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# Effect of permanent bed planting combined with controlled traffic on soil chemical and biochemical properties in irrigated semi-arid Mediterranean conditions

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ABSTRACT

Improving agricultural soil quality in semi-arid regions is necessary for reducing soil erosion and improving water use. Conservation agriculture (CA) can increase soil quality and biodiversity, and reduce operational costs without losing crop productivity both under irrigated or rainfed conditions. However, few studies on soil chemical and biochemical status in irrigated farms under CA in the Mediterranean region are available. Permanent beds with crop residue retention (PB) have been proposed as an alternative to conventionally tilled beds with residue incorporation into the soil (CB). These two soil management systems combined with controlled traffic were compared during two different seasons (2009 and 2010) in a loamy alluvial Typic Xerofluvent soil under a maize (*Zea mais* L.)–cotton (*Gossypium hirsutum* L.) crop rotation trial established in 2007 in Southern Spain. Total organic carbon (TOC), water soluble carbon (WSC), Kjeldahl nitrogen (Kjel-N), dehydrogenase (DHA) and β-glucosidase (β-Glu) activities and microbial biomass carbon (MBC) and nitrogen (MBN) were analysed in soil from beds and furrows after crop harvest. Results indicated that Kjel-N, TOC and enzymatic activities were significantly higher in soil from furrows in PB than in CB, but practically no differences were found in soil from the bed zone. Moreover, traffic did not affect chemical and biochemical parameters in spite of its compacting effect. Major differences were found between samplings due to different quantity and nature of the residues (maize vs. cotton). Principal component analysis confirmed that TOC, Kjel-N and β-Glu (and DHA to a less extend) are useful indicators of soil management impact on soil quality in this irrigated Mediterranean conditions; however, this is not the case of WSC, a common indicator in rainfed conditions. Results confirmed that conservation agriculture is the better option to increase soil biological and biochemical quality in irrigated farms under Mediterranean semi-arid conditions.

## 1. Introduction

Conservation agriculture (CA) has been proposed as a management strategy to improve the sustainability and profitability of the farming system in semi-arid regions (Kassam et al., 2009). The adoption of CA could in principle reduce irrigation water needs, risk of soil erosion and production costs (Jones et al., 2006; Sayre and Hobbs, 2004). Despite its potential benefits, CA adoption has been undertaken mainly by large scale farmers and for rainfed cropping (Sayre and Hobbs, 2004). However, irrigated agriculture accounts for about 40% of agricultural production (Molden et al., 2007). In the future, if enough food should be produced to fill global food needs, irrigation systems are expected to increase their contribution by improving their efficiency (Rosegrant et al., 2009). In view of this pressure, CA can play a key role for improving sustainable intensification of irrigated cropping systems.

In irrigated Mediterranean agriculture, lack of adoption of CA is associated to the management of excessive crop residues and/or the possible soil compaction problems (Gómez-Macpherson et al., 2009). On a wet clay soil, one single wheel pass can compact the soil severely (Alakukku and Elonen, 1995) and such compaction has been associated with reduced yields (Raper et al., 2000). The traditional solution for soil compaction is tillage, an approach to be avoided under CA systems which aims at minimal soil disturbance. To avoid compaction, CA farmers may use low pressure wheels and restrict their traffic to specific paths by using GPS-controlled devices (Tullberg et al., 2007). When crops, such as cotton and maize, are planted on beds, traffic can be restricted to specific furrows, which can occasionally be deep-ripped (Boulal and Gomez-Macpherson, 2010). This avoids the requirement for special GPS-controlled machinery though all the equipment has to be adapted to fit the distance between furrows.

Several methods are used for maize and cotton crops under irrigation, ranging from intensive tillage such as deep ripping, disc-ploughing, chisel

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ploughing, and bed preparation, to minimum tillage or permanent beds (Gómez-Macpherson et al., 2009; McKenzie et al., 2003; Schoenfisch, 1999). By definition, a permanent bed implies that the bed stays in place for several seasons. The term permanent bed does not, however, imply that all soil disturbances are totally excluded as reforming may be needed before sowing. Maize and cotton crops have been cultivated on permanent beds successfully in Mexico and Australia (Hulugalle and Daniells, 2005; Sayre and Hobbs, 2004) but rarely in the Mediterranean basin countries (Boulal and Gomez-Macpherson, 2010).

