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Soil quality, microbial functions and tomato yield under cover crop mulching in the Mediterranean environment

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ABSTRACT

An experiment concerning the biological and chemical responses of soil to cover crop mulching was carried out in two adjacent experimental fields (2012 and 2013) under different climatic conditions in the Mediterranean environment (Central Italy). The Monthly Aridity Index was calculated in order to verify the relationship between soil properties and climatic factors under three different cover crop mulches: *Vicia villosa Roth* (HV), *Phacelia tanacetifolia* Benth. (LP), and *Sinapis alba* L. (WM). A conventional management was also included in the experimental fields as control (C). Soil samples were collected at 0–20 cm depth after the transplanting and the harvesting of tomato (May and August, respectively), in order to assess the initial and residual effects of mulching on soil quality. In the two experimental years, the amount of precipitation from May to August was 110 mm in 2012 and 172 mm in 2013. The average values of AI were 18 and 49 in 2012 and 2013, respectively. LP mulching was sensitive to low precipitation levels in terms of aboveground decomposition rate (the variation of dry matter from May to August 2012 was −53% in LP, 64% in HV and 69% in WM) and a lower tomato yield compared to the control in 2012 (4.2 kg m^{-2} in LP and 5.2 kg m^{-2} in C). WM mulching was sensitive to low precipitation in terms of soil nutrient storage (from May to August 2012 the variation of soil C was 19% in WM., 6% in C, −5 % in LP and 10% in HV; the variation of soil N was 44% in WM, 2% in C, −2% in LP and 13% in HV). Soil microbial activity and functional diversity were strongly affected by the climatic conditions in all mulching treatments. In particular, precipitation influenced soil C availability, which enhanced microbial functional diversity. In short, the effects of lacy phacelia, white mustard and hairy vetch mulching on soil quality, microbial functions and tomato yield were influenced by summer precipitation and temperature in the Mediterranean environment.

1. Introduction

In the last century, humans have intensely started cultivating land for producing plants for food thus causing a depletion of natural resources and environmental degradation (Pankhurst et al., 1997). Recently people have become more and more environmentally friendly toward environmental pollution, food quality and strategies for sustainable agriculture in order to preserve non-renewable natural resources such as soil. Soil is a dynamic, living, natural body which is vital for the correct functioning of terrestrial ecosystems and it represents a unique balance between physical, chemical and biological factors (Pankhurst et al., 1997; Shukla and Varma, 2011). It is important to establish sustainable agriculture, environmental quality, plant, animal and human health in order to maintain soil quality and health (Pankhurst et al., 1997; Doran and Zeiss, 2000). Karlen et al. (1997) define soil quality as the "capacity of soil to function". Since it is difficult to measure and quantify this capacity, it is useful to examine related properties to biological processes and environmental quality. There are some measures which are suitable for quantifying soil quality by means of soil biological characteristics (e.g. microbial biomass and its activities), soil chemical (e.g. soil organic matter), and physical characteristics (e.g. water infiltration rates or bulk density) (Campbell et al., 2001). Among all soil properties, microbial biomass and soil enzyme activities prove to be sensitive indicators of soil quality as they are measurements which rapidly respond to changes due to different management and environmental factors (Alvear et al., 2005). Soil perturbations, such as tillage, can alter microbial processes, biogeochemical nutrient cycles (overall C stored) (Janzen et al., 1997) thus modifying the structural and functional diversities of the soil microbial communities (Lienhard et al.,

