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Soil texture and nitrogen mineralization potential across a riparian toposequence in a semi-arid savanna

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Abstract

Soil texture is an important influence on nutrient cycling in upland soils, with documented relationships between mineral particle size distribution and organic matter retention, nitrogen (N) mineralization, microbial biomass and other soil properties. However, little is known of the role of mineral particle size in riparian soils, where fluvial sorting creates strong spatial contrasts in the size distribution of sediments in sedimentary landforms. We studied total organic carbon (TOC) and total N (TN) storage and net N mineralization relative to soil texture and landform in soils of a riparian toposequence along the Phugwane River in Kruger National Park, South Africa. TOC, TN and potential N mineralization related strongly to particle size distribution in all soils along the toposequence. TOC and TN were positively correlated with silt and clay concentration ($r^2 = 0.78$). In long-term laboratory incubations, N mineralization was greatest in fine-textured, N-rich soils, although the proportions of soil N mineralized were inversely related to fine particle concentrations ($r^2 = 0.61$). There were differences in TOC, TN and potential N mineralization among landform types, but none of these soil properties were statistically significant after accounting for the effect of particle size. These results demonstrate the influence of particle size in mediating N retention and mineralization in these soils. Predictable differences in soil texture across alluvial landforms contribute to corresponding contrasts in soil conditions, and may play an important role in structuring riparian soil and plant communities.

Keywords: Soil texture; N mineralization; Riparian soils; Phugwane River; Kruger National Park

1. Introduction

Riparian areas are recognized as among our most important—and threatened—ecological resources, supporting high productivity, high biodiversity, and playing an important role in mediating terrestrial-aquatic exchanges (Gregory et al., 1991). Although maintaining natural stream flow regimes is critical to conserving the integrity of riverine ecosystems (Poff et al., 1997), the functional relationships between flooding and ecosystem dynamics are incompletely understood. Redistribution of sediments is a defining characteristic of alluvial environments. The importance of mineral particle size distribution to soil organic matter (OM) and nutrient dynamics has long been recognized (Jenny, 1941). Numerous studies have documented correlations of mineral particle size distribution and mineralogy with OM storage (Burke et al., 1989; Schimel et al., 1994; Bird et al., 2000), microbial biomass (Kaiser et al., 1992*; Franzluebbers et al., 1996), N mineralization (Motavalli et al., 1995; Franzluebbers et al., 1996; Côté et al., 2000) and primary productivity (Pastor et al., 1984; Reich et al., 1997). However, almost all studies have been conducted in mature upland soils, and little is known of mineral–organic interactions in floodplain or other riparian soils.

Alluvial soils are typically much younger than those of the surrounding landscape, and are distinguished by exchange of sediments, OM, nutrients and contaminants between terrestrial and aquatic environments, creating unique contexts for mineral-OM interactions. Stream flows cause strong and predictable patterns in the distribution of sediments and sedimentary landforms. Coarser sediments are sorted into a variety of channel, bar, and emergent floodplain landforms while silt, clay and OM with no mineral association are deposited in overbank flows and other areas of reduced stream energy (Nanson and Croke, 1992). In addition to variation in soil texture, these landforms subsume differences in soil age, hydrology and other unspecified influences that might affect nutrient transformations and fluxes within soils. Spatial and temporal contrasts in sedimentary landforms are viewed

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as important sources of ecological heterogeneity (Ward et al., 2002), contributing to biodiversity (Ward et al., 1999), and with plainly visible relationships with the distribution of vegetation (Puhakka et al., 1992; Mendonça Santos et al., 1997). However, the mechanisms contributing to this heterogeneity are incompletely understood.

Two disparate perspectives have developed regarding the influence of particle size on N dynamics in well-drained soils. The first emphasizes the importance of mineral surfaces in inhibiting decomposition (Christensen, 1996; Sollins et al., 1996) while the second points to field evidence of positive relations between fine particles and N turnover (Pastor et al., 1984; Reich et al., 1997). Most soils include large amounts of OM adsorbed to the high surface area of clays or encapsulated within soil aggregates. Association with mineral surfaces also exerts a stabilizing influence on much of the associated OM, decreasing its availability to biota but contributing to water holding capacity, cation exchange capacity and other important soil properties. Mineral-associated OM that persists for hundreds to thousands of years typically constitutes one half or more of total soil OM in temperate climates (Trumbore, 1993). Retention times of 10 years or less for mineral-associated OM in tropical soils (Trumbore, 1993) indicate little long-term OM stabilization. However, consistent increases in the proportion of mineral-associated OM with decreasing latitude (Amelung et al., 1998) suggest an important role for mineral particles in mediating OM turnover over shorter time scales.

