National Student Paper Competition

Title: Risks and opportunities for agricultural soils and farm performance in an era of changing climate

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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.

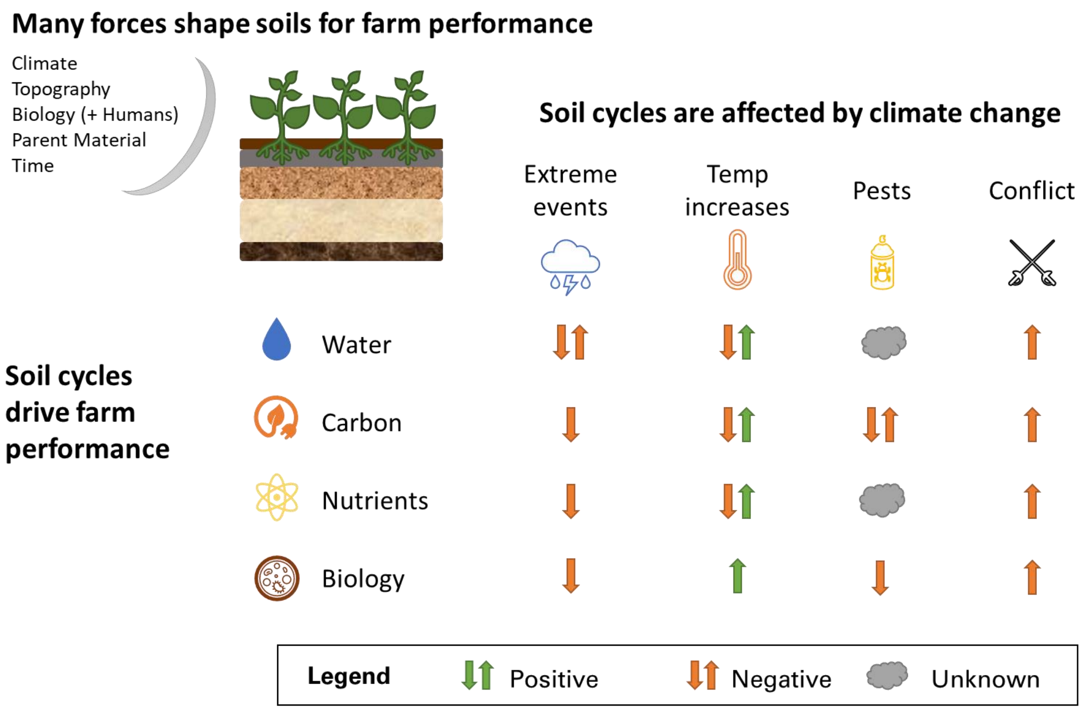
The risks of climate change interface with the pressures of an increasing population and decreasing land base on which humans can sustainably live and produce food, risks amplified by a highly concentrated and efficient global food system (Lal, 2006a, Sage, 2012, Monbiot, 2022). The diversity of soil properties and biogeographical priorities challenges the development of common policy guidance and collective action.

The opportunity to restore carbon-rich soil organic matter (SOM) and soil biology has the potential to future-proof agricultural soils, especially when considered in combination with the encouragement of bioregional food systems that celebrate local differences.

