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Influences on the spatial pattern of soil carbon and nitrogen in forested and non-forested riparian zones in the Atlantic Coastal Plain of the Delaware River Basin

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This study investigated the landscape characteristics that influence C and N in unsaturated surface soils of riparian zones along 1st to 3rd order streams in the Atlantic Coastal Plain of the Delaware River Basin. Unsaturated surface soils (0–30 cm) were sampled in forested and non-forested sites at 29 locations throughout S New Jersey and SE Pennsylvania. Overall, the soil %C and %N in forested and non-forested riparian sites studied in this investigation were comparable to similar riparian zone soils in eastern North America. However, the soil C and N contents of these Atlantic Coastal Plain soils were 3 to 8-fold greater which underscores the value of these riparian soils as C pools. Soil C content (100.3 ± 15.0 Mg ha^{-1}) in forested riparian sites was consistently higher but not statistically different ($P > 0.05$) from soil C content (90.6 ± 12.1 Mg ha^{-1}) in non-forested riparian sites. Likewise, neither soil N storage or the C:N ratio were different between the contrasting land covers but forested sites with forest floor organic horizons had significantly greater (82%, $P = 0.004$) soil C storage than the non-forested sites. Of the forested sites, 70% did not have organic horizons. All of the forested sites without organic horizons had abundant earthworms and comparisons of sites with and without forest floor suggests that earthworms and the removal of native forest cover may be responsible for a loss of 75–93 Mg ha^{-1} of soil C from these riparian zones. Multivariate regression tree analysis was able to explain $\geqslant$50% of the variability in soil C and N and as much as 68% of the variability in the C:N ratio. The analysis indicated that watershed-scale land cover, local soil series, and elevation above the active channel had the greatest influence on C and N storage. Moreover, this analysis indicated that a combination of easily measured, reach-scale characteristics and GIS-based watershed-scale variables can be used to estimate regional riparian soil C pools and identify restoration sites with the potential to store soil C.

1. Introduction

Riparian zones are unique ecological corridors that provide important ecosystem services and influence the hydrology, water quality and biodiversity of both terrestrial and aquatic ecosystems (Peterjohn and Correll, 1984; Correll and Weller, 1989; Lowrance et al., 1984, 1992, 1997; Naiman et al., 1993; Mitsch et al., 1995; Hill, 1996; Fennessy and Cronk, 1997; Anbumozhui et al., 2005; Hunt et al., 2007). The type of riparian vegetation has also been shown to influence channel morphology, aquatic habitat, and the in-stream processing of non-point source pollutants (Cooper et al., 1987; Daniels and Gilliam, 1996; Hession et al., 2003; Sweeney et al., 2004; Allmendinger et al., 2005). The soil properties and soil organic matter (SOM) content of riparian ecosystems are known to influence redox potential, improve water quality, and the ability to process non-point source pollution (Alpert et al., 1999; Giese et al., 2003; Amezketa and del Valle de Lersundi, 2008; Tomer et al., 2009). Thus restoring SOM content is considered essential for restoring degraded riparian zones (Correll, 2005).

Despite the importance of riparian ecosystems, their degradation and removal have been widespread and their reestablishment has become a paradigm of best management practices (e.g., Fredrickson and Reid, 1986; Décamps et al., 1988; Lowrance

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Abbreviations: ACP, Atlantic Coastal Plain; DRB, Delaware River Basin; GIS, Geographic Information System; MRT, multivariate regression tree; SOM, soil organic matter; SS, sums of squares.

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et al., 1997). In response, guidelines regarding the establishment of riparian buffer zones have been suggested by several researchers (e.g., Welsch, 1991; Correll, 2005; del Tánago and de Jalón, 2006; Tomer et al., 2009) and techniques have recently been developed to help prioritize the placement of riparian buffers to maximize their environmental benefit. These techniques have utilized indices of erosion-risk (Wissmar et al., 2004), soil classification and salinity (Amezketa, 2006), and soil survey information and topography (Tomer et al., 2009). Although the importance of riparian soil C is widely acknowledged, it has not been explicitly considered in riparian restoration strategies. Furthermore, only a few investigations have quantified riparian soil C or N storage in relation to landscape features and vegetation cover (e.g., Pinay et al., 1992; Corre et al., 1999; Giese et al., 2000, 2003; Groffman et al., 2003; Hazlett et al., 2005; Hunt et al., 2007; Gift et al., 2010). The limited number of studies which have compared soil C and N under different riparian vegetation cover types in the mid-Atlantic region collectively suggest that forested riparian soils do not support quantitatively larger soil C pools than either herbaceous or grass cover (Corre et al., 1999; Groffman et al., 2003).

