SOIL PHYSICAL QUALITY EFFECTS OF NOVEL PERENNIAL GRAIN CROPPING AT TWO CONTRASTING SITES IN ALBERTA, CANADA

E.J. Daly, K. Kim, G. Hernandez-Ramirez, and K. Klimchuk
University of Alberta, Alberta, Canada
edaly@ualberta.ca (780) 686-7746

ABSTRACT

Novel perennial grain crops have been proposed as a solution to several environmental issues facing modern agriculture, namely the loss of soil quality often associated with annual monocrops. This study evaluated soil physical and hydraulic properties in three cropping systems (perennial forage, perennial grain, and spring grain) at two sites in central Alberta, Canada with contrasting soil types over three growing seasons (2017 to 2020). Soil physical and hydraulic properties were measured during the 2020 growing season for three soil depths (5-10, 15-20 and 25-30 cm). Root samples from 0-60 cm were obtained during crop anthesis in 2018 and 2019. Perennial treatments (forage and grain) showed consistently elevated root density relative to the spring grain treatment.. In general, increases in bulk density in the spring grain treatment were mirrored by relative increases in total porosity of the perennial treatments. Specifically, the perennial forage treatment increased macroporosity in the 25-30 cm at the Edmonton and Breton sites ($p < 0.05$ and $p < 0.001$, respectively). Improvements in S-index materialized at the 25-30 cm depth at the Edmonton site alone, and only in the perennial forage treatment ($p < 0.05$).

INTRODUCTION

Abundant literature has stressed the importance of good soil quality for maintaining and improving ecosystem services provided by agricultural systems including, but not limited to, soil carbon sequestration, disease suppression, water filtration and greenhouse gas mitigation (Kim et al., 2021; Lal, 2016; Palm et al., 2014; Powlson et al., 2011). Conversion of annual croplands to perennial systems has shown improvements, largely attributable to reduced tillage, enhanced root growth and carbon inputs (Culman et al., 2013; So et al., 2009), however, it is unclear if these improvements will manifest in a perennial grain system that only survives 2-3 years (Daly et al., 2021).

The effects on soil physical quality from contrasting cropping systems can be characterized by measuring properties that may be sensitive to management effects, such as total porosity (TP), bulk density (BD), pore volume fractions (PVF) and the S-Index (Hebb et al., 2017). As such, specific objectives of this study were to i) determine the effects of perennial grain, spring grain and perennial forage on soil physical and hydraulic properties in two contrasting soil types, and ii) relate potential differences in physical and hydraulic properties to differences in root density and management between the aforementioned systems.

MATERIALS AND METHODS

Field sites were established in Edmonton, Alberta, Canada (53° 29' 43.33", 113° 31' 59.24") and Breton, Alberta, Canada (53° 5' 16.72", 114° 26' 29.35") in August 2017. Soils at the Edmonton have a long-term management history of continuous barley for silage. Soils at the Breton site were harvested for forage for > 60 years prior to the experiment. Baseline soil chemical and physical properties are summarized in Table 1.

Table 1. Baseline soil properties from the Edmonton and Breton sites.

Soil Properties	**Site**	
	Edmonton	Breton
Canadian classification	Black Chernozem	Gray Luvisol
Total carbon (TC) (g C kg^{-1}) (0-30 cm)	41.6 ± 7.5	19.2 ± 3.9
Total nitrogen (TN) (g N kg^{-1}) (0-30 cm)	3.6 ± 0.5	1.7 ± 0.3
Available nitrogen (NH_4^+ & NO_3^-) (mg N kg^{-1}) (0 – 15 cm)	48.3 ± 4.5	55.5 ± 2.5
pH (1:5 H_2O)	7.3 ± 0.09	6.1 ± 0.08
Bulk density (g cm^{-3}) (5-30 cm)	1.0 ± 0.06	1.1 ± 0.06
Soil texture	clay	loam
% clay	48.3	24.8
% silt	35.7	41.8
% sand	16.0	33.3

Both experimental sites were arranged in identical randomized complete block designs consisting of four block replicates. Treatments consisted of contrasting cropping systems: two analogous grain cultivars, perennial [ACE-1 rye (*Secale cereale L.* × *S. montanum Guss]* and spring [Gazelle rye (*S. cereale L.*)], as well as perennial forage [(meadow brome (*Bromus commutatus*) and alfalfa (*Medicago sativa*)]. The perennial forage and perennial grain treatments were seeded in late summer 2017. The spring grain treatments were tilled and seeded in spring 2018, 2019 and 2020.

