Candidacy Examination

Question 1: What are the key risks, opportunities, and trade offs with regards to agricultural soils and farm performance in an era of changing climate?

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> "*We begin to realize that an overcrowding of people on a diminished soil base may impinge on the intellect, lead to physical and nervous disorders, and break forth ultimately in the hidden hunger that brings on wars*."
>
> ~Dr. John Detweiler, Canadian Conservation Society, President. 1942 meeting of the US Soil Conservation Service, Quoted in Jackson, 1985, p.53

1. Introduction

The climate is changing, manifesting a series of cascading, transdisciplinary risks and opportunities for agricultural soils and farm performance, across local and global scales. This review consolidates insights into these risks and opportunities, in order to understand the trade offs that arise from the need to produce more food for more people, on a land base that is at significant risk due to increasing demand for productivity from less soil in this changing context.

The right combination of soil and climate at the right time in the right place has tipped the fate of farmers, communities and societies since time immemorial (Montgomery, 2012). Soils are the foundation of 97.5 percent of all food consumed by humans (Brevik et al., 2017), and provide an estimated $12 trillion in ecosystem goods and services annually (Costanza et al., 1997, MEA, 2005). Soil and plant processes are intricately linked to the climate through carbon, hydrogen and nitrogen cycles (Singh, 2017), and as the climate changes, these services are increasingly at risk.

The risks of climate change interface with the pressures of an increasing population and decreasing land base on which humans can sustainably live and produce food, risks amplified globally due to a highly concentrated and efficient food system (Lal, 2006a, Sage, 2012, Monbiot, 2022). The functionality and characteristics of farm performance are highly location and soil specific, creating regional climate impacts, experienced and interpreted through unique and sometimes conflicting cultural, environmental and economic lenses. The diversity of soil properties and bioregional priorities challenges the development of common guidance and collective action.

Agriculture is an important contributor to climate change, releasing 5.1-6.1 Gt of carbon dioxide (CO_2) equivalents in 2005, accounting for 10-12 percent of global greenhouse gas (GHG) emissions (IPCC, 2007). Agriculture is responsible for virtually all global methane (CH_4) emissions, and 33-66 percent of nitrous oxide (N_20) emissions (IPCC, 2000, 2007). It is hoped that approximately half of the carbon that has been lost from agricultural and other degraded soils can be restored, mitigating the impact of increasing climate risks, while providing adaptive cobenefits including biodiversity, soil quality, and local food security (Lal, 2004a, IPCC 2018).

Soil degradation contributes to reduced crop yield and is associated with losses in biodiversity and a reduction in ecosystem services that ensure food, water and air quality (Wall et al., 2015). Soil erosion undermines the security of local, national and international food systems, and contributes to increased GHG emissions, accelerating the risks of climate change (Montgomery, 2012).

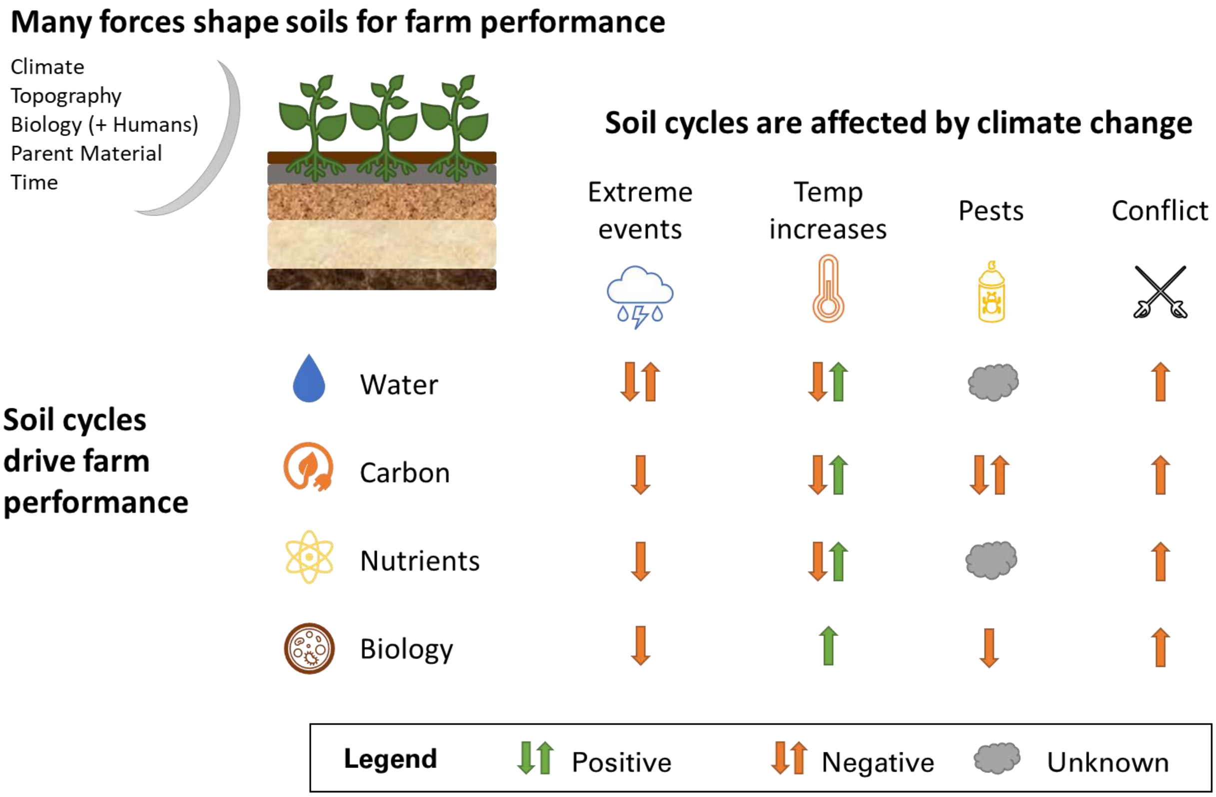
The opportunity to restore carbon-rich soil organic matter (SOM) and soil biology has the potential to sustain agricultural soils, alongside the development of more biogeographically aligned regional food systems. Both of these opportunities require complex, nuanced approaches and language to make soil both strategic and central to solving the crisis in our food systems.

