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Soil quality response to long-term tillage and crop rotation practices

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ABSTRACT

Soil quality is influenced by inherent and anthropogenic factors. This study was conducted to provide multiple groups guidance on how to achieve and maintain improved soil quality/health. Our hypothesis was that tillage intensity was the primary anthropogenic factor degrading soil quality, and our objective was to prove that hypothesis through an intensive 2005 sampling of a central Iowa, USA field study. Chisel plow, disk tillage, moldboard plow, ridge-till and no-till treatments, used for 31 years in a two-year, corn (*Zea mays* L.)/soybean [*Glycine max* (L.) Merr.] (C/S) rotation or for 26 years of continuous corn (CC) production, were evaluated by measuring 23 potential soil quality indicators. Soil samples from 0 to 5- and 5 to 15-cm depth increments were collected from 158 loam or clay loam sampling sites throughout the 10-ha study site. Nine of the indicators were evaluated by depth increment using the Soil Management Assessment Framework (SMAF) which has scoring functions for 13 soil biological, chemical, and physical measurements and can be used to compute individual indicator indices and an overall soil quality index (SQI). Water-stable aggregation (WSA), total organic carbon (TOC), microbial biomass carbon (MBC), and potentially mineralizable nitrogen (PMN) were all significantly lower for the 0 to 5-cm and generally lower for 5 to 15-cm increments after long-term moldboard plowing and its associated secondary tillage operations. This presumably reflected greater physical breakup and oxidation of above- and below-ground plant residues. Bray-P concentrations in moldboard plow plots were also significantly lower at both depth increments. Between soil texture groups, significant differences were found for WSA, Bray-P, TOC and MBC at both depth increments and for both cropping systems. When combined into an overall SQI, both soil texture groups were functioning at 82–85% of their potential at 0–5-cm and at 75% of their potential at the 5–15-cm depth. Our hypothesis that moldboard plowing would have the greatest negative effect on soil quality indicators was verified. Based on this assessment, we recommend that to achieve and maintain good soil health, producers should strive to adopt less aggressive tillage practices.

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1. Introduction

Soil quality/health is a product of inherent (parent material, climate, and topography) and anthropogenic (tillage and crop rotation) interactions (Karlen et al., 1997). Tillage, which evolved as part of anthropogenic soil management, gradually became an integral part of crop production systems such that by 4000 years before present (BP), wooden plows drawn by oxen were used to scratch the soil surface in Europe, China, and many other regions. However, plows that actually inverted the soil were not developed until the 17th century. European advancements during the 18th century resulted in the moldboard plow which turned the soil by 135° and significantly improved weed control (Derpsch, 1998). This was of tremendous importance to many Europeans and especially the Germans because with soil inversion, they could overcome quackgrass (*Agropyron repens*) infestations that had become nearly impossible to control.

Presumably the European experience with moldboard plowing contributed to its widespread use when immigrants from those regions needed to break the prairie as they settled the U.S. Midwest (Karlen et al., 2010). Unfortunately by the mid 1930s, plowing had caused 40% of the land area in Iowa to lose 50–70% of its surface soil, which was often deposited in rivers and lakes as silt (Chase, 1936). Opportunities to slow this natural resource degradation by decreasing the intensity of tillage became scientifically feasible following World War II. Development of plant growth regulators (*i.e.*, herbicides) and improved fertilizer management strategies

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made it feasible to grow crops with less and less tillage (Phillips and Phillips, 1984).

The need for information on less intensive tillage systems for Midwestern USA soils was a primary reason for initiating tillage and crop rotation studies at this research site in 1975 (Erbach, 1982). To quantify long-term effects of those practices after 31 years of known management (Karlen et al., 2013), an intensive sampling and soil quality indicator assessment was conducted to test our hypothes that intensive tillage practices were degrading soil quality/health.

To quantify long-term tillage effects, the Soil Management Assessment Framework (SMAF) developed by Andrews et al. (2004) was used as a soil quality assessment tool. The SMAF uses a 3-step process to assess soil quality. This includes indicator selection, indicator interpretation, and integration into an overall soil quality index or SQI. Soil taxonomy provides the foundation for each assessment based on soil suborder characteristics. Assessment values are generally expressed as a fraction or percentage of full performance for soil functions such as crop productivity, nutrient cycling, or environmental filtering and buffering. Currently, the SMAF has scoring curves or interpretation algorithms for 13 indicators: water-stable macroaggregation (WSA), plant-available water (PAW), water-filled pore space (WFPS), bulk density (BD), electrical conductivity (EC), pH, sodium adsorption ratio (SAR), extractable P and K, soil organic carbon (SOC), microbial biomass carbon (MBC), potentially mineralizable N (PMN), and β-glucosidase (BG) activity (Andrews et al., 2004; Wienhold et al., 2009; Stott et al., 2010).

