40% of the full crop rotation is required to linearly increase soil C concentration.

In a horticultural context, Bilenky et al. (2024) found that integrating chickens has the potential to improve soil health indicators such as microbial biomass without affecting the productivity of organic vegetables.

Reducing pathogen contamination when using raw manure: The use of raw manure in food production may pose a risk of E. coli and Salmonella contamination. Bilenky et al. (2024) found no pathogens on the spinach crop when the leaf surface was exposed, even though the pathogens were present in the field after chicken integration.

The dynamics of disease regulation in the Canadian beef production industry is also a concern in Canada (Pogue et al., 2018). In Canada, raw manure must be incorporated into the soil at least 120 days prior to harvest if the edible portion of the crop is in contact with the soil, or at least 90 days prior to harvest for all other food crops. **Grazing crop residues could reduce the risk of disease from pathogens while improving soil health**. In a review, Rakkar and Blanco-Canqui (2018) reported that residue grazing has less negative impact on wind and water erosion than residue baling and less negative impact on soil properties than grassland grazing.

Conclusion

While there is a large literature resource on the effects of organic farming on SOC, few global studies have examined the effects of organic farming on other chemical, physical, and biological parameters of soil health. Research conducted in the Canadian context, particularly for horticultural crops, is also lacking when considering soil health.

Compared to conventional production, most studies suggest that organic management can maintain soil health and SOC. This is especially true when best management practices are used and combined in organic systems. These practices include reduced tillage intensity and frequency, cover crops, forages, and integration of livestock into the system.

Farming practices in organic systems vary widely in intensity (Lynch, 2022). Therefore, more research is needed to properly assess the impacts of organic management with a variety of practices in Canada's diverse agricultural system.

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