Numerous researches have pointed out the positive effects of CA in soil quality under rainfed conditions in the Mediterranean basin (Álvaro-Fuentes et al., 2008; Madejón et al., 2009; Melero et al., 2011; Mrabet et al., 2001); however, little is known about these effects under irrigation. To define soil quality, the simple operational definition of Gregorich et al. (1994) may be used: 'The degree of fitness of a soil for a specific use'. In this sense, soil quality depends on the use and the management of the soil (Singer and Ewing, 2000). In terms of agricultural production, high soil quality equates to the ability of the soil to maintain a high productivity without significant soil or environmental degradation (Govaerts et al., 2006) and to promote plant and animal health. Interest in defining soil quality has focused on identifying some properties that affect soil health and quality (Doran and Parkin, 1994) but a more appropriate approach could be the use of indices based on a combination of different soil properties (Trasar-Cepeda et al., 2000). For example, microbial biomass and soil enzymes have been suggested as potential indicators of soil quality because of their relationship to soil biology, ease of measurement, rapid response to changes in soil management and high sensitivity to temporary soil changes originated by management and environment factors (Jiménez et al., 2002; Marx et al., 2001).

The aim of this work was to assess the effects of a permanent bed system combined with controlled traffic on several soil chemical and biochemical properties related to soil quality. Both furrow and bed zones in an irrigated maize-cotton rotation under semi-arid Mediterranean conditions were evaluated. Results were compared to those obtained under conventional tillage also combined with controlled traffic. We hypothesized that: i) CA could have a positive effect in increasing soil fertility by enhancing soil organic matter and soil biological status 3 years after the introduction of the system; ii) soil biochemical properties could be bioindicators of the impact of management systems on soil quality also under irrigation.

To prove these hypothesis soil chemical properties such as total organic carbon (TOC), Kjeldalh-N (Kjel-N), and water-soluble carbon (WSC), and soil biochemical properties like microbial biomass carbon (MBC) and nitrogen (MBN), dehydrogenase (DHA) and β-glucosidase (β-glu) activities were measured in furrows, with and without traffic, and in the centre of the beds in two cropping seasons. Some of these parameters provide a fast response to changes that originated by tillage, such as WSC, MBC, MBN, DHA and β-glu, whereas others needs more time to express differences, such as TOC, and Kjel-N.

## 2. Materials and methods

### 2.1. Study site and experimental design

The study was conducted at the Alameda del Obispo experimental farm (latitude 38°N, longitude 5°W, altitude 110 m), Cordoba, Spain. The climate is Mediterranean with a mean annual rainfall of 595 mm, most of it occurring from late autumn to early spring. Accumulated rainfall during agricultural seasons included in this study (September 2008–September 2009 and September 2009–September 2010) was 526 and 992 mm, respectively. The amount of irrigation water applied during the same years was 357 and 438 mm, respectively. The maximum and minimum mean temperatures were similar in both seasons (Fig. 1).

The soil is a loamy alluvial, Typic Xerofluvent (Soil Survey Staff, 1999), Eutric Fluvisol according to FAO system (Fitzpatrick, 1980). Particle-size distribution in the upper soil layer (0–15 cm) is 351 g $kg^{-1}$ sand, 443 g $kg^{-1}$ silt, and 206 g $kg^{-1}$ clay. The pH (1:2.5 water extract) and the electrical conductivity were 8.4 and 0.3 dS $m^{-1}$, respectively.

### 2.2. Crop rotation and management

Since the start of the trial, cotton (*Gossypium hirsutium* L.) and maize (*Zea mays* L.) production was rotated every year (cotton: 2007 and 2009, maize: 2008 and 2010). No crops were planted during the winter fallow periods. Crop management from 2007 to 2009 has been described in detail by Boulal et al. (2012). For this experiment only 2009 and 2010 crops were evaluated. In 2009, cotton (cv. Juncal) was sown on the 14th of May and hand-harvested on the 29th of September. This crop did not receive fertilizers, according to local recommendations. In 2010, a few days after cotton residues were chopped up, maize (cv. Sancia) was sown on the 9th of April and hand-harvested on the 6th of September. The maize crop fertilization consisted of 90 kg $ha^{-1}$ each of N, P and K broadcasted 6 days after sowing and one top dressing application of urea 46% (280 kg $ha^{-1}$) on 10th May 2010. Pre-sowing, pre-emergence and post-emergence herbicide treatments were applied to control weeds. Hand weeding was necessary 2 or 3 times in some areas of both crops. Treatments for insect control were applied when necessary. In the case of cotton, integrated pest-management practices were followed.

