Soil & Tillage Research 109 (2010) 110–115

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Soil microbial biomass and activity under different agricultural management systems in a semiarid Mediterranean agroecosystem

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ARTICLE INFO

Article history:
Received 14 January 2010
Received in revised form 10 May 2010
Accepted 11 May 2010

Keywords:
enzyme activities
herbicides
metabolic quotient
microbial biomass
oat straw
soil quality

ABSTRACT

A field experiment was carried out in a semiarid agricultural Mediterranean area located at the ''El Teularet'' experimental field in the Enguera Sierra (Valencia, southeast Spain) to assess the influence of different agricultural management systems on indicators of soil biological quality and activity (microbial biomass C, basal respiration, C mineralization coefficients, metabolic quotient (qCO_2), respiratory quotient (RQ: moles CO_2 evolved/moles O_2 consumed), soluble C and dehydrogenase, urease, protease-BAA, phosphatase and β-glucosidase activities), one year after treatment establishment. The management practices assayed were as follows: application of the herbicides paraquat, glyphosate or oxyfluorfen, addition of olive tree pruning residues, ploughing, sowing of oats + addition of crop residues + ploughing, sowing of *Medicago sativa*, sowing of oats and vetch + addition of crop residues and addition of oat straw. A non-treated plot was used as control soil and a plot under natural vegetation was used as a standard of local, high quality soil. The plots with addition of oat straw had higher values of enzymatic activity, microbial biomass and respiration, reaching similar values to soil under native vegetation. The lowest levels of soil biological quality indicators were observed in the plots with application of some type of herbicide. Low RQ values were observed in these plots as consequence of the scarce-null inputs of organic matter, suggesting an increase in organic matter recalcitrance. The addition of oat straw to soil can be considered an effective technology, due to the rapid improvement of soil quality, for carrying out sustainable agriculture in semiarid Mediterranean agroecosystems.

1. Introduction

Inadequate agricultural management in the Mediterranean area are one of the main causes of soil degradation and diminution of its biological quality (Caravaca et al., 2002). These degradation processes intensify with the clearing of natural vegetation and with adverse environmental and climate factors, including low and irregular precipitation and frequent drought periods (Garcia et al., 1997). In soils from arid and semiarid environments the risk of loss of soil fertility loss with cultivation is high due to their low levels of organic matter.

Agricultural management influences soil microorganisms and soil microbial processes through changes in the quantity and quality of plant residues entering the soil, their spatial distribution and through changes in nutrient input and physical changes (Christensen, 1996). For example, intensive arable farming causes a progressive decline in soil organic matter levels (Caravaca et al., 2002), which affects physical, chemical, biochemical and biological soil properties. The excessive use of herbicides can modify drastically the function and structure of soil microbial communities thus altering the normal functioning of terrestrial ecosystems, which in turn has important implications for soil fertility and quality (Pampulha and Oliveira, 2006). The application of conservation management system, which allows crop residues to remain on the soil surface and minimizes soil disturbance, it becoming more and more common because of increasing interest in sustainable agriculture (Roldán et al., 2003). Thus, soil surface mulching reduces soil temperature oscillations, keeping it cool, maintaining soil moisture during the hot and dry seasons, and promoting microbial activity and crop development (Souza Andrade et al., 2003).

Soil quality maintenance is an integral part of agricultural sustainability (Stenberg, 1999). Hence, in order to carry out sustainable farming systems, it is necessary to apply soil

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0167-1987/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.still.2010.05.005

management systems which improve or maintain soil quality. Some soil microbial properties, such as microbial biomass and enzyme activities, are used as bioindicators for soil quality and health in environmental soil monitoring (Schloter et al., 2003). Thus, soil enzyme activities, microbial biomass, respiration rates and metabolic quotients (qCO_2) have been shown to be sensitive indicators of changes produced by tillage (Roldán et al., 2005), cropping and management systems, crops, additions of fertilisers or environmental conditions (Spedding et al., 2004; Roldán et al., 2005). Likewise, the bioactive or labile fraction of soil organic matter, mainly soluble C, may indicate the soil's potential microbial activity, which is sensitive to land use and management. Furthermore, these fractions have been closely linked to soil productivity because of their capacity to furnish nutrients for plants and soil organisms. For semiarid regions in southeast Spain, some of these fractions such as water-soluble carbon or carbohydrates have been evaluated as an indicator of soil quality and gross organic matter trends (Caravaca and Roldán, 2003; Moreno et al., 2008). Information on biochemical and microbial indicators of soil exposed to herbicides provides valuable insight into the extent of soil disturbance and perturbation. Little is known of their effects on soil biological attributes in semiarid areas under different agricultural management systems. The soluble C fraction is strongly influenced by soil management (Izquierdo et al., 2003), and can be seen as reflecting soil microbial activity (De Luca and Keeney, 1993).

