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Seven years of enhanced water availability influences the physiological, structural, and functional attributes of a soil microbial community

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Abstract

Water availability is known to influence many aspects of microbial growth and physiology, but less is known about how complex soil microbial communities respond to changing water status. To understand how long-term enhancement of soil water availability (without flooding) influences microbial communities, we measured the seasonal dynamics of several community-level traits following >7 years of irrigation in a drought-prone tallgrass prairie soil. From late May to mid-September, water was supplied to the irrigated treatments based on calculated plant water demand. Phospholipid fatty acids (PLFA) were used to assess changes in microbial community structure and physiology. To assess the community-level physiological profile, microbial utilization of BIOLOG substrates was determined. After incubation for 2 days, the distribution of added ^{13}C-glucose in microbial and respired pools was used as an index of substrate utilization efficiency. We also measured the relative contribution of fungi and bacteria to soil microbial biomass via substrate-induced respiration (SIR). Multivariate analysis of mol% PLFA and BIOLOG substrate utilization indicated that both water availability and sampling time influenced both the physiological and structural characteristics of the soil microbial community. Specific change in biomarker PLFA revealed a decreased ratio of cyclopropyl to ω7-precursors due to water addition, suggesting community-level stresses were reduced. Over the growing season, continuously greater water availability resulted in a 53% greater ratio of fungal to bacterial biomass using SIR, and a 65% increase in fungal PLFA. The number of substrates utilized by the cultivable microbial community tended to be greater in continuously wetted soil, especially during periods of low rainfall. While water dynamics appeared to be associated with some of the shifts in microbial community activity, structural and functional changes in the community appeared to be more closely linked to the cumulative effects of water regime on ecosystem properties. Seasonality strongly influenced microbial communities. The environmental factors associated with seasonal change need to be more closely probed to better understand the drivers of community structure and function.

Keywords: Water availability; PLFA; Microbial community; Physiology; Stress; Substrate use efficiency

1. Introduction

Soil water availability is a critical resource for microbial activity. Through its impacts on osmotic potential, transport of nutrients and energy, cellular metabolism, competitive interactions, and as a medium

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for bacterial motility (Harris, 1981; Yancey et al., 1982; Bremer, 1999), changes in water status could impact the physiology and structure of the soil microbial community. Dissimilar types of microorganisms are differentially affected by various and changing amounts of water potential (Todd et al., 1999; Griffiths et al., 2003; Drenovsky et al., 2004). For example, gram-negative type bacteria are thought to be more sensitive to dramatic changes in water potential, while fungi have been implicated as more tolerant of low water availability (Harris, 1981; Nesci et al., 2004). While many management, plant and soil factors are important mediators of soil microbial community structure (Waldrop et al., 2000; Yao et al., 2000; Calderon et al., 2000; Baath and Anderson, 2003; Clegg et al., 2003; Parham et al., 2003; Soderberg et al., 2004), only a few short-term (weeks), and no long-term (multiple years) studies have been conducted to assess the influence of water status on the structure and physiology of the soil microbial community (Lundquist et al., 1999; Fierer et al., 2003; Griffiths et al., 2003; Drenovsky et al., 2004). As such, it is not known how water status directly alters and indirectly feeds back to change the form and function of soil ecosystems and their associated microbial communities.

Greater above and below-ground productivity as a result of irrigation in the water-limited tallgrass prairie ecosystem provides a clear example of how changing water status works indirectly to change ecosystem properties that may feedback to influence microbial communities and their function (Knapp et al., 1998; Williams, 2001). In oligotrophic environments such as soil (Hattori, 1984), changes in C availability derived from greater root growth and enhanced rates of rhizodeposition have been shown to impact soil microbial communities (Drenovsky et al., 2004). Among many other potential changes, temperature may be reduced in irrigated systems during hot summer days because of water's high heat of evaporation that fuels evaporative cooling (Bremer and Ham, 2002).

The objective of the experiment was to assess the microbial community responses through a growing season following 7 years of enhanced soil water availability We expected that microbial community structure and function would be sensitive, as noted, to immediate changes in water availability in naturally drought-prone soils. Long-term cumulative effects of continuously available water should also change the nature of the microbial community compared to drought-prone soils even during periods when water contents were similar between the two water regimes.

2. Materials and methods

2.1. Study site

The experiment was conducted in a native (annually burned in spring) upland tallgrass prairie located at the Konza Prairie Biological Station near Manhattan, Kansas. Soils of the upland summit topographic position are dominated by mesic Typic Hapludolls (Benfield silty clay loam). Vegetation on the site was a mixture of C_3 and C_4 species, dominated by big bluestem (*Andropogon gerardii*) and indiangrass (*Sorghastrum nutans* (L.) Nash). Average peak aboveground biomass from 1993 to 2000 was approximately 575 and 455 g m^{-2} in continuously moist and drought-prone transects, respectively, of which 35–50 g m^{-2} was forbs (Knapp et al., 1998; Williams, 2001). Standing root biomass did not differ between treatments, but was approximately 785 g m^{-2} in the top 10 cm of soil. Many of the dominant grasses and forbs responded to irrigation through increased biomass production, but forbs showed the largest response (http://www.konza.ksu.edu/data_catalog/wat01/wat013/).

Established in 1990 and 1993, the irrigation pipelines traversed a 70 m long by 30 m wide transect in the upland (280 m MSL) topographic position. Penman equations and meteorological data were used to calculate plant water demand, and water was added during the months of May/June through September (Knapp et al., 1998; Williams, 2001). During the other months of the year, precipitation exceeds evapo-transpiration. In the driest year of 1991, an additional 470 mm of water was added in the irrigated treatments, whereas the wettest year of 1993, only 80 mm of water was added. On average, 245 mm of water was added each growing season, an amount equivalent to 60% of the average total rainfall during the four-month period. The year of 2000 was a typically dry year with only 343 mm of rainfall recorded during the peak growing season months of May through September, resulting in an additional 369 mm of water added via irrigation. Four replicate irrigation plots (1.0 m^2) were interspersed by four un-watered control plots. Details of the irrigation transects in the Konza Prairie LTER and their experimental design have been published previously (O'Lear and Blair, 1999; Todd et al., 1999). Soils that were irrigated were maintained at water potentials consistently above ~ -1000 kPa during the growing season, whereas soils that receive only natural rainfall inputs often drop well below -5000 kPa for extended periods of time (Williams, 2001).

Twenty 2.2 cm dia by 10 cm deep soil cores were collected from each plot. PLFA were extracted from soil