2. Climate change impacts agricultural soils and farm performance

Since the industrial revolution in the 1750s, the atmospheric concentration of CO_2 has risen from 280 parts per million volume (ppmv) to 454 ppmv in 2017 (IPCC 2018). Increases in GHGs include anthropogenic contributions from carbon dioxide, methane, and nitrous oxide, the combination of which are anticipated to increase global temperatures by at least 1.5 degrees over the next decades (IPCC, 2018). As visualized in Figure 1, climate impacts affecting agricultural soils and farm performance include:

a) Extreme climate events
b) Temperature increases
c) Pests and pathogens
d) Conflict for resources

Figure 1: Relationships between soil cycles that drive farm performance, and an assessment of the ways in which a changing climate will influence those cycles (positive, negative, and unknown).



a) Extreme climate events: The seasonality and unpredictability of climate has always been a risk to agricultural soils and farm performance. Extreme climate events such as fires, floods and heat waves create risks to crop yields and productivity of soils. Extreme events disrupt supply chains, the movement of people and goods, cause damage and destruction to soils and surrounding ecosystems, and create significant costs to replace infrastructure and restore productivity (Brevik et al., 2017).

b) Temperature increases: As temperatures rise, soil water cycles are affected. As snowpack melts, water evaporation increases, and seasonal access to water shifts. Large scale deglaciation is expected to raise sea levels, which will inundate some productive lands, displacing urban and rural residents, increasing conflict for land and fresh water (Mimura, 2013). Atmospheric water can impact regions far from the site of evaporation. For example, 40 percent of east Africa’s rainfall comes from the irrigation of crops in India and Bangladesh, 6,000 km away (Monbiot, 2022).

Higher temperatures increase health risks, particularly for agricultural workers. Agricultural workers are often marginalized or disenfranchised, a combination of factors which can make it difficult to ensure safe working conditions. Temperatures are also anticipated to shift growing seasons and require changes to crop varieties and management practices (IPCC, 2018). Higher latitudes are expected to warm faster than those near the equator, which could result in the thawing of permafrost across vast regions of Canada's north (IPCC, 2018, Lal et al., 2000). This could potentially increase the amount of land available for agricultural activity, but will also release large stocks of carbon into the atmosphere, accelerating and exacerbating climate risks.

c) Pests and pathogens: As the climate shifts, patterns of biodiversity of plants and animals are expected to adjust, with implications for agricultural soils and farm performance (Ozenda and Borel, 1990, Rosenzweig and Hillel, 1998). For 460 million years, plants have co-evolved with the soil microbiome, adapting and persisting through countless climate changes, including 20 glaciations over the last 2 million years (Montgomery, 2012, Lambers et al., 2009).

