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Distribution of Soil Density at a Bottomland Hardwood Forest Wetland Restoration, Chicot County, Arkansas

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Running title: Soil Density at a Bottomland Hardwood Wetland Restoration

Abstract

Bottomland hardwood forest (BLHF) soils provide a myriad of ecosystem services, yet much information is lacking with respect to how soil physical properties influence biogeochemical cycling along topographic gradients. Current patterns of vegetation at a 149ha wetland restoration site in Chicot County, Arkansas, suggest the presence of ecologically significant variation in soil properties within the Perry Clay soil series. A study was initiated in the Lower Mississippi Alluvial Valley (LMAV) to map soil bulk density and texture as well as to identify the interrelationships between soil physical properties, soil organic carbon, and total nitrogen. A random grid was used to extract 132 fixed-volume soil cores to a depth of 90cm for bulk density and texture determination. Bulk density was mapped for three depth increments: 0-30cm, 30-60cm, and 60-90cm, using ordinary kriging. Bulk density differed significantly ($\alpha=0.05$) by depth with mean densities and 95% CI of $1.37 \pm 0.19 \text{ Mg m}^{-3}$, $1.46 \pm 0.22 \text{ Mg m}^{-3}$, and $1.52 \pm 0.25 \text{ Mg m}^{-3}$, respectively. The coefficient of variation at each depth was 7.0%, 7.5%, and 8.5%. Increasing variation with depth can be attributed to surface homogenization during crop production as well as differential accumulation of parent material during pedogenesis in the LMAV. These results presented provide a benchmark and will be used for further quantification of soil nutrient pools during the progression of afforestation of the forested wetland.

Introduction

Bottomland Hardwood forested wetland loss in the Lower Mississippi Alluvial Valley (LMAV) has generated considerable interest in wetland preservation and restoration. When wetland loss in the United States is unavoidable, mitigation is required within the respective watershed (CWA 1972). Alternative to legal means, 12,000 landowners are voluntarily restoring

Figure 1. Location of the Bob White Memorial Wetlands Research and Teaching Station.

wetland, 2.6 million acres, by taking part U.S. Natural Resources Conservation Service Wetland Reserve Program (WRP). The objective of both voluntary restoration and mitigation is to establish an appropriate hydrologic regime for the maintenance or development of characteristic soil properties and vegetation which are essential for wetland ecosystem functions.

The physical properties of a soil determine its hydraulic character and influence the type of plant community that establishes upon it (Mistch and Gosslink 2000, Richardson and Vepraskas 2001). Depositional events in the LMAV are variable over time and result in differential microtopography and hydrological gradients. These features include sloughs, terraces, flats, and natural levees and are known to support vegetative communities which are uniquely adapted to the conditions characteristic of their soils and hydroperiods (Hodges 1997). Patterns of vegetation establishment throughout a 149 ha wetland restoration suggest the presence of ecologically significant variation in soil properties.

Materials and Methods

This study was conducted in November 2012, on the Bob White Memorial Wetlands Research and Teaching Station (BWMW) in Chicot County, Arkansas (Figure 1). The entire site is mapped within the Perry Clay (Very-fine, smectitic, thermic Chromic Epiaquerts): a hydric soil, very poorly drained, 0-3% slopes, composed of Arkansas River sediments (Cloutier and Finger 1967). The study area was formerly BLHF, converted into row crop production in the mid 1960's, then enrolled in WRP in 2001. In 2001 and 2002 restoration activities included excavating swales and planting hardwood species, including bald cypress (*Taxodium distichum*), water oak (*Quercus nigra*), overcup oak (*Quercus lyrata*), and green ash (*Fraxinus pennsylvanica*).

To determine bulk density throughout the site, a random sampling grid was used to collect 132 fixed-volume soil cores, sampling density 1.11 ha^{-1} . Sampling positions were logged in a Trimble GeoXH GPS unit. Soil samples were collected with a Giddings hydraulic soil-sampling probe to a 90 cm depth (Giddings Machine Co. Fort Collins, CO). Cores were separated into three equal depth groups and dried at 105°C . Samples were then weighed and divided by their volume to determine bulk density.

Histograms and normal quantile-quantile plots were drawn to investigate density distributions. Moran's I and semi-variogram plots were used to test spatial autocorrelation in bulk density at each depth increment. Moran's I statistic measures spatial clustering or dispersion, ranging ± 1 (Moran 1950).