Most studies have examined the mid- and long-term (10 years or more) effects of agricultural systems on the microbial biomass and microbial processes, but less is known of the relative value of such indicators for differentiating agricultural management in the short-term, particularly in semiarid agroecosystems. Short-term monitoring of the variation of these microbial activity indicators allows the planning and adoption of systems aimed at minimising the negative effects of crop production practices.

The study reported here is part of a project to identify the best management systems for reducing the high erosion rates on rainfed agricultural land in eastern Spain. Indicators of soil erosion such as soil and water losses, runoff rates, sediment concentration, water infiltration, soil aggregate stability and vegetation cover have been previously discussed by García-Orenes et al. (2009). The aim of this work was to compare the effects of different agricultural systems one year after application on the biomass and activity of soil microorganisms in a semiarid agroecosystem.

Table 1
Analytical characteristics of the soil used in the experiment (N = 20).

Texture (%)[a]	39,38,23
pH (1:5, H_2O)	8.30 ± 0.02
Electrical conductivity EC (1:5, $\mu S\ cm^{-1}$)	185 ± 4
$CaCO_3$ (%)	60 ± 3
Total organic Carbon ($g\ kg^{-1}$)	12.5 ± 0.1
Soluble C ($\mu g\ g^{-1}$)	74 ± 1
Microbial biomass carbon (C_{mic}) ($\mu g\ g^{-1}$)	270 ± 2
Total N ($g\ kg^{-1}$)	0.78 ± 0.03
Available P ($mg\ kg^{-1}$)	2 ± 0
Extractable K ($mg\ kg^{-1}$)	303 ± 12
Basal respiration rate ($\mu g\ CO_2\ g^{-1}\ h^{-1}$)	5.7 ± 0.3

Mean ± Standard deviation.
[a] Sand: 2-0.02mm, Silt: 0.02-0.002 mm, Clay: <0.002mm.

2. Material and Methods

2.1. Experimental site

This research was conducted at the El Teularet Experimental Station (Cerdá, 2006; Garcia-Orenes et al., 2009), in the Enguera range (38° 50′ N; 0° 42′ W) in Valencia Province (southeast Spain). The experimental station is a rainfed orchard mainly cultivated with almond and wheat crops, where the soil has been intensively ploughed for centuries. The climate is typically Mediterranean characterized by irregular and intense rainfall events and a harsh dry summer period, usually from late June to September. The average annual temperature is 14.2 °C, and rainfall averages 479 mm per year, occurring mostly in autumn and spring. The predominant soil is a Typic Xerorthent developed from Cretaceous marls (Soil Survey Staff, 2006). The main characteristics of the soil are shown in Table 1.

2.2. Experimental design and layout

The experimental area (a homogeneous terrace with a 5% slope) was ploughed to create uniform surface soil conditions prior to conducting our experiment. The soil was sampled at different points across the terrace and the results of analysis showed that initially there were no significant statistical differences across the study area in the soil properties prior to the establishment of the different treatments. The initial state of soil is shown at Table 1. The terrace was then divided and nine different agricultural

Table 2
Treatment description of the different soil agricultural management systems.