Modern agriculture has dramatically affected above and belowground biodiversity, primarily through habitat destruction, but also through the intensive use of chemicals, including fertilizers and biocides (Gomeiro et al., 2011, Liu et al., 2007). Changing crop varieties and management practices creates new opportunities for pests and pathogens to affect soils and farm performance. The use of monocultures and the simplification of agricultural practices exacerbates the risk of agricultural pests and pathogens (Hsu et al., 2009).

d) Conflict: As food and soil resources are put under pressure by an increasing population and proportion of people affected by climate change, increased conflict is anticipated over access to and distribution of food and natural resources (Brevik et al., 2017). Extreme climate events can displace both humans and animals, increasing pressure on remaining lands. Resource decisions are made in a context of unequal power, and climate risks are expected to further entrench economic, social, and environmental inequities and injustices (FAO, 2015).

Most farmers are isolated and hold little political power, making them susceptible to external decisions that affect their agency and success. Conflict over resources and decision making are additional sources of stress that increase the prevalence of mental health challenges for farmers and the communities where they reside (Brannen et al., 2009, Hagen et al., 2021).

3. Water, carbon and nutrient cycles facilitated by biology and climate connect agricultural soils with farm performance

At the macro-scale, climate, topography, and chemical and physical properties influence soil formation and function (Brady and Weil, 2019, Krzic, 2021). Agricultural management decisions and soil health characteristics are moderated by natural cycles at the micro-scale that impact how a soil will respond to climate change, including the amount of water and soil amendments required to enable productivity, and the eventual amount of carbon that is fixed into food, fuel or fibre (Brady and Weil, 2019, Krzic, 2021, Adhikari and Hartenmink, 2016). Climate-moderated cycles that connect soils and farm performance include:

a) Water
b) Carbon
c) Nutrients
d) Biological

a) Water: Water is required for plant growth and directly impacts farm performance and soil health. Different soil types and plants hold and cycle water differently between the soil and atmosphere, and soil biology impacts how water is made available to plants (Pimentel and Kounang, 1998, Brady and Weil, 2019).

b) Carbon: An important driver of the interactions between plants, agricultural soils and biological life on earth is the release of carbon-based photosynthetic exudates by plants into the soil (Broeckling et al., 2008, Pollierer et al., 2007). The energy from this carbon-based food chain is consumed by a diverse soil food web responsible for cycling nutrients, carbon and water to plants and animals, and which ultimately generates biodiversity and sustains life on earth.

c) Nutrients: Macro and micro-nutrients required for plant and human health originate in the soil, in mineral particles, in soil organic matter (SOM), and in soil organisms (Pimentel and Kounang, 1998). These nutrients play roles in brain function, anemia, immunity, physical and mental development, and degenerative diseases (Golden, 1982, Singh, 2017, Lal, 2009). Globally, 780 million people are undernourished, and billions suffer from micronutrient deficiencies including iron and zinc (FAO, 2015, IFPRI, 2014). Soil nutrients are cycled through plant and animal lifecycles, at rates influenced by factors such as temperature, moisture, soil texture, pH, organisms and human intervention (Kemper et al., 2017). Nutrients are added to the soil by plants and animals in the form of organic matter, and removed from the soil due to gasification, leaching, and removal of plant and animal materials. Nutrients in soils and their availability for uptake by plants directly affects the health of the animals which consume these products.