### 2.3. Soil management systems

The experimental plot (0.78 ha) was initially ploughed April 2007 using a double pass of a disc harrow approximately 15 cm deep, a single pass of a chisel plough 25 cm deep, and a single pass of a rotavator 15 cm deep. Raised beds spaced 0.85 m apart were created three days later. In early 2008 the plot was divided into three 18 × 144-m blocks, which were each subjected to two tillage treatments: 1) permanent beds not subjected to tillage with crop residues left on the soil surface, hereafter referred to as "PB"; and 2) conventional beds formed annually and crop residues ploughed into the soil, hereafter referred to as "CB". Every year, following crop harvest, crop residues were mowed and left on the soil surface. In the case of CB, residues were incorporated into the soil under a ploughing regime that differed slightly from year to year. In February 2008, the CB plots were ploughed with a double pass of a disc harrow followed by a single pass of a chisel plough. In February 2009, residues in CB were incorporated into the soil with a single pass of a chisel plough followed by a single pass of a rotavator. In April 2010, residues in CB were incorporated during soil preparation that consisted of a single pass of subsoiling (60 cm deep) and a single pass of a disc harrow followed by a single pass of both a chisel plough and a cultivator (kongskilde).

Traffic was strictly controlled in the experimental plots. Ten furrows were formed in each plot, with five furrows subject to wheeled traffic (+T) alternating with five furrows not subject to wheeled traffic (−T). The separation width between two trafficked furrows was 1.70 m, which was imposed by the width between the rear tires (2.08 m) and the rear tire width (0.38 m) of the tractor used. Following the initial ploughing in April 2007, non-trafficked furrows in PB (PB−T) were not traversed with wheeled equipment during the study. In CB, after tillage and bed formation, the two types of furrows (+T and −T) were marked. CB−T furrows were not traversed by wheeled equipment until the soil was ploughed the following year. In +T furrows the number of wheeled passes per year varied between 5 and 9. For further details on the type of equipment used in each treatment see Boulal et al. (2012).

### 2.4. Residue measurements

Crop residues were collected from four random points on furrows with and without traffic (F+T and F−T, respectively) and on the bed.

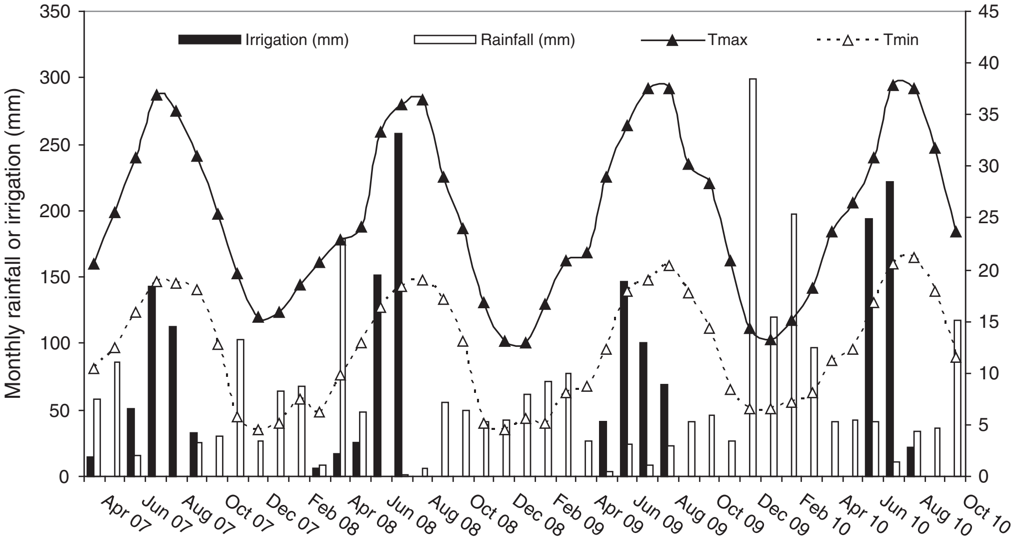

**Fig. 1.** Monthly precipitation (rainfall and irrigation) and average maximum and minimum temperature (Tmax and Tmin, respectively) between April 2007 and October 2010.

The area sampled at each point was 0.59 × 0.50 $m^2$ and 0.26 × 0.50 $m^2$ in the furrows and bed, respectively. Residue samples were washed to remove soil. Standing residues were collected separately. All components were dried at 75 °C to constant weight and mass per unit area was calculated. Samples were taken once after planting and once after harvest: on 31st March and 28th of November in 2008, on 19th of June and 14th of October in 2009 and on 23th of March in 2010. Data for 2008 and 19 June 2009 were taken from (Boulal et al., 2012).

### 2.5. Soil sampling and chemical and biochemical analysis

Soil samples were taken at the end of each cropping season in 2009 and 2010 (Sampling 1C and Sampling 2M, respectively) following harvest. At the time of sampling period 1 (26th of October), cotton stalks were left standing on the beds, while the furrows contained mostly maize residues from the previous year. By sampling period 2 (4th of November), maize plants (stalks and leaves) were still standing on the beds while the furrows contained cotton crop residues from the previous year mixed with a small quantity of maize residues from 2008.

