Soil Quality Improvements from Implementation of Controlled Traffic

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Introduction

The use of current land management systems has given rise to reductions in soil quality within the Canadian prairies. In intensive agricultural systems, excessive tillage and compaction associated with conventional farming or Random Traffic Farming (RTF) has had a profound degradation in soil structure (Strudley et al., 2008). The use of Controlled Traffic Farming (CTF) as a management system can potentially aid in the recovery of soil quality and reduce the harmful effects of soil compaction (McHugh et al., 2009). CTF is described as the confinement of in-field production vehicle movement to a predefined area known as a tramline. Tramlines are permanent tracks inside the field boundary that are travelled on by the production equipment for every stage of farming. The tramline frequency within the field boundary is based upon a uniform implement width, where the uniform width or multiples of the width can be used for implement sizing. Conventional farming techniques utilize uncontrolled production vehicle movement within the field, with a random traffic regime compacting 20-35% of the field area per farming stage (Tullberg, 2000). With a minimum of 3 farming stages occurring throughout the growing season, conventional farming can cause 40-70% more spatial compaction than CTF. CTF has been shown to improve soil structure which overall leads to a decrease in fuel usage and greenhouse gas emissions, reduction in soil erosion, improvement in plant productivity, increase in resource use efficiencies and potential increase in crop yields (Gasso et al., 2013; Gasso et al., 2014).

Soil structure has been shown to directly affect the movement and storage of water within the soil, which ultimately affects the amount of available water for plants and the resulting soil quality. It is the goal of this study to evaluate how soil properties change in response to the presence of compaction and to determine how CTF affects soil quality in the Canadian prairies. A better understanding of innovative management systems, such as CTF, can yield a reduction in quantifiable inputs which will help mitigate the risk of uncontrollable factors encountered, such as drought and crop disease. A management practice that is capable of reducing the risk involved in farming warrants meticulous examination and documentation.

Methods & Materials

To understand how soil properties vary within the management system, data was obtained from a field located within Alberta in which the producer was actively practicing CTF. The field in question is fully managed through CTF and has 3 conventional farming (RTF) check strips distributed throughout the field which serves as a reference control treatment. The RTF check strip is comprised of a normal swath managed by CTF with the addition of extra traffic distributed over the entire swath to simulate the traffic regime experienced in conventional farming management systems. The purpose of the RTF check strip is to allow for a direct side-by-side comparison between the two management systems while accounting for in-field variability experienced within that specific location.

Figure 1

To quantify soil physical and hydraulic properties, undisturbed soil core samples were collected from both the trafficked areas in the conventional farming check strip and the un-trafficked areas in the adjacent CTF swath. Soil samples were collected in the inter-rows (Figure 1) at depths of 5-10cm and 15-20cm in August of 2015. By comparing soil samples taken from sites that employ both CTF and conventional farming techniques, the existence of any improvements in soil structure caused by CTF implementation can be measured and documented. The use of undisturbed soil core samples allows for accurate calculations of soil physical properties such as bulk density, pore volume fractions, unsaturated hydraulic conductivity, water availability and water retention curves to be analyzed.

The study site is located near Dapp, Alberta (SW & SE ¼-35-62-1-W5M) and is undulating with low relief. The soil within the field consists of a Dark Grey Luvisol and has a sandy clay loam texture. CTF has been used as the dominant management system for five consecutive growing seasons prior to sample collection, with RTF reduced tillage being employed beforehand.

Figure 2

Following the collection of soil samples, a simple evaporation analysis was carried out through the use of a UMS HYRPOP system. The simple evaporation experiment is a method where a soil core sample at room temperature is saturated and then left to naturally evaporate, in which the matric potential or energy state of the water within the soil can be monitored (Peters & Durner, 2008). The hyprop system is a laboratory instrument that uses tensiometers to measure the matric potential within the soil at heights of 1.75cm and 3.75cm during the evaporation process (Figure 2) (Schelle et al., 2013). The tensiometers are capable of measuring the matric potential to ranges of pF 0.0 to 3.0, which translates to suction pressures of 0 to -100KPa (Schindler et al., 2010a).