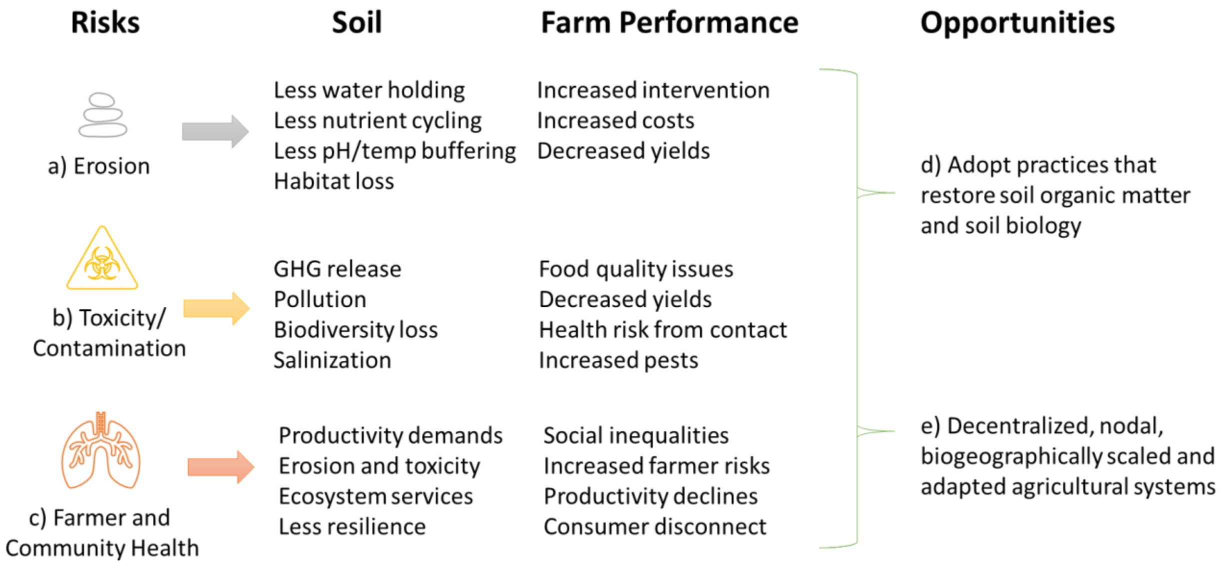
d) Biological: Organisms operating within micro-habitats play important roles in nutrient and water cycling associated with soil health and functionality (Fierer and Jackson, 2006, Lavalle and Spain, 2002, Saleem et al., 2019). The value attributed to soil biology in ecosystem services derives from their roles in aggregation (Mäder et al., 2002), resource (nutrients and water) cycling (deVries et al., 2012), and biostimulation effects (Crecchio 2018). High diversity communities of organisms have been shown to improve plant-beneficial traits, although gene and species level correlation to plant function is still limited (Saleem et al., 2019). Soil organisms are responsive to land management practices and climate, and directly contribute to soil productivity and farm performance (Doran and Zeiss, 2000).

The presence and role of the microbiome is consistently understated in soil processes, and there are gaps in the literature related to the functional roles and spatial and temporal patterns of soil organisms (Bardgett and van der Putten, 2014, Mishra, 2022, Brussard, 1997). In general, increased temperatures increase the rate of biological activity in the soil. Every 10 degrees of increase is estimated to result in a doubling of the rate of biochemical processes (Brady and Weil, 2019). Increased biological activity can increase consumption and release of carbon and other nutrients stored in stable humus compounds, accelerating carbon emissions and nutrient cycling (Crowther and Bradford, 2013, Monbiot, 2022).

4. Risks and opportunities for agricultural soils and farm performance in a changing climate

Considering the myriad impacts to soil cycles arising from a changing climate outlined in Figure 1, several cross-cutting risks become apparent to soils and farm performance overall. The key risks for agricultural soils arising from a changing climate are erosion, toxicity/contamination, and farmer and community health. These risks are interrelated and visualized at a high level in Figure 2, alongside two opportunities to address these risks.

Figure 2. Overview of the key risks to soil and farm performance arising from a changing climate, and opportunities to address these risks.



a) Risk – Erosion

Soil erosion has been described as “the greatest threat to providing food for a rapidly growing human population” (Pimentel and Kounang, 1998), and occurs at an estimated rate of 23 billion tons of soil per year from agricultural lands (Montgomery, 2012). Approximately 80 percent of the world’s agricultural soils are suffering from moderate to severe erosion (Pimentel, 1993). Climate change accelerates soil erosion through increased extreme events, such as flooding and landslides, and through the increase in biological consumption of organic matter, which results in decreased aggregate stability and compaction. Soil erosion rates are affected by soil type and depth, slope, levels of SOM, management practices, crops, rotation, and climate (Pimentel and Kounang, 1998, Jackson, 1985). Erosion makes the soil less resilient to changes in temperature, pH, moisture, and nutrient regulation (Brady and Weil, 2019), and increases the frequency, duration and intensity of drought (Lal, 2009).

The relationship between intensive agriculture and the loss of SOM through soil erosion is “the most important and intensively studied and documented consequences of agriculture” (Gomiero et al., 2011). The practices of intensive agriculture that destroy soil aggregates, such as extensive tillage, the overuse of synthetic fertilizers and biocides, and monocropping/ simplification of crops, contributes to increased rates of soil erosion and loss of SOM and soil biology (Lal, 1993, Brady and Weil, 2019, Sullivan, 2002). The loss of soil aggregates decreases niche diversity, and reduces the ability of soil organisms to support plant growth without human intervention (Pimentel and Kounang, 1998). The simplification of complex soil systems reduces the number of weak biological links, resulting in fewer strong actors competing for the same resources, which amplifies stress signals, and weakens overall system integrity and resilience (Monbiot, 2022). Additionally, eroded soil particles can become airborne and create respiratory issues and spread pathogens, with human health impacts (Singh 2017, Jardine et al., 2007).

