Perennial Grains for the Cessation of Soil Degradation and the Sustainability of Cattle Production.

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Submission with respect to: (a) the measures for the adaptability and resilience of the agriculture, agri-food and forestry sectors; including the opportunities and risks associated with climate change in terms of the expansion of farmland, grazing land, and forestry production.

Summary:

- Producers willingness to adopt new crops has been readily demonstrated in western Canada with the ascendency of canola and the current increase in soybean.
- Loss of soil and soil carbon are impacting the sustainability of agriculture.
- Use of annual crops and annual management practices is reducing soil carbon.
- Use of perennials can reverse this loss.
- Potential for perennial grains as a human food source is foreseeable in the very near future.
- Perennial grains can deliver most of the ecosystem services that forages can without the negative impacts of animal production.
- May also be utilized as a dual grain/animal crop to reduce animal impacts.

Problem:

The loss of the soil resource through erosion as a consequence of attempting to grow enough annual grains to satisfy humanity’s dietary demands poses a long-term threat (1). Erosion however is not the only ecosystem disservice that has resulted from our conversion of high diversity perennial ecosystems (prairies) to low diversity, annual agrarian ecosystems (2). Inputs and capital-intensive approaches have been advanced such as nitrification inhibitors, variable rate fertilizer application, and patented and genetically engineered herbicide tolerant crops to address some of these issues. While often effective at easing specific ecosystem disservices, these and other solutions continue agriculture’s reliance on the status quo of annual crop production system requiring expensive responses to worsening problems (e.g. herbicide tolerance issues (3,4). The re-establishment perennial systems using new perennial crops holds the unique potential to curb ecosystem disservices and while still meeting the nutritional needs of a growing population.

History offers numerous examples of annual grain production leading to large-scale soil degradation which in turn became a primary driver of social collapse (5-8). And in spite of large investments and sweeping campaigns to halt soil erosion and degradation over the last century, a 2015 FAO report involving over 200 soil scientists from around the world indicated, "*while there is cause for optimism in some regions, the overwhelming conclusion from the regional assessments is that the majority of the world's soil resources are in only fair, poor or very poor condition. The most significant threats to soil function at the global scale are soil erosion, loss of soil organic carbon and nutrient imbalance. The current outlook is for this situation to worsen unless concerted actions are taken by individuals, the private sector, governments and international organizations*"(9).

Solution:

Perennial crops, similar to perennial forage crops, could provide the protection to the soil required to halt soil degradation. Lemaire et al. state, *"…, temporary or ley grassland should be considered not only in terms of fodder production for livestock, but also as a landscape area for realizing some essential ecosystem services, such as absorbing negative environmental impacts resulting from intensive agriculture*" (10). Kunrath et al. (11) noted that, ``*For example, nitrate leaching was greatly reduced after the introduction of ley grassland into a cropping cycle* ."

Forage production, hay and pasture, increases productive land under perennial vegetation, however it is directly tied to livestock production which is the source of several challenging ecosystem disservices (12). Forage seed production in Canada, accounts for approximately 65,000 ha $year^{-1}$, and is almost exclusively located in western Canada (13). While not an insignificant area, it is unlikely that forage seed production will dramatically increase due to limited markets (13) and concern over the ecological footprint of animal production (12). Therefore perennial grains, grains for human consumption, could greatly increase the land area dedicated to perennial seed production and provides alternative markets to forage products and forage seed (13).

The development of new perennial crop species is gaining momentum as a promising approach to change the fundamental nature of ecosystem processes in agriculture. Every potential new crop species is unique in: where it is situated in the breeding pipeline; the nature of genetic challenges it faces; the traits that require breeding attention; and the progress made in breeding improvements to date.

Numerous papers have been published over the last decade, describing predicted improvements in soil carbon balance, nutrient retention, soil water uptake efficiency, soil microbiome functions and weed suppression, as annual crops that required soil disturbance and/or frequent exposure to maintain, are replaced by perennial crops that require minimal soil disturbance or periods of exposure (14–20). In western Canada it appears that the likely perennial grain candidate will be intermediate wheatgrass marketed under the name Kernza®. Selections have been made (21) and some preliminary agronomy work has been initiated. In other parts of the world potential crops include perennial rice in Asia (22) and perennial wheat in Australia and the US (wheat x perennial relative) (23), with work ongoing with perennial cereal rye in western Canada, perennial barley in Sweden (24), perennial sorghum in the US and Africa (25), *Silphium*, a perennial oilseed, in the United States and Argentina (26) and perennial sunflower in the US and Canada (13) to name major projects at this time. Additionally new work is beginning on perennial legumes in the US (27) and is continuing on the ratooning of pigeon pea in Africa (S. Snapp, Michigan State University, personal communication; 28).

