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LONG term management systems under semiarid conditions: Influence on labile organic matter, β-glucosidase activity and microbial efficiency

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ABSTRACT

Conservation agriculture (CA) practices have been widely applied on a variety of agro-ecosystems in order to prevent soil degradation and to improve fertility. We studied the long term influence of different management systems on soil properties in an experimental field located in semiarid central Spain. Soil organic carbon (SOC), dissolved organic carbon (DOC), soil basal respiration (CO_2–C), microbial biomass carbon (MBC) and β-glucosidase activity have been measured during three cropping seasons. Results showed a high influence of date of sampling on the evaluated parameters and on the microbial status and activity, most likely due to variations in soil water content (SWC). Microbial efficiency and β-glucosidase activity were improved under CA, as SOC, DOC and MBC were accumulated in the surface. Microbial efficiency ratios, e.g., qR (qR = MBC/SOC), qCO_2 ($qCO_2 = CO_2$–C /MBC) and qCO_2/SOC, were useful to explain the influence of sampling date and the management practices on the microbial status. A stepwise procedure reduced considerably our data set, allowing the selection of MBC, DOC and qCO_2/SOC as reliable indicators to evaluate soil quality in semiarid areas.

1. Introduction

In semiarid regions of central Spain, rainfed cereal production is often subjected to scarcity of water due to low, erratic and unpredictable precipitations during the cropping season (García et al., 1997). During the summer period, soil is commonly left in fallow and effective rainfall events (>10 mm) are usually rare. Semiarid soils are often coarse-textured, inherently low in fertility, low in SOM and are highly susceptible to degradation (Parr et al., 1990). In addition, inadequate long term intensive tillage practices are one of the main causes of SOM loss and structure deterioration in Mediterranean agricultural lands, thus reducing fertility and productivity (Caravaca et al., 2002). Is then of major concern to provide farmers with suitable farming techniques for a sustainable crop production that may improve or maintain soil quality.

Conservation agriculture (CA) has been recognized as a sustainable alternative to the conventional practices (Verhulst et al., 2010). By reducing tillage intensity and retaining crop residues, SOM accumulation is enhanced and soil crusting and erosion are prevented.

Long term application of a given soil management practice will produce changes especially in the labile fractions of SOM and consequently may cause a shift in the microbial community structure (Calderón et al., 2001; Cookson et al., 2005). A large and diverse soil microbial biomass pool and a high biological activity are fundamental for sustainable agricultural management (Insam, 2001). The soil living fraction (i.e., MB) represents only between 0.5 and a 5% of the SOC, but its activity is responsible for the regulation of SOM transformations and associated energy and nutrient cycling in soil (González-Quiñones et al., 2011; Shi, 2011). The initial stages of insoluble SOM decomposition to dissolved organic molecules, i.e., Dissolved Organic Carbon (DOC), are caused by extracellular enzymes (Schimel and Weintraub, 2003; Cookson et al., 2005; Burns et al., 2013). DOC usually represents between 0.3 and 1% of SOC in arable fields and comprises easy mineralizable substrates. DOC is mobile within the soil solution and therefore plays a major role in transport and supply of C to microbial populations (Cookson et al., 2005), being taken up by soil microbes (i.e., respired) to provide for their needs: extracellular enzyme synthesis, cellular maintenance and growth. Under unstressed

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conditions, C (and nutrient) allocation to enzyme production is prioritized in order to prevent starvation (Schimel and Weintraub, 2003; Schimel et al., 2007; Burns et al., 2013), whereas under stressed conditions microbes prioritize cellular maintenance. Two quotients have been successfully used to study the shift in the microbial communities due to changes in soil management, that is qR, i.e., MBC/SOC, and qCO_2, i.e., CO_2–C/MBC, where CO_2–C is the soil basal respiration (Anderson and Domsch, 1990; Sparling, 1992). Soil disturbance as it occurs in conventional agricultural fields tend to increase qCO_2 rates (usually by an increase in soil respiration). However in situations like in CA when soil tillage is minimized, qCO_2 rates tend to decrease, leading to a more stable system. Disturbances like fertilization or liming can either increase or decrease qCO_2 values depending on whether the disturbance alleviates stress or not (Wardle and Ghani, 1995). The C-use efficiency of the ecosystems can be evaluated by using the qCO_2/SOC ratio (Dilly, 2005). After several years of study in soils located in two areas in Germany, Dilly et al. (2001) found significant differences in C use efficiency among the studied sites (mainly due to climate, soil texture and land use) and proposed qCO_2/SOC as a sensitive indicator (Dilly et al., 2001). Values of qCO_2/SOC above 400 μg CO_2–C mg^{-1} MBC h^{-1} (g SOC g^{-1} soil)$^{-1}$ were considered inefficient by these authors.

