Effect of long-term cropping systems on soil hydrophobicity of a clay loam soil under dryland conditions in southern Alberta

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Source: Canadian Journal of Soil Science, 102(2) : 573-576

Published By: Canadian Science Publishing

URL: https://doi.org/10.1139/CJSS-2021-0117

SHORT COMMUNICATION

Effect of long-term cropping systems on soil hydrophobicity of a clay loam soil under dryland conditions in southern Alberta

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Abstract: The objective was to quantify the effect of crop rotations, crop type, life cycle, nitrogen fertilizer, manure application, and fallow on soil hydrophobicity (SH). The SH was measured for a long-term (16 yr) dryland field experiment on a Dark Brown clay loam soil in southern Alberta, Canada. Mean SH was significantly ($P \leq 0.05$) greater in rotations with grass, perennial crops, manure application, and continuous cropping; whereas cereal–legume rotations and N fertilizer effects were undetectable. A strong, positive correlation occurred between SH and soil organic carbon concentration ($r = 0.73$). Soil water repellency should be measured on these plots using water-based methods.

Key words: legume–cereal rotation, wheat, lentils, hay, grass, nitrogen fertilizer, manure application, fallow, soil water repellency.

Résumé : Les auteurs voulaient quantifier les effets de l'assolement, du type de culture, du cycle de vie, de l'application d'un engrais azoté, de l'épandage de fumier ainsi que de la jachère sur l'hydrophobicité du sol (HS). Cette dernière a été calculée dans le cadre d'une expérience de longue haleine (16 ans), sur un loam argileux aride dans la zone des sols brun foncé du sud de l'Alberta, au Canada. La HS moyenne est significativement ($P \leq 0,05$) plus élevée pour les assolements de graminées, les cultures vivaces, l'application de fumier et la monoculture. Les effets de l'assolement céréales-légumineuses et de la fertilisation avec un engrais azoté sont indiscernables. La HS et la concentration de carbone organique dans le sol présentent une forte corrélation positive ($r = 0,73$). Pour mesurer le pouvoir hydrofuge du sol sur de telles parcelles, on devrait recourir à des méthodes hydriques. [Traduit par la Rédaction]

Mots-clés : assolement légumineuses-céréales, blé, lentille, foin, graminées, engrais azoté, épandage de fumier, jachère, pouvoir hydrofuge du sol.

Introduction

Long-term and diverse cropping systems, perennial crops, nitrogen fertilizer and feedlot manure application, and reduced fallow frequency may increase soil organic carbon (SOC) concentration and enhance soil water repellency (SWR) and soil hydrophobicity (SH). The terms SWR and SH have generally been used interchangeably since hydrophobic compounds are the main cause of soil water repellency (Doerr et al. 2000). Slight SWR or SH may have positive effects while excessive SWR or SH may have negative effects on soil, crops, and the environment (Miller et al. 2021*a*). The SWR is generally measured by physical methods involving water such as contact angle, water drop penetration time, molarity of ethanol test, water repellency index method, and capillary rise method (Wallis and Horne 1992). The soil hydrophobicity (SH) index measures the chemical quality of soil organic matter with respect to ratio of quantity of hydrophobic and hydrophilic compounds and can be measured using Fourier Transform

Received 24 August 2021. Accepted 28 November 2021.

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 Published at www.cdnsciencepub.com/cjss on 7 January 2022.

Infrared (FTIR) analysis (Capriel 1995). However, inconsistent correlations between SWR (using repellency index method) and SH (Miller et al. 2019*a*, 2021*a*, 2021*b*) suggest that SH (indirect method) may not always be a reliable predictor of SWR using water-based methods.

Few studies have been conducted on the effect of long-term and diverse crop rotations, N fertilizer and feedlot manure application, and fallow on SH in the Dark Brown soil zone of Chernozemic soils under dryland conditions in western Canada. Miller et al. (2019*a*) studied SH under different crop residue levels and N fertilizer under no-till at Lethbridge and found that SH was significantly greater by 33% for N-fertilized than unfertilized treatments. Miller et al. (2021*a*) compared SH for crested wheat grass, a native grass mix, continuous wheat, and wheat fallow under N fertilizer treatments under dryland at Lethbridge. They reported significantly greater SH for perennial grasses than annual cropping, but similar SH between continuous wheat and wheat fallow and between N fertilized and non-fertilized crops.