Seed yields of new crops are generally low and increase over time with investment in breeding and through agronomic package development. An additional benefit of perennial grains is that they should allow for incorporation into animal based agricultural systems. This potential use may provide an economic advantage to the initial adoption of using a perennial grain (29) and could be used as a stockpile forage in a beef system (13,30). Timing of grazing on a perennial grain may also be different depending upon the production system. In an organic system, straight-combining or using a stripper-header would facilitate grazing immediately after harvest and allow for a `natural fertilization` of the production area and promote the much needed regrowth for continued grain productivity. Under a conventional system a stockpile graze would allow for post-harvest fertilization providing both good regrowth and a nutritious feed for livestock heading into the winter months (13,30).

Producers can be very quick to adopt new crops and technologies. The recent rapid increase in soybean acres in Manitoba and the historic development and adoption of rapeseed/canola are now a major success stories for western Canadian agriculture. The approximately 60 year rise of the rapeseed/canola industry that saw not only increased acres but also investment and value-added industry, initially public but more recently private, that have increased seed productivity almost three-fold in Manitoba (Figure 1). There will always be year to year variability in seed yields due to the growing conditions experienced in the production areas but investment in plant improvement has proven successful in these cases.

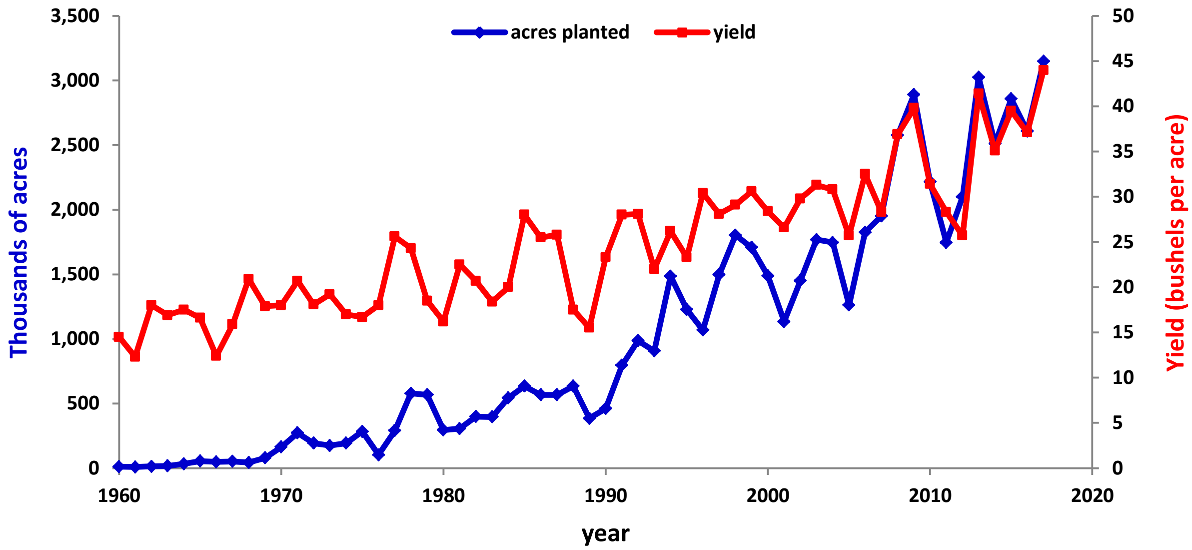

Figure 1. Average harvested acres (blue diamonds) and yield per acre (red squares) for canola in Manitoba 1960-2017. (data from http://www5.statcan.gc.ca/cansim/a47).

Work on perennial grain agriculture is taking place on six continents, in 17 countries and at 41 institutions (2). This work draws from the disciplines of plant breeding, genetics, ecology, agronomy, microbiology, sociology, plant pathology, physiology, and others. As promising as this expansion appears, more plant breeders, geneticists, agronomists, ecologists and soil scientists, initiating new perennial crop breeding and agronomic programs, are needed. The level of intra- and inter-specific diversity needed to achieve the ecological intensification described above is far greater than can be provided with the crops under development today. Opportunities exist to develop more perennial crops through wide hybridization as numerous annual grain or row crops such as corn, cotton, oat, soybean and chickpea have closely related wild perennial relatives (31). A far greater number of domestication candidates exist in the wild, and considerable thought has gone into strategic breeding approaches for this group (32).

