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Soil organic carbon in playas and adjacent prairies, cropland, and Conservation Reserve Program land of the High Plains, USA

Jessica L. O'Connell[a], Dale W. Daniel[b,*], Scott T. McMurry[b], Loren M. Smith[b]

[a] Department of Marine Sciences, University of Georgia, Athens, GA 30602-3636, USA
[b] Department of Integrative Biology, Oklahoma State University, Stillwater, OK 74078, USA

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ABSTRACT

Soil organic carbon (SOC) is an important reservoir for atmospheric CO_2 associated with climate warming. The High Plains, USA, lacks region-wide SOC estimates within playa wetlands and their adjacent watershed. Croplands often have less SOC than grasslands, and the Conservation Reserve Program (CRP; former croplands planted to grass) may return SOC. Our goals were to estimate SOC within playa wetlands and investigate small scale differences within wetland catchments across a broad agriculturally modified landscape. We estimated SOC ($kg\,m^{-2}$) to 50 cm depth from 4 soil cores/catchment (in playas and 10, 40 and 100 m into uplands) at 56, 52, and 54 sites in native grassland, CRP and cropland, respectively. At a subset of sample locations within each land use type, we estimated SOC to 1 m depth to characterize SOC missed by shallow sampling. In playa wetlands, CRP SOC from 0 to 50 cm was 18% greater than croplands, but native grassland playa SOC did not differ from other land-uses. From 0 to 1 m, SOC in native grassland wetlands and uplands was 20% greater than the same habitats within croplands, while CRP lands were intermediate. Native grassland playa SOC also was 16% greater than in surrounding native short grass prairie. Playas therefore represent an important SOC repository in the High Plains ecoregion. CRP playas and uplands may require an additional 10–30 years to resemble native grassland SOC. SOC increased with playa area throughout CRP and native grassland catchments, suggesting playa hydrogeomorphology influences adjacent upland SOC. High Plains playas store 20.8 Tg C and cropland conversion caused a cumulative loss of 2.0 Tg C from 82,000 ha of playas. Currently, CRP enrollment on over 25,000 ha of playas has returned 0.2 Tg C (95% CI: 0.1–0.3), only half the historic SOC lost by cropland conversion within CRP playas. To promote SOC storage, native grasslands and large playas should be preserved and CRP enrollments should be maintained over long timescales.

1. Introduction

Terrestrial soils are significant reservoirs for carbon, and play an important role in the climate system (Post et al., 1982; Swift, 2001). Conversion of natural ecosystems to other land-uses generally results in losses of soil organic carbon (SOC) from soils by reducing organic residue inputs, increasing SOC loss by soil erosion, and exposing stored SOC to microbial activity (Daniel et al., 2015; Lal, 2003; Schlesinger and Andrews, 2000; Syswerda et al., 2011). Land management practices and land restoration may restock some of the SOC pool lost following land-use change (Guo and Gifford, 2002; Post and Kwon, 2000). However, the efficacy of many management and restoration strategies for increasing SOC remains uncertain (Powlson et al., 2011), due in part to spatial variability in factors regulating C storage.

The High Plains region of the United States was historically upland prairie habitat with depressional recharge wetlands (playas) scattered throughout. Though only occupying 2% of the High Plains landscape, playas may play an important role in C sequestration for the region (Smith et al., 2011). As a result of varying amounts of seasonal precipitation, playas experience plant community shifts during wet and dry phases (Smith and Haukos, 2002). Environmental differences among wetlands and uplands may result in different local SOC storage estimates (Raich and Schlesinger, 1992; Trumbore, 1997). Climate also differs across the High Plains, such that the southern portions are drier and hotter than the northern portions (High Plains Regional Climate Center, 2011). Until now, catchment SOC within High Plains playas and adjacent uplands has not been investigated across broad landscapes and climate gradients.

* Corresponding author. Fax: +1 405 744 7824.
E-mail address: dale.daniel@okstate.edu (D.W. Daniel).

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Wetland loss due to land conversion has resulted in net fluxes of C into the atmosphere (Armentano and Menges, 1986; Maltby and Immirzi, 1993) and in the High Plains, cropland is the largest land-use alteration affecting playas (Luo et al., 1999; O'Connell et al., 2012). Cultivation disrupts soil structure, increases bulk density and decomposition of SOC (Burke et al., 1995; Post and Kwon, 2000). Cropland playas also are often cultivated when dry, concomitantly with surrounding uplands. Further, cropland playas are subject to continuous disturbance from deposition of eroded upland sediments (Luo et al., 1997). Excessive upland sediment accumulation within playas reduces playa volume and hydroperiod (Tsai et al., 2007), potentially altering SOC formation processes. Upland sediment accumulation in wetlands also buries wetland hydric soils, possibly altering SOC estimates (Maynard et al., 2011).

Cropland soils removed from cultivation and converted to grassland can restore SOC to historic levels given adequate time (Leifeld et al., 2011; Post and Kwon, 2000). In the United States, the largest coordinated conversion of cropland to perennial grassland has been through the United States Department of Agriculture (USDA) Conservation Reserve Program (CRP), initiated in 1985 (Young and Osborn, 1990). Gebhart et al. (1994) showed that retired cropland soils placed into the CRP gained an average of 1.1 tons C ha^{-1} $year^{-1}$ with the potential to sequester 45% of the C released annually from U.S. agriculture. In the High Plains, CRP covers approximately 15% of the landscape (O'Connell et al., 2012) and is established on more than 2.8 million ha of playa watersheds, making it the dominant conservation program influencing playas (Smith et al., 2011).

