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Comparison of soil quality and productivity at two sites differing in profile structure and topsoil properties

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ABSTRACT

Improved means for assessing the impact of management on soil quality (SQ) are needed. Objectives of this study were to assess SQ of two soils with similar taxonomy but dissimilar soil profile characteristics and compare SQ ratings with crop productivity. Soils evaluated included a glacial-till derived (GTD) loam/clay loam and an alluvial-derived (AD) sandy loam in central North Dakota, USA (403 mm mean annual precipitation). Application of the Soil Management Assessment Framework (SMAF) to seven properties showed the soils had similar SQ index (SQI) values of 69 and 68 (out of 100 possible) for GTD and AD soils at 0–30 cm depth, respectively, while they had SQI values of 89 and 87 at 0–5 cm depth. The GTD soil had 17.1 g kg^{-1} organic C compared to 9.8 g kg^{-1} for AD soil, and higher SMAF scores for organic C and available water capacity (AWC), but lower scores for Olsen P and potentially mineralizable N. Soil productivity, as expressed by seed yield of dry pea (*Pisum sativum* L.), spring wheat (*Triticum aestivum* L.), and maize (*Zea mays* L.), was determined from two multi-crop sequence experiments conducted under no-tillage. Seed yields of spring wheat following spring wheat in 2003 and 2005 were 35% and 14% greater on GTD soil than on AD soil, but not different in 2003. Dry pea and maize forage yields were generally equivalent between soils, but 2004 maize seed yields on GTD soil following dry pea, spring wheat, and maize were 28%, 30%, and 54% lower, respectively, than on AD soil. Lower maize yields on GTD soil compared to AD soil during 2004 were associated with low subsoil hydraulic conductivity and shallower soil water depletion and root growth on GTD soil. Although GTD soil had higher levels of more stable SQ indicators (organic C, AWC) than AD soil, their similar, relatively high SQI values indicate positive responses to soil conservation management. Our results show the need for integration of soil profile and subsoil information with near-surface SQ assessments.

1. Introduction

Natural sciences have increasingly embraced the concept of the soil resource as an integral contributor of ecosystem services necessary to support plant-based life (Robinson et al., 2012). Soil quality (SQ), defined as the capacity of a soil to function (Doran and Parkin, 1994; Karlen et al., 2001), serves as an important metric for quantifying soil's role to support multiple ecosystem services. Monitoring a balance of biological, physical, and chemical soil properties is central to assessments of SQ status (Doran and Jones, 1996).

The Soil Management Assessment Framework (SMAF) was designed to make quantitative assessments of SQ status with the purpose of determining the sustainability of management (Andrews et al., 2002, 2004). The SMAF was designed to assess the response of a given type of soil to management, and to indicate the SQ status within a relative range of potential for that soil; it was not designed to directly compare different soils (Andrews et al., 2004). A set of SQ indicator properties are scored through a series of relationships between soil properties and management goals, including soil productivity, waste recycling, and environmental protection. A management goal is designated by the user, and a SQ index (SQI) value is calculated from application of SMAF scoring algorithms to indicator properties.

An earlier proposal for SQ assessment was that of Larson and Pierce (1994), whereby indicator properties would be evaluated over the entire soil rootzone, weighted by root function with

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Abbreviations: AD, alluvial-derived (soil); ANOVA, analysis of variance; AWC, available water capacity; EC, electrical conductivity; GTD, glacial till-derived (soil); MDS, minimum data set; NOAA, National Oceanic and Atmospheric Administration; PMN, potentially mineralizable nitrogen; SMAF, Soil Management Assessment Framework; SQ, soil quality; SQI, soil quality index; SWD, soil water depletion; TOC, total organic carbon.

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Table 1
Soil properties and conditions at two land locations at which soil quality evaluations and crop sequence experiments were conducted. Depths of textural information were as indicated; depths of TOC and AWC were 0–30 cm. Values in parentheses indicate mean standard error (MSE).

Part A. General properties and conditions

Property/Condition	Alluvial-derived soil	Glacial till-derived soil
Total organic carbon (TOC) (g kg^{-1})	9.8 (0.4)	17.1 (1.7)
Available water capacity (AWC) (kg kg^{-1})	0.147	0.221
Soil taxonomy	Lihen-Parshall complex: Sandy, mixed, frigid Entic Haplustolls and Coarse-loamy, mixed, superactive, frigid Pachic Haplustolls	Temvik-Wilton silt loam: Fine-silty, mixed, superactive, frigid Typic and Pachic Haplustolls
Profile structure	Alluvial-derived material throughout	Loess-derived upper zone over glacial-till
Management history	Approx. 40 yr in perennial grass before 2000	Approx. 80 yr in crop production before 2000
Shelterbelt presence	Tree shelterbelts on three sides	No shelterbelts

