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High specific activity in low microbial biomass soils across a no-till evapotranspiration gradient in Colorado

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ABSTRACT

The need to identify microbial community parameters that predict microbial activity is becoming more urgent, due to the desire to manage microbial communities for ecosystem services as well as the desire to incorporate microbial community parameters within ecosystem models. In dryland agroecosystems, microbial biomass C (MBC) can be increased by adopting alternative management strategies that increase crop residue retention, nutrient reserves, improve soil structure and result in greater water retention. Changes in MBC could subsequently affect microbial activities related to decomposition, C stabilization and sequestration. We hypothesized that MBC and potential microbial activities that broadly relate to decomposition (basal and substrate-induced respiration, N mineralization, and β-glucosidase and arylsulfatase enzyme activities) would be similarly affected by no-till, dryland winter wheat rotations distributed along a potential evapotranspiration (PET) gradient in eastern Colorado. Microbial biomass was smaller in March 2004 than in November 2003 (417 vs. 231 μg g^{-1} soil), and consistently smaller in soils from the high PET soil (191 μg g^{-1}) than in the medium and low PET soils (379 and 398 μg g^{-1}, respectively). Among treatments, MBC was largest under perennial grass (398 μg g^{-1}). Potential microbial activities did not consistently follow the same trends as MBC, and the only activities significantly correlated with MBC were β-glucosidase ($r = 0.61$) and substrate-induced respiration ($r = 0.27$). In contrast to MBC, specific microbial activities (expressed on a per MBC basis) were greatest in the high PET soils. Specific but not total activities were correlated with microbial community structure, which was determined in a previous study. High specific activity in low biomass, high PET soils may be due to higher microbial maintenance requirements, as well as to the unique microbial community structure (lower bacterial-to-fungal fatty acid ratio and lower 17:0 cy-to-16:1ω7c stress ratio) associated with these soils. In conclusion, microbial biomass should not be utilized as the sole predictor of microbial activity when comparing soils with different community structures and levels of physiological stress, due to the influence of these factors on specific activity.

1. Introduction

Microbial communities are the driving force of many soil ecosystem services, but much research has yet to be done to identify the biotic and abiotic factors that affect the rates of these services. For years, microbial biomass has received attention as a predictor of microbial activities related to decomposition, including C and N mineralization. While some have found success (Jenkinson et al., 1976; Rice et al., 1996; Shen et al., 1997), others have found no relationship of MBC to C and N mineralization activities (Puri and Ashman, 1998; Rochette et al., 1999; Sato and Seto, 1999; Raubuch and Joergensen, 2002; Wang et al., 2003; Lagomarsino et al., 2009), or that the relationship was dependent on whether total or active MBC was determined (Hassink, 1995; Franzluebbers et al., 1999a, 1999b). The need to identify microbial community parameters that predict microbial activity is becoming more urgent, due to the desire to manage microbial communities for ecosystem services (Barrios, 2007) as well as the desire to incorporate microbial community parameters within ecosystem models (Moorhead and Sinsabaugh, 2006; de Bruijn and Butterbach-Bahl, 2010; McGuire and Treseder, 2010). In fact, about 70% of contemporary models already include at least one microbial biomass parameter for

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prediction of organic matter decomposition or N mineralization activity (Manzoni and Porporato, 2009).

Humans can manipulate and increase soil microbial biomass by reducing soil disturbance and increasing the availability of limiting resources, including organic matter and water. For example, MBC in dryland agroecosystems can be increased by adopting alternative management strategies (e.g., no-tillage and increased cropping intensity) that increase nutrient reserves, improve soil structure and result in greater water retention (Campbell et al., 1992; Franzluebbers et al., 1994a; Lupwayi et al., 1998; Schomberg and Jones, 1999; Frey et al., 1999; Balota et al., 2003; Feng et al., 2003; Biederbeck et al., 2005). In the central Great Plains of the United States, no-till and intensive crop rotations have been implemented as a means to improve soil quality after decades of conventionally tilled, winter wheat (*Triticum aestivum* L.)-fallow cropping. Soils of this semi-arid region were managed this way to conserve moisture by leaving the soil fallow 14 months out of a 24 month period with a winter wheat crop grown every other year. Peterson et al. (1993) observed that frequent fallowing and intensive tillage had severely degraded the quality of dryland soils over time and suggested both replacement of the winter wheat–summer fallow system by more sustainable rotations and adoption of no-tillage practices. Twelve years after implementation of a no-till cropping intensity study across eastern Colorado Great Plains, organic C levels in continuously cropped, no-till surface soils were 35% greater than amounts found in the traditional winter wheat–summer fallow system (Sherrod et al., 2003). After an additional six years, SOC levels under a continuous, annual opportunity crop (Opp) treatment were equivalent to levels under perennial grass (Stromberger et al., 2007). Microbial biomass did not respond the same as SOC, however, as MBC was lower under Opp than perennial grass (Stromberger et al., 2007). The same study also reported that MBC was strongly affected by the location of study sites along a potential evapotranspiration (PET) gradient, where MBC was lowest at the high PET study site in Walsh, Colorado. Thus, management treatment and PET which influence soil water availability may be strong determinants of MBC.