Three samples were taken per treatment and block in the centre of beds and in adjacent F+T and F−T furrows, 9 samples for each treatment and sampling area for a total of 54. Soil samples were collected at 0–10 cm depth in furrows and 0–20 cm in beds. The soil was sieved (2 mm) and stored at 4 °C for a few days to prevent moisture loss before assaying for microbiological analysis. One sub-sample was air dried for chemical analysis.

In air-dried subsamples, total organic carbon (TOC) was analysed by dichromate oxidation and titration with ferrous ammonium sulphate according to Walkley and Black (1934) and Kjeldahl-N by the method described by Hesse (1971). Water soluble carbon (WSC) was determined in an (1/10) aqueous extract using a TOC-VCSH/CSN Shimadzu analyser.

In moist-field subsamples, the microbial biomass carbon content (MBC) and nitrogen content (MBN) were determined by the chloroform fumigation–extraction method modified by Gregorich et al. (1990) and Brookes et al. (1985), respectively. Dehydrogenase activity was determined according to Trevors (1984) after soil incubation, with INT (2(*p*-iodophenyl)-3-(*p*-nytrophenyl) 5-phenyl tetrazolium chloride) as the electron acceptor and measurement of iodonitrotetrazolium formazan (INTF) absorbance at 490 nm. β-glucosidase activity was measured as indicated by Tabatabai (1982) after soil incubation with *p*-nitrophenyl glucoside and measurement of *p*-nytrophenol absorbance at 400 nm. Results were based on the oven-dried weight of the soil.

### 2.6. Statistical analysis

Analyses were carried out separately for furrows and beds. Data normality was checked prior to analysis. In both zones, significant differences between systems were tested by a Student's *t*-test at $p<0.05$. To check the effects of tillage system and traffic a multifactor analysis of variance (MANOVA) was performed. From this analysis, the significance level of each variable was obtained. The correlation matrix of all soil parameters in furrows was based on Pearson correlation coefficients ($p<0.01$ and $p<0.05$). Data from furrows were also treated by a Principal Component Analysis (PCA) to examine variation with respect to the different measured parameters. PCA was forced to generate only three eigenvalues. Statistical analyses were carried out using SPSS 19.0 (SPSS Inc., Chicago, IL).

## 3. Results

### 3.1. Crop residues

Grain in maize and lint (and seeds) in cotton crops were removed at harvest. The rest of the maize and cotton crops (stover) were left in the field (1290 g $m^2$ in 2008 maize for both systems and 445 and 345 g $m^{-2}$ in PB and CB, respectively, in 2009 cotton) according to Boulal et al. (2012). In CB plots, crop residues were incorporated into the soil, whereas in PB plots they were left on the ground. Fig. 2 shows the evolution of residue's biomass on the ground in PB plots. As a rule, a higher amount of residues was found in the furrows than in bed zones, except at the beginning of the 2008 maize season. The highest amount was observed after maize harvest (November 2008 sampling): nearly 1200 g $m^{-2}$ on the furrows and 330 g $m^{-2}$ on the beds. These residues decayed during the winter season to around 50% when compared to values determined after cotton sowing in 2009 (June sampling). A similar pattern took place with post-harvest residues of cotton in 2009 (October sampling), which were reduced around 35% in furrows when compared to the values determined after maize sowing in March 2010 (Fig. 2).

### 3.2. Soil quality: Nitrogen, soil TOC fractions and enzymatic activities

Results obtained in furrows showed a great influence of tillage system on some of the analysed parameters (Table 1). Kjel-N, TOC and enzymatic activities (β-Glu and DHA) were significantly higher in soil under permanent beds (PB) than in conventional beds (CB)

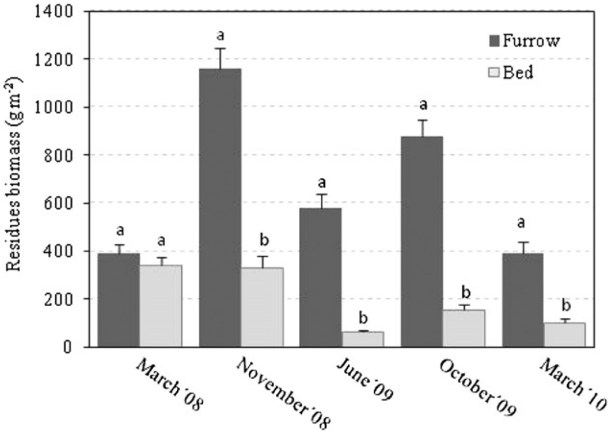

**Fig. 2.** Crop residues' biomasses in furrow and bed sections in the permanent bed system. For each date, values followed by different letter in the same bar differ significantly at $p<0.05$. Vertical bars indicate the standard error.

in both seasons (Table 2). On the contrary, wheel traffic did not have a significant effect on any chemical or biochemical soil property studied (Table 1). No significant interaction between tillage and traffic was observed.