Recognition of the benefits of riparian forests has led to a number of riparian restoration initiatives in the mid-Atlantic region of the US (Hession et al., 2000; Sweeney et al., 2004; Bernhardt et al., 2005; Hassett et al., 2005) and the restoration and protection of riparian ecosystems within the (Delaware River Basin) DRB have been identified as strategic goals of the Delaware River Basin Commission (DRBC, 2004). In light of these initiatives and goals, we conducted an investigation of non-wetland surface soils in riparian zones throughout the Atlantic Coastal Plain (ACP) of the DRB. The objectives of this study were to (i) quantify soil C and N concentration and content in riparian soils of the ACP of the DRB, (ii) compare soil C and N storage between forested and non-forested riparian zones, and (iii) determine the landscape factors that can explain the spatial variability of soil C and N and be used to guide future restoration efforts. In view of these objectives, we developed and tested two hypotheses: (1) non-wetland forested ACP riparian soils have greater soil C and N storage than non-forested riparian soils and (2) readily measured landscape characteristics can be used to explain the spatial variation of soil C and N in ACP riparian zones. To address these objectives and hypotheses, we sampled soils in forested and non-forested riparian zones of 1st to 3rd order streams in the ACP of the DRB region in the summer of 2009. The ACP was selected as a focal region because it has the lowest% riparian cover of all the physiographic regions in the DRB, with only 28% of the 1st to 3rd order streams having riparian forest cover (Mead et al., 2010).

2. Materials and methods

2.1. Sampling area

In the summer of 2009, soils were sampled in riparian zones at 29 locations throughout the Atlantic Coastal Plain physiographic province in southern New Jersey and southeastern Pennsylvania, primarily in the DRB (Fig. 1). The DRB is a ~35,000 km^2 watershed with drainage tributaries in New York, Pennsylvania, New Jersey, Maryland, and Delaware (Rupert and Owens, 2009). The ACP is a distinct, relatively low relief, ~6200 km^2 physiographic province within the DRB that primarily consists of layered unconsolidated sediments that thicken to the southeast (Fischer et al., 2004). Climate (e.g., growing season length, precipitation, mean annual temperature) was similar across the sampling area and the region has a long history of occupation, agriculture, and farming that began prior to European colonization (Wacker and Clemens, 1995).

2.2. Plot description

Surface soils were sampled in 29 sites in the ACP of the DRB in S New Jersey and SE Pennsylvania. Following the selection methods of Mead et al., (2010), each site was a continuous, tributary-free, 120 m long stream reach that extended 30 m landward from the active channel (Fig. 2). All of the sampling sites were located in active floodplains that are adjacent to 1st to 3rd order streams that had active channel widths between 2 and 5 m. Twenty-five of the sampling sites were located within the DRB while 4 were located just outside of the DRB (Fig. 1). Each site was classified as either forested or non-forested and was either located proximal to a US Geological Survey gauging station or selected at random during an on-ground survey. Non-forested sites were not necessarily completely devoid of tree cover, but were open, mowed areas that were actively managed as open space. Within the 29 sites was a subset of 9 paired forested and non-forested sites. These paired sites were located on either adjacent or opposite banks of the stream where the contrasting vegetation cover types were observed and soil characteristics were similar. Four paired sites were not located within the same reach as local site conditions (e.g., restricted access, steep banks) prevented co-location within the same reach. These pairings were determined using field observations of similar soil characteristics.

Forested sites were typically closed canopy, mesic mixed-hardwoods. The dominant tree species were similar across all the forested sites and included red maple (*Acer rubrum* L.), sweetgum (*Liquidambar styraciflua* L.), tulip-poplar (*Liriodendron tulipifera* L.), white ash (*Fraxinus americana* L.), or sycamore (*Platanus occidentalis* L.). There were minor local occurrences of black cherry (*Prunus serotina* Ehrh.), silver maple (*Acer saccharinum* L.), oak (*Quercus* spp.), American holly (*Ilex opaca* Ait.), and American beech (*Fagus grandifolia* Ehrh.). In addition, Atlantic white cedar (*Chamaecyparis thyoides* (L.) B.S.P.) and pitch pine (*Pinus rigida* Mill.) were common in four sites sampled within the Pinelands of New Jersey.

Understory and herbaceous vegetation in forested sites were typically characterized by multiflora rose (*Rosa multiflora* Thunb.), greenbrier (*Smilax* sp.), poison ivy (*Toxicodendron radicans* (L.) Kuntze), ironwood (*Carpinus caroliniana* Walt.), Japanese stiltgrass (*Microstegium vimineum* (Trin.) Camus), and, in the Pinelands sites, highbush blueberry (*Vaccinium corymbosum* L.). In forested sites, the density of both the understory vegetation and the herbaceous layer ranged from sparse to nearly impenetrable.

Soils at sampling locations were typical of the region. Although wetland areas and other areas with hydric soils are important components of the landscape, those soils were not sampled because they are not typically suited or considered for riparian reforestation. The sampled soils were mapped as mesic Entisols, Histosols, Inceptisols, or Ultisols and were comprised of various combinations of clay, silt, sand, and larger coarse fragments (STATSGO2, 2010). The soils at most sites were mapped as either well/excessively drained or moderately well drained, though field observations indicated that some were poorly drained. While mottling was observed near the bottom of some soil cores, thus indicating occasional saturation, all the soils sampled and analyzed were above the local water table at the time of collection.

2.3. Soil sampling and analysis

At each site, surface soils were sampled at five locations throughout the reach at ~30 m intervals (Fig. 2). At each of the 5 locations, soils were sampled with a cylindrical soil corer to a depth of 30 cm. Each soil core was stored and processed individually but, for site-wise comparisons, soil properties were averaged across the 5 sampling locations at each site. Soils were air-dried, sieved through a stainless steel screen (2 mm), and weighed in