Without SOM, soil biology, and the aggregates that they create, water infiltration is reduced, and soil can become compacted, salinized and anaerobic (Lal, 2009, Krzic 2021). When soil and SOM are eroded, the ecosystem goods and services of the soil microbiome are compromised (Smith et al., 2015), with negative effects on ability of soils to provide provisioning and regulatory ecosystem services (Smith et al., 2013). This necessitates costly intervention, often in the form of irrigation, tillage, and chemical application, further reducing SOM, soil organisms and the services they provide.

b) Risk – Toxicity and Contamination

Agricultural activities that contribute to greenhouse gas (GHG) emissions and exacerbate climate change include livestock enteric fermentation, manure management, soil emissions (including from application of amendments and tillage), crop residue burning, and application of urea, lime and carbon-containing fertilizers (IPCC, 2018). In 2019, Canadian agriculture was responsible for 59 Mt CO_2 equivalent GHG emissions annually (Qualman, 2022).

The excess use of fertilizers on agricultural soils is associated with nitrogen leaching, a serious environmental pollution issue (Brady and Weil, 2019, Krzic, 2021). Leached nitrogen can contaminate groundwater, and volatilize into the potent greenhouse gas nitrous oxide (N_2O). Over the last 150 years, 80 percent of the increase in atmospheric N_2O has been attributed to agriculture, and 50 percent of this is due to the use of synthetic fertilizers (Tilman et al., 2002, Robertson and Vitousek, 2009, Vitousek et al., 2009). Human interference has destabilized the global nitrogen cycle, affecting safe operating parameters for planetary life (Rockström et al., 2009).

Only one percent of pesticides reach the target pest (Jackson, 1985), and the remainder have devastating impacts on soil life and other organisms. Over 95 percent of herbicides, and 98 percent of insecticides influence non-target soil organisms (Meena, 2020). Antibiotics used in animal production systems alter the soil biome (Kemper and Lal, 2017), and create selection pressure for antibiotic-resistant organisms (Monbiot, 2022).

Many soils are affected by accumulated heavy metals from waste and chemicals (e.g., arsenic, cadmium and lead), which can be transmitted to humans and other organisms through food and water (Singh 2017, Paoletti et al., 1995). Irrigation with groundwater virtually always results in the distribution of dissolved salts onto the soil, which with evaporation, can result in salinization, dehydration of plants and loss of organisms (Montgomery, 2012).

Toxicity and soil contamination present risks for farm performance, including costs of remediation, increased pest pressure, reduced yields on soils affected by contamination, and reduced quality of products associated with accumulated heavy metals (Brevik et al., 2017).

c) Risk – Farmer and Community Health

Current food systems are designed based on market policies of competition and consumption, which internalize social values of winners and losers, and create policies and practices that seek highest efficiency and lowest costs (Monbiot, 2016, Conway, 1997). Inequalities arising from this system have resulted in a highly concentrated and corporatized global food system, with a disenfranchised middle, and externalized costs borne by ecosystems (Sage, 2012, Berry, 1977).

The increased demand for agricultural productivity for a growing population falls to an aging and decreasing population of farmers, often in rural communities where they have reduced access to services and supports (Stats Canada, 2017, Berry et al., 2011, Monbiot, 2022, Sage, 2012).

Farmer mental health and soil health are critical to future human health and food security (Daghagh 2019, Finnigan 2019, Howard 2011, Tait and Leeder, 2019). Recent research identified that 58 percent of Canadian farmers meet the criteria for an anxiety disorder, 35 percent meet the criteria for depression, and that suicide is common and underreported (Jones-Bitton et al., 2019b).

Poor mental health impacts the ability of producers to work effectively, lowering farm productivity (Jones-Bitton et al., 2019a, Hagen et al., 2019) which can cause further stress and anxiety. Stress in farming populations has been linked to an increase in rates of farm work injuries (Low, et al., 1996; Simpson et al., 2004), farm animal welfare issues (Farm Management Canada, 2020) and increased risk of farmer suicide (Andersen, et al., 2010).