Though CRP establishment generally increases SOC, its influence on C storage potential of associated playas is unknown. Grasses used in most CRP plantings in the High Plains were introduced tall-grasses planted in both the uplands and wetland basins (O'Connell et al., 2012). These grasses provide barriers to overland sheet flow in catchments (the largest input to playa hydroperiod), reducing soil erosion, but also reducing inundation frequency in wetlands (Cariveau et al., 2011; Detenbeck et al., 2002; O'Connell et al., 2012; Van der Kamp et al., 2003). Less inundation will alter soil moisture and influence SOC in playas and their upland catchments.

Our goals were to estimate SOC within playa wetlands and investigate small scale differences within wetland catchments across a broad agriculturally modified landscape. Specifically, we quantify SOC in playas and surrounding uplands among dominant land-uses (native grassland, cropland, and CRP lands) to identify land management influences on SOC across an entire region (the High Plains, USA). Spatial variability in factors regulating C storage can increase the uncertainty of the impacts many land management strategies may have on SOC (Powlson et al., 2011) thus, land use decisions that have the potential to increase SOC at regional scales should either account for these variables or be robust across them.

2. Materials and methods

2.1. Study area

We sampled playas and their immediate watersheds from the High Plains region, covering six states from western Nebraska and eastern Colorado, south to eastern New Mexico and western Texas (Fig. 1). Playas here are in high density, with up to 75,000 individual wetlands occurring in the region (Playa Lakes Joint Venture (PLJV), www.pljv.org). The High Plains is largely a flat expanse of short-to mixed grass prairie, little topographical variation and a semiarid climate (Smith, 2003). Total average annual precipitation ranged from 21-63 cm along a west–east gradient over 1971–2000 (www.ncdc.noaa.gov). Average annual temperature ranged from 7.2 to 18.3 °C along a north–south gradient over 1971–2000 (www.ncdc.noaa.gov) (Fig. 1). Agricultural cultivation has increased since the 1940s and wheat, cotton, corn, and sorghum are common crops (Bolen et al., 1989; USDA, 2009). Approximately 30% of cultivated lands in the High Plains are irrigated (Scanlon et al., 2012). Remaining native prairie is largely grazed by domestic livestock (Samson et al., 2004).

Geologically, the High Plains is a depositional environment, and much of the land surface consists of eolian and alluvial material deposited over older soils (Kelly et al., 2008). Depositional and erosional processes were spatially variable and occurred numerous times during the Holocene, resulting in paleosols more than 2 m deep in some areas (Kelly et al., 2008). Soil age ranges from older than 600,000 years to that of recent age (Kelly et al., 2008). Soils throughout the Great Plains are most often Mollisols, Alfisols, Aridisols and Entisols (USDA-NRCS, 2006). Playas have hydric (reduced soils with gleyed soil matrices), clay Vertisol soils, of Randall, Lipan, Ness, Lofton, Stegall, Pleasant, and Scott clays (Smith, 2003; Soil Survey Staff, 2011). Playas average 7 ha (Daniel et al., 2014) and are generally circular in shape, especially in the south (Bolen et al., 1989).

2.2. Data collection and experimental design

We sampled 162 wetlands and adjacent watersheds (56 in native grassland, 52 in CRP, and 54 in cropland) to 50 cm depth, in a random design stratified by playa density/region and county. Of these, we sampled to 100 cm depth in 17, 15, and 17 sites each in native grassland, CRP, and cropland, respectively, to account for patterns of SOC storage in deeper soils (Fig. 1). To select sample sites, we initially chose locations in native grasslands because these are most limited, and then paired these with nearby sites in the other land- uses.

We sampled SOC during the growing season in 2009. We first surveyed playa area with a GPS (Trimble GeoXT) by walking playa visual edges (Luo et al., 1997). We delineated playa visual edges by noting changes in vegetation from hydrophytic to upland plants and changes in topography from sloped basin edge to flat upland (Luo et al., 1997). We refined playa boundary estimates by coring to locate heavy clay, gleyed hydric soil edges (Luo et al., 1997). We cored along transects perpendicular to the visual edge boundary and used two such transects on opposite sides of playa basins (Tsai et al., 2007). The hydric soil edge was where soil color and texture changed from wetland soils of heavy clay Vertisols with matrix chroma <3 to coarser, browner upland soils (Luo et al., 1997; Tsai et al., 2007). We used Muncell soil color charts to confirm hydric and upland soil classifications (Schoeneberger et al., 2002). See Luo et al. (1997) for chromas distinguishing Randall clay playa wetland soil series from upland soils. A similar process was followed for other wetland soil series.

To estimate patterns in SOC with soil depth, we took intact soil cores from playas at multiple depth intervals within the soil profile: 0–5 cm, 5–25 cm and 25–50 cm. Sample playas did not contain surface water. We additionally collected 50–75 cm and 75–100 cm depth intervals from playa subsets. We used soil cores, slide hammers and augers to sample soils (AMS Inc., American Falls, ID, USA). We used a 5.08-cm soil core and a slide hammer to collect the 0–5 cm depth interval. For other depths, we used a 3.81-cm soil core and slide hammer. To minimize compaction, we collected each depth interval separately, extracted it, and then used a 7.62 cm soil auger to excavate a wider pit down to the next depth interval surface. This minimized friction and suction on the soil core, as well as compaction of collected soil. Some compaction did occur, but to account for this we used the internal volume of the core, rather than of the retained soil as our soil volume estimate (Bronson et al., 2004).