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

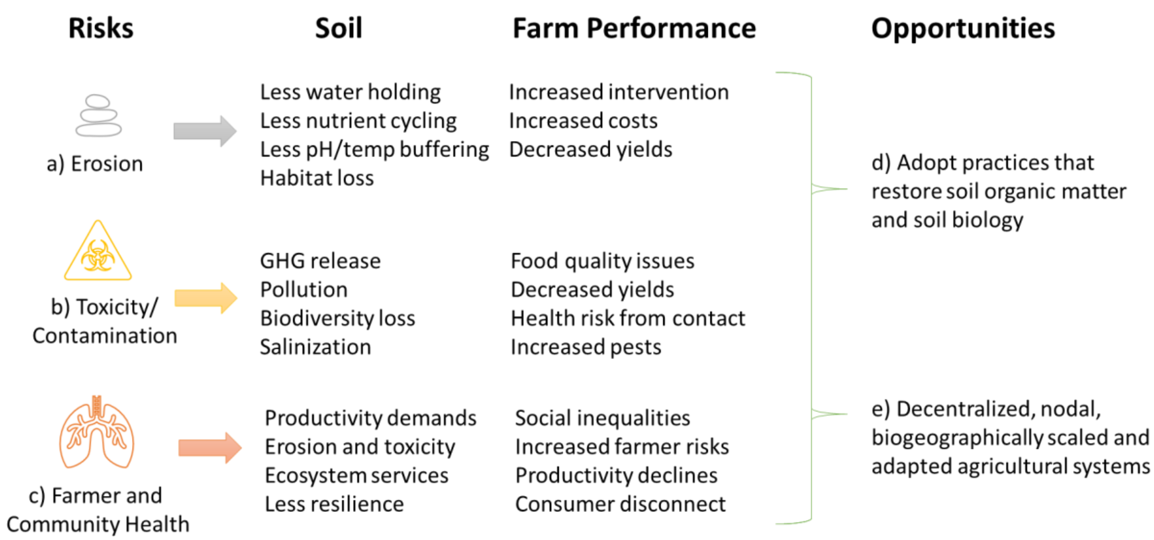
Agriculture is an important contributor to climate change, releasing 5.1-6.1 Gt of carbon dioxide (CO_2) equivalents in 2005, accounting for 10-12 percent of greenhouse gas (GHG) emissions globally (IPCC, 2007). Agriculture is responsible for virtually all global methane (CH_4) emissions, and 33-66 percent of nitrous oxide (N_20) emissions (IPCC, 2000, 2007). In 2019, Canadian agriculture was responsible for 59 Mt CO_2 equivalent GHG emissions (Qualman, 2022). As visualized in Figure 1, climate affects agricultural soils and farm performance in various ways (positive, negative and unknown), from forces such as extreme events, temperature increases, pests and pathogens, and conflict.

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).



Considering the myriad impacts to soil cycles arising from a changing climate, several cross-cutting risks emerge, including 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 and opportunities for soil and farm performance arising from a changing climate.



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). 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).

b) Risk – Toxicity and Contamination

Agricultural activities that contribute to toxic greenhouse gas (GHG) emissions that exacerbate climate change include livestock enteric fermentation, manure management, soil emissions (e.g. arising from tillage), crop residue burning, and application of urea, lime and fertilizers (IPCC, 2018, Brady and Weil, 2019, Krzic, 2021).

Toxicity and soil contamination present risks for farm performance, including costs of remediation (Jackson, 1985), increased pest pressure (Meena, 2020, Kemper and Lal, 2017), reduced yields (Monbiot, 2022), and reduced quality of products associated with bio-accumulated heavy metals and reduced nutrient density (Brevik et al., 2017).

c) Risk – Farmer and Community Health

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).