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2012). In fact, physical disturbance exposes Soil organic matter (SOM) to biological activity, thus facilitating the penetration of water at greater depths and accelerating its decomposition. Tillage modifies the physical and chemical environment of the soil and affects soil water content, soil temperature, aeration and the contact between SOM and mineral particles, globally influencing the soil microbial population which in turn effects the physical/chemical environment of the soil (Kladivko, 2001; Bünemann et al., 2006; Pascault et al., 2010). Modern and intensive agriculture, using large amounts of mineral N and water, affects soil microbial biomass and its activity in different ways (Bünemann et al., 2006) just as deep soil tillage causes a faster oxidation of SOM (Mancinelli et al., 2008). The advantages of no tillage for improving soil organic matter are greatly enhanced by growing cover crops and mulches (Franzluebbers, 2005). Cover crop is any living ground cover which is planted into or after a main crop and then killed before planting the next crop. In the Mediterranean environment, cover crops are generally planted in the autumn after harvesting the summer crop and they grow during the winter. There are numerous benefits of using cover crops for enhancing soil health. They prevent soil erosion, protect water quality, improve yields by enhancing soil health (soil structure and tilth), cut fertilizer costs by fixing the atmospheric N, conserve soil moisture, and reduce the need for herbicides and other pesticides (Hartwig and Ammon, 2002). Cover crops can be cut and left on the soil surface as dead mulches (Bond and Grundy, 2001). For instance, straw mulching and no-till technologies have improved grain yields in the 250-mm-rainfall wheat belt of the northern Negev region of Israel (Landau et al., 2007). In the Mediterranean environment dead mulches are generally cut during spring, just before cultivating the main crop and are left on the soil until the end of the growing season, thus causing a reduction in soil water evaporation, an increase in soil water content, a decrease in daily soil temperature excursion (Dahiya et al., 2007) and weed control thus enhancing the yield of the main crop (Campiglia et al., 2014). The total surface area used for cultivating processing tomato in Italy is about 75.525 ha (ISTAT, 2012), representing the most important vegetable crop. Conventional practices are often used such as deep tillage, plastic mulching and chemical fertilization in order to obtain high tomato yields (Carrera et al., 2007). On the other hand, sustainable farming in tomato cultivation can be used to improve organic matter in the soil (green manuring of cover crops), to reduce synthetic inputs and environmental pollution caused by chemical fertilizers and pesticides, and reduce crop losses caused by diseases and pests thus enhancing environmental characteristics (Briar et al., 2007). However, until recently little was known about the biological, chemical, and physical responses of soil to cover crop mulching. Since seasonal fluctuations of soil microbiological processes can be caused by variable climatic conditions (Manzoni and Porporato, 2009; Mancinelli et al., 2013), the aim of this study was to verify the effects of cover crop mulching on soil quality and microbial functions under fluctuating climatic factors occurring during the two-year study period in the Mediterranean environment (Central Italy).

2. Materials and methods

2.1. Experimental site and design

The research was carried out over a two-year period (2011–2013) in two adjacent and homogeneous fields established in September 2011 at the experimental farm of the University of Tuscia (Viterbo) located approximately 80 km North of Rome (45°25′N, 12°04′E). The climate of the area is typical of the Mediterranean environment with a mean annual precipitation of 760 mm, mostly concentrated during the autumn and spring seasons, minimum temperatures a little below 0 °C in the winter and maximum temperatures of about 36 °C in the summer. The monthly Aridity Index (AI) was calculated according to the following Eq. (1) to verify the differences between the months of the cover crop and main crop (tomato) growing seasons during the two-year study (De Martonne, 1926):

$$AI = \frac{Pi}{Ti + 10} \tag{1}$$

where AI = Aridity Index; Pi = monthly precipitation amount; Ti = monthly mean air temperature (Mancinelli et al., 2013). The Aridity Index was used to verify the relationship between the soil properties and climatic factors. The soil water holding capacity (WHC) was estimated in the laboratory measuring the amount of water absorbed and detained by soil capillarity.

Chemical and physical analyses were carried out on three soil samples collected from the experimental fields before starting the trials (autumn) in order to verify the homogeneity of each field. The soil of the experimental field is of volcanic origin classified as a *Typic Xerofluvent*. Physicochemical characterization was carried out using the official methods of analysis (MiPAF, 2000). The particle size distribution analysis indicated that the textural class of the surface horizon (0–20 cm depth) fell within the sandy–loam USDA classification with 63% sand, 22% silt, and 15% clay; pH of 6.9 in 2012 and 7.2 in 2013 (1:2.5 w:v) (Table 1). The soil N content in the two fields was similar, while the organic C was higher in 2013 compared to 2012. The amount of carbonates also varied between the two fields since it was five times higher in 2013 compared to 2012 (Table 1).

2.2. Experimental field and treatments

In both experimental years, the fields were arranged in a randomized block design with three replications. In autumn (on September 26th, 2011 and September 30th, 2012) three cover crops, *Vicia villosa* Roth (HV), *Phacelia tanacetifolia* Benth. (LP), and *Sinapis alba* L. (WM), were sown; they were then cut in spring to be used as mulches. The three cover crop mulches were compared with a control treatment without mulching (C). In May the tomato seedlings were transplanted into the mulches. The tomato plants were irrigated with 100% of potential evapotranspiration and they were left unfertilized.

The area of the experimental plots was 4400 m^2 (55 m × 80 m) which makes it possible to carry out all farming operations with

Table 1
Soil properties of the two experimental fields (2012 and 2013).

	pH_{H_2O}	Corg (mg g^{-1})	Ntot (mg g^{-1})	C/N	Clay (%)	Silt (%)	Sand (%)	Carbonates (%)	Texture
2012	6.9	11.0	1.0	9.7	15	22	63	1.3	Sandy-loam
2013	7.2	11.9	1.1	10.6	15	22	63	6.3	Sandy-loam