The objective of our study was to study the effect of long-term and diverse crop rotations, crop type and life cycle, N fertilizer, manure application, and fallow frequency on SH for a clay loam soil in the Dark Brown soil zone. We hypothesized that SH (due to expected effect on SOC) might follow: grass > legume > annual for crop types; perennial > perennial–annual > annual for life cycle; legume-cereal > cereal crop rotation; N fertilized > non-fertilized; manured > unamended; and continuous cereal > cereal rotation with fallow.

Materials and Methods

The long-term (since 1951) field experiment known as Rotation 120 was established at the Agriculture and Agri-Food Canada Research Centre at Lethbridge, Alberta, Canada (lat. 49.7058 N, long. 112.7758 W). The soil is an Orthic Dark Brown Chernozem clay loam with level and uniform topography and calcareous subsoil. The original objective of this experiment was to evaluate the influence of cropping frequency and nutrient amendments on grain yield and sustainability. Details on the treatments were reported previously (Smith et al. 2012, 2015). The design is a randomized complete block, and plot size is 3.2 m × 36.6 m. The long-term experiment had seven crop rotations from 1951 to 1954 (Rotation 96), eight rotations from 1955 to 1984 (Rotation 100), 13 rotations from 1985 to 1994 (Rotation 116), was uniformly cropped under continuous wheat from 1995 to 2000 (bioassay study), and has had 13 rotations from 2001 to present (Rotation 120; Table 1).

The 13 crop rotations used in this study (Table 1) were as follows: (1) continuous wheat (*Triticum spp.*) (W); (2) 2 yr fallow–wheat (FW); (3) 3 yr fallow–wheat–wheat (FWW); (4) continuous wheat plus N fertilizer [W(+N)] where ammonium nitrate (45 kg N·ha^{-1}) is broadcast prior to pre-seeding tillage; (5) 2 yr fallow wheat plus N fertilizer [FW(+N)]; (6) 3 yr fallow–wheat–wheat plus N fertilizer [FWW(+N)]; (7) 3 yr Oat (*Avena sativa*) + field pea (*Pisum sativum*, forage) (+ manure)–wheat–wheat (OpmWW) where manure is applied at 11.2 Mg·ha^{-1} (wet) in the fall in every second cycle (6th yr) of the rotation; (8) 3 yr lentil (*Lens culinaris*, green manure)–wheat–wheat (LWW); (9) 3 yr fallow (+ manure)–wheat–wheat (FmWW) where manure is applied at 11.2 Mg·ha^{-1} (wet) in the fall of the fallow year; (10) 6 yr fallow–wheat–wheat–hay–hay–hay (FWWHHH) where hay is a mixture of crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.] and alfalfa (*Medicago sativa)*; (11) continuous corn maize (*Zea mays*) plus N fertilizer [M(+N)]; (12) continuous hay (H), which is a mixture of crested wheatgrass and alfalfa (grass legume); and (13) continuous seeded native grass (G) mix, which is a mixture of needle and thread (*Hesperostipa comata*), blue grama (*Bouteloua gracilis*), June grass (*Koeleria macrantha*), green needle grass (*Stipa* sp.), and western wheat grass (*Pascopyrum smithii*). The grass was not harvested, but the plots were periodically burned in the spring to remove accumulated plant litter. Five treatments (W, FW, FWW, FmWW, FWWHHH) were established in 1951, five treatments in 1985 (W + N, FW + N, FWW + N, LWW, G), and three treatments (OpmWW, M + N, H) in 2001. There were four replications of each rotation, and all phases were present each year (30 treatment plots per replicate), resulting in a total of 120 treatment plots.

Surface (0–10 cm) soil samples (~2 kg) were collected from each of the 120 treatment plots with a flat spade on 10 and 11 May 2017 after 16 yr (since 2001) of the most recently imposed treatments. The soils were processed, and SOC, total nitrogen, C/N ratio, and SH were determined as outlined previously (Miller et al. 2019*a*). Fine-ground (<150 um) soil subsamples were analyzed using FTIR analysis using a bench-top Bruker 37 instrument (Bruker Optik, Ettlingen, Germany). The Mid-IR spectra were analyzed at absorption bands of 3020–2800 cm^{-1} (hydrophobic CH- functional groups) and 1740–1600 cm^{-1} (hydrophilic CO- functional groups); and the SH index was calculated as the ratio of CH to CO functional groups. (Miller et al. 2020). Capriel (1997) suggested that the hydrophobicity of soil organic matter was mainly caused by aliphatic CH- units present in methyl, methylene, and methine groups. The SWR was not determined for this study because of time constraints with measuring the large number (120) of samples using the repellency index method.