Moreover a clear influence of the sampling time was detected in almost all the parameters analysed in soil sampled in furrows (Table 2). The differences between the two samplings were especially noticeable for biochemical parameters (MBC, MBN, DHA and β-Glu) compared to those found in chemical parameters. Contents of MBC, DHA and β-Glu were higher in the first sampling after cotton harvest (Sampling 1C) than in the second after maize harvest (Sampling 2M) whereas the opposite was observed for MBN. The decrease between both samplings accounted ($p<0.05$) between 48–83% for MBC, between 266–522% for DHA and between 61–92% for β-Glu. Values of TOC and N-Kjel were similar in both samplings.

Except for MBN in Sampling 1C, the tillage system did not have any effect on the analysed soil parameters in samples from bed centre (Table 3). In general, values of chemical and biochemical parameters obtained in PB were not statistically different than those obtained in CB. However, a remarkable decrease of MBC and enzyme activities was also observed in the second sampling (2M). Contents of MBN, as it occurred in furrows, were higher in the second sampling. Values of chemical parameters in beds were similar in both samplings, although a slight increase of TOC and a decrease of WSC were observed in Sampling 2M.

Among the chemical parameters measured in soil sampled in furrows, TOC and Kjel-N were highly correlated ($r=0.816$, $p<0.01$) whereas WSC was not correlated with any other variable. Among the biochemical parameters, β-Glu was significantly correlated ($p<0.001$) with Kjel-N ($r=0.834$), DHA ($r=0.683$), MBC ($r=0.530$) and TOC ($r=0.683$). DHA was correlated with Kjel-N, β-Glu, MBC ($r=0.662$, $p<0.01$) and MBN ($r=0.266$, $p<0.05$).

### 3.3. Principal component analysis

Fig. 3 shows the graphical representation of chemical and biochemical properties in both samplings projected on the plain defined by the three first principal components. In Sampling 1C, eigenvalues from the PCA analysis indicated that the first three principal components (PC) accounted for 88.71% of the variance of data (PCI: 58.07%, PCII: 18.55%, PCIII: 12.09%). The first component was highly positively correlated with Kjel-N, β-Glu, DHA and TOC. The second component was positively correlated with Nitrogen and Carbon of microbial biomass (MBN and MBC) and the third component was only positively correlated with WSC (Table 4).

In Sampling 2M, the PCI, PCII and PCIII explained 55.21%, 19.20% and 12.56%, respectively, of the total variance (86.97%). Moreover, the correlations between principal components and the soil chemical and biochemical properties were similar to Sampling 1C.

## 4. Discussion

Little research on CA under irrigation in the Mediterranean region has been published. Results of this work show that the PB system conserved and increased soil total organic carbon in furrows compared to the conventional system (CB), and that obtained values were similar to those found after 26 years of no tillage in a rainfed wheat-based trial in a nearby location (Melero et al., 2009). The increase of organic matter under CA has been widely observed in rainfed conditions in the region (Álvaro-Fuentes et al., 2008; Cantero-Martínez et al., 2003; Madejón et al., 2009). Several works have demonstrated that organic matter increases under CA as a result of physical protection of soil organic matter within more stable aggregates, reduced aeration and reduced plant residue contact with the soil (Mikha and Rice, 2004; Puget and Lal, 2005). The residues in PB protect the soil from raindrop impact whereas in CB the lack of a protective cover increases soil susceptibility to further disruption (Boulal et al., 2011a; Six et al., 2000). Moreover, surface residues tend to decompose more slowly than soil-incorporated residues (CB), because of greater fluctuations of temperature and moisture in surface and reduced availability of nutrients to microbes colonising the residues (Schomberg et al., 1994). However, Verhulst et al. (2011) did not find an effect of the CA system on soil organic carbon after 3 years of establishing a similar trial that compared irrigated PB and CB in northern Mexico. In their case, the soil was a Vertisol in which the organic carbon in CB might have been relatively protected (compared to our loamy soil) and the wheat monocropping probably produced less than half of the stover produced in our study.

The effects of PB on total soil nitrogen generally reflect those of organic matter as the nitrogen cycle is closely linked to the carbon cycle. An accumulation of organic matter in soil confers important improvements in soil quality, soil fertility and carbon sequestration (Six et al., 2000). Furthermore, tillage reduces micro and macrofauna populations in comparison with systems without tillage (Kladivko, 2001), thus decreasing their potentially positive effect on physical properties (Six et al., 2004). In our study, the tillage system had also an effect on soil biochemical properties in furrows and this effect was especially remarkable for β-Glu activity.