Code	Treatment	Description
RH	Residual herbicide Oxyfluorfen 1.5 kg ha^{-1}*	3 applications yr^{-1} [2-chloro-1-(3-ethoxy-4-nitrophenyl)-4-(trifluoromethyl) benzene] [240 g l^{-1}];
SH	Systemic herbicide Glyphosate 4.25 kg ha^{-1}	3 applications yr^{-1} [N-(phosphonomethyl)-glycine] [68%]:
CH	Contact herbicide Paraquat 1.25 kg ha^{-1}	3 applications yr^{-1} [1,1′-dimethyl-4, 4′-bipyridylium-dichloride] [200 g l^{-1}]
RP	Olive tree pruning residues	Amount: 0.05 kg m^{-2} yr^{-1}
P	Ploughing	4 times yr^{-1} (ploughing depth 20 cm)
OP	Oats + Ploughing	Ploughing: 4 times yr^{-1} (ploughing depth 20 cm) Sown 100% oats (ground and added to soil in Spring)
L	Legume	*Medicago sativa* L. sowing
OV	Oats and Veza	Sown 60% oats-40% Veza sp. (ground and added to soil in Spring)
OS	Oats straw	Amount: 0.25 kg m^{-2} yr^{-1}
C	Control	Abandoned field with natural colonization (*Moricandia arvensis*, *Plantago lanceolata* and *Diplotaxis muralis*)
NC	Natural cover	Adjacent non-cultivated area (*Rhamnus lycioides*, *Quercus coccifera*, *Juniperus oxycedrus*, *Juniperus phoenicea*, *Arbutus unedo*, *Chamaerops humilis*, *Lavandula latifolia*, *Lavandula dentata*, *Rosmarinus officinalis*, *Salvia blancoana*, *Thymus vulgaris*, *Erica multiflora* and *Cistus albidus*).

* In each application, 125 mL of each herbicide were applied to the field plots by mixing with 7.5 litters of irrigation water.

management systems were established, all the details are shown in Table 2. For each treatment three subplots were created (each of them 60 m^2; 6 × 10 m). A non-treated plot was used as control soil and a plot under natural vegetation was used as a standard of local, high quality soil (Table 2).

One year after treatment establishment, three soil samples of each treatment were collected. Each sample consisted of six bulked sub-samples (150 cm^3 cores) randomly collected at 0-5 cm depth. Field-moist soil samples were sieved at 2 mm and stored at 2 °C for biological and biochemical analysis.

2.3. Biochemical and biological analyses

Soluble carbon was determined in extracted soil with K_2SO_4 0.5 M by wet digestion with potassium dichromate (Nelson and Sommers, 1982). The microbial biomass carbon (C_{mic}) was determined by the fumigation-extraction methods (Vance et al., 1987). The basal respiration of soil was measured in a multiple sensor respirometer (Micro-Oxymax, Columbus, OH, USA).

Dehydrogenase activity was determined according to Garcia et al. (1997). For this, 1 g of soil, at 60% of its field capacity, was exposed to 0.2 ml solution of 0.4% INT (2-*p*-iodophenyl-3-*p*-nitrophenyl-5-phenyltetrazolium chloride) for 20 h, at 22 °C in darkness. The INTF formed (iodo-nitrotetrazolium formazan) was extracted with 10 ml of methanol by shaking vigorously for 1 min and filtered through a Whatman N°. 5 filter paper. The INTF was measured spectrophotometrically at 490 nm.

Urease and N-α-benzoyl-L-argininamide (BAA) hydrolyzing protease activities were determined in 0.1 *M* phosphate buffer at pH 7; 1 *M* urea and 0.03 *M* BAA were used as substrates, respectively. Two millilitres of buffer and 0.5 mL of substrate were added to 0.5 g of sample, which was incubated at 30 °C (for urease) or 39 °C (for protease) for 90 min. Both activities were determined as the NH_4^+ released in the hydrolysis reaction (Nannipieri et al., 1980).

Phosphatase and β-glucosidase activities were determined using *p*-nitrophenyl phosphate disodium (PNPP, 0.115 M) and *p*-nitrophenyl-β-D-glucopyranoside (PNG, 0.05 M) as substrates, respectively. These assays are based on the release and detection of PNP. Two milliliters of 0.1 M maleate buffer at pH 6.5 and 0.5 mL of substrate were added to 0.5 g soil sample and incubated at 37 °C for 90 min. The reaction was stopped by cooling at 2 °C for 15 min; 0.5 mL of 0.5 M $CaCl_2$ and 2 mL of 0.5 M NaOH were then added and the mixture centrifuged at 2287 x g for 5 min. To stop the reaction of β-glucosidase activity, 0.1 M trishydroxymethyl aminomethane (THAM) pH 12.0 was used according to Tabatabai (1982). The amount of *p*-nitrophenol (PNP) was determined in a spectrophotometer at 398 nm (Tabatabai and Bremner, 1969).

For all enzyme assays, controls were included with each soil analysed. The same procedure as for the enzymatic assay was followed for the controls but the substrate was added to the soil after incubation but prior to stopping the reaction. All data were expressed on the oven-dry (105 °C) weight of soil.