A MIXED model analysis (Miller et al. 2021*a*) was conducted on the dependent variables using crop rotation (all 13 rotations) as the main treatment factor and replicate as the random effect in the model. Other treatment effects of interest (crop type, life cycle, N fertilizer, manure, fallow, 3 yr rotations, etc.) were also evaluated using separate mixed model analyses. Crop type compared grass (Treatment 13), cereal–legume (Treatments 7, 8), cereal–grass–legume (Treatment 10), and cereal crops (Treatments 1–6, 9, 11). Life cycle compared perennial

Table 1. Influence of long-term (16 yr) cropping rotations and other treatment effects on soil organic carbon (SOC) and soil hydrophobicity index (SH) of surface (0–10 cm) clay loam soil at Lethbridge.

Treatment*	Crop rotation	Number of replicates	SOC (mg·kg^{-1})	SH
1	W	4	18.9 ± 0.4bcd	0.20 ± 0.01bcde
2	FW	8	15.0 ± 0.4f	0.13 ± 0.01e
3	FWW	12	15.6 ± 0.3ef	0.14 ± 0.01e
4	W + N	4	20.8 ± 0.3bc	0.25 ± 0.04abcd
5	FW + N	8	15.8 ± 0.1ef	0.13 ± 0.01e
6	FWW + N	12	16.9 ± 0.3de	0.15 ± 0.01e
7	OpmWW	12	19.4 ± 0.3c	0.17 ± 0.01cde
8	LWW	12	18.7 ± 0.3c	0.17 ± 0.02de
9	FmWW	12	19.4 ± 0.4c	0.19 ± 0.02bcde
10	FWWHHH	24	21.3 ± 0.4b	0.23 ± 0.01bc
11	M + N	4	18.2 ± 0.6 cd	0.13 ± 0.02de
12	H	4	27.8 ± 1.5a	0.28 ± 0.05ab
13	G	4	29.8 ± 0.9a	0.35 ± 0.04a
$P > F$			<0.0001	<0.0001

Note: Means ± standard error by column (13 crop rotations) not sharing a lowercase letter differs significantly at the $P < 0.05$ level using a Tukey–Kramer test (cropping system).

*Crop rotations: FmWW = fallow(+manure)–wheat–wheat; FW = fallow–wheat; FWW = fallow–wheat–wheat; FWWHHH = fallow–wheat–wheat–hay–hay–hay; FW + N = fallow–wheat plus N fertilizer; FWW + N = fallow–wheat–wheat +N fertilizer; H = hay; G = seeded native grass; LWW = lentil (green manure)–wheat–wheat; M + N = corn (maize) + N fertilizer; OpmWW = oat+field pea (forage)(+manure)–wheat–wheat; W = continuous wheat; W + N, Continuous wheat + N fertilizer.

(Treatments 12, 13), annual–perennial (Treatment 10), and annual crop rotations (Treatments 1–9, 11). Nitrogen fertilizer, manure, and fallow compared with and without N fertilizer, manure, and fallow, respectively. Continuous wheat (W) was also compared with wheat in cereal–legume rotation (OpmWW, LWW). The five 3 yr rotations compared were FmWW, OpmWW, LWW, FWW + N, and FWW. Significant differences ($P \leq 0.05$) among the 13 means were compared using a Tukey–Kramer test, and a least-significant or LSD test used for the other treatment factors. Mean ± standard errors in the text followed by different lower-case letters denote significant differences. The data were first examined using a Proc Univariate procedure to determine if a logarithmic transformation was required. Correlation analysis in SAS was conducted using the CORR procedure and was considered significant at the $P \leq 0.05$ level.

