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Carbon sequestration and nutrient accumulation in floodplain and depressional wetlands

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ABSTRACT

We measured soil organic carbon (C) sequestration and nutrient (nitrogen-N, phosphorus- P) burial in Czech and Midwest U.S. freshwater floodplain and depressional wetlands to evaluate how landscape position and agricultural land use intensity affects C, N, and P retention. Land use in the South Bohemia of the Czech Republic is dominated by forest and pasture, whereas in the Midwest U.S., land use is dominated by row crop agriculture. Cs-137 and ^{210}Pb dating of soil cores revealed comparable rates of soil accretion among wetland types, ranging from 0.5 mm/yr in a Czech floodplain wetland to 2.3 mm/yr in a U.S. depressional wetland. Carbon sequestration and N & P burial did not differ among floodplain (47 + 14 g C/m^2/yr, 3.7 + 1 g N/m^2/yr, 0.47 + 0.16 g P/m^2/yr) and depressional wetlands (50 + 19 g/m^2/yr, 3.6 + 1.3 g N/m^2/yr, 0.51 + 0.14 g P/m^2/yr). However, sediment deposition in Czech floodplain and depressional wetlands was only 10–50% (150–340 g/m^2/yr) of rates measured in U.S. wetlands (650–1460 g/m^2/yr). Our results suggest that, in agricultural landscapes, land use intensity rather than landscape position – floodplain versus depression – drives wetland C sequestration and nutrient retention through increased sediment deposition.

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1. Introduction

Freshwater wetlands are agents of materials exchange and nutrient transformations between terrestrial and aquatic ecosystems and often serve as sinks for sediment and nutrients (Hopkinson 1992; Craft and Casey 2000; Dunne et al., 2007; Bernal and Mitsch 2012; Wolf et al., 2013; Marton et al., 2015). Their ability to retain these materials depends on their position in the landscape, and hence their opportunity to intercept materials from terrestrial lands adjacent to and upstream. Floodplains often trap large amounts of sediment and phosphorus (P) (Craft and Casey 2000; Noe and Hupp 2005). Considerable nitrogen (N) also is buried in floodplain soils (Bannister et al., 2015). Depressional wetlands receive less overland flow than floodplains and may be expected to sequester C and bury N & P at lower rates than floodplain wetlands.

In addition to landscape position, wetland C sequestration and nutrient retention also is affected by land use. In Europe, the history of human alteration of wetlands by ditching and drainage is a long one, extending for hundreds to a thousand years. Wetlands of central Europe have been exposed to a long history of hydrologic alteration with many flooded and converted to fish ponds 400–600 years ago while others were drained (Šusta, 1995). Nutrient enrichment of European freshwaters and wetlands also has a long history where the application of manure to enhance soil fertility and fertilize fish ponds has occurred for hundreds of years (IUCN, 1996) though at lower intensity than occurs today. Low intensity agriculture such as hay cutting and fertilizer application using manure was employed for most of this time with more intensive row crop agriculture becoming common following the decline and fall of the Soviet Union.

In the Midwest U.S., also known as the *Corn Belt*, land conversion to agriculture is more recent but much more intense. In this region, nearly 90% of the wetlands were drained during the past 150–200 years (Dahl 1990). Today, the land is farmed for nutrient intensive row crops that require large and frequent fertilizer (N, P) applications.

We compared C sequestration and N & P burial by floodplain and depressional wetlands in the Czech Republic and in the Midwest U.S. Corn Belt. We hypothesize that landscape position determines

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the rate of C sequestration and N & P burial with floodplain wetlands having the highest C sequestration and N & P burial. We further hypothesize that the intensity of agricultural land use has a secondary effect on nutrient accumulation and C sequestration. In the Corn Belt region of the U.S., floodplain and depressional wetlands will exhibit greater rates of sedimentation and P burial than wetlands in the south Bohemian region of the Czech Republic.

2. Methods

2.1. Site description

We collected soil cores from freshwater wetlands of the Czech Republic and the midwestern (Indiana, Illinois) U.S. Two types of wetlands were sampled: floodplains and depressional wetlands.

In the Czech Republic, soils were collected from depressional (n = 1) and floodplain wetlands (n = 3) in South Bohemia in the UNESCO MAB Třeboň Biosphere Reserve. The Třeboň basin is a low-lying region that consists of extensive fish ponds and natural wetlands. Beginning in the 13th century, fish ponds were constructed from existing wetlands facilitated by channelization of several rivers and construction of the Golden Canal that moved water from ponds in the upper basin to its lower reaches (IUCN, 1996). Today, the ponds continue to be used to produce common carp (*Cyprinus carpio*) and other fish for food. The climate of South Bohemia is temperate continental with mean annual temperature of 7.1 °C and annual precipitation of 66 cm (1961–2008), which includes 70 cm of snow (8 cm liquid) (Czech Hydrometeorological Institute, 2017).