Conclusion:

New "hardware" in the form of perennial crops is needed to achieve the level of ecological intensification that is possible, and necessary, as the human population approaches eight billion, to keep our soils healthy and productive. Decades will be required to continue to create new, viable crop species, even employing the latest molecular and cytogenetic tools. But the return on investment could contribute substantially to assuring the sustainability of our soils and therefore, of agriculture over the next millennium.

References:

1. Crews, T.E. and D.J. Cattani. 2018. Strategies, advances and challenges in breeding perennial grain crops. Sustainability. Guest Editorial.
2. Crews, T.E., Carton, W. and Olsson, L. 2018. Is the future of agriculture perennial? Glob Sustain. in review.
3. Heap, I. 2014. Global perspective of herbicide-resistant weeds. Pest Management Science 70 (9):1306-1315.
4. Walsh, M.J. and S.B. Powles. 2007. Management Strategies for Herbicide-resistant Weed Populations in Australian Dryland Crop Production Systems. Weed Technology 21(2):332-338.
5. Carter, Vernon Gill and Dale T. Topsoil and Civilization. Norman, Oklahoma: University of Oklahoma Press; 1955. 292 p.
6. Hillel D. Out of the Earth: Civilization and the Life of the Soil [Internet]. University of California Press; 1992 [cited 2017 Oct 31]. 321 p. Available from: https://books.google.com/books?id=KMWuj5gpnH0C&dq=daniel+hillel+out+of+the+earth&source=gbs_navlinks_s
7. Montgomery DR. Dirt: the Erosion of Civilizations [Internet]. University of California Press; 2007 [cited 2017 Oct 31]. 285 p. Available from: https://books.google.com/books?id=D2im0qYGG2YC&dq=david+montgomery+dirt+the+erosion+of+civilization&source=gbs_navlinks_s
8. Gomiero T. Soil degradation, land scarcity and food security: Reviewing a complex challenge. Sustainability. 2016;8(3):1–41.
9. Food and Agriculture Organization of the United Nations. Status of the World's Soil Resources: Technical Summary [Internet]. 2015. Available from: http://www.fao.org/documents/card/en/c/c6814873-efc3-41db-b7d3-2081a10ede50/
10. Lemaire, G., F. Gastal A. Franzluebbers and A. Chabbi. 2015 Grassland-cropping rotations: an avenue for agricultural diversification to reconcile high production with environmental quality. Environmental Management 56(5):1065-1077.
11. Kunrath, T.R., C. de Berranger, X. Charrier, F. Gastal, P.C.F. Carvalho, G. Lemaire, J.C. Emile and J.-L. Durand. 2015. How much do sod-based rotations reduce nitrate leaching in a cereal cropping system? Agricultural Water Management 150 (2015) 46–56
12. Park, Y.S., G. Egilmez and M. Kucukvar. 2016. Energy and end-point impact assessment of agricultural and food production in the United States: A supply chain-linked Ecologically-based Life Cycle Assessment Ecological Indicators 62:117-137.

