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Cover Crop and Irrigation Effects on Soil Microbial Communities and Enzymes in Semiarid Agroecosystems of the Central Great Plains of North America

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ABSTRACT

Cover crops can have beneficial effects on soil microbiology by increasing carbon (C) supply, but these beneficial effects can be modulated by precipitation conditions. The objective of this study was to compare a fallow-winter wheat (*Triticum aestivum* L.) rotation to several cover crop-winter wheat rotations under rainfed and irrigated conditions in the semiarid US High Plains. Experiments were carried out at two sites, Sidney in Nebraska, and Akron in Colorado, USA, with three times of soil sampling in 2012–2013 at cover crop termination, wheat planting, and wheat maturity. The experiments included four single-species cover crops, a 10-species mixture, and a fallow treatment. The variables measured were soil C and nitrogen (N), soil community structure by fatty acid methyl ester (FAME) profiles, and soil β-glucosidase, β-glucosaminidase, and phosphodiesterase activities. The fallow treatment, devoid of living plants, reduced the concentrations of most FAMEs at cover crop termination. The total FAME concentration was correlated with cover crop biomass ($R = 0.62$ at Sidney and 0.44 at Akron). By the time of wheat planting, there was a beneficial effect of irrigation, which caused an increase in mycorrhizal and protozoan markers. At wheat maturity, the cover crop and irrigation effects on soil FAMEs had subsided, but irrigation had a positive effect on the β-glucosidase and phosphodiesterase activities at Akron, which was the drier of the two sites. Cover crops and irrigation were slow to impact soil C concentration. Our results show that cover crops had a short-lived effect on soil microbial communities in semiarid wheat-based rotations and irrigation could enhance soil enzyme activity. In the semiarid environment, longer time spans may have been needed to see beneficial effects of cover crops on soil microbial community structure, soil enzyme activities, and soil C sequestration.

Key Words: crop rotation, enzyme activity, FAME profile, fatty acid methyl ester, winter wheat

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INTRODUCTION

Cover crops have historically been defined as plantings between grain crops used to manage overly wet soils, prevent nitrate leaching, control soil erosion, suppress weeds, and/or enhance soil conservation without providing a direct economic benefit. Cover crops have been very effective in improving soil physical quality in relatively moist regions (Blanco-Canqui *et al.*, 2011; Liu *et al.*, 2005), but the benefit of cover cropping in semiarid regions is questionable because cover crops use water (Unger and Vigil, 1998). Cover cropping in different geographic areas has shown clear benefits to soil enzymes and soil microbiology.

Agricultural scientists have long recognized that increases in plant growth are not determined by total available resources, but by increases in the most scarce resource in a particular situation (van der Ploeg *et al.*, 1999). In the Central Great Plains of USA, the most scarce resource for crop growth is water, followed secondarily by nitrogen (N). In rainfed semiarid systems, the cover crop can reduce the water recharge of the soil profile relative to a fallow period, which can lead to a yield reduction of the following grain crop (Lyon *et al.*, 1995; Nielsen *et al.*, 2015). In the Central Great Plains, wheat yields decrease by 141 kg ha^{-1} for every cm of available soil water deficit found at wheat planting (Nielsen and Vigil, 2005). Because of this, the cover crop water demand has to be balanced against the possible conservation and management benefits resulting from the cover crop.

The composition and biomass of soil microbial co-

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mmunities are markedly influenced by soil moisture regimes (Williams and Rice, 2007; Clark *et al.*, 2009; Cregger *et al.*, 2012) and by changes in vegetation cover (Buyer *et al.*, 2002) because different plant species can favor distinct soil microbial taxa (Zak *et al.*, 2003; Kardol *et al.*, 2009, 2010; Mitchell *et al.*, 2010). Soil microbial communities have a profound effect on soil function through their enzymes, which catalyze the cycling of several nutrients (*e.g.*, C, N, P, and S) and regulate soil organic matter (SOM) dynamics. Measurement of several enzyme activities can provide early signs of changes in soil metabolic capacity due to soil disturbances such as tillage (Acosta-Martínez and Tabatabai, 2001), land management (Acosta-Martínez *et al.*, 2003), and crop rotations (Acosta-Martínez *et al.*, 2007b).