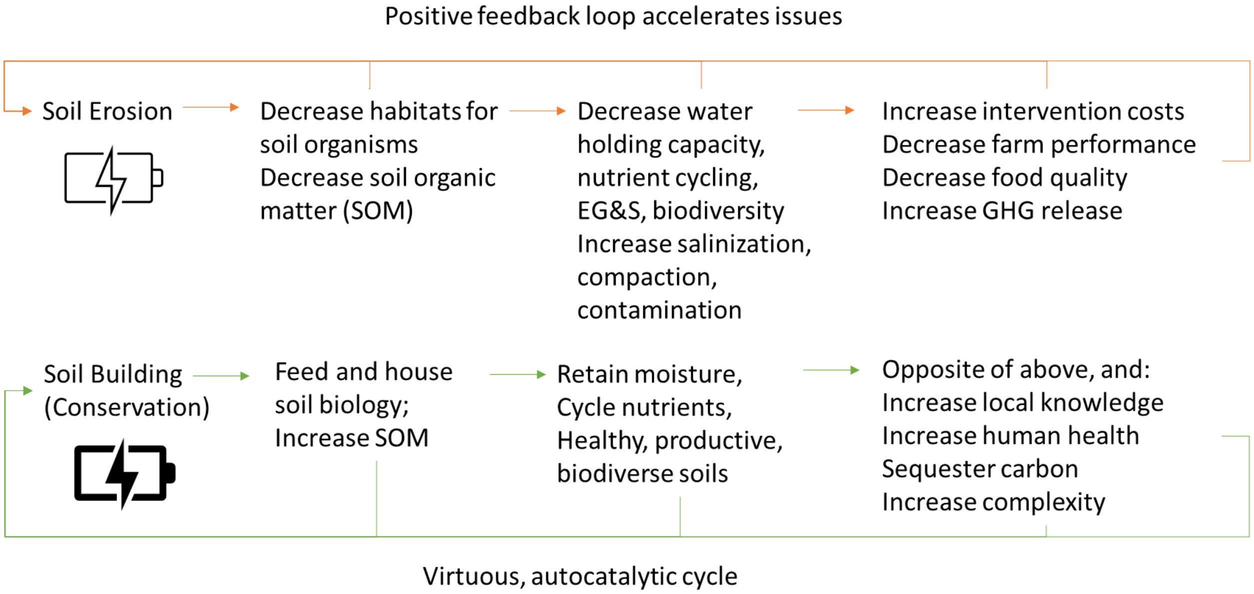
Canadian agricultural policies are designed to absorb the inherent risks of large, specialized farming operations, and most public and private resources and infrastructure (e.g. extension supports, consultants, funding programs) are oriented to support these large producers. In this system, farmers are heavily capitalized, and faced with increased debt, are vulnerable to volatile global markets. Financial uncertainty is a well-established driver of poor mental health (Hagen et at., 2019).

Farmers are allies in the adoption of carbon-capturing soil management practices, but the motivations and needs of this community are often poorly understood (Beedle 2000, Daghagh 2019, Howard 2011). While the connection between soil quality and food quality has received some academic attention, the connection between soil health and human health is a relatively new area of study (Berry, 2011, FAO, 2015, Tun, 2017). Current academic literature at this intersection focuses on the role of nutrient deficiencies, chemical toxicity, and disease-causing microbes (Kemper 2017; Pimentel and Kounang, 1998; Singh 2017, Brevik et al., 2017).

d) Opportunity: Adopt practices that restore soil organic matter and soil biology

As shown in Figure 3, a key opportunity for both agricultural soils and farm performance is the return of soil biology, along with a food source, SOM, to build soil health and human health through ecological production practices. This combination of activities can animate carbon and nutrient cycles that build a virtuous, autocatalytic soil health cycle with cascading benefits.

Figure 3. Visualization of the cascading risks or benefits of soil erosion and soil conservation, based on differential impacts on soil biology and broader soil and farm performance cycles.



The role of soil biodiversity is increasingly recognized as central to ecological goods and services (EG&S) (Cardinale, 2012), but research efforts have primarily focused on aboveground impacts (Bardgett and van der Putten, 2014). About 25 percent of the world's species reside in the soil, with the vast majority undescribed, and non-pathogenic to humans (Kemper et al., 2017). The impact of species loss belowground is not well understood (Bardgett, 2014), although biological diversity in soils has been associated with soil health (Fanzo, 2013), plant health (Wolfe, 2000), animal health and human health (Dobson et al., 2006).

Microbes in the rhizosphere play important roles in the acquisition of nutrients, in the protection and response to pathogens, and in the selection of plant fitness traits, particularly related to drought (Philippot et al., 2013, Bardgett and van der Putten, 2014, Lau and Lennon, 2012, Crecchio, 2018). Droughts are anticipated to increase in intensity and severity as a result of climate change, and a diverse and abundant microbiome plays a well described role in conferring resilience to crop production.

This opportunity capitalizes on the popular idea of returning carbon to the soil, in the form of SOM and in the bodies of soil organisms. SOM is a heterogeneous mix of plant and animal materials in various states of decay, which is on average approximately 58 percent soil organic carbon (Brady and Weil, 2019).