2.4. Statistical analyses

The biological and biochemical parameters were log-transformed to compensate for variance heterogeneity, before analysis of variance. The effects of agricultural practices on the measured variables were tested by a one-way analysis of variance and comparisons among means were made using the Least Significant Difference (LSD) test calculated at $p < 0.05$. Statistical procedures were carried out with the software package SPSS for Windows.

3. Results

The total organic C content was higher in the uncultivated plot, under natural vegetation (NC), followed by that which had the application of oat straw (OS), as shown in Table 3. In contrast, the lowest values were recorded in the plots treated with one of the herbicides used for weed control. The rest other system showed a similar content of organic carbon and without statistical differences to the control soil. The highest content of soluble C was found in the oat straw system even above the value of soil with natural cover. The herbicide treatments have shown the lowest soluble organic carbon content (Table 3). The behaviour of C_{mic} was similar; the highest value was recorded in soil with addition of oat straw (OS) followed by the soil with natural cover. The rest of the systems have not varied too much with respect to the value of control soil (Table 3). The soil basal respiration rate was significantly higher in the plot treated with oat straw and lower in the plots treated with the herbicides glyphosate and oxyfluorfen. The other systems show similar values for this parameter between 6 and 8 μg of CO_2 g^{-1} h^{-1} (Table 3). The levels of enzymatic activities in response to the application of conservation management systems are shown in the Table 4. An increase of biological activity was also revealed also by the variations in dehydrogenase activity. The agricultural practices based on the addition of oats-veza and oat straw increased dehydrogenase activity with respect to the non-treated control soil, pointing to a higher microbial activity. The increase in dehydrogenase activity with respect to the control soil was least evident in soils treated with oat residues in combination with ploughing and probably resulted from the incorporation and mixing of such plant residues within the ploughing layer. The plots treated with the herbicides glyphosate and oxyfluorfen presented the lowest dehydrogenase

Table 3
Total organic carbon, carbon fractions and basal respiration in response to different agricultural management systems (N = 3).

Plots	Total organic carbon (g kg^{-1})	Soluble organic carbon (μg g^{-1})	Microbial biomass carbon (C_{mic}) (μg C g^{-1})	C_{mic}/Corg ratio (%)	Basal respiration rate (μg CO_2 g^{-1} h^{-1})
RH	9.2 ± 2.5 a	79 ± 10 ab	220 ± 75 a	2.37 ab	4.7 ± 2.5 ab
SH	10.7 ± 0.5 a	71 ± 11 a	223 ± 43 a	2.08 a	3.1 ± 0.8 a
CH	11.5 ± 0.8a	81 ± 30 ab	351 ± 82 b	3.04 bc	6.1 ± 0.5 bc
RP	11.8 ± 0.9 ab	85 ± 15 ab	360 ± 5 b	3.07 bc	8.4 ± 0.9 c
P	12.3 ± 1.4 ab	112 ± 13 c	267 ± 86 a	2.52 ab	6.5 ± 1.7 bc
OP	12.6 ± 1.0 ab	104 ± 1 bc	247 ± 95 a	2.35 ab	7.0 ± 0.4 bc
L	13.6 ± 1.4 ab	94 ± 9 abc	390 ± 71 bc	2.86 abc	8.0 ± 1.4 c
OV	14.1 ± 1.4 ab	101 ± 14 bc	382 ± 26 bc	2.72 abc	7.6 ± 1.4 c
OS	17.0 ± 3.4 b	207 ± 65 e	726 ± 9 d	3.38 c	26.8 ± 3.4 e
C	13.5 ± 1.6 ab	91 ± 26 abc	348 ± 36 b	2.59 abc	6.0 ± 1.7 bc
NC	22.2 ± 7.2 c	143 ± 98 d	449 ± 287 c	2.69 abc	15.4 ± 2.8 d

The meaning of the treatment codes is explained in the Table 2.
Mean ± standard error
Different letters in one column indicate statistical differences between treatments.

Table 4
Soil enzyme activities in response to different agricultural management systems (N = 3).

