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Changes in soil surface chemistry after fifty years of tillage and nitrogen fertilization

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ABSTRACT

Knowledge gained on the long-term effects of crop management practices on soil fertility is critical in developing nutrient management strategies to optimize crop yields. This study examined the long-term effects of nitrogen (N) fertilizer application rates (0, 22, 45 and 67 kg N ha^{-1}) and tillage intensity [conventional tillage (CT), reduced tillage (RT) and no-tillage (NT)] on soil phosphorus (P), micronutrients and soil acidity in a dryland winter wheat (*Triticum aestivum* L.) – sorghum (*Sorghum bicolor* L.) – fallow cropping system. Results showed soil organic matter (SOM), iron (Fe) and manganese (Mn) concentrations were greater under NT compared to CT or RT. Similarly, NT (32 mg kg^{-1}) increased P accumulation in the upper 7.5 cm soil depth compared to CT (21 mg kg^{-1}) or RT (26 mg kg^{-1}). After 50-yr of tillage and N fertilizer application, pH at the soil surface (0 to 7.5 cm) declined markedly with increasing N application, ranging from 6.4 with the unfertilized control to 5.7 when 67 kg N ha^{-1} was applied. Averaged across N rates, Δ pH in the soil surface over the 50-yr was greater with NT compared to CT or RT treatments. Iron and Mn concentrations increased with increasing N application rates, possibly due to the decrease in pH associated with N application. Based on our findings, growers adopting NT need to monitor changes in soil surface chemistry and take necessary corrective measures such as liming to maintain satisfactory pH and nutrients levels to optimize crop yields.

1. Introduction

Dryland farmers in the semi-arid environment of the central Great Plains region of the USA are increasingly adopting conservation tillage practices such as no-tillage (NT). In 2012, there were 111.5 million ha of planted cropland in the USA, out of which an estimated 38.6 million ha (~35% of total planted acreage) were under NT practices (USDA NASS, 2012). Previous research documented the benefits of NT practices such as reduced soil erosion and runoff (Dick et al., 1991; Baveye et al., 2011; Singh et al., 2012), improved soil physical properties (Blanco-Canqui et al., 2010; Jin et al., 2011), enhanced soil organic matter (SOM) content (Thomas et al., 2007; Blanco-Canqui and Lal, 2008; de Santiago et al., 2008; Kumar et al., 2012), and increased soil water retention (Unger, 1984; Peterson et al., 1996; Stone and Schlegel, 2006; Nielsen and Vigil, 2010). In the Great Plains region of the USA, adoption of NT is credited for reducing wind and water erosion specifically in dryland cropping systems (Hansen et al., 2012).

Despite the benefits mentioned earlier, continuous NT practice tends to cause soil nutrients and SOM stratification (Dick et al., 1991; Guzman et al., 2006; Thomas et al., 2007; Deubel et al., 2011; Mikha et al., 2013), increase acidification in the upper soil surface (Franzluebbers and Hons, 1996; Duiker and Beegle, 2005; Limousin and Tessier, 2007; Tarkalson et al., 2006; Lopez-Fando and Pardo, 2009), and may increase bulk density near the soil surface (Wander and Bollero, 1999; Halvorson et al., 2002; Zuber et al., 2015). Unlike NT, in conventional tillage (CT) or reduced tilled (RT) practices, soil inversion and mixing with the lower depth (the depth of tillage) through tillage operations could reduce nutrients stratification, bulk density, and soil acidity. The incorporation of crop residue with CT and RT enhances residue decomposition rate depending on the local climate, depth of tillage, and residue incorporation which could lead to SOM depletion (Beare et al., 1994; Paustian et al., 1997; Mikha et al., 2014). Whereas, in NT systems, the accumulation of crop residue at the surface leads to SOM build-up and stratification of nutrients and SOM compared to CT or RT systems.

