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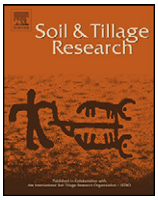

Tillage and drainage impact on soil quality
I. Aggregate stability, carbon and nitrogen pools

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ABSTRACT

Effects of two tillage treatments, tillage (T) with chisel plough and no-till (NT), were studied under un-drained and drained soil conditions. Soil physical properties measured were bulk density (ρ_b), total porosity (f_t), water stable aggregates (WSA), geometric mean diameter (GMD), mean weight diameter (MWD), organic carbon (OC) and total N concentrations in different aggregate size fractions, and total OC and N pools. The experiment was established in 1994 on a poorly drained Crosby silt loam soil (fine mixed, mesic, Aeric Ochraqualf) near Columbus, Ohio. In 2007, soil samples were collected (0–10, 10–20, and 20–30 cm) from all treatments and separated into six aggregate size classes for assessing proportions of macro (5–8, 2–5, 1–2, 0.5–1, 0.25–0.5) and micro (<0.25 mm) aggregates by wet sieving. Tillage treatments significantly ($P \leq 0.05$) influenced WSA, MWD, and GMD. Higher total WSA (78.53 vs. 58.27%), GMD (0.99 vs. 0.68 mm), and MWD (2.23 vs. 0.99 mm) were observed for 0–10 cm depth for NT than T treatments. Relative proportion of macro-aggregates (>0.25-mm) was also more in NT than T treatment for un-drained plots. Conversely, micro-aggregates (<0.25-mm) were more in T plots for both drained and un-drained treatments. The WSA, MWD and GMD decreased with increase in soil depth. The OC concentration was significantly higher ($P \leq 0.05$) in NT for un-drained ($P \leq 0.01$) treatment for all soil depths. Within macro-aggregates, the maximum OC concentrations of 1.91 and 1.75 g kg^{-1} in 1–2 mm size fraction were observed in NT for un-drained and drained treatments, respectively. Tillage treatments significantly ($P < 0.01$) affected bulk density (ρ_b), and total porosity (f_t) for all soil depths, whereas tillage × drainage interaction was significant ($P < 0.01$) for 10–20 and 20–30 cm depths. Soil ρ_b was negatively correlated ($r = -0.47$; $n = 12$) with OC concentration. Tillage treatments significantly affected ($P \leq 0.05$) OC pools at 10–20 cm depth; whereas drainage, and tillage × drainage significantly ($P \leq 0.05$) influenced OC pools for 0–10 cm soil layer. The OC pool in 0–10 cm layer was 31.8 Mg ha^{-1} for NT compared with 25.9 Mg kg^{-1} for T for un-drained treatment. In comparison, the OC pool was 23.1 Mg ha^{-1} for NT compared with 25.2 Mg ha^{-1} for T for the drained plots. In general, the OC pool was higher in NT system, coupled with un-drained treatment than in drained T plots. The data indicate the importance of NT in improving the OC pool.

1. Introduction

Sustainable production of upland crops on poorly drained soils necessitates provisions for subsurface drainage, which is a common agricultural practice in large areas of highly productive, but poorly drained soils in Ohio. Approximately 3 million hectares (M ha) in Ohio, 40 M ha in USA and 146 M ha in the world are in need of some drainage (Randall and Iragavarapu, 1995; USDA-NRCS, 1992). Poor drainage and the attendant anaerobiosis are among major constraints to obtaining high yields in these soils (Schwab et al., 1985). Plant growth in poorly drained soils is adversely affected by restricted aeration leading to reduced concentration of O_2 and increased concentrations of CO_2, CH_4, C_2H_6, and reduction in nutrient availability (Lal and Taylor, 1970). In addition, poorly drained soils may also affect plant growth and yield through deterioration of soil structure, decline in total porosity, change in pore-size distribution (Lal and Fausey, 1993; Baker et al., 2004); and depletion of soil organic matter (SOM) concentration (Mitra et al., 2005).

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Increase in concentration of greenhouse gases (GHG, e.g., CO_2, CH_4, and N_2O) in the atmosphere is an important global issue. Fossil fuel combustion, and land use change (i.e., deforestation, biomass burning, conversion of natural to agricultural ecosystems, drainage of wetlands, and intensive cultivation) are among major factors affecting GHG emissions (Lal, 2004). Increase in atmospheric concentration of CO_2 and other GHGs has discernible impact on global climate (IPCC, 2007). Atmospheric abundance of CO_2 has increased from 280 ppmv around 1750 to 380 ppmv in 2006 and is currently increasing at the rate of $\approx$2 ppmv year^{-1} or 3.5 Pg year^{-1} (IPCC, 2007; Lal, 2004). Agricultural soils can be an important sink for atmospheric CO_2. Cropland soils comprise 1.7 billion hectares globally (Angela et al., 2005), and 111–170 Pg C (peta gram = 1 Pg = 1 × 10^{15} g) or approximately 10% of the global C pool of 1576 Pg is stored within agricultural soils.