Plots	Dehydrogenase (μg INTF g^{-1})	Protease (μmol NH_3 h^{-1} g^{-1})	Urease (μmol NH_3 h^{-1} g^{-1})	Glucosidase (μmol PNP h^{-1} g^{-1})	Phosphatase (μmol PNP h^{-1} g^{-1})
RH	90.2 ± 5.1a*	0.60 ± 0.12 a	0.41 ± 0.10 a	0.69 ± 0.10 a	0.50 ± 0.20 a
SH	96.5 ± 13.5 a	0.64 ± 0.20 ab	0.64 ± 0.30 ab	0.89 ± 0.10 ab	0.56 ± 0.10 a
CH	124.4 ± 1.8 b	0.74 ± 0.10 abc	0.98 ± 0.20 abc	1.25 ± 0.20 bc	0.74 ± 0.10 ab
RP	129.1 ± 4.3 b	0.84 ± 0.20 abcd	0.99 ± 0.40 abc	1.20 ± 0.10 bc	1.05 ± 0.30 bc
P	119.5 ± 10.3 b	1.14 ± 0.10 de	0.74 ± 0.20 ab	1.25 ± 0.20 bc	0.98 ± 0.10 bc
OP	135.0 ± 22.0 bc	0.69 ± 0.10 ab	0.78 ± 0.30 ab	1.43 ± 0.01 c	0.91 ± 0.10 bc
L	143.0 ± 23.0 bc	1.23 ± 0.40 e	1.17 ± 0.10 bcd	1.40 ± 0.30 c	1.21 ± 0.20 c
OV	159.9 ± 7.2 d	1.10 ± 0.12 cde	0.88 ± 0.20 ab	1.49 ± 0.01 c	1.22 ± 0.20 c
OS	146.5 ± 9.3 cd	1.98 ± 0.10 f	1.71 ± 0.60 d	1.95 ± 0.01 d	1.67 ± 0.01 d
C	124.1 ± 7.7 b	0.97 ± 0.30 bcde	1.14 ± 0.30 bcd	1.11 ± 0.20 abc	1.00 ± 0.10 bc
NC	132.7 ± 5.9 bc	1.82 ± 0.98 f	1.65 ± 0.70 cd	1.46 ± 0.60 c	2.23 ± 0.20 e

The meaning of the treatment codes is explained in the Table 2.
Mean ± standard error.
Different letters in one column indicate statistical differences between treatments.

activity. The values of protease-BAA, which catalyses the hydrolysis of simple peptidic substrates to ammonium, and urease, a hydrolase related to the terminal N-cycle in which organic N is transformed to plant-available ammonia, were higher in the soil treated with the oat straw and lower in the soil treated with the residual herbicide oxyfluorfen. Thus, the highest β-glucosidase activity was recorded in the plot with the addition of oat straw, suggesting an enrichment in fresh plant materials of a cellulolitic nature, which act as substrate for the β-glucosidase enzyme. Only phosphatase activity, which plays an essential role in the mineralisation of organic P, was higher in the soil under natural vegetation than in the plot treated with oat straw.

Table 5 shows the values for three different quotients (C mineralization, metabolic and respiratory quotients). The highest values were obtained in the plot with the addition of oat straw and the plot with natural cover, the rest of agricultural systems show similar values for these three quotients analyzed.

4. Discussion

The soluble C fraction is an important pool with respect to soil organic matter turnover in agricultural soils, since it acts as readily-decomposable substrate for soil microorganisms and as a short-term reservoir of plant nutrients (Gregorich et al., 1994). The addition of oat straw has been found to be good agricultural management to increase the content of organic carbon and soluble carbon and as a consequence an increase of C_{mic}, because this material contains organic compounds such as celluloses, which can be easily used by microbes. It has been suggested that the biomass-C/TOC ratio reflects the potential for soil's organic matter mineralization after the addition of organic materials (Pascual et al., 1997); the higher the ratio, the higher the tendency of the organic matter to mineralize. According to this ratio, the soil treated with oat straw would be characterized by the high mineralization potential of its organic matter, which in turn corresponds to the high C mineralization quotient recorded in this soil. The high soil basal respiration in this system can be explained by an increase in the contents of soil organic matter and nutrients, which would stimulate microbial activity (Emmerling et al., 2000), and also greater microbial biomass cycling, thus leading to an increase in basal respiration (Fernandes et al., 2005). These fractions of carbon (organic carbon, soluble carbon and C_{mic}) play an important role in the structure formation and stabilization of soil (Roldán et al., 2006). Other work, that has been developed in the same study area, has shown the effectiveness of this treatment (oat straw addition) in subsequently increasing the aggregate stability (Garcia-Orenes et al., 2009).

