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Research paper

Effects of sediment removal and surrounding land use on carbon and nitrogen storage in playas and watersheds in the Rainwater Basin region of Nebraska

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ABSTRACT

Eroded soil from cropland watersheds is deposited as sediment into depressional wetlands such as playas degrading their ability to provide ecosystem services. Sediment removal from these degraded playa wetlands restores water storage volume. However, the effects of this restoration practice on carbon (C) and nitrogen (N) concentrations and C sequestration potential in playas has not been determined. One of the most important wetland systems and intensively cultivated regions in North America, the Rainwater Basin (RWB) of Nebraska, contained over 4000 playas but has lost 90% of them due to agricultural activities. Our objective was to examine the effects of sediment removal on wetland C and N concentrations and determine subsequent C sequestration potential. We also were interested in determining the importance of the presence of wetlands on the landscape to C sequestration given the loss of wetlands that has occurred. We hypothesized that sediment removal might decrease C sequestration potential and that the presence of wetlands on the landscape provides important C sequestration sites. To accomplish these objectives we sampled 60 playas and their immediate watersheds (20 each from reference condition, cropland, and restored through sediment removal) in 2013 and 2014 by coring soil/sediments (mollisols) to a depth of 50 cm. Restored playas contained 29% lower C and N in the top 5 cm than in reference and cropland land uses. The C in the top 5 cm was also 36% higher in the wetland than in the watershed. There were no differences in C and N among land uses/landscape positions at depths > 5 cm. However, because restored playas had sediment removed, in some cases down to the clay pan of the historic playa soil surface, on an areal basis, restored playas stored 21% more soil organic carbon (SOC) in deeper horizons (25–50 cm) than reference or cropland conditions. Overall, SOC was similar among restored, cropland and reference wetlands to a 50 cm depth, indicating that sediment removal does not have a negative effect on C sequestration potential. On average, SOC was 15% higher in playas than in adjacent uplands, demonstrating the importance of playa wetlands on the landscape to C sequestration. Results of this study have widespread applicability because depressional wetlands are the dominant wetland type in temperate agroecosystems.

1. Introduction

Wetlands are important ecosystems in global biogeochemical processes and are a major continental sink for atmospheric carbon (C) (Mitra et al., 2005; Reddy and Delaune, 2008). As much as 771 GtC are contained within global wetland soils, though C pools vary across climatic and geomorphological gradients (IPCC, 2007). The net C sink strength of wetlands is due to lower rates of organic matter decomposition which are influenced by factors including hydrology, temperature, nutrient availability, and soil properties (Jobbágy and Jackson, 2000; Zhang et al., 2002; Kayranli et al., 2010). Due to substantial concentrations of C stored in their soils (e.g., 378 Tg potential in North American prairie potholes; Euliss et al., 2006), the presence of functioning wetlands on the landscape has important implications for global climate (Roulet, 2000; Whiting and Chanton, 2001).

Under future C sequestration scenarios, wetlands are projected to be the second leading ecosystem in C stored per-area in the U.S. Great Plains, contributing 52.1 g C m^{-2} yr^{-1} to the overall C sink strength of the region (Bouchard et al., 2011). However, wetland losses in the Great Plains have been substantial (Dahl, 2000; Smith, 2003; Johnson et al., 2012). The Rainwater Basin (RWB) of Nebraska has lost 90% of

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its historic depressional playa wetlands (Gersib, 1991). Remaining playas in the RWB have suffered areal extent losses to various agricultural practices including from construction of irrigation reuse pits and drainage tiles.

However, the greatest threat to hydrologic function of the remaining playas in the Great Plains is soil erosion from cultivated watersheds (Smith, 2003). This causes sediment accretion in playas, which reduces water storage volume and hydroperiod (the length of time a wetland has surface water) as well as shifts in floral and microbial communities (Luo et al., 1997; Tsai et al., 2007; Daniel et al., 2014), all of which influence C sequestration. By definition, depressional wetlands are embedded within closed watersheds, and therefore, sedimentation is a major threat to depressional wetland hydrology in all global agroecosystems (e.g., Martin and Hartman, 1987; Craft and Casey, 2000; Kleeberg et al., 2016). The negative effects of sedimentation on depressional wetland hydrology influences delivery of wetland ecosystem services (e.g., Euliss et al., 2010; Nitzsche et al., 2017). Also, because depressional wetlands are focal points within closed watersheds, any materials existing in the watershed are transported through runoff into the wetland (Smith et al., 2011; Nitzsche et al., 2016). Nitrogenous materials may enter a playa through fertilizer application to crops, cattle manure, and municipal wastewater facilities (Irwin et al., 1996).

Virtually all remaining playas in the RWB have some portion of their watershed under cultivation and thus it is likely that all playas have been affected by watershed soil erosion (Daniel et al., 2015). Although sediment removal and vegetative buffer establishment (the most common restoration practice) in degraded depressional wetlands can restore water storage volume, it also exports accumulated nutrients and extant seed banks, which can change C and nitrogen (N) cycling. Plant litter and organic-rich topsoils can be less developed in restored wetlands resulting in changes to microbial community structure, C turnover, and denitrification rates (Galatowitsch and Van Der Valk, 1996; Hunter and Faulkner, 2001; Bruland et al., 2006).