Tillage effects on soil nutrients distribution within the soil profile specifically for less mobile nutrients such as phosphorous (P), potassium (K), or calcium (Ca) is well documented (Guzman et al., 2006; Thomas et al., 2007; Houx et al., 2011). However, P and K concentrations tend to be greater in the upper 15 cm of soils under NT compared

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to RT or CT systems (Dick, 1983; de Maria et al., 1999; Guzman et al., 2006; Costa et al., 2010; Deubel et al., 2011). Houx et al. (2011) observed that NT resulted in greater accumulation of P and K concentrations in 0 to 5 cm soil depth when compared to CT. However, the accumulation of P and K concentration below 5 cm depth associated with NT was observed to be less or similar to that under CT, suggesting significant nutrient stratification in the NT compared with CT. Tillage effects on micronutrients, iron (Fe), Zinc (Zn), cupper (Cu) and manganese (Mn) distribution in the soil is less consistent. Previous studies reported greater accumulation of micronutrients, particularly Zn and Mn in upper surface of soils under NT (Edwards et al., 1992; Franzluebbers and Hons, 1996; Martin-Rueda et al., 2007; de Santiago et al., 2008; Moreira et al., 2016), yet others found tillage had no effect on Zn and Mn availability in the soil (Lavado et al., 1999; Hickman, 2002).

The combination of different tillage practices and fertilizer management were found to affect soil chemical properties at different depths (Blevins et al., 1983; Schroder et al., 2011). Soil acidification was significantly greater in the upper soil surface under NT compared to CT systems, but the decrease in pH was exacerbated with increasing N rate regardless of tillage intensity (Blevins et al., 1983; Fageria et al., 2010; Das et al., 2012). In a long-term (30-yr) study in Oklahoma, Schroder et al. (2011) found a significantly negative relationship between soil pH and the amount of N fertilizer applied regardless of N source. Soil acidification near the soil surface is usually caused by nitrification of ammonium containing fertilizers and decomposition of SOM (Barak et al., 1997; Bolan and Hedley, 2003; Fageria et al., 2010).

Soils in the central Great Plains region of USA are general calcareous with high buffering to changes in pH due to the semi-arid climate that limit leaching of basic cations (Soil Survey Staff, 2016). However, recent adoption of no-till coupled with intensified crop production systems that required inorganic N fertilizer application to achieved optimum grains yields can result in soil acidification. In a dryland NT wheat-corn (*Zea mays*)-fallow rotation study in Colorado, USA, Bowman and Halvorson (1998) found a significant decrease in pH from 6.5 to 5.1 at the surface 5 cm after nine annual applications of ammonium nitrate at 112 kg N ha^{-1}. This decrease in soil pH can reduce nutrient availability and uptake and may also cause plant injury. Long-term experiments are needed to investigate soil management effects on soil chemistry and nutrient dynamics to aid in developing nutrient management strategies to optimize crop yields.

Few studies have investigated the effects of long-term (> 20-yr) tillage and N fertilizer management on soil chemistry in semi-arid dryland crop production systems (Thompson and Whitney, 2000; Tarkalson et al., 2006). In a 30-yr tillage and N fertilizer application study on a silt loam soil in Kansas, Thompson and Whitney (2000) found significant decline in soil pH and extractable P concentration in the upper 7.5 cm of the soil with increasing N fertilizer application rate. Regardless of tillage intensity, soil pH in the upper 7.5 cm increased in the control treatment compared to the initial soil test levels. In addition, the authors showed P and SOM concentrations were greatest near the soil surface with NT when compared to soils under CT or RT plots. Due to lower precipitation amounts, changes in soil chemistry in semi-arid dryland systems may take longer time compared to environments with greater precipitation. To our knowledge, long-term soil management effects on nutrient dynamics, particularly micronutrients has not been extensively studied in the semi-arid Great Plains. The current manuscript is a follow up of the findings by Thompson and Whitney (2000) to examine soil profile distribution of pH and soil nutrients after 50-yr of tillage and N fertilizer application to a Typic Agriustoll soil. We hypothesized that soil acidification and SOM accretion will be confined to the surface of soils under long-term no-till production. The objective of the current study was to investigate changes in soil chemical properties within 0 to 60 cm of the soil after 50-yr of tillage and nitrogen applications to a wheat-sorghum-fallow (W-S-F) crop rotation system in the semi-arid central Great Plains.