Appropriate models were fitted to the experimental variograms, assuming isotropy, by weighted least squares in R (Diggle and Ribeiro 2001). Ordinary kriging was used to model bulk density at each depth in ARCMAP (ESRI 1999-2012). Due to the low number of samples all points were used to cross validate interpolation models by "leave one out" with variogram re-estimation (Diggle and Ribeiro 2001). One x_i at a time was left out of the variogram model and its value was estimated. Final models were chosen based on selected accuracy measures, mean square error (MSE) and mean square deviation ratio (MSDR) (Webster and Oliver 2007). The value of MSDR should be close to one because it is the ratio of MSE to the kriging variance at x_i .

Results and Discussion

Means and coefficients of variation for bulk

density each depth are presented in Table 1. Bulk density ranged from $1.12 - 1.55 \text{ Mg m}^{-3}$, $1.15 - 1.70 \text{ Mg}$

Figure 2. Kriged surfaces for bulk density (Mg m^{-3}) at each depth. Scoured depressions are superimposed (black lines) over each image to show water features.

Soil Density at a Bottomland Hardwood Wetland RestorationTable 1. Sample mean and coefficient of variation (CV) for bulk density (Mg m^{-3}). Letters indicate significant differences ($p < 0.05$).

Depth		ρ_b
0 - 30 cm	mean	1.37 ^a
	CV %	7.0
30 - 60 cm	mean	1.46 ^b
	CV %	7.5
60 - 90 cm	mean	1.52 ^c
	CV %	8.5

ρ_b = bulk density (Mg m^{-3})

m^{-3} , and 1.26 - 1.73 Mg m^{-3} , by depth increment, respectively. Mean surface bulk density is comparable to BLHF wetland restoration sites in the Tensas River watershed in northeast Louisiana, 1.34 Mg cm^{-3} after six years (Hunter et al. 2008). Tensas River mature BLHF soil bulk density, 0-15cm, was 0.96 Mg m^{-3} at two study areas. Bruland and Richardson (2005a,b) found three year old restored wetland mineral soil density to be 1.02 and 1.30 Mg m^{-3} but greater than paired natural wetland composed of mineral soil from 0.45 – 0.80 Mg m^{-3} .

Spatial analysis using Moran's I showed that bulk density has a significant degree of positive spatial autocorrelation at each depth class (Table 2). Positive spatial autocorrelation indicates that an attribute is spatially clustered. Prediction surfaces from ordinary kriging are shown in Figure 2. The coefficients of determination utilized in ordinary kriging are presented in Table 3.

Bulk density shows a considerable low (1.21 Mg m^{-3}) to high ($>1.50 \text{ Mg m}^{-3}$) pattern from northwest to southeast. Land cover change does not help explain this general bulk density pattern. Conversion from

Table 2. Moran's I statistics.

Depth	Statistic
0-30 cm	0.19 ($p < 0.05$)
30-60 cm	0.28 ($p < 0.05$)
60-90 cm	0.42 ($p < 0.05$)

BLHF to row crops was uniform throughout the study area. The frequency saturation throughout the year from southeast to northwest helps explain the bulk density gradient. Runoff drains north from center of the study area toward a large swale in the northwest and leaves the study area through a water control structure. These saturated conditions during the winter months promote the accumulation of surface organic matter and lower surface soil bulk density (Mistch and Gosslink 2000, Richardson and Vepraskas 2001).

Within group CV increased from 7.0% to 8.5% with depth (Table 1). It can be inferred that the 0-30cm depth has been frequently homogenized by row cropping and deeper soil has been compacted by repeated tractor passes. Other sources of bulk density variation include differing deposition events, frequencies of saturation, and accumulation of organic matter.

The overall wetland restoration objective in the LMAV is to recreate the structure and function of the former BLHW ecosystem. Though the Perry Clay series exhibits hydric soil characteristics, soil bulk density change toward reference conditions lags behind vegetation character and depends on the accumulation of organic matter as well as root action over an uncertain length of time. The results presented set a benchmark for soil bulk density during bottomland hardwood afforestation.

Table 3. Variogram parameters (nugget, sill, and range) associated with the trend surfaces for spatially dependent soil depths.

Depth (cm)	Type	Nugget	Range	Sill	MSE	MSDR
			-m-			
0-30	Exp	0.0075	550	0.014	8.02×10^{-3}	1.010
30-60	Exp	0.008	600	0.015	7.74×10^{-3}	1.110
60-90	Exp	0.008	580	0.017	4.42×10^{-3}	0.864

Exp = Exponential

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