The high soil organic carbon content in the plot with natural cover could be due to the higher input of root exudates and plant residues as well as their long term accumulation in this soil, the soluble organic carbon level being lower, and as consequence the C_{mic}, than in the oat straw system.

The low level of microbial C_{mic} found in the plots treated with whichever herbicide is due to the very limited organic carbon content, and also to the toxic effect of the herbicide, the adsorption of herbicide in soil and the possibility that the soil microorganisms were not adapted to these agrochemicals. Duah-Yentumi & Johnson (1986) also reported that repeated paraquat application significantly produced a decrease in C_{mic} (mainly fungal biomass). The results showed that in our experiment there is a clear relationship between the C_{mic} and the soluble carbon fraction ($r = 0.801$, $P < 0.001$).

The high increase of the dehydrogenase activity, in the soil treated with oat residues addition, may be attributed to higher C_{mic} due to the addition of available organic substrates that would promote the growth and activity of indigenous microorganisms. This activity has been considered as a sensitive indicator of soil quality (Garcia et al., 1997; Caravaca et al., 2003) and a valid biomarker to indicate changes in total microbial activity due to changes in soil management, under different agronomic practices and climates (Roldán et al., 2007) The presence of herbicides glyphosate and oxyfluorfen had a negative effect on the dehydrogenase activity and carbon dioxide released. These findings suggest that the native soil microbiota is not capable of using glyphosate as a source of energy and nutrients and/or these herbicides could be toxic to some microbial groups. However,

Table 5
Mineralization quotient (MQ), metabolic quotient (qCO_2) and respiratory quotient (RQ) in response to different agricultural management systems (N = 3).

Plots	Mineralization Quotient (MQ) (mg C-CO_2 g^{-1} Corg h^{-1})	Metabolic quotient (qCO_2) (mg C-CO_2 g^{-1} Cmic h^{-1})	Respiratory quotient (RQ) (moles CO_2 $moles^{-1}$ O_2)
RH	5.27 ab	0.023 abc	0.55 b
SH	2.83 a	0.014 a	0.53 a
CH	5.36 ab	0.018 ab	0.55 b
RP	7.11 bc	0.023 abc	0.57 b
P	5.23 ab	0.021 ab	0.56 b
OP	5.53 ab	0.024 abc	0.57 b
L	5.81 ab	0.020 ab	0.57 b
OV	5.43 ab	0.020 ab	0.56 b
OS	12.46 d	0.037 d	0.62 c
C	6.39 bc	0.026 bcd	0.57 b
NC	8.81 c	0.033 cd	0.62 c

The meaning of the treatment codes is explained in the Table 2.
Mean ± standard error.
Different letters in one column indicate statistical differences between treatments.

studies by Araújo et al. (2003) found that the addition of glyphosate stimulated soil microbial activity in short- and long-term as consequence of its microbial degradation.

Measurements of soil hydrolases provides an early indication of changes in soil fertility, since they are related to the mineralisation of such important nutrient elements as N, P and C. Likewise, such enzyme assays have the potential to indicate the impact of the biocides assayed on soil microbial communities. In this way the oat straw system could have improved the fertility status of soil because it shows the highest value for this activity.

It is important to point out that soil with natural cover showed the highest values for phosphatase activity. This enzyme is predominantly secreted by plant roots and associated mycorrhiza and other fungi, as pointed out by Joner et al. (2000). On the other hand, the glyphosate can be degraded by soil microbes and interact with soil in much the same way as inorganic phosphate (Krzysko-Lupicka and Orlik, 1997). So, measuring phosphatase activity is particularly relevant to this treatment. It is worth noting that the biocide did not make a significant impact on soil phosphatase activity.

The metabolic quotient was calculated to estimate the activity and efficiency of decomposition (or C use) by the soil microbes (Anderson and Domsch, 1990). This index establishes that, as the C_{mic} becomes more efficient in using the resources available, less C is lost as CO_2 through respiration. The plot with the addition of oat straw, which had greater sources of easily mineralizable compounds, led to low efficiency. This could be due to the native microbial population not being able to incorporate available C from oat straw for their proliferation and thus, a fraction of added organic matter was mineralised to obtain enough energy for their maintenance. This hypothesis could be supported by the fact that higher evolved CO_2 was observed in the plot treated with oat straw. In this sense, the respiratory quotient (RQ) was also positively correlated with the metabolic quotient ($r = 0.777$, $P < 0.001$) and the organic C mineralization coefficients ($r = 0.895$, $P < 0.001$). The high presence in this plot of easy decomposable compounds such as carbohydrates leads to high metabolic rates. Conversely, the plots with low inputs of organic matter had low easy mineralizable compounds, and as a consequence, low mineralization rates occurred. In these plots the lack of fresh organic matter caused the mineralization of more recalcitrant compounds. This hypothesis was supported by the lower values of RQ observed.