Undisturbed soil cores were collected from the perennial forage, perennial grain, and perennial forage treatments from three depths: 5-10 cm, 15-20 cm and 25-30 cm in May (Edmonton) and July (Breton) of 2020. Two replicates were taken for each depth in each plot and averaged, for a total of 48 cores per site. Soil cores from 0-60 cm were obtained for root density determination using a truck-mounted auger. Two cores were collected and composited for each plot, then separated into 0-15 cm, 15-30 cm, and 30-60 cm intervals.

Soil physical and hydraulic properties were obtained using a HYPROP® instrument system (*Meter Environment, Munich, Germany*) using the simple evaporation method (Schindler and Müller, 2017) in combination with WP4 potentiometer® dewpoint method, for the very dry range (*Meter Environment, Munich, Germany)*. Data was analyzed using the HYPROP-FIT® software, which used measured data values and supplemental WP4® data points to fit the constrained van Genuchten model (van Genuchten, 1980) for moisture retention.

The PVF were calculated using the relationship between points on the water retention curve (kPa) and pore diameters (µm) as follows: macro (0 to -5 kPa, >60 µm), meso (-5 to -33 kPa, 60-9 µm), micro (-33 to -50 kPa, 9-6 µm) and nano (< -50 kPa, < 6 µm) as in Hernandez-Ramirez et al. (2014) and Guenette et al. (2019).

RESULTS AND DISCUSSION

Root Density

Root density differed significantly between treatments at the Edmonton and Breton sites (Figs. 1A-D). At the Edmonton site, root density was consistently highest in the perennial forage, followed by perennial grain, and lowest in the spring grain. Notably, in 2018, in the 15-30 cm depth interval perennial forage root density was significantly greater than the perennial grain, which was greater than the spring grain ($p < 0.001$) (Fig. 1A). Results from the 15-20 cm depth in 2019 were similar. Perennial forage had greater root density than spring grain ($p < 0.001$) (Fig. 1B). Trends at the Breton site mimicked those at the Edmonton site, however, differences between the perennial treatments (forage and grain) and the spring grain were less pronounced at the 15-20 cm depth. Increased root density of the perennial forage compared to spring grain was only evident in 2019 ($p < 0.001$) (Figs. 1C, 1D).

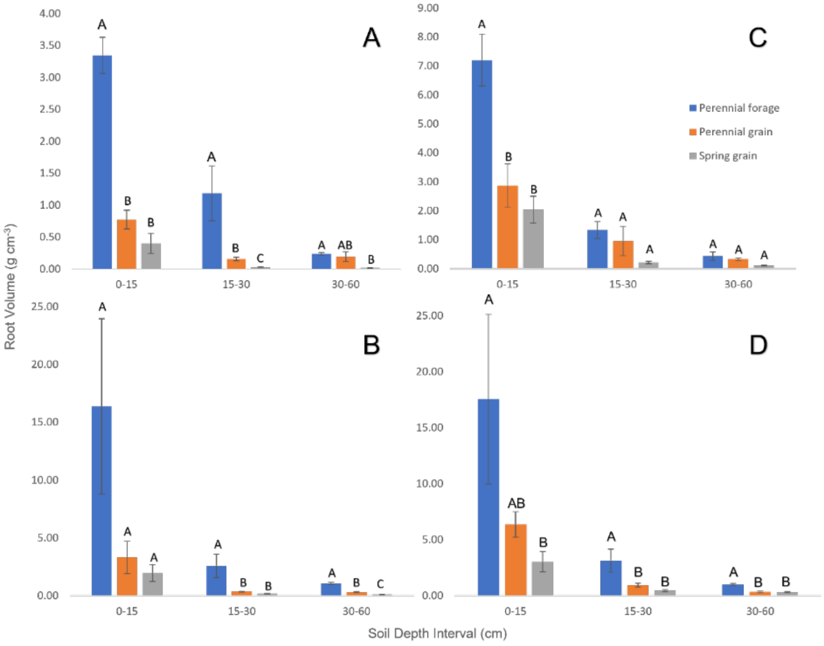

Figure 1. Average root densities for the 0-15, 15-30 and 25-30 cm depth intervals at the Edmonton site in 2018 (A) and 2019 (B) and the Breton site in 2018 (C) and 2019 (D). Uppercase letters denote significant differences between treatments within each depth for each year at each site (α = 0.05). Error bars are ± SE (n=4).