2. Materials and methods

2.1. Site description

This long-term study was conducted at the Kansas State University Agricultural Research Center near Hays, Kansas (38°86′ N, 99°27′ W, 609 m elevation) on a Harney silt loam soil (fine, montmorillonite, mesic Typic Agriustoll). The Harney series consists of deep, well-drained soils formed in calcareous, medium-textured loess, and has slopes of 0–7% (Soil Survey Staff, 2016). Long-term average annual precipitation at the experimental site is 560 mm, of which > 75% (438 mm) is received from April through September. Mean annual air temperature is 12 °C.

Soil fertility analysis conducted at the beginning of the study in 1965 was not different among the preassigned crop rotation and tillage treatment plots. Average soil pH in the upper 0 to 7.5 cm of the soil was 6.3, extractable P was 62.5 mg kg^{-1}, and SOM was 2.1 g kg^{-1}. Similarly, soil pH measured at 7.5 to 15 cm depth was 6.6, while P and SOM concentrations were 40.1 mg kg^{-1} and 1.9 g kg^{-1}, respectively. Prior to the initiation of the study in 1965, the experimental site was managed as a CT wheat-fallow crop production system.

2.2. Study set-up and treatments

The study was established in 1965 to investigate the effects of tillage intensity on winter wheat and grain sorghum yields in a W-S-F rotation scheme. The three tillage treatments were conventional tillage (CT), reduced tillage (RT) and no-tillage (NT) arranged in randomized complete blocks with four replications. Each phase of the W-S-F crop rotation was present in each year of the study. Then in 1975 the experiment was modified to superimposed N fertilizer application rates to the tillage treatments in a split-plot arrangement. The original tillage treatments (CT, RT, and NT) were the main plots and sub-plot factor was four N application rates (0, 22, 45 and 67 kg N ha^{-1}). Individual plot sizes of each tillage treatment were 20.4 m × 30.5 m, which were the split into four 3.4 m × 30.5 m sub-plots to accommodate the N application rate treatments. There was a 3.5 m wide border between tillage treatments. Ammonium nitrate was the N fertilized source from 1975 to 2002, thereafter; urea was the N fertilizer source applied to the plots. Nitrogen fertilizer was broadcasted in the fall prior to wheat planting while N application to grain sorghum plots were done in early spring before sorghum planting in June. Fertilizer was incorporated in the CT and RT tilled plots while fertilizer applied remained on the soil surface under NT. Because soil test levels for available P were medium to high over the study period and exchangeable potassium (K) are inherently high in this soil, therefore, N was the only fertilizer applied over the 50-yr study period.

2.3. Crop management

The W-S-F cropping system starts with winter wheat planted in late September to the first week in October and harvested the following June or July. The cropland is left fallow after wheat harvest then planted to grain sorghum the following year in June and harvested in November. The land remains fallow until the following September or October when it is planted again to winter wheat. This W-S-F cropping system allows production of two crops in 3-yr with a 10 to 11-month fallow period between grain sorghum and winter wheat crops. Details of all field operations and crop management are presented in Thompson and Whitney (2000). Briefly, the CT plot were plowed and disked to 15 cm soil depth to incorporate crop residue using a tandem disk. In addition, a field cultivator was used for the last tillage operation before wheat planting. However, tillage in the RT treatments was done with a sweep plow. Tillage operations with a sweep plow doesn't involve soil inversion therefore significant amount of crop residue are left on the soil surface compared to disking and plowing in the CT plots.