Once the simple evaporation experiment is completed, the data can then be analyzed through the use of UMS HYPROP FIT software (Schelle et al., 2013). This software is able to calculate the water retention curve and unsaturated hydraulic conductivity curve from the measured data points. To fit the water retention curves, the van Genuchten model (van Genuchten, 1980) was used and is shown by equation [1].

$$\theta = \theta_r + \frac{(\theta_s - \theta_r)}{(1 + (\alpha h)^n)^m} \quad [1]$$

Where, θ is the calculated water content (%), θ_r is the residual water content (%), θ_s is the saturated water content (%), α is the inverse of the air entry potential (KPa^{-1}), h is the matric potential (KPa), and n & m are shape parameters. Using the modeled water retention curve, a general indicator of soil quality, S-index, was postulated by Dexter (2003). The S-index was calculated based on the slope of the inflection point from the van Genuchten modeled water retention curve and is shown by equation [2].

$$S = -n(\theta_s - \theta_r)\left(\frac{2n-1}{n-1}\right)^{\left(1/n-2\right)} \quad [2]$$

The resulting S-index or calculated value of the slope of the inflection point is a representation of the quality of the soil, where values greater than 0.025 indicate good soil quality and values less than 0.025 indicate poor soil quality (Dexter, 2003).

Results & Discussion

The results are based on comparisons with the 3 RTF check strips to their adjacent CTF swath and are described as locations 1, 2 and 3. Locations 1, 2, and 3 are respectively situated in the south, center and north areas of the study site, as the tramlines and seed rows run east to west. The values for each soil sample depth were averaged and presented as values for either traffic, which represents the trafficked portion in the RTF check strip, or un-trafficked, which represents the un-trafficked portion in the adjacent CTF swath.

Bulk Density

The bulk density (Figure 3) was determined through a soil dry mass and corresponding core volume. When averaging the two soil depths, the bulk density was lower in the un-trafficked samples compared to the samples receiving the conventional traffic treatment ($\rho = 0.004$). The average change in bulk density from trafficked to un-trafficked was 0.115 g/cm^3. This is to be expected, as any compaction created by the vehicle traffic within the field is confined to the tramlines. Decreases in bulk density can be an indicator of soil amelioration; however it may not be the best indicator of increases in soil rootability (Hernandez-Ramirez et al., 2014). Soil rootability allows plants to have greater access to water and nutrients within the soil, which can ultimately aid in plant productivity (Taylor & Brar, 1991).

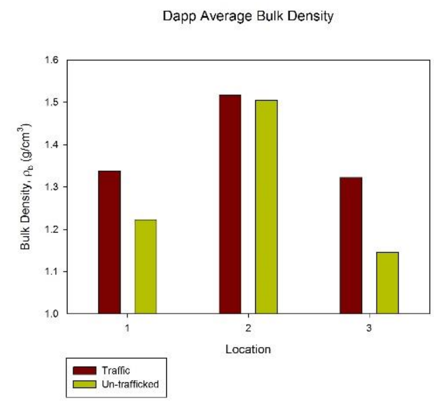

Figure 3

Pore Volume Fractions

Porosity of the soil was determined through the analysis of different pore volume fractions. Averages of the macroporosity (Figure 4) of the soil was determined from pore radii greater than 30μm, while the mesoporosity (Figure 5) was determined from a pore radii between 30 and 4.5μm, and the microporosity (Figure 6) was determined from pore radii less than 4.5μm (Hernandez-Ramirez et al., 2014).