The SMAF has been used in the U.S. and abroad to evaluate near-surface (0–5 and 5–15 cm) soil properties and processes (e.g. Fernandez-Ugale et al., 2009; Imaz et al., 2010; Jokela et al., 2009; Karlen et al., 2006, 2011; Liebig et al., 2006; Stott et al., 2011; Wienhold et al., 2006; Zobeck et al., 2008). The unique aspect of this study is the longevity of the tillage and crop rotation treatments and the intensive analysis of soil samples representing two important texture groups (loam and clay loam). We hypothesized that intensive tillage (*i.e.*, moldboard plowing) and acidification due to higher N fertilizer applications for continuous corn (CC) would have the most notable effects on soil quality. We also hypothesized that the differences would be more detectable within loam sampling sites because they are located at a slightly higher elevation (~2–3 m) and are often more eroded than the clay loam sites. We tested these hypotheses by intensively sampling 40, 0.3 ha plots where five tillage practices had been evaluated for C/S or CC rotations for 31 or 26 years, respectively.

2. Methods and materials

2.1. Site characteristics and general experimental design

The long-term tillage and crop rotation study for which this soil quality/soil health assessment was conducted was initiated in 1975 (Erbach, 1982) at the Iowa State University (ISU) Agronomy/Ag Engineering Research and Education Center (AAEREC) in Boone County, IA (latitude 42°01′ N, longitude 93°45′ W). As summarized by Karlen et al. (2013) there initially were eight "replicates" of each tillage system with four each managed in each phase of a corn and soybean rotation. Each tillage plot was 33 m wide and 91 m long except on the northwest and southeast corners of this 10-ha research site, where grass waterways (installed to capture and divert surface runoff from the research site) resulted in slightly shorter plots (Fig. 1). The tillage systems were: (1) slot plant on ridges which was eventually transitioned to a no-till operation; (2) spring disk; (3) till plant (ridge tillage) where surface soil to a depth of ~5–8 cm is "thrown off" during planting and then the ridges are later rebuilt through cultivation; (4) fall moldboard plowing; and (5) fall chisel plowing. From 1976 through 1980, the plots were managed in an alternating corn and soybean rotation. Starting in 1979 and continuing through 2006, the four replicates in the south half of the site (Fig. 1) were used for continuous corn (CC) production, while the north half was maintained in the corn/soybean (C/S) rotation with each crop occurring every other year.

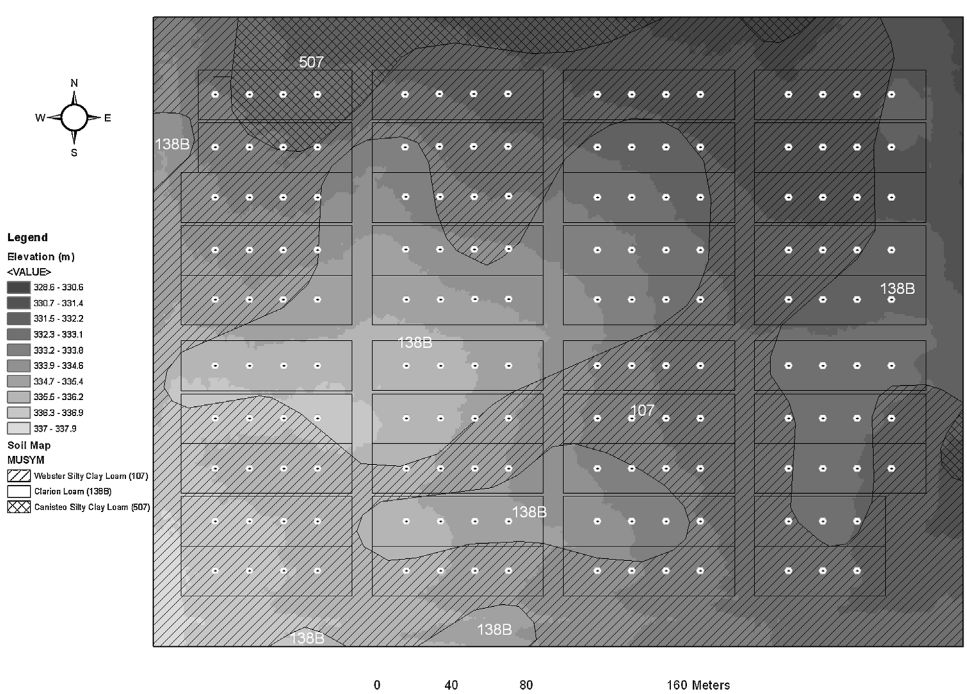

Fig. 1. Elevation, soil series, and plot layout for the long-term tillage evaluations on the ISU Agronomy/Agricultural Engineering Research Center near Boone, Iowa, USA The bottom half was in continuous corn (CC) from 1979 through 2005, while the top half was in a corn and soybean(C/S) rotation from 1975 through 2005. The points represent the 2005 soil sampling sites.