The SOM plays a key role in enhancing crop production (Causarano et al., 2006), improving soil structural stability (Gregorich et al., 1994) and mitigating climate change (Hao et al., 2002). Rapid oxidation of SOM with intensive cultivation causes deterioration of soil physical properties (Shang and Tiessen, 2003). The aggregate stability is closely related to SOM concentration (Tisdall and Oades, 1982), as is also the soil erodibility (Kay, 2000). Soil bulk density (ρ_b) and total porosity (f_t) are functions of SOM, aggregate stability and its size distribution (Baldock and Nelson, 2000). Decrease in SOM increases soil bulk density, decreases total porosity, reduces soil infiltration, and decreases water and air storage capacities (Celik, 2005).

The SOM has been studied intensively with reference to the formation and stabilization of macro- and micro-aggregates (Annabi et al., 2007). However, SOM induced changes in the physical and bio-chemical characteristics of aggregates in relation to drainage are not well understood. Soil aggregation influences seedling emergence and root growth (Annabi et al., 2007), soil moisture retention and aeration (Madari et al., 2005), and OC sequestration and dynamics (Denef et al., 2004) and thereafter aggregates response to soil management are needed to assess OC turnover and identify residue management strategies for restoration of degraded soils. Effect of aggregate size on distribution of OC in aggregates is a debatable topic. Decrease in OC concentration with decrease in aggregates size was reported by Adesodun et al. (2005), while an inverse relationship between OC and aggregate size was reported by Tamboli et al. (1964).

The beneficial effects of reduced tillage on aggregate stability, soil C sequestration, favorable distribution of C and N in aggregate size fractions and reduction in bulk density, have been widely reported (Madari et al., 2005; Jiao et al., 2006; Alan et al., 2007). However, the effect of tillage systems on soil physical properties has not been widely studied for poorly drained or un-drained soils. Land use and management practices affecting change in plant cover, intensive soil tillage and removal of plant biomass from the fields may decrease SOM concentration, thus deteriorating soil physical properties (Li et al., 2007). Because of a strong relationship between physical and chemical properties and crop growth, understanding how these properties are influenced by the interactive effects of subsurface drainage and tillage is crucial to sustainable management of these soils.

Thus, the objective of the present study was to quantify the impact of tillage and drainage treatments on selected soil physical properties, and to understand soil processes that affect SOC and nitrogen (N) pools in intensively managed agricultural soils.

2. Materials and methods

2.1. Site description

A field experiment was initiated in 1994 at the Waterman Farm of The Ohio State University, Columbus (40°02″00″N, 83°02″30″W), Ohio on a Crosby (fine, mixed, mesic, Aeric Ochraqualf) silt loam soil. The mean annual precipitation is 1016 mm and mean annual air temperature is 11 °C (USDA-NRCS, 2006). The field layout comprised of a factorial experiment involving two factors at two levels of each with three replications. Each replication block contained four plots comparing both drainage and tillage combinations. Each plot was 27.4 m × 27.4 m. The plots were separated by a 6.1 m drive way on all sides. The drainage factor consisted of two levels: drained (D) with tile drainage and un-drained (UD). There were two tillage treatments, tillage (T) and no-till (NT). The T consisted of fall chisel plowing to a depth of about 0.2 m, and spring disking to prepare the seedbed for planting. The NT plots were not disturbed either before or after the establishment of the experiment. Thus, the four different management treatments were (1) NT-D, (2) NT-UD, (3) T-D, and (4) T-UD. The site is under continuous corn (*Zea mays* L.) since the establishment of the experiment. Subsurface drainage was installed in the spring of 1994 using perforated corrugated plastic tubing (Sullivan, 1997).

2.2. Soil sampling, processing and analysis

Soil sampling was done during April 2007. Three sampling locations were selected in each plot at approximately the same elevation with respect to the surface slope. These locations were midway between the drain lines and approximately 8.5 m from the north or south edge of the plots nearest to the main drain and outlet. The exact distance from the edge of the plot varied slightly to avoid wheel tracks. At each of the three sample locations within a replicated plot, six soil samples from 0–10, 10–20, and 20–30 cm were taken with stainless steel sampling tube. Sub-samples for each depth were composited, placed in plastic bags and dried at room temperature for 1 week. These samples were labeled as bulk soil (BS). A bucket type core sampler was used to obtain samples from 0–10, 10–20, and 20–30 cm depths for aggregate stability analysis from the specific location within each plot. These samples were also returned to the laboratory and air dried for 1 week. These soil samples were used for obtaining aggregates and conducting aggregate size analyses.

The bulk density was determined by the core method (Grossman and Reinsch, 2002) using 5.4 cm diameter and 6.0 cm long cores. The duplicated cores were obtained for three depths mentioned above. Total porosity (f_t) was calculated from the measured values of bulk density and assumed value of soil particle density of 2.65 Mg m^{-3}.

2.3. Soil analyses

2.3.1. Aggregate size distribution and stability

A wet sieving procedure was used for determination of aggregate-size distribution and stability (John and Perkins, 2002). Aggregates ranging in diameter from 5 to 8 mm were obtained from the air-dried samples, which had been broken apart gently by hand at approximately 10–20% field moisture contents. Fifty grams of dry soil aggregates were placed on a set of five nested sieves of 4.75, 2, 1, 0.5, and 0.25 mm diameter. Soil aggregates on the upper 4.75 mm sieve were pre-soaked by capillarity for 30 min. The nest of sieve was then oscillated vertically with an amplitude of 3 cm at a rate of 2 oscillations/s for 30 min. The soil aggregate