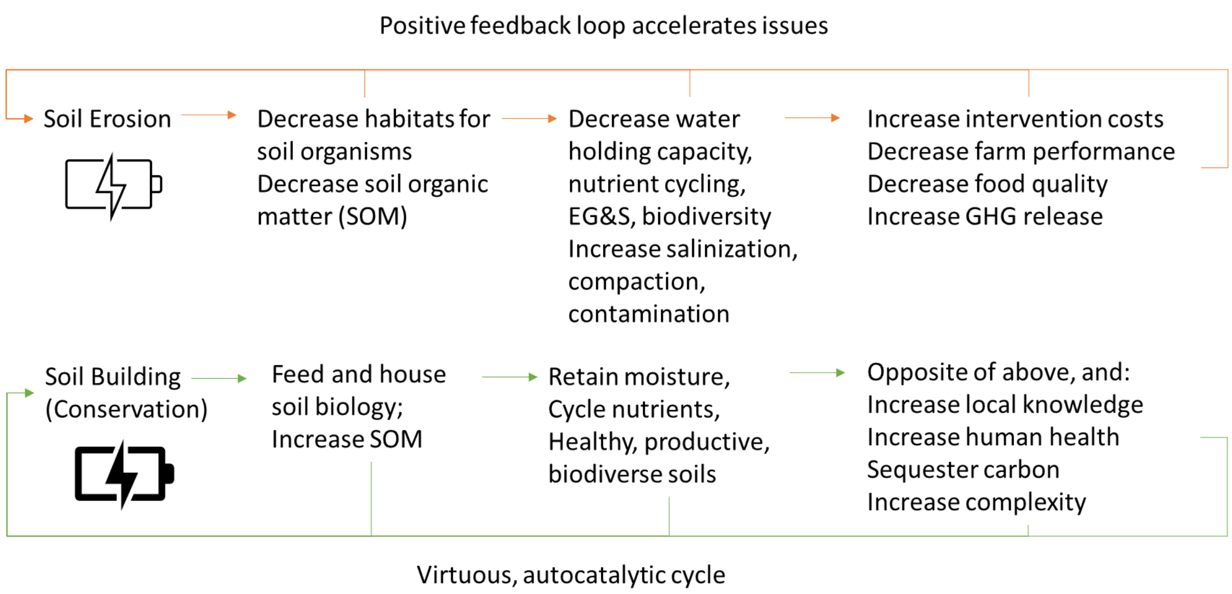
Farmer mental health and soil health are critical to future human health and food security (Daghagh 2019, Finnigan 2019, Howard 2011, Tait and Leeder, 2019). Recent research identifies that 58 percent of Canadian farmers meet the criteria for an anxiety disorder, 35 percent meet the criteria for depression, and that suicide is common and underreported (Jones-Bitton et al., 2019b). Poor mental health impacts the ability of producers to work effectively, affecting farm productivity (Jones-Bitton et al., 2019a, Hagen et al., 2019), an issue of national concern (Finnigan, 2019).

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, making them vulnerable to volatile global markets. Financial uncertainty is a well-established driver of poor mental health (Hagen et al., 2019).

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

The proposed mechanism to restore soil carbon and soil health more generally is to return soil biology, along with a food source, SOM 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, as shown in Figure 3.

Figure 3. Visualization of the cascading risks or benefits of soil erosion and soil conservation.



It is estimated 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 co-benefits including biodiversity, soil quality, and local food security (Lal, 2004a, IPCC 2018). Increased soil carbon can reduce erosion (Reganold et al., 1987, Reganold, 1995, Siegrist, 1998, Acton and Gregorich, 1995), reduce losses of carbon and nitrogen (Drinkwater, 1998, Pimentel et al., 2005), improve biological diversity (Fließbach and Mader, 2000, Fließbach et al., 2000, Fließbach, 2007), improve performance during droughts (Lotter et al., 2003), and improve water retention (Pimentel et al., 2005). The most common criticisms of these concepts are reduced yields and weed control issues (Teasdale et al., 2000, 2007, Cavigelli, 2007).

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 meet supply and demand for communities, in a way that is 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). By restoring healthy soils to produce locally adapted and available products, resiliency is built into the food system, creating pathways for communities and cultures to differentiate and adapt. This shift allows for restoration of relationships between people, place and products, building consumer awareness and farmer agency.

3. Conclusion

If we continue to enable practices and policies that privilege efficiency at all costs within our food systems, we will continue to experience the current trade offs of low priced food for externalized costs borne by the environment and communities, including soil erosion, contamination, biodiversity loss, and decreased farmer mental health, supporting a 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 corporations and consumers seeking convenience with a limited budget, where short-term economic priorities 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. Here, corporate profits are exchanged for ecosystem 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.

Transitions require time and energy, new mindsets, structures, and new language. 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.

References

Acton, D.F., Gregorich, L.J., (1995). The Health of Our Soils: Toward Sustainable Agriculture in Canada. Agriculture Agri-Food Canada, CDR Unit, Ottawa.

Berry, H.L., Hogan, A., Owen, J., Rickwood, D., Fragar, L., (2011). Climate Change and Farmers' Mental Health: Risks and Responses. Asia Pacific Journal of Public Health. doi:10.1177/1010539510392556.

Berry, Wendell, (1977). The Unsettling of America: culture and agriculture. Counterpoint. Berkeley, CA.

Brady, N. C., Weil, R. R. (2019). Elements of the nature and properties of soils. 4th Ed. Pearson, New York.

Brevik, E. C., et al. (2017). Links Between Soil Security and the Influence of Soil on Human Health, Springer International Publishing: 261-274.