Fatty acid profiling followed by multivariate analysis has been used to study soil microbial community structure under different agronomic regimes (Calderón *et al.*, 2000; Acosta-Martínez *et al.*, 2007b; Bell *et al.*, 2009; Bowles *et al.*, 2014) because different microbial taxa contain fatty acids that vary in their chain length, number of unsaturations, and position of double bonds. The ester-linked total fatty acid (FAME) method has been used successfully to study tillage and crop rotation effects in rainfed wheat systems in agricultural plots (Drijber *et al.*, 2000; Acosta-Martínez *et al.*, 2007b).

The objectives of this study were to determine the effect of the presence or absence of different cover crop species or a 10-species mixture on soil microbial communities throughout a complete cycle of a cover crop-wheat (grain crop) system in the Central Great Plains of USA. Our hypothesis is that in a semiarid environment, soil microbial community structure and microbial enzyme activities will be enhanced by supplemental irrigation and will be negatively affected by fallowing the soil. The effect of cover crop diversity on soil microbial community structure and microbial enzyme activities will be secondary to that of irrigation and fallow. The effect of cover crop diversity was ascertained by comparing 10-species cover crop mixture with individual cover crop species. Soil water effect on soil microbial communities and enzyme activities was also assessed by comparing rainfed and irrigated conditions.

MATERIALS AND METHODS

Study sites

This study was conducted from 2012 through 2013 at two separate sites 135 km apart: the USDA-ARS Central Great Plains Research Station (40°09′ N, 103°09′ W, 1 383 m elevation) near Akron in Colorado of USA and the University of Nebraska-Lincoln High Plains Agricultural Laboratory (41°12′ N, 103°0′ W, 1 315 m elevation) near Sidney in Nebraska of USA. The soil at the Sidney site was a Keith silt loam (fine-silty, mixed, superactive, mesic Aridic Argiustolls in the USDA soil classification system), while the soil at Akron was a Weld silt loam (fine, smectitic, mesic Aridic Argiustolls in the USDA soil classification system). The 0–15 cm soils at Sidney and Akron have a pH of 7.0 as reported by Lyon *et al.* (2007).

Average temperatures during April–December 2012 were 15.1 and 13.7 °C for Akron and Sidney, respectively. These temperatures were higher than the long-term (1946–2013) average at both the sites, which are 12.6 °C for Akron and 12.1 °C for Sidney, respectively. The average temperatures during January–July of 2013 were 8.9 °C for Akron and 8.1 °C for Sidney. The long-term averages for this period were 9.0 and 8.5 °C for Akron and Sidney, respectively.

Precipitation during April–December 2012 was 306 and 284 mm, below the long-term averages of 378 and 388 mm at Akron and Sidney, respectively. Precipitation during January–June 2013 amounted to 214 mm at Akron and 241 mm at Sidney. Long-term average precipitation for this period was 215 and 233 mm at Akron and Sidney, respectively.

Experiments

Experimental design. At both the sites, the experiment was a split-plot design with four replications. The main plot factor was irrigation and the split-plot factor was cover crop species. The spring-planted cover crop treatments were established on no-till proso millet (*Panicum miliaceum* L.) residues under two water availability conditions at both study sites: rainfed (no irrigation) and irrigated to nearly non-water-stressed at Akron and to simulate average precipitation at Sidney. The irrigated treatment at Akron received a total of 588 mm of irrigation during the experiment, divided into 374 mm for the cover crop and 214 mm for the wheat. The irrigated treatment at Sidney received 255 mm, divided into 197 mm for the cover crop and 58 mm for the wheat. Prior to the experiment, the plots had been managed with no-till production practices in excess of 10 years. The cover crop treatments were deployed once in 2012. They consisted of a fallow treatment, a 10-species cover crop mixture of oat (*Avena sativa*), pea (*Pisum sativum*), flax (*Linum usitatissimum*), rapeseed (*Brassica napus*), lentil (*Lens culinaris*), vetch (*Vicia sativa*), clover (*Trifolium repens*), barley (*Hordeum vulgare*), safflower (*Carthamus tinc-*