**Table 1**
Tillage system and traffic effects on the studied soil chemical and biochemical properties in furrows.

| Treatment | TOC ($g\ kg^{-1}$) | MBN ($mg\ kg^{-1}$) | MBC ($mg\ kg^{-1}$) | WSC ($mg\ kg^{-1}$) | Kjel-N ($g\ kg^{-1}$) | β-glu (mg *p*-nitrophenol $kg^{-1}$ dw soil) | DHA (mg INT $kg^{-1}$ dw soil) |
|---|---|---|---|---|---|---|---|
| (T) | *** | ns | ns | ns | *** | *** | * |
| Traffic (Tr) | ns | ns | ns | ns | ns | ns | ns |
| T×TR | ns | ns | ns | ns | ns | ns | ns |

TOC: total organic carbon; MBN: microbial biomass nitrogen; MBC: microbial biomass carbon; WSC: water soluble carbon; Kjel-N: Kjeldahl nitrogen; DHA: dehydrogenase activity; β-glu: β-glucosidase activity. *Significant at the 0.05 probability level. **Significant at the 0.01 probability level. ***Significant at the 0.001 probability level. ns: not significant.

**Table 2**
Mean values ± standard deviation of the studied soil chemical and biological properties in soil in the centre of furrows in the permanent bed (PB) and conventional bed (CB) performed after cotton harvest (Sampling 1C) and after maize harvest (Sampling 2M).

| Tillage system | | TOC ($\text{g kg}^{-1}$) | MBN ($\text{mg kg}^{-1}$) | MBC ($\text{mg kg}^{-1}$) | WSC ($\text{mg kg}^{-1}$) | Kjel-N ($\text{g kg}^{-1}$) | β-glu (mg *p*-nitrophenol $\text{kg}^{-1}$ dw soil) | DHA (mg INT $\text{kg}^{-1}$ dw soil) |
|---|---|---|---|---|---|---|---|---|
| Sampling 1C | PB | 10.9 ± 3.05a | 20.5 ± 7.87a | 461 ± 220a | 118 ± 23a | 1.4 ± 0.32a | 328 ± 113a | 4.65 ± 1.33a |
| | CB | 7.1 ± 1.04b | 17.8 ± 8.61a | 484 ± 216a | 107 ± 27a | 1.1 ± 0.17b | 169 ± 44b | 3.98 ± 1.21a |
| Sampling 2M | PB | 11.1 ± 1.18a | 33.1 ± 16.4a | 311 ± 100a | 81 ± 40a | 1.3 ± 0.13a | 204 ± 54a | 1.27 ± 0.31a |
| | CB | 8.4 ± 1.04b | 26.9 ± 4.73a | 264 ± 49a | 109 ± 53a | 0.9 ± 0.10b | 88 ± 22b | 0.64 ± 0.21b |

TOC: total organic carbon; MBN: microbial biomass nitrogen; MBC: microbial biomass carbon; WSC: water soluble carbon; Kjel-N: Kjeldahl nitrogen; DHA: dehydrogenase activity; β-glu: β-glucosidase activity. Values followed by different letters for each tillage system and sampling are significantly different ($P<0.05$).

β-glucosidase belongs to a group of enzymes that catalyzes the hydrolysis of various glycosides resulting in the release of smaller sugars. This enzyme has a central role in the carbon balance in soils because it degrades carbohydrates and provides substrate to the soil (De la Horra et al., 2003) and it is highly correlated with total organic carbon. Other authors have reported similar effects of tillage in β-Glu activity in annual wheat-based rainfed systems in the region (Madejón et al., 2007; Melero et al., 2009, 2011). Differences in β-Glu between samplings were probably related to the rotation as found by Melero et al. (2011).

For the rest of the biochemical properties analysed, the tillage system had little influence (Table 2). Longer time may be required to show up differences. For example, in Mexico, Limón-Ortega et al. (2006) found higher microbial biomass in PB compared to CB in a wheat-based irrigated system only ten years after the establishment of the trial. Otherwise biochemical properties seem to be more affected by the nature of the most abundant residue (maize in Sampling 1C and cotton in Sampling 2M). Crop residue type plays an important role in organic matter cycling due to differences in C/N ratio or quality and quantity of residue (Potter et al., 1998). In our study, maize and cotton residues differed in their capacity to affect soil organic matter cycling and quality. Maize residues were the most effective in increasing soil microbiological status. On the one hand maize produced more stover and residues on the ground compared to cotton (Fig. 2). On the other hand, cotton residues are poorer in easily-utilizable sugars and proteins, but richer in cellulose and hemicelluloses. Furthermore, cotton roots have a larger diameter and double C/N ratio than maize roots (Ghidey and Alberts, 1993). As a consequence, the organic carbon from cotton residues may have been more slowly incorporated within the soil organic matter than in the case of maize residues.