Results and Discussion

The range of mean SH values (0.13–0.35) in our study was comparable to SH values in previous studies (Miller et al. 2019*a*, 2020, 2021*a*, 2021*b*). Mean SH values were 9–169% greater (P < 0.05) for W + N, H, and G treatments (0.25–0.35) compared with the other 10 treatments (0.13–0.23) (Table 1). Mean SH values for crop type were greatest for seeded native grass (0.35 ± 0.04a), followed by cereal–grass–legume (0.23 ± 0.01b), and then cereal–legume (0.17 ± 0.01c) and cereal (0.16 ± 0.01c) crops. Mean SH values were greatest for perennial (0.32 ± 0.03a), followed by annual–perennial (0.23 ± 0.01b), and then annual (0.16 ± 0.01c) cropping. Similar trends were found for the effect of crop type and life cycle on SOC concentration. Our findings of significantly greater SH for grass than other crop types were consistent with previous studies on soil (Capriel 1995; Miller et al. 2020, 2021*b*). Miller et al. (2019*b*) also reported significantly greater SH values for pure residues of grass compared with four other crop types (cereal, legume, pulse, oilseed). Greater SH for grass than other crop types may be related to higher-than-normal grass residues returned to the soil, which are a major source of hydrophobic compounds (Miller et al. 2019*b*, 2020). Grass leaves are also superhydrophobic, and wax coatings are mainly composed of β-diketone wax crystals (Barthlott et al. 2017).

Mean SH values were similar for continuous W compared with cereal–legume rotations (OpmWW, LWW) and may have been caused by similar SOC concentrations. We expected that inclusion of legumes in a W rotation would increase SOC and SH because previous research has reported severe SWR under legumes (Doerr et al. 2000). In contrast, Miller et al. (2020) reported significantly greater SH for the alfalfa phases a

4 yr legume rotation (corn–oat–alfalfa–alfalfa) compared with continuous corn in southwestern Ontario. Similar SH for continuous W and cereal–legume in our study may have been related to the less frequent inclusion of legumes (1 in 3 yrs compared with 2 of 4 yr in their study, as well as different soils, geographic location, and other factors. The non-significant trend in our study was for greater SH for FmWW, followed by OpmWW and LWW, and then FWW + N and FWW, which was similar to the SOC trend. This suggested a potential for SH in 3 yr rotations to be enhanced by manure on fallow, legumes and manure, and legumes.

Nitrogen fertilizer had no effect on SH values for W, WF, and FWW rotations and did not support our hypothesis that fertilizer would enhance the quantity of hydrophobic compounds. No fertilizer effect may have been related to similar SOC. Miller et al. (2021*a*) reported similar SH despite significantly greater SOC for N-fertilized than non-fertilized treatments in southern Alberta. In contrast, other studies in southern Alberta (Miller et al. 2019*a*) and southwestern Ontario (Miller et al. 2020) have reported that N fertilizer significantly increased SH compared with non-fertilized treatments. As noted by Miller et al. (2021*a*), contrasting findings for fertilizer effects SH may be due to location of study site, soil type and texture, SOC concentration, crop type, crop rotations and duration, and type, rate, and incorporation method and depth of fertilizer applied.

Mean SH values were significantly greater by 36% for manured FmWW than non-manured FWW rotation, and SOC followed a similar trend. Greater SH has also been reported for manured than non-manured soils in southern Alberta; and manure amendments may contain many different hydrophobic organic compounds that could potentially cause SWR or hydrophobicity (Miller et al. 2021*b*).

Mean SH values were significantly greater by 54% for W than FW rotation and supported our hypothesis that SH would be greater under continuous cereal than fallow–cereal rotations. There was a strong, positive correlation between SOC and SH ($r = 0.73$, $P < 0.0001$, $n = 120$), suggesting that soil hydrophobicity was related to the quantity of SOC. Similar findings were also previously reported (Miller et al. 2019*a*, 2021*a*, 2021*b*).

Conclusions

Our findings after 16 yr suggested that grass, perennial crops, manure application, and continuous cropping increased the hydrophobicity of SOC, whereas cereal–legume rotations and N fertilizer effects were undetectable. A strong positive correlation between SOC and SH indicated that the concentration of SOC might be used to predict SH. For the five 3 yr rotations, SOC was significantly enhanced by manure on fallow, legumes with manure, and manure compared with fertilized and non-fertilized FWW. In contrast, these management effects on SH were undetectable for the 3 yr rotations. Further research is required on this field experiment using repellency index or other methods to directly measure SWR and the possible relationship with SH.

Acknowledgements

Research funding was provided by Agriculture and Agri-Food Canada. We thank Bruce Beasley (AAFC, Lethbridge, AB; retired), the soils field crew (AAFC, Lethbridge, AB), Weili Xu (AAFC, Harrow, ON), and Brett Hill (AAFC, Lethbridge, AB) for field and lab assistance.

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