In the U.S., floodplains (n = 2) and depressions (n = 3) were sampled in the Corn Belt of the Midwest, in northern Indiana and Illinois. Floodplain wetlands were located along the Kankakee River (Newton County), Indiana. Depressional wetlands were located in the Willow Slough Wildlife Management Area (Newton County) and the Iroquois County Conservation Area (Iroquois County) across the state line in Illinois. The landscape of the Midwest consists of flat topography dominated by high-intensity row crop agriculture, mostly corn and soybeans. Extensive draining and ditching in the 1800′s was followed in the mid 20th century by widespread application of inorganic fertilizers, especially N. Today, it is estimated that 85–90% of wetlands that were present in the region 200 years ago have been drained for agriculture (Dahl 1990). Like the Czech Republic, the climate of the Midwest U.S. is temperate continental, with slightly warmer temperature (11.5 °C), more precipitation (91) cm and comparable snowfall (84 cm, 9 cm liquid) (U.S. National Weather Service, Chicago IL).

The Czech and U.S. wetlands dramatically differ in the land use and intensity of fertilizer use (Appendix A Table A1). In the U.S., agricultural land use (73%) is double that of the south Bohemia region of the Czech Republic (30%). Of the agricultural land in the U.S., 93% is cultivated (Northwest Indiana Regional Planning Commission, 2012) where most agricultural land in the south Bohemia region of the Czech Republic is in pasture (Pokorný et al., 2000). Agricultural intensity in the Midwest U.S. watershed also is greater than in the Czech Republic with much greater rates of N and P fertilization for corn relative to Czech pastures (Table 1).

In both countries, depressional wetlands were dominated by grasses and sedges whereas floodplain wetlands were dominated by forest (U.S.) or grasses (Czech Republic).

2.2. Soil sampling and lab analysis

Soil cores, one to two per site, each 8.5 cm (U.S.) or 5 cm (Czech Republic) in diameter, were collected for a total of 13 cores, five from the Czech Republic and eight from the U.S. (Table 2). Core length ranged from 35 cm to 50 cm. Cores were sectioned into 2 cm increments in the field, then transported to the lab where they were air dried and weighed for bulk density. Once dried, increments were ground, passed through a 2 mm mesh sieve, and analyzed for ^{137}Cs, ^{210}Pb, total C, N and P.

Bulk density of each depth increment was calculated from the dry weight per unit volume after correcting for moisture content of an oven-dried (70 °C) soil sample (Blake and Hartje 1986). Samples containing carbonates were treated with 0.1 mol L^{-1} HCl to remove carbonates prior to C analysis so measured values represent organic C. Carbon and N were analyzed using a Perkin-Elmer 2400 CHN analyzer (Perkin-Elmer, Waltham MA USA). Total P was determined colorimetrically after digestion in nitric-perchloric acid (Sommers and Nelson 1972). Recovery of NIST standard #1646a (estuarine sediment, 270 μg/g) yielded 92% for total P (n = 23 samples). For C and N, recovery of NIST standard 1632b (bituminous coal, 76.9% C, 1.56% N) yielded 90% for C and 92% N (n = 20). Analysis of in-house soil standard (6.1% C, 0.37% N) recovered 102% for C and 103% for N (n = 20). All analyses were expressed on a dry weight basis by correcting for the moisture content of the soil, determined by weighing 1 g of subsoil before and after drying at 70 °C for 24 h.

Ground soils were packed into 50 mm diameter by 9 mm petri dishes and analyzed by gamma spectrometry for Cs-137 (661.6 keV photopeak) andPb-210 (46.5 keV photopeak). Cesium-137 (half life 30 years) is an impulse marker produced as fallout by aboveground nuclear bomb blast tests (Ritchie and McHenry 1990). We used the increment with maximum ^{137}Cs activity to represent the year 1964, the year of greatest atmospheric fallout. Lead-210 (half life 22 years) is a naturally occurring radioisotope produced by decay of ^{235}Uranium and is used to estimate soil accretion during the past 100–150 years. We used the constant activity model to calculate accretion using the exponential decrease of excess ^{210}Pb with depth as it undergoes radioactive decay (Oldfield and Appleby, 1984). Excess ^{210}Pb was calculated by subtracting background ^{210}Pb, determined from uniform low level ^{210}Pb activity that occurred at depth in each core.

Rates of C sequestration and N & P burial were calculated using ^{137}Cs and ^{210}Pb-derived accretion rates, bulk density (BD), and C, N, and P concentration in depth increments above and including the ^{137}Cs maxima, and within increments containing excess ^{210}Pb. The rate of C accumulation (g/m^2/yr), for example, is calculated as cm^2/m^2

$$C(g/m^2/yr) = Accretion(cm/yr) \times BD(g/cm^3) \times C(g/g) \times 10000$$

3. Results and discussion

3.1. Bulk soil properties

Floodplain and depressional wetlands of the Czech Republic contained much higher percent C and N than comparable wetlands in the U.S. (Table 1). In the U.S., floodplain and depressional wetlands were underlain by mineral soils with high bulk density (0.87–0.94 g/cm^3) and low organic C (4–5%). Phosphorus concentrations also were greater in wetlands of the Czech Republic and they were twice as high (>1000 μg/g) as comparable wetlands in the U.S. (400–450 μg/g).

Soil C:N of depressions and floodplains was less than or equal to 20 (Table 1) suggesting that sufficient N is available to meet microbial needs. Carbon:N of depressions of the southeastern U.S. (12–18; Craft and Chiang 2002) were similar to our measurements in depressions (Table 1). Soil N:P of floodplain and depressional wetlands ranged from 18 to 26, suggesting that N is more limiting in these wetlands (Koerselman and Mueleman 1996). Nitrogen:P of our depressions and floodplain soils are low relative to depres-

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