Cavigelli, M. A., Teasdale, J. R., and Conklin, A. E. (2007). Long-term agronomic performance of organic and conventional field crops in the Mid-Atlantic Region. *Agronomy J*. 100: 785–794.

Crecchio, C. et. al. (2018). Beneficial Soil Microbiome for Sustainable Agriculture Production. *Sustainable Agriculture Reviews 31: Biocontrol*. 31(443-481).

Daghagh, Y., Wheeler, Z., (2019). Key Risk Factors Affecting Farmers' Mental Health: A Systematic Review. *Int. J. Environ. Res. Public Health*. doi:10.3390/ijerph16234849.

Drinkwater, L. E., Wagoner, P., and Sarrantonio, M. (1998). Legume-based cropping systems have reduced carbon and nitrogen losses. *Nature* 396: 262–265.

Finnigan, P., (2019). Mental Health: A Priority for our Farmers. Standing Committee on Agriculture and Agri-Food, Government of Canada.

Fließbach, A., and Mader, P. (2000). Microbial biomass and size-density fractions differ between soils of organic and conventional agricultural systems. *Soil Biol. Biochem*. 32: 757–768.

Fließbach, A, Mader, P., and Niggli, U. (2000). Mineralization and microbial assimilation of 14C-labeled straw in soils of organic and conventional agricultural systems. *Soil Biology & Biochem*. 32: 1131–1139.

Fließbach, A., Oberholzer, H. R., Gunst, L., and Mader, P. (2007). Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. *Agric. Ecosyst. & Environ*. 118: 273–284.

Gomiero, T., et al. (2011). Environmental Impact of Different Agricultural Management Practices: Conventional vs. Organic Agriculture. Critical Reviews in Plant Sciences 30(1-2): 95-124.

Hagen B.N.M., Albright A, Sargeant J, Winder CB, Harper SL, O'Sullivan TL, et al. (2019). Research trends in farmers' mental health: A scoping review of mental health outcomes and interventions among farming populations worldwide. *PLoSONE 14(12)*:e0225661. https://doi.org/10.1371/journal.pone.0225661.

Howard, A. (1945). An agricultural testament. Oxford University Press, New York.

Howard, A. (2011). The Soil and Health: A Study of Organic Agriculture. Oxford City Press.

IPCC (Intergovernmental Panel on Climate Change), (2000). Emissions Scenarios. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Nakicenovic, N., and Swart, R., Eds. Available online at http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0 (accessed 6 December 2022).

IPCC (Intergovernmental Panel on Climate Change), (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (Eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, (2018): Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.

Jackson, Wes, (1985). New Roots for Agriculture. University of Nebraska Press.

Jones-Bitton, A., Best, C., Mactavish, J., Fleming, S., & Hoy, S. (2019a). Stress, anxiety, depression, and resilience in Canadian farmers. *Social Psychiatry and Psychiatric Epidemiology*, 1-8.

Jones-Bitton, A., Hagen, B., Fleming, S.J., Hoy, S., (2019b). Farmer burnout in Canada. *Int. J. Environ. Res. Public Health*, 16(5074), 1-15.

Kemper, Kathi, Lakritz, J., Lal, Rattan, (2017). The soil-animal-human health nexus. In: The Nexus of Soils, Plans, Animals and Human Health. Eds. Singh, McLaughlin, Brevik. International Decade of Soils. Catena Soil Science, Stuttgart, Germany.

Krzic, M., Walley, F., Diochon, A., (2021). Digging into Canadian Soils: An introduction to soil science. Canadian Society of Soil Science. Accessed online October 4, 2022 at: openpress.usask.ca/soilscience/.

Lal R (1993). Tillage effects on soil degradation, soil resilience, soil quality, and sustainability. *Soil Tillage Res* 27:1–8.

Lal, R. (2004a). Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. *Science* 304(5677): 1623-1627.

Lal, R. (2006a). Managing soils for feeding a global population of 10 billion. *J Sci Food Agric*. 86(14): 2273-2284.

Lal, R., (2009). Soil degradation as a reason for inadequate human nutrition. *Food Sec*. 1:45-57. DOI 10.1007/s12571-009-0009-z.

