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Importance of soil organic carbon on surface soil water content variability among agricultural fields

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SUMMARY

Improvements to the downscaling estimates of soil water content (SWC) from passive microwave retrievals require detailed knowledge of field scale influences on SWC variability. The Soil Moisture Active Passive Validation Experiment (SMAPVEX-12) field campaign provided SWC and physical properties from 50 cropland fields to assess the influence of soil organic carbon (SOC) on SOC variability in a range of SOC, SWC and soil textural class over a 6 week period. Field average SWC over the duration of the experiment was optimally predicted by combination of soil texture and SOC in all soil wetness conditions, although either %Sand or SOC separately also expressed 82% of variance in SWC over all fields covering three soil textural groups. Soil OC explained greater variance in SWC than texture in dry conditions, while texture predominated in moist conditions. The high correlation between SOC and SWC suggests soil OC may contribute to the initiatives to downscale SWC estimates from satellite to field scale where SWC data are sparse or inaccurate.

1. Introduction

The Soil Moisture Active Passive (SMAP) mission scheduled to launch in 2014 will provide frequent global coverage of SWC (Entekhabi et al., 2010) at relatively coarse resolution (9 km in the combined active and passive retrieval). This intensive soil water content (SWC) data will enable strides in weather and climate prediction, agricultural management and improve our understanding of hydrological processes and land-surface interactions (Entekhabi et al., 2010). There are numerous efforts to further downscale these products from the generally coarse resolution of SMAP products (9×9 km) to field scale ($\sim$0.5 km) based on the characterization of vegetation, soil, land surface, topography and rainfall that influence the variability of SWC at the field scale (e.g. Zhu and Lin, 2011). This application requires knowledge of the numerous spatial and temporal controls that affect SWC variability at the field scale including soil physical properties (texture, bulk density), tillage (roughness) and cropping systems (vegetation). While the complexity of soil characteristics relating to texture, organic matter and porosity has been recognized (Crow et al., 2012), to-date, watershed scale studies to validate remote sensing SWC measurement frequently represent soil factors by soil textural class alone (Choi and Jacobs, 2011; Cosh et al., 2004; Famiglietti et al., 2008; Joshi and Mohanty, 2010; Joshi et al., 2011; Ryu and Famiglietti, 2006).

Soil textural classification has been considered the dominant factor affecting the rate of soil water absorption and drainage in initial hydrological models (Saxton et al., 1986) as represented in the moisture characteristic curve (Tuller and Or, 2004). Soil bulk density (SBD) and soil organic carbon (SOC) or organic matter, are considered at times to improve SWC estimation (Rawls et al., 1982, 2003; Saxton and Rawls, 2006). Soil bulk density refers to the ratio of volume to mass of soils and is commonly calculated as:

$$\text{Soil bulk density} = \frac{\text{mass of soil (g)}}{\text{volume of soil (cm}^3)} \quad (1)$$

Porosity refers to the volume of pores that can be filled with either water or air in relation to the total volume of soil and computed as (Brady, 1990):

$$\text{Porosity} = 1 - \left(\frac{\text{soil bulk density}}{\text{particle bulk density}}\right) \quad (2)$$

Particle density is commonly equated to 2.65 g m^{-3}. Porosity is the soil variable frequently applied in hydrological models to accommodate change in the rate of water movement through soils and thus represents SOC, SBD and water infiltration capacity (Pollacco, 2008; Zacharias and Wessolek, 2007). Several studies have included SBD as a measure of soil organic matter (Pollacco, 2008), however, analysis of SOC and SBD data have often been absent from multiple field SWC sampling experiments at remote sensing footprint scale (e.g. $\sim$40 km).

Organic matter [approximated by $1.8 \times$ SOC (Broadbent, 1965)] is considered a state variable in soil affecting aggregate size and

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the aeration and water retention in surface soil (Franzluebbers, 2002). The increase in field capacity from SOC can be attributed to greater macroaggregates and increased porosity for rain infiltration in no-till studies (Franzluebbers, 2002; Shaver et al., 2002). In recent years, the effect of soil organic matter has been studied in the field (Franzluebbers, 2002), through meta data analysis (Hudson, 1994; Rawls et al., 2003) and in models (Pollacco, 2008; Saxton and Rawls, 2006) as a factor that can also affect soil wetting and drying rates. From a compilation of data from the USDA agricultural soil data base over multiple years, soil textural classes and ranges of WC, Rawls et al. (2003) found that including SOC increased the predictive capacity of SWC by 10% over soil textural class alone. This relationship has been explained from the greater effect of organic matter on increasing the field capacity (water holding capacity of soil) compared to the wilting point of soil (Hudson, 1994).

Soil BD and SOC are also highly correlated in soil (Blanco-Canqui et al., 2006; Blanco-Canqui and Lal, 2007; Franzluebbers, 2002). Soil OC presents a single variable that changes slowly over time compared to SWC. Soil OC has been measured to change by 1% within a single growing season under optimal conditions (Manns et al., 2007, 2009), however, in large scale field trials significant differences are difficult to detect over multiple seasons and crops (Vandenbygaart et al., 2003). Soil OC requires less sampling time and effort than SBD and there are a variety of methods to estimate SOC without physical samples. Soil OC has the potential benefit of being detected by several different methods of multispectral remote sensing (Chen et al., 2000; Serbin et al., 2009; Morgan et al., 2009; Ladoni et al., 2010).