The PCA procedure allowed us to examine changes in chemical and in biochemical variables in relation to soil management. Multivariate analysis has proven to be effective in identifying soil properties that respond to agronomic practices (Monreal and Bergstrom, 2000). Results obtained for this analysis suggested that TOC, Kjel-N, β-glucosidase and, to a less extend, dehydrogenase were useful as indicators of management practices impact on soil quality. Additionally, dehydrogenase and β-glucosidase were useful indicators to reflect changes in soil total biological activity and biochemical status involved in the carbon cycle. The activities of both dehydrogenase and β-glucosidase showed a positive correlation with organic matter in both seasons. Microbial biomass C and N had an important contribution in PCII but seemed to be worse indicators of soil quality than enzyme activities. The large amount of residues produced by maize probably had masked their contribution to PCA (Limón-Ortega et al., 2006). Additionally, sampling took place several months after soil preparation and the tillage effect may have been weak by then and overridden by the residue type effect (Feng et al., 2003). Although WSC content has been suggested as a reliable soil quality indicator for assessing the impact of different soil management in rainfed conditions (Madejón et al., 2007; Roldan et al., 2005), results from this experiment did not confirm this behaviour under irrigation. In general, the WSC was much lower than the values obtained in rainfed wheat-based experiments in the region (Madejón et al., 2009) and may reflect a rapid microbial response to irrigation (Reicosky et al., 1999). However, Roldan et al. (2005) did not find an effect of irrigation on WSC except in the no-tilled top 5 cm layer in a maize monocrop system in Mexico. In the present experiment, samples were collected from a 0–10 cm deep layer and this may have masked some differences at shallower depths between treatments. In addition, divergences in porosity and water permeability between the Vertisol studied by Roldan et al. (2005) and the Fluvisol studied in this experiment could have led to a different WSC distribution among soil profiles.

The differences due to the management system observed in furrows were not detected in the centre of the beds in which soil parameters were similar in both tillage systems (Table 3). The low organic matter in the centre of the PB beds was probably the result of the reduced amount of residues falling on this section as they tended to roll and accumulate in the furrows (Fig. 2). On the contrary, most roots will be in the bed section and they seemed to provide enough substrate in PB bed soil to reach similar values of measured parameters as in both the CB beds and furrows where all residues were incorporated into the soil.

Wheel traffic did not have a significant effect on any of the soil parameters studied (Table 1). This was unexpected as traffic results in soil compaction and lower water infiltration (Boulal et al., 2011b) and therefore would have influenced soil microbial activity. The size of the sampled soil layer (10 cm) may have reduced any existing difference occurring in the top soil. Runion et al. (2004) found higher MBN and DHA content in trafficked areas than in non trafficked area only in the top 4 cm in no-till plots but not in deeper layers or in the conventional systems. Besides, Lee et al. (1996) did not find a consistent effect of traffic on MBC, probably because of the coarse textured soil they studied.

**Table 3**
Mean values ± standard deviation of soil chemical and biological properties in soil in the centre of the permanent beds (PB) and conventional beds (CB) performed after cotton harvest (Sampling 1C) and after maize harvest (Sampling 2M).

| Tillage system | | TOC ($\text{g kg}^{-1}$) | MBN ($\text{mg kg}^{-1}$) | MBC ($\text{mg kg}^{-1}$) | WSC ($\text{mg kg}^{-1}$) | Kjel-N ($\text{g kg}^{-1}$) | β-glu (mg *p*-nitrophenol $\text{kg}^{-1}$ dw soil) | DHA (mg INT $\text{kg}^{-1}$ dw soil) |
|---|---|---|---|---|---|---|---|---|
| Sampling 1C | PB | 7.1 ± 1.30a | 14.0 ± 4.90b | 381 ± 182a | 114 ± 42.5a | 1.00 ± 0.15a | 119 ± 29a | 2.56 ± 1.11a |
| | CB | 7.1 ± 0.92a | 22.7 ± 5.04a | 436 ± 206a | 93 ± 20.1a | 1.06 ± 0.13a | 139 ± 18a | 2.95 ± 0.67a |
| Sampling 2M | PB | 8.0 ± 0.71a | 30.3 ± 7.67a | 309 ± 47a | 67 ± 23.5a | 0.96 ± 0.08a | 89 ± 17a | 0.66 ± 0.18a |
| | CB | 7.9 ± 1.20a | 28.2 ± 4.24a | 283 ± 67a | 89 ± 57.7a | 0.96 ± 0.13a | 99 ± 13a | 0.66 ± 0.17a |

TOC: total organic carbon; MBN: microbial biomass nitrogen; MBC: microbial biomass carbon; WSC: water soluble carbon; Kjel-N: Kjeldahl nitrogen; DHA: dehydrogenase activity; β-glu: β-glucosidase activity. Values followed by the same letter for each treatment and sampling are significantly different ($P<0.05$).