5. Conclusions

Some of the agricultural management systems studied showed clear short-term effects on microbial biomass carbon and activity, mainly due to the changes in organic matter inputs to soil. In particular, the addition of oat straw to soil can be considered an effective soil management, because it produced an important increase of the different fractions of organic carbon and microbial activity, that it will be translated into a rapid improvement of soil quality.

The application of the herbicides studied produced a decreases in all the soil parameters, these practises are not recommendable for a sustainable agricultural system in semiarid Mediterranean agroecosystem.

References

Araújo, A.S.F., Monteiro, R.T.R., Abarkeli, R.B., 2003. Effect of glyphosate on the microbial activity of two Brazilian soils. Chemosphere 52, 799–804.

Anderson, T.H., Domsch, K.H., 1990. Application of eco-physiological quotients (qCO_2 and qD) on microbial biomass from soils of different cropping histories. Soil Biology & Biochemistry 22, 251–255.

Caravaca, F., Masciandaro, G., Ceccanti, B., 2002. Land use in relation to soil chemical and biochemical properties in semi-arid Mediterranean environment. Soil and Tillage Research 68, 23–30.

Caravaca, F., Azcón-Aguilar, C., Figueroa, D., Roldán, A., 2003. Alteration in the rhizosphere soil properties of afforested *Rhamnus lycioides* seedlings in short-term response to inoculation with *Glomus intraradices* and organic amendment. Environmental Management 31, 412–420.

Caravaca, F., Roldán, A., 2003. Microbial biomass, enzyme activities, respiration, water soluble C and mineralization kinetics of three soils treated with a composted organic residue as affected by the addition of *Eisenia foetida* earthworms. Biology and Fertility of Soils 38, 45–51.

Cerdá, A. 2006. Influencia de la longitud de la ladera sobre la pérdida por erosión hídrica de suelo y planta. In: Contribución de la estación experimental para el estudio de la erosión del suelo de El Teularet-Sierra de Enguera (eds A. Pérez Alberti & J. López Bedoya), Geomorfología y territorio Santiago de Compostela Spain, pp. 177-188.

Christensen, B.T., 1996. Matching measurable soil organic matter fractions with conceptual pools in simulation models of carbon turnover: revision of model structure. In: Powlson, D.S., Smith, P., Smith, J.U. (Eds.), Evaluation of Soil Organic Matter Models Using Existing Long-Term Datasets. Global Environmental Change. Springer Berlin, pp. 143–160.

De Luca, T.H., Keeney, D.R., 1993. Soluble anthrone-reactive carbon in soils: effect of carbon and nitrogen amendments. Soil Science Society of America Journal 57, 1296–1300.

Emmerling, C., Liebner, C., Haubold-Rosar, M., Katzur, J., Schröder, D., 2000. Impact of application of organic waste materials on microbial and enzyme activities of mine soils in the Lusatian coal mining region. Plant and Soil 22, 129–138.

Fernandes, S.A.P., Bettiol, W., Cerri, C.C., 2005. Effect of sewage sludge on microbial biomass, basal respiration, metabolic quotient and soil enzymatic activity. Applied Soil Ecology 30, 65–77.

Garcia, C., Roldán, A., Hernández, T., 1997. Changes in microbial activity after abandonment cultivation in a semiarid mediterranean environment. Journal of Environmental Quality 26, 285–291.

Garcia-Orenes, F., Cerdá, A., Mataix-Solera, J., Guerrero, C., Bodí, M.B., Arcenegui, V., Zornoza, R., Sempere, J.G., 2009. Effects of agricultural management on surface soil properties and soil-water losses in eastern Spain. Soil and Tillage Research 106, 117–123.

Gregorich, E.G., Carter, M.R., Angers, D.A., Monreal, C.M., Ellert, B.H., 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils. Canadian Journal of Soil Science 74, 367–385.