The SMAPVEX-12 field sampling campaign was held near Elm Creek Manitoba from June 6 to July 17, 2012. In preparation for the SMAP launch in 2014, the SWC algorithms were validated using remotely derived and ground sampled SWC data, soil and plant sample analysis and surface roughness. This analysis focused on the SWC of ground sample measurements to the soil physical properties of SOC, SBD and soil texture in the top 5 cm of soil at the field scale. The objective was to understand the amount of variability of SWC that can be explained through observations of SOC, as compared to SBD and soil texture, over a large number of agricultural fields.

2. Methods

2.1. SMAPVEX-12 field site

Surface SWC was measured in 50 cropland fields around Elm creek, Manitoba (98°23″W, 49°40.48″N) from June 6 to July 17, 2012 for the pre-launch validation experiment of the types of sensors that will be used on the SMAP satellite. The study site included a mix of the common field crops and a range of soil texture from sand to clay (Fig. 1). The topography is relatively level with elevation changing less than 30 m over the study area, characteristic of the Red River valley. The sandy soils to the west were elevated by a moraine dividing them from the heavy clay soils to the east which accounts for most of the elevation change. Loam soils predominated in the south of the study area nearest to Carman. The soils are of the order Chernozem, characteristic of the Canadian prairie, with high organic matter (2–5%), water holding capacity and fertility (Michalyna et al., 1988). Further detail is available from the 1988 survey of the area (Michalyna et al., 1988) or as current digital information in the Soil Landscapes of Canada, (Government of Canada, 2011).

The climate of the region is Continental with long, cold winters and short hot summers with average total rainfall of 398 mm/year. The weather conditions were well suited for the SWC study; the study commenced after a week of dry weather, followed by periods of substantial wetting and drying (Fig. 2). At the beginning of the experiment winter wheat was well established, but most seeded crops were at the early emergence/growth stage (<20 cm). Dominant crops included canola (*Brassica napus*), corn (*Zea mays*), soybean (*Glycine max*) and wheat (*Triticum aestivum*). At the end of the sampling time, winter wheat was ready for harvest, corn was at tassel stage and soybean and canola were at pod filling stage.

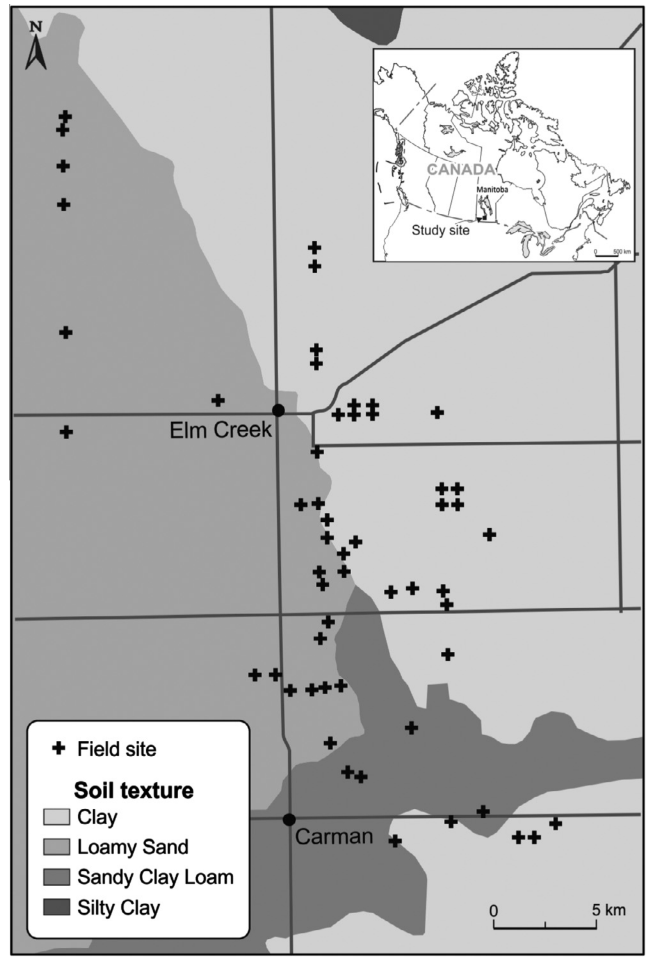

Fig. 1. Location of SMAP field sites in southern Manitoba, Canada in relation to soil texture map. Data from Soil Landscapes of Canada Version 3.2, (Government of Canada, 2011) and National Road Network Version 2.0 (Government of Canada, 2007).

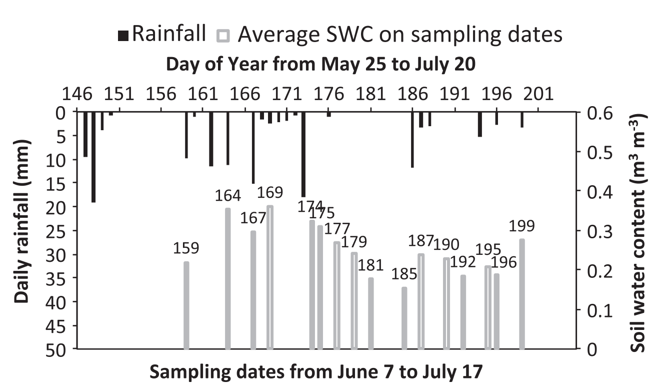

Fig. 2. Rainfall (mm) (dark bars) from May 25 to July 20 and soil water content ($m^3\ m^{-3}$) averaged over all 50 fields at each sampling time during the SMAPVEX-12 field campaign from Jun 7 to July 17, 2012.