Proponents of methods that increase soil carbon cite short and long-term soil benefits, including reduced erosion (Reganold et al., 1987, Reganold, 1995, Siegrist, 1998, Acton and Gregorich, 1995), reduced losses of carbon and nitrogen (Drinkwater, 1998, Pimentel et al., 2005), improved biomass and biological indicators (Fließbach and Mader, 2000, Fließbach et al., 2000, Fließbach, 2007), improved SOM (Glover, 2000, Marriott and Wander, 2006, Stockdale et al., 2001, Stolze et al., 2000), improved performance during droughts (Lotter et al., 2003), and improved water retention capabilities (Pimentel et al., 2005). The most common criticisms of organic agriculture and methods that adopt more systems- or soil-based approaches are reduced yields, and weed control issues (Teasdale et al., 2007, Cavigelli, 2007).

Yield may not always be a sacrifice in this system. An increase of one Mg carbon ha^{-1} per year could increase grain yields by as much as 100-300 kg ha^{-1} year^{-1} for corn, 20-70 kg ha^{-1} year^{-1} for wheat, and 10-45 kg ha^{-1} year^{-1} for rice (Lal, 2006b). Under drought conditions, organically managed agricultural systems consistently produce higher yields than conventional systems (Lockeretz et al., 1981; Stanhill, 1990; Smolik et al., 1995; Teasdale et al., 2000; Lotter et al., 2003; Pimentel et al., 2005). For every increase of SOM by one percent, 10-11,000 litres of plant-available water can be held in the first 30 cm per hectare (Sullivan, 2002). Soil organisms contributing to soil aggregation is a possible mechanism for improved water holding capacity and yield (Lotter et al., 2003).

There are debates about the amount of carbon that can be stored through soil conservation practices, and estimates of the potential for carbon sequestration in agricultural soils vary widely.

Modern agriculture has released 42-78 Gt of stored soil carbon, and it is estimated that with changes in management practices, 50 to 66 percent of this carbon could be restored (Paustian et al., 1998, Lal, 2004b). This sequestration could be achieved at a rate of 0.4-1.2 Gt of carbon annually, which represents 5-15 percent of global fossil fuel emissions (Lal, 2004b). Smith et al. (2008) estimate that 20 percent of total global CO_2 emissions could be offset by improved agricultural practices.

Practices that have been cited for their ability to restore SOM include the adoption of organic principles and practices (Bengtsson, 2005, Birkhofer and Bezemer, 2008, Kasperczyk and Knickel, 2006), reduced or no till systems, (Jackson, 1985), cover crops; managed grazing (Lal, 2004a), rotation of crops and increased crop diversity (Lal, 2004a, Jackson, 1985), inclusion of perennial crops (Jackson, 1985), and improved irrigation, among others.

Rates of carbon sequestration depend on crops grown, soil management practices, and abiotic factors such as soil texture, moisture and temperature (Lal, 2004b, Brady and Weil, 2019, Krzic, 2021). It takes time for changes in practice to manifest detectable changes in SOM, typically three to five years (Clark et al., 1998).

If all agricultural soils were to shift to maximal carbon-sequestering practices and sustain these practices indefinitely, in approximately 100 years, the upper levels of carbon carrying capacity would be reached, and little additional carbon could be stored (Foerid and Høgh-Jensen, 2004). It is also important to note that stored soil carbon has the potential to be released through disturbance, and that the value of this carbon in production systems arises from its dynamic release in broader nutrient cycling processes (Janzen, 2006, Lal, 2004b, Kramer et al., 2006). Because nutrient cycling is enabled by soil biology and climate, any conversation about soil carbon sequestration without considering the flow of carbon, nutrients and water through biotic and abiotic systems is incomplete.

The value of SOM and soil biology are recognized broadly, as are the benefits of adopting soil conservation practices (Lal, 2004b). The role of the soil microbiome as a potential positive force in human health is beginning to be recognized (Kemper et al., 2017).

e) Opportunity: Decentralized, nodal, biogeographically scaled and adapted agricultural systems

Issues with agricultural soils and farm performance reflect issues with broader food systems (Berry, 1977). Consolidated, corporatized food chains are highly efficient and vulnerable to disturbance (Sage, 2012). The current food system has maximized the flow of energy in terms of food calories and capital, resulting in a “global standard diet, and a global standard farm” (Monbiot, 2022). This efficiency has come at the cost of the loss of the genetic and cultural diversity of our foods (Jackson, 1985), alongside issues with erosion, toxicity and conflict (Montgomery, 2012).