Izquierdo, I., Caravaca, F., Alguacil, M.M., Roldán, A., 2003. Changes in physical and biological soil quality indicators in a tropical crop system (Havana, Cuba) in response to different agroecological management practices. Environmental Management 32, 639–645.

Joner, E.J., van Aarle, I.M., Vosatka, M., 2000. Phosphatase activity of extra-radical arbuscular mycorrhizal hyphae: a review. Plant and Soil 226, 199–210.

Krzysko-Lupicka, T., Orlik, A., 1997. The use of glyphosate as the sole source of phosphorus or carbon for the selection of soil-borne fungal strains capable to degrade this herbicide. Chemosphere 34, 2601–2605.

Moreno, J.L., Bastida, F., Hernández, T., García, C., 2008. Relationship between the agricultural management of a semi-arid soil and microbiological quality. Communications in Soil Science and Plant Analalysis 39, 421–439.

Nannipieri, P., Ceccanti, B., Cervelli, S., Matarese, E., 1980. Extraction of phosphatase, urease, protease, organic carbon and nitrogen from soil. Soil Science Society of America Journal 44, 1011–1016.

Nelson, D.W. & Sommers, L.E. 1982. Total carbon, organic carbon and organic matter. In: Chemical and Microbiological Properties (eds A.L. Page, R.H. Miller & D.R. Keeney), ASA and SSSA Madison Wi, pp. 539-579.

Pampulha, M.E., Oliveira, A., 2006. Impact of an herbicide combination of bromoxynil and prosulfuron on soil microorganisms. Current Microbiology 53, 238–243.

Pascual, J.A., García, C., Hernández, M.T., Ayuso, M., 1997. Changes in the microbial activity of an arid soil amended with urban organic wastes. Biology and Fertility of Soils 24, 429–434.

Roldán, A., Caravaca, F., Hernández, M.T., García, C., Sánchez-Brito, C., Velásquez, M., Tiscareño, M., 2003. No-tillage, crop residue additions, and legume cover cropping effects on soil quality characteristics under maize in Patzcuaro watershed (Mexico). Soil and Tillage Research 72, 65–73.

Roldán, A., Salinas-García, J.R., Alguacil, M.M., Caravaca, F., 2005. Changes in soil enzyme activity, fertility, aggregation and C sequestration mediated by conservation tillage practices and water regime in a maize field. Applied Soil Ecology 30, 11–20.

Roldán, A., Carrasco, L., Caravaca, F., 2006. Stability of desiccated rhizosphere soil aggregates of mycorrhizal *Juniperus oxycedrus* grown in a desertified soil amended with a composted organic residue. Soil Biology and Biochemistry 38, 2722–2730.

Roldán, A., Salinas-García, J.R., Alguacil, M.M., Caravaca, F., 2007. Soil sustainability indicators following conservation tillage practices under subtropical maize and bean crops. Soil and Tillage Research 93, 273–282.

Schloter, M., Dilly, O., Munch, J.C., 2003. Indicators for evaluating soil quality. Agriculture, Ecosystems and Environment 98, 255–262.

Souza Andrade, D., Colozzi-Filho, A., Giller, K.E., 2003. The soil microbial community and soil tillage. In: El Titi, A. (Ed.), Soil Tillage in Agroecosystems. CRC Press, Boca Raton FL, pp. 51–81.

Spedding, T.A., Hamel, C., Mehuys, G.R., Madramootoo, C.A., 2004. Soil microbial dynamics in maize-growing soil under different tillage and residue management systems. Soil Biology and Biochemistry 36, 499–512.

Stenberg, B., 1999. Monitoring soil quality of arable land: Microbiological indicators; Review article. Acta Agriculturae Scandinavica—Sect. B: Soil and Plant Science 49, 1–24.

Tabatabai, M.A., Bremner, J.M., 1969. Use of *p*-nitrophenyl phosphate for assay of soil phosphatase activity. Soil Biology and Biochemistry 1, 301–307.

Tabatabai, M.A., 1982. Soil enzymes. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), Methods of soil analysis. ASA and SSSA Madison Wi, pp. 501–538.

Vance, E.D., Brookes, P.C., Jenkinson, D., 1987. An extraction method for measuring microbial biomass carbon. Soil Biology and Biochemistry 19, 703–707.