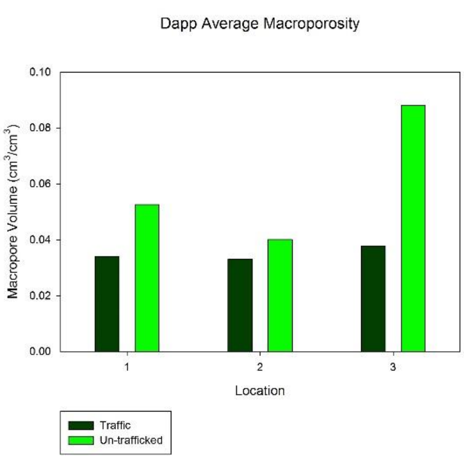

Figure 4

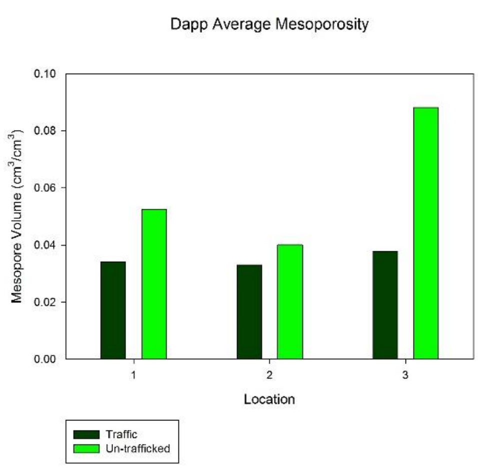

Figure 5

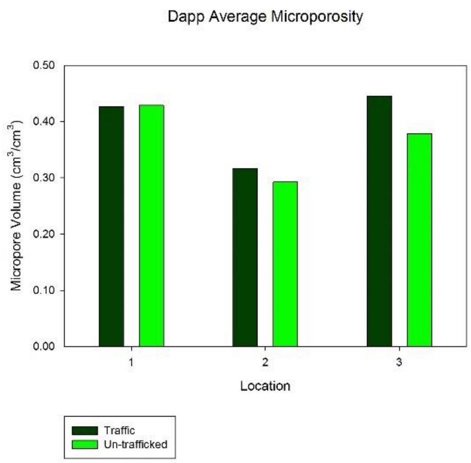

Figure 4

The macroporosity (ρ = 0.003) and mesoporosity (ρ = 0.002) both significantly increased by an average of 0.025cm^3/cm^3 and 0.020cm^3/cm^3 within the un-trafficked samples, respectively. The increases in the larger pore volume fractions indicates that water transmission pore volume has increased. These transmission pores are largely responsible for increases in infiltration rates and available water storage capacity of the soil (Lipiec et al., 2006). If the un-trafficked areas within CTF are capable of supporting higher infiltration rates and water storage capacities, then it can be hypothesized that the overall water capture and availability would increase in a CTF environment when compared to a conventional farming environment. This hypothesis can be supported through CTF managed fields receiving 40-70% less spatial compaction than RTF managed fields, as each farming stages covers 20-35% of the field with compaction (Tullberg, 2000). This leads to a greater area of soil within a CTF environment having an increased ability to transmit water. The increases in transmission pore volume fractions may be a good indicator of increases in soil quality as there are direct correlations of water intake, redistribution and storage in soils with plant productivity (Whalley et al., 1995).

The micropore volume fractions correspondingly decreased in the un-trafficked samples by an average of 0.030cm^3/cm^3. This is an expected response as the total porosity of the soil will change very little, while increases in both macro and mesoporosity should correlate to decreases in microporosity.

S-Index

The average S-index was calculated for each location from the slope of the inflection point of the van Genuchten modeled water retention curve (Figure 7).