Extracellular enzymes (e.g., β-glucosidase) are exudated by active roots and a variety of microorganisms to the soil solution, with a variable amount being stabilized on soil colloids as an abiontic form (Knight and Dick, 2004). Those bound exo-enzymes can maintain their activity for extended periods of time and constitute a reservoir of potential activity. The β-glucosidase is involved in the final step of cellulose degradation releasing glucose, the first energy source of soil microorganisms. Some authors document that the abiontic form of β-glucosidase represents a significant amount of the total activity of this enzyme. For example β-glucosidase's abiontic form accounted for the 64% of its total activity in a managed *Typic Haploxeroll* in Oregon (Knight and Dick, 2004). However, other authors indicate that only between 2 and 7% of β-glucosidase activity came from the humic associated enzyme in a semiarid sandy clay loam soil (Doni et al., 2012). Thus, in semiarid soils, β-glucosidase activity might be very sensitive to management, especially to residue placement (Acosta-Martínez et al., 2003).

Most of the studies carried out in semiarid agro-ecosystems in Spain have addressed the influence of management practices on SOM fractions and biochemical parameters susceptible of being soil quality indicators (Madejón et al., 2007; Melero et al., 2009a; García-Orenes et al., 2010). However, few studies have dealt with the long term influence of CA practices on microbial C-use efficiency or with the seasonality of soil biological properties in semiarid agro-ecosystems. Seasonal variations of those properties might be of special interest considering the high variations in rainfall and the drought periods that characterize these areas. Recently, special attention has been focused on the influence of drought on soil organic matter (SOM) fractions, on enzyme activities and on C and N mineralization (Acosta-Martínez et al., 2014; Harrison-Kirk et al., 2014). Our main objectives were (1) to study the effects of soil management and crop rotation on different soil biochemical parameters, (2) to monitor seasonal variations of these parameters between autumn and spring during three cropping seasons, (3) to assess if the metabolic quotients are suitable to explain microbial status, (4) and to identify those soil parameters which are suitable as soil quality indicators on an Alfisol under Mediterranean semiarid conditions. The assessed parameters include soil organic carbon content (SOC) and soil biochemical properties related to the C cycle, e.g., dissolved organic carbon (DOC), basal soil respiration (CO_2–C), microbial biomass carbon (MBC) and β-glucosidase activity. To compare microbial communities, the metabolic quotient (qR = MBC/SOC), the specific maintenance of respiration ($qCO_2 = CO_2$–C/MBC) and the microbial C efficiency as the qCO_2/SOC ratio were calculated. In previous work, we found higher contents of SOM, biologically active organic matter and higher aggregate stability under CA compared to CT, indicating a significant improvement in soil structure and fertility (Martín-Lammerding et al., 2011; Martín-Lammerding et al., 2013). Since the experimental field started back in 1994, we did not acknowledge significant differences in cereal production among the different management systems (Fernández-Getino et al., 2015). We hypothesized that after 18 years of management differentiation after many years of traditional cereal production, plots under CA will display higher levels of microbial biomass, higher β-glucosidase activity and higher microbial efficiency (lower qCO_2 and qCO_2/SOC rates) than those conventionally tilled.

2. Material and methods

2.1. Experimental design

The area of the field trial is located in a semiarid region in central Spain, 42 km northeast of Madrid (40° 32′N, 3° 20′W; altitude 600 m.a.s.l.), characterized by low and irregularly distributed rainfall (average of 353 mm $year^{-1}$). The soil was classified as a *Calcic Haploxeralf* (Soil Survey Staff, 2014); it has a sandy-loam texture, it is moderately alkaline, non-saline and it has low carbon content (Table 1).

The experimental design was a split plot with four randomized blocks. Since its establishment back in 1994, three different tillage systems were tested: conventional tillage (CT), minimum tillage (MT) and no tillage (NT). As the secondary factor, a winter wheat monoculture (*Triticum aestivum* var. Marius) was compared to a four year crop rotation (fallow – winter wheat – vetch, *Vicia Sativa* var. Senda – barley, *Hordeum vulgare* var. Kika). Out from the whole 60 subplots (10 × 25 m), 24 were selected to accomplish our objectives with 12 subplots sown with winter wheat (named MONO) and other 12 subplots corresponding to the rotation (named ROT).

Seedbed preparation was performed around two weeks before seeding; mouldboard plowing to 25 cm deep was done in the CT

Table 1
Soil main characteristics.

Soil depth cm	Sand [a] (50–2000 μm) g kg^{-1}	Silt [a] (2-50 μm)	Clay [a] (<2 μm)	SOC	$CaCO_3$	AWC [b]	pH (1:2.5)	EC [c] (1:5) dS m^{-1}
0–7.5	505	376	119	7.5	41.6	110	7.9	0.123
7.5–15	510	379	111	6.3	41.3	100	8.0	0.119
15–30	501	351	148	5.6	43.4	114	8.1	0.116

[a] Particle size distribution.
[b] Available water content (between −30 and −1500 kPa).
[c] Electric conductivity.