Strong positive relationships between soil texture, net N mineralization and primary productivity are frequently observed in field studies (Pastor et al., 1984; Reich et al., 1997; Prescott et al., 2000). Positive correlations of texture and net N mineralization could result from stimulation of N mineralization by other related to soil texture, such as water holding capacity and thermal conductivity. Favorable moisture and temperature regimes in fine-textured soils directly stimulate N mineralization, and may indirectly contribute to N mineralization through their influence on plant uptake and growth, contributing to N returns in litterfall (Pastor et al., 1984). Environmental variability affects the efficiency of internal cycling through soil-plant pathways, and fine-textured soils tend to be less affected by pulsed C and N mineralization that accompanies repeated wetting and drying (Fierer and Schimel, 2002). In addition to increasing water retention, capillary water movement through fine sediments can be an important source on soil moisture in areas with shallow water tables such as commonly found in riparian areas (Décamps, 1996).

Within an overall goal of understanding the influence of sediment distribution on N mineralization within the riparian corridor of a savanna landscape, we considered patterns in TOC, TN and potential net N mineralization relative to sediment particle size and landforms in riparian soils of the Phugwane River, South Africa. We hypothesized that TOC and TN distribution and potential N mineralization would relate to both soil texture and riparian landscape position.

2. Materials and methods

2.1. Study site

The study area is along the Phugwane River in Kruger National Park (KNP), South Africa. The climate is semi-arid, annually receiving 400-600 mm rainfall, mostly between November and March. The Phugwane River originates in the eastern foothills of the Drakensberg escarpment and descends to a slightly undulating alluvial plain extending 30–40 km to either side of the river. The Phugwane River has a limited alluvial character. The meandering river is incised 8–12 m into the surrounding plain, with abundant narrow terraces indicating active channel movement within the incised area. Migration rates across the alluvial plain appear to occur over millennial time scales. Surface flows on the Phugwane are highly variable and cease for at least part of the dry season most years. Infrequent cyclones originating in the Indian Ocean produce severe floods (Venter et al., 2003), most recently in February 2000.

The riparian landscape consists of an approximately 100 m wide annual floodplain and riparian toposequence that is representative of alluvial sections of the Phugwane. The floodplain was extensively scoured during the 2000 flood and consisted mostly of recently deposited sand, with thin crusts of silt and clay forming in low areas during the dry season. Small sedimented islands, extending to 1.5 m above the floodplain, contain small rocks and fine sand. Surface water covers most or all of the floodplain following rain storms but is reduced to isolated pools for much of the dry season. The riparian toposequence, in contrast, is finer textured, and consists of steep riverbanks, narrow fluvial terraces, and a more gradual hillslope leading up to the terrestrial plain. Soils consist of stratified alluvium derived primarily from granite rock and are classified as luvisols in the FAO soil classification (FAO, 1998); most soils would be classified as Inceptisols or Entisols in the USDA classification (Soil Survey Staff, U., 1998). They are moderately weathered, sandy, high in base saturation and low in cation exchange capacity (Venter, 1990). Riverbank soils contain weakly developed 5–15 cm thick A horizons while terrace, hillslope and alluvial plain soils contain well-developed A horizons with a hard, blocky structure ranging from 20 to >50 cm in thickness. An eluvial horizon was present at >30 cm depth in the terrestrial soil.

The floodplain is sparsely vegetated with annual grasses, forbs and reeds, with stunted trees, mostly leadwood (*Combretum imberbe*) on sedimented islands. Riverbanks are intermittently vegetated with the perennial grass panicum (*Panicum maximum).* Terraces and hillslope areas are open woodland with leadwood and appleleaf (*Lonchocarpus capassa)* as the canopy species and near continuous cover of panicum. The terrestrial plain is savanna dominated by mopane (*Colophospermum mopane)* trees with sparse groundcover of diverse grasses. No plants with N-fixing root symbioses are known to exist on the site. Atmospheric N deposition is estimated to be 21.6 kg N ha^{-1} $year^{-1}$ (due mostly to regional influences of coal burning power plants), and is assumed to be