Carbon fractions and enzymatic activities in two cultivated dryland soils under conservation tillage

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Abstract
Long-term soil management experiments are expected to provide important information regarding sustainable crop production systems. In this study we evaluated the long-term effect of conservation tillage (CT) on biological properties in two different textured soils [Entisol (soil A) and Vertisol (soil B)].The results were compared with those obtained under traditional tillage (TT). Soil labile carbon fraction was measured by the determination of active carbon (AC) and water soluble carbon (WSC). Biological status was evaluated by the measurement of soil microbial biomass carbon (MBC) and enzymatic activities [dehydrogenase activity (DHA) and β-glucosidase activity (β-glu)].Contents of AC, MBC, and β-glu in soil A and contents of DHA in soil B were higher in CT than in TT, at 0-5 cm depth. Discriminant analysis (DA) showed that the discriminant function was strongly correlated with MBC and AC in soil A and with TOC, AC and WSC in soil B. According to this study, AC content was the most sensible and reliable indicator for assessing the impact of different soil management strategies on soil quality in the two soils. Long-term dryland soil conservation management improved the quality of both soil types (Entisol and Vertisol), especially near the surface, by enhancing its biological status.

Key Words
Permanganate oxidizable carbon; microbial biomass carbon (MBC) to TOC ratio, dehydrogenase activity, β-glucosidase activity.

Introduction
Conservation agriculture attaches great importance to maintain soil structure, productivity and biodiversity. Conservation tillage reduces the negative impacts of tillage, preserves soil resources and could lead to accrual of the soil carbon lost during tillage (Conant *et al.* 2007). Organic matter is involved in the enhancement of soil quality since it acts on soil structure, nutrient storage and biological activity. Small changes in TOC resulting from changes in soil management are often difficult to measure and several years are required to detect changes resulting from management practices. However, changes in small but relatively labile fractions of soil organic carbon may provide an early indication of improvement in response to management practices. The labile fractions of soil organic carbon are important to study as these fractions of soil C are more easily available carbon sources for soil microorganisms, and therefore influence nutrient cycles and many biologically-related soil properties. The labile fractions of soil C are often called the active C pool to distinguish from the passive C pool that is only very slowly altered by microbial activities. Active C (AC) is more related to microbial activity and more sensitive to soil management than TOC (Weil *et al.* 2003). Fractions of soil organic carbon that represent active C include microbial biomass C (MBC), particulate organic matter and sugars. Soil microbial properties such as MBC and activity of microbial populations and soil enzymes have been used to predict soil biological status and the effect of farm management as it relates to soil quality (Melero *et al.* 2007). The main aim of this work was to asses the long-term effect of conservation tillage on soil organic C fractions and biological properties in two different textured soils (sandy clay loam and clay) under a Mediterranean dryland cropping system. We hypothesised that long-term conservation tillage may have a positive effect on soil quality by improving soil organic carbon sequestration and biochemical properties. Moreover, we considered these parameters as reliable indicators of changes in soils with a long history of conservation tillage.

Methods
Localization and management systems
A long-term soil management experiment was established in 1991 at the experimental farm of the Instituto

de Recursos Naturales y Agrobiología de Sevilla (IRNAS-CSIC) on a sandy clay loam soil (Soil A) classified as a Xerofluvent (Entisol), with a $CaCO_3$ content in the 25-28% range and a clay content of about 25%. The second experiment (Soil B) was carried out in a long-term soil management experiment established in 1982 at the "Tomejil" dryland farm in Carmona (Seville) on a clay soil classified as a Chromic Haploxeret (Vertisol), containing 60% clay.

Both experiments were carried out using completely randomised designs (three replicates per treatment) and were conducted in 6 subplots of 300 m^2. Two treatments were tested: traditional tillage (TT) and conservation tillage (CT). In both trials, TT consisted of mouldboard ploughing (aprox 30 cm depth). The CT in soil A was characterized by leaving the crop residues on the soil surface, chiselling 25-30 cm depth every two years and a yearly disk harrowing to 5-7 cm depth. In soil B, CT was only characterized by leaving the crop residues on the soil surface. A wheat–sunflower-legume crop rotation was established for both treatments. The soil was fertilized in the same way in both treatments, following the regular practices of the local farmers. A basal dressing of 400 kg of a compound fertilizer (15N–15P_2O_5–15K_2O) (Soil A) and of 220 kg /ha (18N-46 P_2O_5-0 K_2O) more a top dressing of 200 kg /ha of urea (Soil B) were applied during the cereal season. Weeds were controlled in TT by tillage and in CT by the application of glyphosate.