Part B. Textural properties

	Alluvial-derived soil: sandy loam			Glacial till-derived soil: loam/clay loam		
Soil depth, cm	Sand (g kg^{-1})	Silt	Clay	Sand (g kg^{-1})	Silt	Clay
0–20	723 (46)	174 (24)	103 (22)	258 (11)	484 (13)	258 (7)
20–41	708 (46)	176 (30)	116 (16)	311 (47)	399 (52)	290 (11)
41–61	718 (50)	167 (34)	115 (16)	263 (35)	434 (47)	303 (13)

depth. While this concept of SQ assessment would involve evaluations of soil properties throughout the profile, more current SQ practices have focused on dynamic and accessible properties responsive to management in topsoil depths (Cambardella et al., 2004; Karlen et al., 2008; Liebig et al., 2012). However, soil productivity is affected by both topsoil and profile characteristics over depth (Hewitt, 2004). Accordingly, examination of soils closely related by soil genesis as reflected in their taxonomy, but having different parent materials and profile structure presents an opportunity to evaluate influences of topsoil vs. whole profile attributes on SQ.

An opportunity to explore topsoil versus full profile aspects of the SQ-soil productivity relationship arose through a pair of crop sequence experiments performed in the northern Great Plains on two soils classified as Haplustolls (Merrill et al., 2012; Tanaka et al., 2007). One soil had an alluvial-derived (AD) sandy loam profile, the other a glacial till-derived (GTD) loam/clay loam profile.

Here we present results of applying SMAF to compare SQ assessments of two contrasting soils. Soil productivity was examined by comparisons of crop yields from crop sequence experiments. To better understand influence of soil profile characteristics on productivity, measurements of soil water depletion (SWD) and root growth were examined.

A guiding hypothesis for the study was that topsoil properties of the coarser-textured AD soil with lower organic C content would result in lower SQ assessment and lower productivity compared to the finer-textured GTD soil with higher organic C content. Goals of the study were to (a) compare SQ assessments of the two soil types with their soil productivities as indicated by crop sequence experiment results, and (b) analyze effects of soil profile characteristics on productivity differences indicated by crop yield results.

2. Research methods

2.1. Locations, soils, and climate

Soil properties and soil productivity were measured at two locations in south central North Dakota on lands of the USDA-ARS Northern Great Plains Research Laboratory (NGPRL). One location (46°45′30″ N, 100°55′00″ W) was at the Area IV Soil Conservation Districts Cooperative Research Farm, approximately 7 km south from NGPRL headquarters, and has GTD loam/clay loam soil classified as Temvik-Wilton silt loams (fine-silty, mixed, superactive, frigid Typic and Pachic Haplustolls (Table 1). The other location (46°48′15″ N, 100°54′45″ W) was about 1 km south of NGPRL headquarters and has AD, sandy loam soil which is classified as a Lihen-Parshall complex (sandy, mixed, frigid Entic Haplustolls and coarse-loamy, mixed, superactive, frigid Pachic Haplustolls), with the Parshall series apparently dominant. Both locations consisted of gently rolling land with slopes no greater than 3° (USDA-NRCS, 2012).

The climate pattern of the area is continental, semi-arid to subhumid. Based on a 1971 to 2000 period (NOAA, 2004), mean annual temperature was 5.5 °C, and January and June averages were −12.2 and 21.2 °C, respectively. Mean annual precipitation was 403 mm, greatest monthly precipitation, 69 mm, occurs in June, and April-September growing season precipitation is 318 mm.

2.2. Soil productivity assessment through crop sequence experiments

Soil productivity was assessed through two crop sequence experiments conducted by the USDA-ARS NGPRL, descriptions of which have been previously published: on GTD soil by Tanaka et al. (2007); on AD soil by Merrill et al. (2012). The pattern by which the experiments were conducted featured (a) growth of spring wheat or other small grain crop in the year before start of the experiments; (b) seeding of either 10 or 4 crop species in 9-m-wide strips one year – the *residue crops*; (c) seeding of the same suite of crop species in 9-m-wide strips perpendicular to the first sets of strips during the second year of the experiment–the *matrix crops* – thereby creating checkerboard-like crop matrices whereby the results of either 100 or 16 different crop sequences could be observed; and (d) seeding of spring wheat over the crop matrix in the third year of the experiment – the *spring wheat follow crop*.

The 10 × 10 crop sequence experiment (GTD soil) and the 4 × 4 experiment (AD soil) had three species in common, which were used for purposes of this paper: dry pea (*Pisum sativum* L.), maize (*Zea mays* L.), and spring wheat (*Triticum aestivum* L.). Details of the agronomic management of the two experiments were closely similar, and can be found in Tanaka et al. (2007) for work on GTD soil and in Merrill et al. (2012) for work on AD soil. The experiments were conducted under no-till management, principally including pre-seeding application of the herbicide glyphosate. Fertilizer was applied annually at rates of 78 kg N ha^{-1} (no N applied to dry pea) and 11 kg P ha^{-1}. Subplot size was 9.1 m square and harvest was by a small research combine.