Bulk Density and Total Porosity

At the Edmonton site, BD from 5-10 cm was lower in the perennial forage treatment compared to the perennial and spring grain treatments, which did not differ from one another ($p < 0.05$). Statistically significant differences were not detected between treatments in the other depths; however, spring grain BD was consistently higher than the perennial grain and forage treatments. In Breton, the BD trend from highest to lowest in all depths was as follows: spring grain > perennial grain > perennial forage (Table 2).

The TP of the perennial forage at the Edmonton site was greater than the TP of the spring grain in the 5-10 cm depth increment ($p < 0.05$). Neither the perennial forage nor the spring grain differed from the perennial grain, which had a TP that was numerically higher than the spring grain, but lower than the perennial forage. No differences were found for the 15-20 or 25-30 cm depths, but perennial grain and perennial forage had elevated TP relative to the spring grain. In Breton, TP for each depth trended from highest TP to lowest as follows: perennial forage > perennial grain > spring grain, but the treatments did not statistically differ from one another (Table 2).

Reduced BD and increased TP in the no-till perennial treatments (forage and grain) versus the annually tilled spring grain, contrasts with studies that found increased BD with the implementation of no-till practices (Dam et al., 2005; Li et al., 2020). However, these studies did not account for the reduced seeding traffic and elevated root mass in perennial systems, which we hypothesize had an effect on BD and TP.

Macroporosity

At the Edmonton site, macroporosity trends were consistent for the 5-10 and 15-20 cm depths, from highest to lowest: perennial forage > perennial grain > spring grain. Only the 25-30 cm depth showed significant differences between treatments; perennial forage had increased macroporosity compared to the perennial and spring grain treatments, which did not differ from one another ($p < 0.05$). Similarly, macroporosity at the Breton site was consistently higher in the perennial forage treatment. From 15-20 cm, perennial forage macroporosity was greater than the spring grain ($p < 0.05$). From 25-30 cm, macroporosity was greater in the perennial forage treatment than the perennial and spring grain treatments ($p < 0.001$).

Trends in macroporosity generally mimicked those of root density at both sites, as in, perennial forage > perennial grain > spring grain. Roots can amalgamate microaggregates, and in doing so generate macropores (Lu at al., 2020). Specifically, plants with tap roots such as alfalfa, a component in our perennial forage treatment, can generate preferential flow paths and enhance soil macroporosity (Lu et al., 2020; Song et al., 2017). Previous research supports that these changes can materialize over comparable timescales, with McCallum et al. (2004) reporting significantly improved macroporosity in subsoils under perennial rotations after 3 years.

S-Index

At the Edmonton site, significant differences in the S-index materialized at the 25-30 cm depth, where the perennial forage treatment > perennial grain = spring grain (Fig. 2). However, the S-Index for perennial forage was consistently elevated relative to the spring grain treatment for all depths. Differences at the Edmonton site, but no discernable differences at the Breton site, may be due to a combination of factors:

namely, soil properties (texture and organic matter) and land use history. Soils with higher clay and organic matter content, such as those at the Edmonton site, may be more responsive to structural improvements if beneficial management practices are implemented (Denef et al., 2002). Additionally, the Edmonton site may have had more room for soil quality improvements after years of tillage and continuous cropping, as evidenced by S-index values that are collectively less than 0.035, the S-index value proposed as the division between “good” and “poor” soil quality (Dexter, 2004).

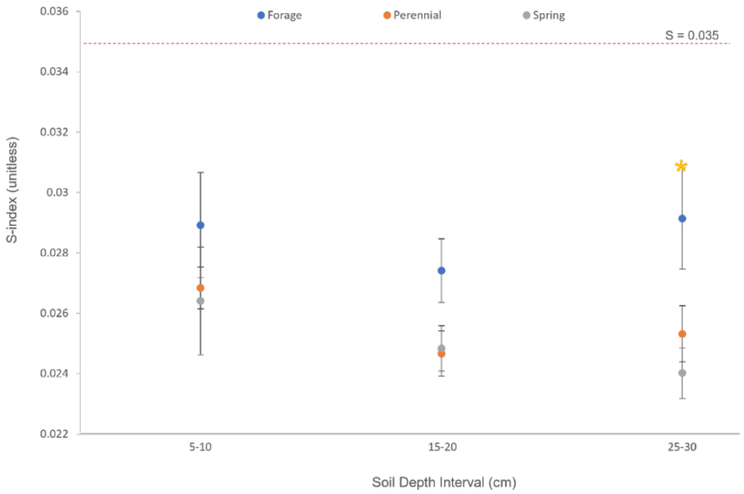

Figure 2. S-Index values for the 5-10, 15-20 and 25-30 cm depth increments at the Edmonton site. The dashed red line at 0.035 indicates the hypothetical division between “good” and “poor” soil quality as proposed by Dexter (2004). The yellow star indicates statistically significant differences between treatments (α = 0.05). Error bars are ± SE (n=8).