Daniel et al. (2015) noted that many ecosystem services provided by playas were improved by removing wetland sediments and restoring hydrology. However, until now no study has examined restoration (wetland sediment removal and watershed grass establishment) effects on C and N concentrations and C sequestration potential in depressional wetlands in the U.S. Great Plains. Therefore, the primary objective of this study is to determine how wetland restoration and land use practices affect these C and N measurements. We also are interested in determining the role played by wetlands on this landscape to C sequestration, given the loss of wetlands that has occurred. We hypothesized that sediment removal might decrease C sequestration potential because of effects on topsoil and that the presence of wetlands on the landscape provides important C sequestration sites.

2. Materials and methods

2.1. Study area

The RWB covers over 16,000 km^2 in south central Nebraska and is characterized by gently rolling loess plains historically dominated by mixed-grass and tall-grass prairie (Stutheit et al., 2004). The area is flat to gently rolling plains formed through deep deposits of loess silt-loam soil (LaGrange et al., 2011). Annual precipitation averages 63 cm in the central portion of the RWB while the annual mean temperature is 10 °C (Smith, 2003). RWB playas ranged from 0.1 to 1000 ha in area and from 1 to 5 m in historical wetland depth (prior to sedimentation; Kuzila, 1984). The hydric soils in the RWB are mollisols and consist of Fillmore, Scott, and Massie series; all have Bt layers (U.S. Department of Agriculture, 1981). Cultivation of the native prairie in the RWB began 100–150 years ago (LaGrange et al., 2011) and the area has served as one of the most productive cropland areas in North America (Musick et al., 1988; Olsen, 1997).

Most RWB wetlands have been destroyed due to agricultural practices (Tiner, 1984; Gersib, 1991). Estimates suggest that approximately 4000 wetlands covering 38,000 ha originally existed in the early 1900s. However, by 1983 only 10% of the wetlands and 22% of the area remained (Gersib, 1991). An area identified by the U.S Fish and Wildlife Service as one of the nine areas of critical concern for wetland loss, conservation programs designed for wetland restoration are of critical importance to the RWB (U. S. Fish and Wildlife Service and Canadian Wildlife Service, 1986; Bishop and Vrtiska, 2008).

Much of the cropland in the RWB received water through gravity irrigation prior to the use of center-pivots (Johnson and Lukassen, 2009). Irrigation reuse pits were placed in playas to collect water runoff from gravity irrigation; however, this practice reduces wetland surface area and overall wetland function. Surface water flow in gravity irrigated watersheds also transported upland soils into playas. Today wetland sediments are excavated for irrigation pit filling and for restoring playa hydrology (Beas et al., 2013).

2.2. Data collection and experimental design

Soil organic carbon (SOC) and total nitrogen (TN) concentrations were measured in 60 playas (20 reference, 20 cropland, and 20 restored) and their adjacent watersheds to assess changes in C and N pools as well as elucidate C sequestration potential among land use types. Reference, cropland, and restored playas occurred intermingled in the same landscape. Playas were classified as reference by the Nebraska Game and Parks Commission based on whether they had little to no hydrologic modification, a natural plant community with few exotics, a watershed with relatively little modification that would impede runoff, and the proper hydroperiod based on the hydric soils (Daniel et al., 2014). Cropland playas were embedded in an annually cultivated landscape, primarily corn and soybeans, and had little to no edge vegetation between the wetland and the field. Restored wetlands had accumulated sediment removed from over the hydric soil and a vegetative buffer planted around them to minimize future sedimentation (Daniel et al., 2014). The depth of sediment removed ranged from approximately 10–60 cm.

Sediment (from playas) and soil (from watersheds) cores at depth intervals (0–5 cm, 5–25 cm, 25–50 cm) were collected from four landscape positions (1. wetland center, 2. half the distance between wetland edge and center, 3. wetland edge, and 4. upland) following a transect outward from the center of the wetland similar to O'Connell et al. (2016). We considered a 50 cm depth sufficient for descriptions of C in this system based on O'Connell et al. (2016) even though some C arrives as dissolved organic C. Sediments were collected when wetlands were dry. Playas have hydroperiods that naturally fluctuate rapidly due to precipitation patterns (Smith, 2003) and wetland zones were delineated based on changes in hydrophytic to upland vegetation (Luo et al., 1997). Soil probes and slide hammers (AMS Inc., American Falls, ID, USA) were used to collect each sample following O'Connell et al. (2016). Bulk density was determined for all samples in study playas and watersheds at each depth interval following Lal et al. (2001). Each core was oven dried at 105 °C until the soil was dry, sieved (2 mm) to remove any rocks or fragments and then weighed. We used fluid displacement in a graduated cylinder to estimate volume of the few fragments > 2 mm. This was subtracted from the volume of the soil core. Because the percent gravel fragments was < 1% it was not used in bulk density calculations.

Organic C and total N were measured using LECO TruSpec C and N analyzers (LECO Corporation, St. Joseph, MI, USA) available at the Oklahoma State University Soil, Water, and Forage Analytical Laboratory. Using temperature ramps, inorganic carbonates can be subtracted from the total C of each sample. Operating temperature for all SOC to be released from soil is 500 °C (Kerven et al., 2000; Gazulla et al., 2012). Following O'Connell (2012), SOC (%) was converted to SOC (kg m^{-2}) using bulk density (d_b) and depth intervals with the