13. Cattani, D.J. and S.R. Asselin. 2018. Extending the Growing Season: Forage Seed Production and Perennial Grains. Can. J. Pl. Sci.. dx.doi.org/10.1139/cjps-2017-0212
14. Glover JD, Culman SW, DuPont ST, Broussard W, Young L, Mangan ME, et al. 2010. Harvested perennial grasslands provide ecological benchmarks for agricultural sustainability.Agric Ecosyst Environ. 137(1–2):3–12.
15. Crews TE, Blesh J, Culman SW, Hayes RC, Steen Jensen E, Mack MC, et al. 2016. Going where no grains have gone before: From early to mid-succession. Agric Ecosyst Environ [Internet]. 223:223–38.
16. Crews TE, Rumsey BE. What agriculture can learn from native ecosystems in building soil organic matter: A review. Sustain. 2017;9(4):1–18.
17. Culman SW, Snapp SS, Ollenburger M, Basso B, DeHaan LR. Soil and water quality rapidly responds to the perennial grain Kernza wheatgrass. Agron J. 2013;105(3):735–44.
18. Baker B. Can modern agriculture be sustainable? Bioscience. 2017;67(4):325–31.
19. Li N, Yao SH, You MY, Zhang YL, Qiao YF, Zou WX, et al. Contrasting development of soil microbial community structure under no-tilled perennial and tilled cropping during early pedogenesis of a Mollisol. Soil Biol Biochem. 2014;77:221–32.
20. Weißhuhn P, Reckling M, Stachow U, Wiggering H. Supporting Agricultural Ecosystem Services through the Integration of Perennial Polycultures into Crop Rotations. Sustainability [Internet]. 2017;9(12):2267. Available from: http://www.mdpi.com/2071-1050/9/12/2267.
21. Cattani, D.J. 2017. Selection of a perennial grain for seed productivity across years: Intermediate wheatgrass as a test species. Canadian Journal of \ Plant Science 97:516-524, doi: 10.1139/CJPS-2016-0280.
22. Zhang, S., J. Hu, C. Yang, H. Liu, F. Yang, J. Zhou, B.K. Samson, C. Boualaphanh, L. Huang, G. Huang, J. Zhang, W. Huang, D. Tao, D. Harnpichitvitaya, L.J. Wade and F. Hu. 2017. Genotype by environment interactions for grain yield of perennial rice derivatives (*Oryza sativa* L./ *Oryza longistaminata*) in southern China and Laos. Field Crops Research 207:62-70.
23. Hayes, R.C., M.T. Newell, T.E. Crews and M.B. Peoples. 2016. Perennial cereal crops: An initial evaluation of wheat derivatives grown in mixtures with a regenerating annual legume. Renewable Agriculture and Food Systems doi:10.1017/S1742170516000260.
24. R.C. Hayes, S. Wang, M.T. Newell, K. Turner, J. Larsen, L. Gazza, J.A. Anderson, L.W. Bell, D.J. Cattani, K. Frels, E. Galassi, A.I. Morgounov, C.K. Revell, D.B. Thapa, E.J. Sacks, M. Sameri, L.J. Wade, A. Westerbergh, V. Shamanin, A. Amanov and G.D. Li. The performance of early-generation perennial winter cereals at 21 sites across four continents. Submitted February 27, 2018. Sustainability.
25. Cox, S., P. Nabukala, A.H. Paterson, W. Kong and S. Nakasagga. 2018. Development of perennial grain sorghum. Sustainability *10*(1), 172; doi:10.3390/su10010172
26. Turner, M.K., D. Ravetta and D. Van Tassel. 2018. Effect of *Puccinia silphii* on yield components and leaf physiology in *Silphium integrifolium*: Lessons for the domestication of a perennial oilseed crop. Sustainability 10(3), 696; doi:10.3390/su10030696.
27. Schlautman, B., S. Barriball, C. Ciotir, S. Herron and A.J. Miller. 2018. Perennial grain legume domestication phase I: Criteria for candidate species selection. Sustainability *10*(3), 730; doi:10.3390/su10030730 (registering DOI)
28. Sharma, D., K. Saxena and J.M. Green. 1978. Potential of ratooning in pigeonpea. Field Crops Research 1:165-172.

29. Bell, L.W., F. Byrne (nee Flugge), M.A. Ewing and L.J. Wade. 2008. A preliminary whole-farm economic analysis of perennial wheat in an Australian dryland farming system. Agricultural Systems 96:166-174.
30. McGeough, E.M., D. Cattani, Z. Koscielny, B. Hewitt and K.H. Ominski. 2018. Extending the growing season: Annual and perennial forages for fall/winter grazing. Canadian Journal of Plant Science, *In press*. http://www.nrcresearchpress.com.uml.idm.oclc.org/doi/pdf/10.1139/CJPS-2017-0228
31. Cox, T.S., J.D. Glover, D.L. Van Tassel, C.M. Cox and L.R. DeHaan. 2006. Prospects for Developing **p**erennial **g**rain **c**rops. Bioscience 56(8):649–59.
32. DeHaan. L.R., D.L. Van Tassel, J. Anderson, S. Asselin, G. Baute, D.J. Cattani, S. Culman, K. Dorn, B. Hulke, M. Kantar, S. Larson, D. Marks, J. Poland, D. Ravetta, E. Rude, M. Ryan, D. Wyse and X. Zhang. (2016). A pipeline strategy for crop domestication. Crop Science, 56:917-930. doi: 10.2135/cropsci2015.06.0356.