Sampling and soil chemical and biochemical analysis

In both experiments, soil samples were collected on the same day at three depths: 0-5, 5-10 and 10-20 cm. Soil sampling was done four months after sowing a pea crop in soil A and a wheat crop in soil B in March 2008. Three soil cores of each individual subplot were taken. The moist field soil was sieved (2 mm) and was homogeneized and subdivided in two subsamples. One of them was immediately stored at 4ºC for microbiological and enzymatic activities and the other one were air-dried for chemical analysis. In air-dried subsamples, TOC was analysed using the Walkley and Black (1934) method. WSC was determined in a (1/10) aqueous extract using a TOC V-CSH Shimadzu analyser, AC according to Weil *et al.* (2003) and MBC content by the method modified by Gregorich *et al.* (1990). DHA and β-glu activities were determined according to Alef and Nannipieri (1995).

Statistical analysis

Statistical analyses were carried out using SPSS 11.0 for Windows and the results were expressed as mean values. Significant differences between management systems (TT, CT) were shown by a Student's t-test at $p<0.05$. The data set of soil chemical and biochemical variables was also analysed using discriminant analysis (DA).

Results and Discussion

In soil A, CT presented higher AC, WSC and MBC contents than TT at 0-5 and 5-10 cm depth but only AC and MBC mean values were statistically different between both treatments (Table 1). In general β-glucosidase activity values were higher under CT than under TT at all studied depths, although only significant differences were observed in β-glucosidase activity at the 10-20 cm depth (Table 1). In soil B, TOC, AC and WSC contents were higher in soils under CT than soil under TT at 0-5 and 5-10 cm depths (Table 1). However, statistical differences between treatments (TT and CT) were only found in TOC and AC values at the superficial layers (Table 1). Values for DHA, in soil B, were higher under CT at 0-5 and 5-10 cm depths, although significant differences were only observed between treatments at 0-5 cm depth (Table 1).

Graphical representation in one dimension of the discriminant analysis of soil chemical and biochemical properties under TT and CT is show in Figure 1. The discriminant analysis showed that MBC and AC in soil A and TOC, AC and WSC in soil B were significantly different between TT and CT (Table 2). Conservation tillage systems have been shown to maintain and/or increase soil organic matter at higher levels than traditional tillage systems (Chivenge *et al.* 2007; Madejón *et al.* 2007; Melero *et al.* 2008). Under conservation tillage systems, the absence/reduction of soil disturbance produces a modification of surface soil conditions, which improves soil physical properties and reduces soil organic matter decomposition. Franzluebbers *et al.* (1995) reported that active fractions of soil organic matter increased in superficial soil layers in no tillage compared to traditional tillage

The increase in TOC, AC, WSH and MBC at the surface in CT in both experiments may also be associated with the high input of crop residues left on the soil surface and with their slower decomposition processes (Salinas-Garcia *et al.* 2002). Differences between the two soils were also observed. The amount of TOC loss

Table 1. Mean values ± standard errors of soil chemical and biological properties in soil A and B under traditional tillage (TT) and conservation tillage (CT). Differences between treatments for each depth from a t-student are indicated by (*) (p< 0.05).

	Treatment	SOIL A Depth (cm)			SOIL B Depth (cm)		
		0-5	5-10	10-20	0-5	5-10	10-20
TOC	TT	9.84± 1	9.03± 1	8.23± 1.6	8.37± 0.2	7.60± 0.2	6.57± 0.8
(g /kg)	CT	10.85± 0.7	8.87± 0.3	8.65± 0.7	11.53*± 0.2	9.70*± 0.1	8.23± 0.9
AC	TT	780± 49	694± 0.9	695± 1.5	697± 1.2	695± 0.0	695± 2
(mg/kg)	CT	1680*± 205	1039*± 19	693± 3.1	708 *± 3.2	702± 2.0	694± 1.2
WSC	TT	60.4± 5.2	50.7± 1.6	42.4± 0.01	46.0± 3.6	38.8± 2.4	35.4± 2.3
(mg/kg)	CT	82.9± 24	65.6± 8.1	46.6± 3.2	112 ± 40	87.6± 30	71± 36
MBC	TT	814± 42	806± 40	780± 53	378 ± 26	357± 13	314± 33
(mg/kg)	CT	1058*± 32	978*± 52	879± 25	766 ± 274	304± 0.2	272± 67
DHA	TT	1.16± 0.3	0.66± 0.2	0.49± 0.2	1.06 ± 0.1	0.64± 0.1	0.56± 0.2
(mg TPF /kg)	CT	1.15± 0.4	0.72± 0.2	0.26± 0.2	3.04*± 0.2	0.94± 0.1	0.29± 0.1
β-Glu	TT	140± 19	84.2± 11	55.6± 11	122 ± 24	63.8± 21	43.1± 11
(mgPNP /kg/h)	CT	169± 19	108± 13	98.8*± 5	128 ± 36	45.4± 14	32.2± 9.2

Table 2. Correlation (in order of importance) of each variable to the discriminant function in both soils.