Lotter, D. W., Seidel, R., and Liebhart, W. (2003). The performance of organic and conventional cropping systems in an extreme climate year. *Am. J. Alternative Agriculture* 18: 146–154.

Magdoff, F. (2012). Food as a Commodity. *Monthly Review*, *63*(8), 15-22.

Magdoff, F., Tokar, B. (2009). Agriculture and food in crisis. *Monthly Review*, *61*(3), 1-16.

Meena, Ram Swaroop, Kumar, Sandeep, Datta, Rahul, Lal, Rattan, Vijayakumar, Vinod, Brtnicky, Martin, Jangir, Chetan Kumar, (2020). Impact of Agrochemicals on Soil Microbiota and Management: A Review. *Land* 9(2):34.

Monbiot, George (2022). Regenesis: Feeding the world without devouring the planet. Penguin Random House. USA.

Montgomery, D, (2012). Dirt: The erosion of civilizations. University of California Press, Berkeley.

Petersen, S. O., Regina, K., Pollinger, A., Rigler, E., Valli, L., Yamulki, S., Esala, M., Fabbri, C., Syvasalo, E., and Vinther, F. P., (2006). Nitrous oxide emissions from organic and conventional crop rotations in five European countries. *Agric. Ecosys. & Environ*. 112: 200–206.

Phelan, P. L., (2009). Ecology-based agriculture and the next green revolution. In: Sustainable Agroecosystem Management, pp. 97–135. Bohlen, P. J., and House, G., Eds, CRC Press, Boca Raton, FL.

Pimentel, D. and N. Kounang (1998). Ecology of Soil Erosion in Ecosystems. *Ecosystems* 1(5): 416-426.

Pimentel, D., Hepperly, P., Hanson, J., Douds, D., and Seidel, R. (2005). Environmental, energetic, and economic comparisons of organic and conventional farming systems. *BioScience* 55: 573–582.

Qualman, D., and National Farmers Union, Agricultural Greenhouse Gas Emissions in Canada: A New, Comprehensive Assessment, Second Edition (Saskatoon: NFU, June 2022).

Reganold, J., Elliott, L., and Unger, Y. (1987). Long-term effects of organic and conventional farming on soil erosion. *Nature* 330: 370–372.

Reganold, J. P. (1995). Soil quality and profitability of biodynamic and conventional farming systems: A review. *Am. J. Alternative Agric*. 10: 36–46.

Sage, C, (2012). Environment and Food. Routledge. New York.

Siegrist, S., Staub, D.; Pfiffner, L. and Mader, P. (1998). Does organic agriculture reduce soil erodibility? The results of a long-term field study on loess in Switzerland. *Agric. Ecosyst. & Environ*. 69: 253–264.

Statistics Canada. (2017). A portrait of a 21st century agricultural operation. Retrieved from https://www150.statcan.gc.ca/n1/pub/95-640-x/2016001/article/14811-eng.htm

Sullivan, P. (2002). Drought Resistant Soil. ATTRA, National Center for Appropriate Technology USDA. https://attra.ncat.org/publication/drought-resistant-soil/. Accessed 6 December 2022.

Tait, C., & Leeder, J. (2019). With high stress, anxiety and depression, 40 per cent of Canadian farmers uneasy about seeking help. The Globe and Mail. Retrieved from https://www.theglobeandmail.com/canada/alberta/article-with-high-stress-anxiety-and-depression-40-per-cent-of-canadian/?utm_medium=Referrer:+Social+Network...%206/75/21/2019

Teasdale, J. R., Rosecrance, R. C., Coffman, C. B., Starr, J. L., Paltineanu, I. C., Lu, Y. C., and Watkins, B. K. (2000). Performance of reduced-tillage cropping systems for sustainable grain production in Maryland. *Am. J. Alternative Agric*. 15:79–87.

Teasdale, J. R., Coffman, C. B., and Mangum, R. W. (2007). Potential long–term benefits of no–tillage and organic cropping systems for grain production and soil improvement. *Agron. J*. 99: 1297–1305.

Weis, T. (2022). A Political Ecology Approach to Industrial Food Production. Critical Perspectives in Food Studies Eds Koc, Sumner, Winson 3rd Ed. 115-132. Oxford University Press.