Overall, the contrasting effects of contrasting cropping systems on soil physical and hydraulic properties were evident after 3 yrs. Perennial forage had the greatest beneficial impact on BD, TP, macroporosity and the S-index relative to the spring grain, whereas effects of the perennial grain treatment were variable, but often intermediate between perennial forage and spring grain.

REFERENCES

Culman, S. W., Snapp, S. S., Ollenburger, M., Basso, B., & DeHaan, L. R. (2013). Soil and water quality rapidly responds to the perennial grain Kernza wheatgrass. Agronomy Journal, 105(3), 735-744.

Daly, E. J., Hernandez-Ramirez, G., Puurveen, D., Ducholke, C., Kim, K., & Oatway, L. (2021). Perennial rye as a grain crop in Alberta, Canada: Prospects and challenges. Agronomy Journal.

Dam, R. F., Mehdi, B. B., Burgess, M. S. E., Madramootoo, C. A., Mehuys, G. R., & Callum, I. R. (2005). Soil bulk density and crop yield under eleven consecutive years of corn with different tillage and residue practices in a sandy loam soil in central Canada. Soil and Tillage Research, 84(1), 41-53.

Denef, K., Six, J., Merckx, R., & Paustian, K. (2002). Short-term effects of biological and physical forces on aggregate formation in soils with different clay mineralogy. Plant and Soil, 246(2), 185-200.

Dexter, A. R. (2004). Soil physical quality: Part I. Theory, effects of soil texture, density, and organic matter, and effects on root growth. Geoderma, 120(3-4), 201-214.

Guenette, K. G., Hernandez-Ramirez, G., Gamache, P., Andreiuk, R., & Fausak, L. (2019). Soil structure dynamics in annual croplands under controlled traffic management. Canadian Journal of Soil Science, 99(2), 146-160.

Hebb, C., Schoderbek, D., Hernandez-Ramirez, G., Hewins, D., Carlyle, C. N., & Bork, E. (2017). Soil physical quality varies among contrasting land uses in Northern Prairie regions. Agriculture, Ecosystems & Environment, 240, 14-23.

Hernandez-Ramirez, G., Lawrence-Smith, E.J., Sinton, S.M., Schwen, A., and Brown, H.E. 2014. Root responses to alterations in macroporosity and penetrability in a silt loam soil.Soil Sci. Soc. Am. J. 78,1392–1403.

Kim, K., Daly, E. J., & Hernandez-Ramirez, G. (2021). Perennial grain cropping enhances the soil methane sink in temperate agroecosystems. Geoderma, 388, 114931.

Lal, R. (2016). Soil health and carbon management. *Food and Energy Security*, *5*(4), 212-222.

Li, Y., Li, Z., Cui, S., & Zhang, Q. (2020). Trade-off between soil pH, bulk density and other soil physical properties under global no-tillage agriculture. Geoderma, 361, 114099.

Lu, J., Zhang, Q., Werner, A. D., Li, Y., Jiang, S., & Tan, Z. (2020). Root-induced changes of soil hydraulic properties–A review. Journal of Hydrology, 589, 125203.

McCallum, M. H., Kirkegaard, J. A., Green, T. W., Cresswell, H. P., Davies, S. L., Angus, J. F., & Peoples, M. B. (2004). Improved subsoil macroporosity following perennial pastures. Australian Journal of Experimental Agriculture, 44(3), 299-307.

Palm, C., Blanco-Canqui, H., DeClerck, F., Gatere, L., & Grace, P. (2014). Conservation agriculture and ecosystem services: An overview. Agriculture, Ecosystems & Environment, 187, 87-105.

Powlson, D. S., Gregory, P. J., Whalley, W. R., Quinton, J. N., Hopkins, D. W., Whitmore, A. P., ... & Goulding, K. W. (2011). Soil management in relation to sustainable agriculture and ecosystem services. *Food policy*, *36*, S72-S87.

So, H. B., Grabski, A., & Desborough, P. (2009). The impact of 14 years of conventional and no-till cultivation on the physical properties and crop yields of a loam soil at Grafton NSW, Australia. Soil and Tillage Research, 104(1), 180-184.

Song, L., Li, J. H., Zhou, T., & Fredlund, D. G. (2017). Experimental study on unsaturated hydraulic properties of vegetated soil. Ecological Engineering, 103, 207-216.

Van Genuchten, M. T. (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil science society of America journal, 44(5), 892-898.