SOIL A		SOIL B	
	Structure matrix Function 1		Structure matrix Function 1
MBC	-0.607	TOC	0.537
AC	-0.373	WSC	-0.406
WSC	-0.202	AC	0.340
TOC	-0.072	DHA	0.236
DHA	0.032	MBC	0.129
β-*Glu*	-0.024	β-Glu	-0.048

TOC: Total organic carbon; AC: active carbon;
WSC: water soluble carbon; MBC: microbial biomass carbon;
DHA: dehydrogenase activity; β-Glu: glucosidase activity.

due to tillage is dependent on the clay content of the soil. In general, higher TOC losses are observed in coarse textured than in fine textured soils (Chivenge *et al.* 2007). Thus, we would have expected to obtain greater values for soil chemical and microbiological properties in the clay soil (soil B). However, in general the values were slightly higher in soil A. These results can be explained by the crop type growing at the sampling time [a pea crop (leguminous) in soil A and a wheat crop (gramineous) in soil B], rather than by soil characteristics. The rhizosphere of leguminous crops may more actively secrete higher amounts of exudates than wheat crops, and may supply therefore more carbon and nitrogen to the soil for succeeding crops than non-legume crops (Nuruzzaman *et al.* 2005).

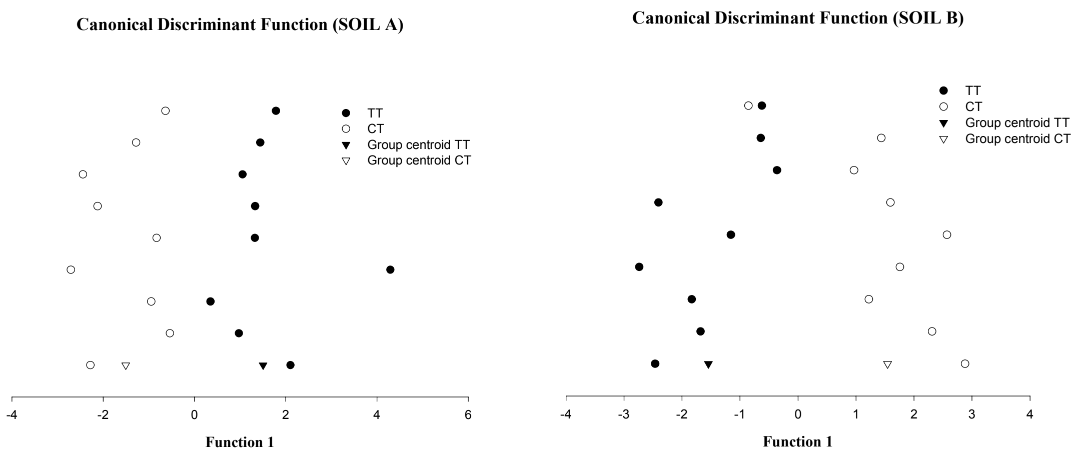

Figure 1. One-dimensional plot of the discriminant analysis of soil chemical and biochemical properties from soil under traditional tillage (TT) and conservation tillage (CT).

In both soils, CT had a positive effect on microbial biomass and enzymatic activities. Soils under CT have been shown to have higher soil microbial biomass and enzymatic activity values than those under conventional tillage systems (Madejón *et al.* 2007; Melero *et al.* 2007), indicating an activation of microorganisms through carbon source inputs of organic residues. The results of the discriminant analysis showed that AC content was the parameter that best explained the total variance of the data set in both soil types, revealing the advantages of conservation tillage. Although WSC content is more commonly used as the soil quality indicator in agroecosystems (Madejón *et al.* 2007), this study showed that AC content is the most sensitive and reliable indicator for assessing the impact of different soil management systems on soil quality.

Conclusions

Long-term soil conservation management improved the quality of both soils (Entisol and Vertisol) through enhancing the organic carbon fraction and biological status, especially near the surface. Enhancement of soil quality may be more related to the crop type existing at the sampling time than to differences in soil texture. In both soils, AC content was the best indicator of the total variance of the data set for assessing the differences between tillage on soil quality.

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