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Seasonal and long-term resource-related variations in soil microbial communities in wheat-based rotations of the Canadian prairie

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Abstract

Like all other living organisms, microorganisms depend on nutrients, carbon and energy. Since microorganisms are central to most soil processes, the sustainable management of agricultural soils may need to consider the impact of soil fertility management on the soil microbial community. We tested the hypothesis that different rates of N and P fertilizers, and cropping frequency (modifying C input to soil) influence the size, structure and physiological condition of soil microbial populations residing in the plough layer (top 7.5 cm). For this study, we used a 37-yr old long-term wheat-based rotation experiment located in the semiarid Brown soil zone of Saskatchewan. The experiment included (1) four input treatments: (i) no N or (ii) no P fertilizer application to wheat (*Triticum aestivum* L.) grown in fallow-wheat-wheat (F-W-W) rotations, and (iii) recommended rates of both N and P fertilizer applied to fallow-wheat (F-W) and (iv) to F-W-W; (2) two rotation phases: fallow and wheat-after-fallow; and (3) four sampling times: 8 June, 4 July, 5 August and 16 September 2003. Increased partitioning into storage lipids of the arbuscular mycorrhizal fungi (AMF) fatty acid methyl ester (FAME) biomarker 16:1ω5 ($P = 0.04$), suggested the accumulation of storage material under low soil N availability. Discriminant analysis detected modifications in soil microbial community structure due to cropping frequency ($P = 0.001$) and sampling time, the effect of which was different in the fallow ($P < 0.0001$) and wheat-after-fallow ($P < 0.0001$) phases of the rotations. Correlation analysis of soil variables conducted in plots growing wheat revealed a dual effect of plants, which stimulated active soil microbial biomass (SMB), possibly through the release of soluble extractable C ($C_{sol-ext}$) in soil and, at the same time, SMB competed with wheat for soil water and N. The 37 y of different nutrient input treatments had no effect upon the active soil microbial biomass according to PLFA measurements, despite changes in soil resource-related variables (soil water potential, soil PO_4-P and NO_3-N fluxes, and $C_{sol-ext}$ concentrations) ($P \leqslant 0.003$). The biomass of each of three microbial populations monitored was lowest on 4 July, when the amounts of the soil resources monitored were average, and greatest on 5 August, when N, P and soil moisture availability was lowest. The temporal effect on the biomass of microbial populations seemed unrelated to variation in nutrient or water availability. We conclude that the soil microbial community is adaptable to a wide range of soil conditions. We propose therefore that the occurrence of sudden and dramatic events, such as a heavy rainfall on a dry soil, is the most important determinant of seasonal variation in active soil microbial biomass.

Keywords: FAME; PLFA; NLFA; Microbial biomass C; Nitrogen input; Phosphorus input; Carbon input; Soil microbial community structure; Temporal variation; Seasonal effect

1. Introduction

Like all other living organisms, microorganisms need nutrients and energy to build their cells and sustain their metabolism. In mineral soils, microbial community size is usually directly related to soil organic matter (SOM) content (Alexander, 1977; Witter and Kanal, 1998; Brady and Weil, 2001). However, it was shown that the

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availability of mineral nutrients, such as N or P, may limit the size of soil microbial communities in some ecosystems (Gallardo and Schlesinger, 1994; Christensen et al., 1996; Cleveland et al., 2002; Sundareshwar et al., 2003). Nutrient availability may influence the constitution of microbial cells and the function of microbial communities in agricultural soils which are typically fertilized. According to the principle of biological stoichiometry, for example, fast growing microorganisms tend to have low C/P ratios (Elser et al., 2000; Elser et al., 2003). This condition is dictated by the requirement for abundant ribosomal RNA, molecules rich in P. Nutrient availability may impact not only on the size, but also on the taxonomic and functional structure of soil microbial communities.

In spite of the importance of soil organisms in the formation, quality and function of agricultural soils, few attempts have been made to understand the impact of nutrient inputs on their communities. The application of fatty acid methyl esters (FAME) analysis has helped identify factors that influence microbial communities in soils. FAME analysis has previously been used to characterize soil or rhizosphere microbial community differences in response to fertilization (Bossio et al., 1998; Bardgett et al., 1999), plant genotype (Fang et al., 2001; Dunfield and Germida, 2003), pH (Bååth and Anderson, 2003), temperature and water potential (Nazih et al., 2001), land use (Bardgett et al., 1997; Yao et al., 2000) land use change (Allison et al., 2005; Grayston et al., 2001), and tillage (Jackson et al., 2003; Spedding et al., 2004). Phospholipids are components of cell membranes and are metabolized rapidly after cell death. Therefore, FAMEs from the phospholipid fraction (PLFAs) of soil-extracted lipids reflect soil microbial biomass (Frostegård and Bååth, 1996). Neutral lipids are storage compounds in fungi, and FAMEs from the neutral lipid fraction (NLFAs) indicate the physiological condition of soil fungi (Bååth, 2003). A large ratio of neutral lipids to phospholipids indicates resting structure abundance.