If MBC is a predictor of microbial activity in these semi-arid Great Plains soils, then microbial decomposition activities could be constrained by certain crop rotations or field locations, thereby affecting the ability of certain soils to stabilize and sequester residue C. In this study, we measured MBC and several potential microbial activities at the same no-till crop rotation experiments as described by Sherrod et al. (2003) and Stromberger et al. (2007). We hypothesized that potential microbial activities and MBC would be similarly affected by site location along a PET gradient and crop rotation management treatments. Specifically, activities broadly related to organic matter decomposition (basal and substrate-induced respiration, net N mineralization, and β-glucosidase and arylsulfatase enzyme activities) would be lowest in soils at Walsh, the high PET site, and among perennial grass and crop rotations, these factors would be greatest under perennial grass and lowest under the Opp treatment.

2. Materials and methods

2.1. Site descriptions

The study was conducted within a long-term experiment (est. 1985) located in the Great Plains of eastern Colorado, which has the objective of identifying crop and soil management systems that maximize precipitation use efficiency and economic return (Peterson et al., 1993). Prior to 1985, the fields had been cultivated mainly in dryland winter wheat–summer fallow or sorghum for >50 years until 1985 when no-till management was established. The long-term experiment includes four driving variables: (i) climate regime (PET), (ii) field topography (soils) (iii) management treatments (crop rotations), and (iv) time. The climate driver consists of three locations that have approximately the same long-term annual precipitation (420 mm y^{-1}) but different levels of potential evapotranspiration (PET) as measured by an open pan evaporation: Sterling (low PET, 1016 mm y^{-1}; 40.37°N, 103.13°W), Stratton (medium PET, 1270 mm y^{-1}; 39.18°N, 102.26°W), and Walsh (high PET, 1900 mm y^{-1}; 37.23°N, 102.17°W). Confounding the PET gradient is a difference in soil texture. The surface texture is a loam at the low PET site (38% sand, 37% silt, and 25% clay), clay loam at the medium PET site (20% sand, 47% silt, and 33% clay), and a loamy sand at the high PET site (67% sand, 16% silt, and 17% clay). Within each PET, field topography consists of three levels, represented by three slope positions (summit, sideslope, and toeslope soils) that result in altered soil properties among the slope positions.

Five management treatments were placed in each of two blocks, arranged across each slope position at each site. These treatments represent a range in cropping intensity and summer fallow frequency. Originally, crop rotations were winter wheat–summer fallow (WF), winter wheat–corn (*Zea mays* L.)–summer fallow (WCF), winter wheat–corn–millet (*Panicum miliaceum* L.)–summer fallow (WCMF), opportunity crop (Opp), and perennial grass, all managed with no-till techniques to maximize water storage potential. Grain sorghum [*Sorghum bicolor* (L.) Moench] replaces corn at Walsh as it is better suited to the high PET and longer growing season (Sherrod et al., 2003). Opportunity crop rotation is a continuous rotation that does not follow a rigid rotation schedule. Instead, a crop is chosen each growing season, without a summer fallow, and planted according to anticipated precipitation and the amount of stored water in soil at planting time. Crops within the Opp rotation can include corn, wheat, millet, and sunflower (*Helianthus annuus* L.). Prior to wheat planting in 2003, the recent crop history of the Opp treatments included Austrian winter pea (*Pisum sativum* L.) (soybean [*Glycine max* (L.) Merr.] at Walsh) in 2000, winter wheat (sorghum at Walsh) in 2001, and corn in 2002. The perennial grass treatment consists of a mixture of crested wheatgrass [*Agropyron desertorum* (Fischer ex Link) Schultes], western wheatgrass [*Pascopyrum smithii* (Rydb.) Love], buffalograss [*Buchloë dactyloides* (Nutt.) Engelm.], side oats grama [*Bouteloua curtipendula* (Michaux) Torrey], blue grama [*Bouteloua gracilis* (Willd. ex Kunth) Lagasca ex Griffiths], and little bluestem [*Schizachyrium scoparium* (Michaux) Nash]. All phases of each crop rotation are present every year. In 1998, the WF rotation was replaced by wheat–corn–millet (WCM), and WCMF was replaced by wheat–wheat–corn–millet (WWCM).

Fertilizer N (urea–NH_4NO_3; 30-0-0) is applied at recommended rates to each experimental unit except for perennial grass plots (which were not fertilized). The rate varies each year and is based on the specific crop grown and according to soil tests performed for each soil (Peterson et al., 1993). This results in the same amount of plant-available soil N under the same crop species across all plots. Fertilizer P (10-15-0) at 9.5 kg ha^{-1} is banded annually at planting of each crop.

For this study, five management treatments (WCF, WCM, WWCM, Opp and perennial grass) on one slope position (summit) were studied at each of the three PET sites. We chose only one slope position because climate regime and management were our factors of interest. Each treatment plot was 6.1 m wide, but varied in length, depending on the length of the summit position (185–305 m long).

2.2. Soil sampling and processing

Soil samples were collected in plots planted to winter wheat in November 2003, shortly after winter wheat planting, and then in March 2004 during the greening-up phase of winter wheat. For the WWCM rotation, soil was sampled in the wheat phase that