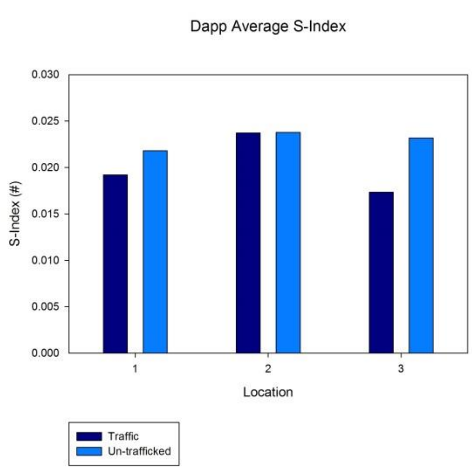

Figure 5

The S-index values for locations 1 and 3 (ρ = 0.048) increased within the un-trafficked samples when compared to the trafficked samples. The average increase in S-index for locations 1 and 3 was 0.004. It can be observed that the increase in the S-index in the un-trafficked portion is nearing the threshold of 0.025, which is the region of good soil quality (Dexter, 2003). The average values of S-index at location 2 did not change; however, there were slight decreases in bulk density and increases in macro and mesoporosity at that location.

Unsaturated Hydraulic Conductivity

The unsaturated hydraulic conductivity (Figure 8) can be interpreted as the effective connectivity of the pore network at different ranges of pore sizes (Peters & Durner, 2008). The average conductivity increased within the un-trafficked samples at locations 1 and 3, but decreased at location 2. The average unsaturated hydraulic conductivity was measured as mesopore conductivity from pore radii between 30 and 4.5μm and micropore conductivity with pore radii less than 4.5μm. The average unsaturated hydraulic conductivity increased at locations 1 and 3 by 1.5×10^{-3}cm/d and 0.5×10^{-3}cm/d for mesopore and micropore volume fractions, respectively. The average unsaturated hydraulic conductivity decreased at location 2 within the un-trafficked samples by 0.4×10^{-3}cm/d and 0.5×10^{-3}cm/d for mesopore and micropore volume fractions, respectively. The increases in conductivity at locations 1 and 3 correspond well with the changes in soil properties and increases in soil quality measured throughout the study.

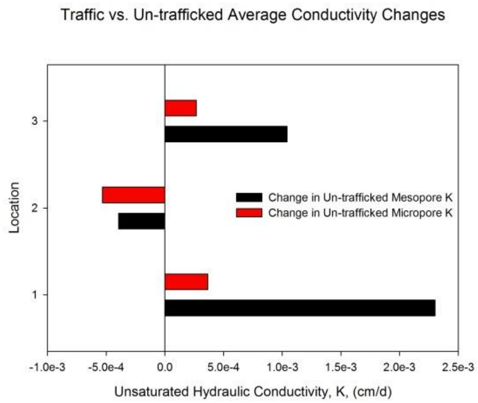

Figure 6

Conclusion

It was the goal of this study to evaluate how soil properties change in response to the presence of compaction and to determine how CTF affects soil quality in the Canadian prairies. When comparing the trafficked soil samples to the un-trafficked soil samples, it was generally observed that the bulk density decreased, the macro and mesoporosity increased, the microporosity decreased, and the unsaturated hydraulic conductivity increased. The presence of compaction caused by farm vehicle traffic has a pronounced effect on soil properties. The continuous application of compaction has contributed to alterations in soil properties which can directly affect the overall quality of the soil. The S-index measurements in this study show that the absence of vehicle-induced compaction has positive effects on the soil quality.

The spatial compaction applied from vehicle movement in controlled traffic equates to 20-35% of the field area, as all the traffic is confined to tramlines (Tullberg, 2000). In modern farming techniques, such as zero tillage, spatial compaction is equal to 50% of the field area (Tullberg, 2007). This shows that CTF is an effective way to reduce the overall compaction footprint within the field. Thus, the reduction in spatial compaction experienced in controlled traffic farming directly correlates to improvements in soil quality in the un-trafficked areas.

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- Figure 1. Courtesy of Kris Guenette.

- Figure 2. UMS. Soil Laboratory: HYROP. HYPROP – Laboratory evaporation method for the determination of pF-curves and unsaturated conductivity. [Online Image]. Retrieved October 28, 2015 from http://www.umsmuc.de/en/products/soil_laboratory/hyprop.html