We used FAME analysis to assess the long-term effects of N, P and C inputs on the size and structure of the microbial community, and on the physiological state of saprotrophic fungi and arbuscular mycorrhizal fungi (AMF), using samples collected from a long-term wheat-based rotation experiment located in the semiarid Brown soil zone of Saskatchewan. We tested the hypothesis that different rates of N and P fertilizers, and cropping frequency (modifying C input to soil) influence the size, structure and physiological condition of soil microbial populations.

2. Materials and methods

2.1. Study site and experimental design

This 37-y experiment was established in 1967, on a Swinton silt loam (Orthic Brown Chernozem) located at Swift Current Saskatchewan, Canada (latitude: 50° 17' N; longitude: 107° 41' W) (Campbell et al, 2005). The region receives 361 mm of annual precipitation and has a yearly mean temperature of 3.6 °C, with mean monthly temperatures ranging from −13.2 °C in January to 18.6 °C in June (54-y averages). The 2003 season was drier than normal (188.6 mm from 1 May to 30 September, as compared to a 54-y average of 242.7 mm) with particularly low precipitation in July and August (Fig. 1). Precipitation and soil temperature at 10 cm were recorded at a weather station located 1 km west of the experiment's site.

The soil microbial community is very dynamic and its measurement at one point in time may be misleading. Therefore, variations in the soil microbial community and in soil conditions were evaluated throughout the 2003 growing season, i.e. from 21 May to 30 September, in four wheat-based rotation treatments involving different fertilization regimes and cropping frequencies. The fallow phase and wheat-after-fallow phase of each rotation were assessed. There were four rotation systems with differing nutrient input regimes: three fallow-wheat-wheat (F-W-W) rotations that received (i) recommended rates of N and P fertilizer (CNP), (ii) N fertilizer only (no-P), and (iii) P fertilizer only (no-N), plus (iv) a low cropping frequency rotation consisting of a fallow-wheat (F-W) rotation that received recommended rates of N and P fertilizer (low-C_f). Input treatments are shown in Table 1. Treatments were

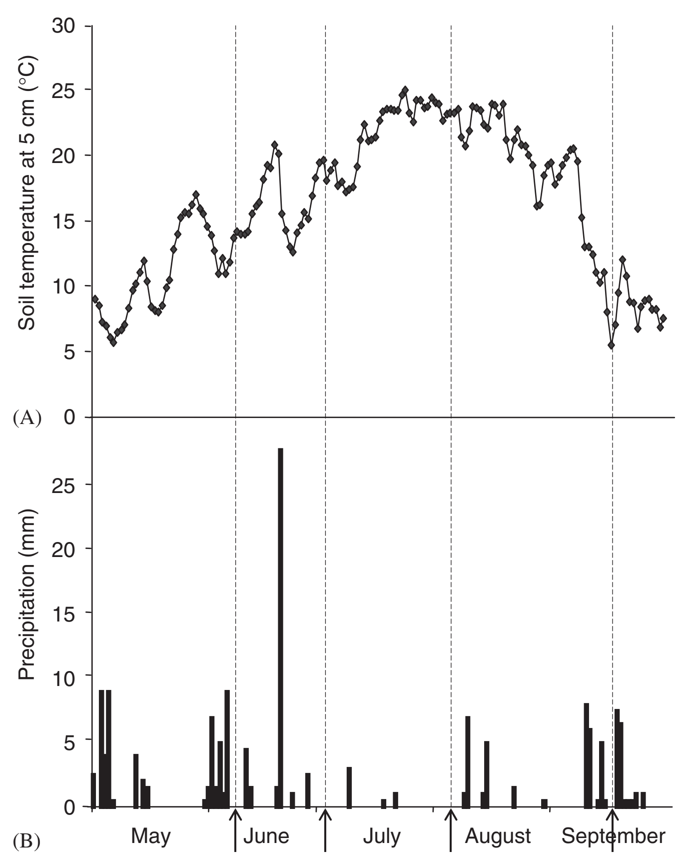

Fig. 1. Amount and distribution of precipitation from 1 May to 30 September 2003 at the field site and soil temperature at 10 cm depth. Arrows indicate sampling times.