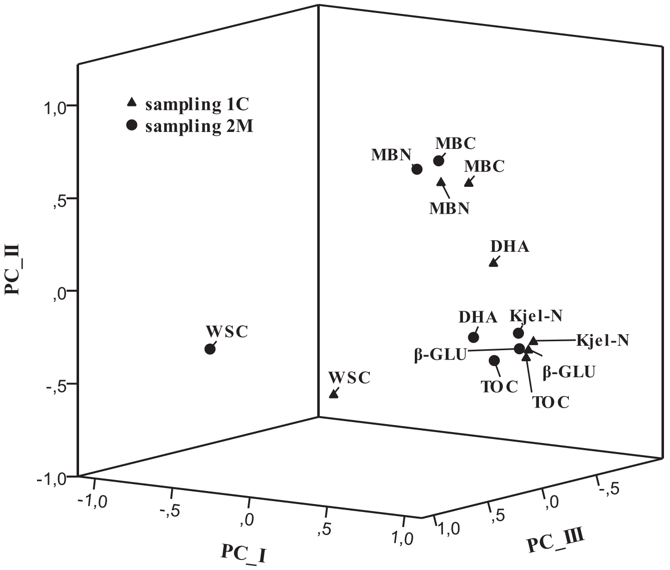

**Fig. 3.** Projected loadings of the soil chemical and biochemical properties measured in Sampling 1C (cotton) and Sampling 2M (maize) on the plain defined by the three first PCs. Kjel-N: Kjeldahl nitrogen; MBN: microbial biomass nitrogen; MBC: microbial biomass carbon; WSC: water soluble carbon; TOC: total organic carbon; DHA: dehydrogenase activity; β-GLU: β-glucosidase activity.

## 5. Conclusion

This study enriches the scarce literature regarding the effect of conservation agriculture on soil quality in irrigated maize-based systems in the Mediterranean region. The introduction of PB clearly resulted in an increased soil organic carbon in those zones where falling residues concentrated, i.e. furrows, and enhanced those enzymatic activities related with organic compounds metabolism, i.e. β-glucosidase, only 3 years after establishing the trial. These results complemented previous findings in this trial in which runoff in PB furrows had few sediments compared to runoff in CB furrows.

Moreover, significant results were found in furrows, while beds did not show important differences between tillage systems. This suggested that sampling under permanent beds should be taken in furrows zones to appreciate the improving effect of conservation agriculture under irrigation.

However, traffic did not affect any chemical or biochemical parameter, even if wheel passes have compacted the soil and reduced water infiltration. Residues' nature and their decomposition pattern influenced biochemical parameters more than other factors such as tillage and traffic. Furthermore, irrigation appears to affect WSC making it an unreliable soil quality indicator for assessing the impact of different soil managements. Nevertheless, further research is needed on the evolution of soil chemical and biochemical properties in the long-term.

**Table 4**
Correlation matrix of principal components with the soil chemical and biological properties studied.

| | Sampling 1C | | | Sampling 2M | | |
|---|---|---|---|---|---|---|
| | PCI | PCII | PCIII | PCI | PCII | PCIII |
| TOC | 0.894 | −0.343 | −0.163 | 0.858 | −0.325 | 0.080 |
| MBN | 0.595 | 0.623 | 0.196 | 0.491 | 0.697 | 0.269 |
| MBC | 0.705 | 0.616 | 0.097 | 0.531 | 0.726 | 0.126 |
| WSC | 0.339 | −0.457 | 0.821 | −0.446 | −0.285 | 0.841 |
| Kjel-N | 0.887 | −0.268 | −0.240 | 0.935 | −0.186 | −0.033 |
| β-glu | 0.889 | −0.306 | −0.191 | 0.900 | −0.282 | −0.092 |
| DHA | 0.850 | 0.196 | 0.076 | 0.850 | −0.175 | 0.260 |

TOC: total organic carbon; MBN: microbial biomass nitrogen; MBC: microbial biomass carbon; WSC: water soluble carbon; Kjel-N: Kjeldahl nitrogen; DHA: dehydrogenase activity; β-glu: β-glucosidase activity. Sampling 1C: after cotton harvest; Sampling 2M: after maize harvest.

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