Biogeographically adapted systems can be scaled to the appropriate supply and demand for communities, and can be attentive to unique considerations such as soil properties and micro-climates. Locally adapted plants and organisms fed by locally cycled nutrients are more resilient to local conditions (Howard, 1945). A geographically scaled nodal food system allows multiple value systems to exist simultaneously, shifting from consumers interacting with nameless, faceless commodities accessed based on cost and convenience, to adaptive systems that derive value from diversity, while reinforcing connection to people and places. By restoring healthy soils to produce locally adapted and available products, resiliency is built into the food system network, creating pathways for communities and cultures to differentiate and adapt. This shift allows for the restoration of relationships between people, place and products, building consumer awareness and farmer and community agency.

Most farmers have no bargaining power to ask for changes to the current food system. They are price takers in global markets, and face climate risks and pressure to meet demands and maximize returns (Weis, 2022). Consumers play an unwitting role in perpetuating a system that values low cost at all costs. Greenwashing is a common corporate practice that seeks to capitalize on the individual’s desire to make sustainable choices, with little to no regulatory oversight. Our existing economy is based on manufactured scarcity and does not reflect true costs. Kimmerer (2022) suggests that if we allowed our economy to reflect the true value of ecological functional value, we would actually increase the size of the economy. Tangible solutions to this problem will require new language and mechanisms to inform and engage consumers in ways that incentivize and enable meaningful behaviour change.

5. Trade Offs

The trade offs required to address the complex and interrelated risks to farms, farmers, soils and ecosystems in the face of a changing climate are inseparable from broader risks to human and societal wellbeing, particularly in rural and marginalized communities (Montgomery, 2012, Brevik and Sauer, 2015).

If we continue to enable practices and systems that privilege efficiency and control within our food systems, we will continue to experience the current trade offs of low commodity costs for externalized costs borne by the environment, including soil erosion, contamination, decreased biodiversity, and decreased food quality, supporting a positive feedback loop that accelerates climate change and conflict for resources (Magdoff, 2012, Magdoff and Tokar, 2009, Sage, 2012, Peterson et al., 2006). The beneficiaries of the status quo are large-scale profit-driven corporations and individual consumers seeking convenience with a limited budget, where short-term economic priorities and control are traded for long-term productivity and environmental sustainability (Berry, 1977, Jackson, 1985).

If, on the other hand, we choose to adopt practices that increase soil biology and SOM, and support decentralized, nodal, biogeographically scaled and adapted agricultural systems, a new set of trade offs emerge. In this situation, we trade corporate profits for ecosystem values and community-level services (Phelan, 2009, Weis, 2022). We trade the global standard diet for locally adapted knowledge and seasonally available, nutrient dense and climate resilient foods (Monbiot, 2022). We trade yield and profitability for local decision making and adaptive resilience. We trade simplification for complexity, which necessitates new language and new ways of governing resources (Howard, 2011, Jackson, 1985).

Our society has deep roots of exploitation in policies and practices relating to soils, and the opportunities presented in this critical review represent a shift in perspective from the rights of the individual to the nested and interdependent rights of the system (Berry, 1977, Wiebe, 2022). With this opportunity we allow for local values to emerge and create weak links that add resilience to food systems. When we know and value our farmers, we support their efforts and reduce the risks associated with transitioning to new approaches.

Conflicting perspectives exist on almost every subject related to agriculture and soils. For example, as a means to shift from intensive agricultural practices reliant on chemical pesticides, Jackson (1985) presents the use of integrated pest management as a potential solution. Pimentel (2005) describes the trade off for this individual shift in practice of a global crop loss for all food and fibre of 33-42 percent. For food crops, the losses would be in the range of 9-11 percent, with downstream impacts on global hunger and conflict for resources. These numbers only tell part of the story, as a shift away from “continued chemotherapy on the land” (Jackson, 1985), could help society regain our connection to healthy places and a healthy spirit, one which is mirrored with an increase in biodiversity and restoration of our natural places. Similar debates exist for other soil building practices, such as organic, regenerative, no till, cover crops, nutrient management, and irrigation, among others (Lal, 2004b).

Transitions require time and energy, new mindsets, structures, and new language. The question is, do we continue down this path of degradation, and continue to defer the ethical, social and environmental implications of our actions, or do we consider Jackson’s (1985) question, “is any level of efficiency worth any cost?” Our ability to feed and sustain ourselves in the age of climate change will greatly depend on the health and functionality of agricultural soils. Soil can no longer be viewed merely as a commodity and a growing medium. The symbiotic relationship between organisms, plants and animals is fundamental to human health and wellbeing. We are a part of the system. If we choose to value and support these relationships, through policy and practice, we begin a virtuous cycle that may enable our mutual survival.

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