Soil & Tillage Research 180 (2018) 10–20

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Crop yield, weed infestation and soil fertility responses to contrasted ploughing intensity and manure additions in a Mediterranean organic crop rotation

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ARTICLE INFO

Keywords:
Chisel plough
Carbon stock
Amendments
Microbial biomass
Cover crop

ABSTRACT

Conservation agriculture and organic farming are two alternative strategies that aim to improve soil quality and fertility in arable cropping systems through reducing tillage intensity, maintaining soil cover and increasing nutrient recycling, using farmyard and green manures. However, these practices can increase weed infestation or decrease nutrient availability. The objectives of this study were to evaluate the effects of tillage type (mouldboard vs. chisel ploughing), fertilization and green manure on soil parameters (SOC, N, bulk density, carbon stocks, and soil microbial biomass C_{mic} and N_{mic}), weed abundance and crop yields in a four-year rotation of spelt, chickpea, winter wheat and lentil in the Mediterranean region (Catalonia, Spain). Tillage and green manure did not affect crop yields or weed biomass, although during the last year of the experiment, plots with mouldboard ploughing had less weed biomass and higher lentil biomass. Fertilization was the most important factor, increasing the cereal yields, SOC, N and soil microbial biomass (C_{mic} and N_{mic}) content of the soil. However, fertilization did not favour chickpea and lentil crops because weed competition limited legume crop growth. Overall, there was a loss of SOC and a reduction of carbon stocks over the four years of the trial in the soil because of the deep soil tillage (25 cm) and low crop productivity irrespective of tillage type. In contrast, N content increased in all of the plots and was enhanced by fertilization. The use of chisel plough stratified the distribution of SOC and N in the surface layers (0–10 cm). Both C_{mic} and C_{mic}/SOC ratio increased in fertilized treatments, suggesting an increased lability of SOC. The application of more stabilized organic matter may be a better practice to build up soil organic matter and to maintain crop yields in organic farming systems.

1. Introduction

Soils play a key role in agricultural systems because they represent the basis of food production (Fließbach et al., 2007). However, most arable soils are prone to degradation, mainly caused by intensive soil use (Gadermaier et al., 2012). Crop rotation, cover crops and reduced or no tillage practices aim to improve soil quality in arable cropping systems. Farmyard manure and green manure (organic fertilizers) can also contribute to soil fertility and quality. While most of these practices are used in organic farming cropping systems, the adoption of reduced tillage practices is not widespread in such systems (Gadermaier et al., 2012). The increase of weed infestation and the limited availability of N mainly at the beginning of the growing season are probably the main problems that reduced tillage pose to organic farmers (Gadermaier et al., 2012; Peigné et al., 2007; Sans et al., 2011). On the other hand, reduced tillage is highly suited to conserve soil fertility and prevent erosion (Berner et al., 2008; Gadermaier et al., 2012) by enhancing soil organic carbon (SOC) content, microbial activity and soil structure (Mäder and Berner, 2012; Peigné et al., 2013).

Cover crops can also contribute to the accumulation of organic matter in the upper soil layer and they can reduce weed infestation (Hobbs et al., 2008; Masilionyte et al., 2017). However, the use of cover crops must consider the possible consequences of competition for nutrients and water with cash crops (Plaza-Bonilla et al., 2017).

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https://doi.org/10.1016/j.still.2018.02.006
Received 24 July 2017; Received in revised form 9 February 2018; Accepted 16 February 2018
0167-1987/

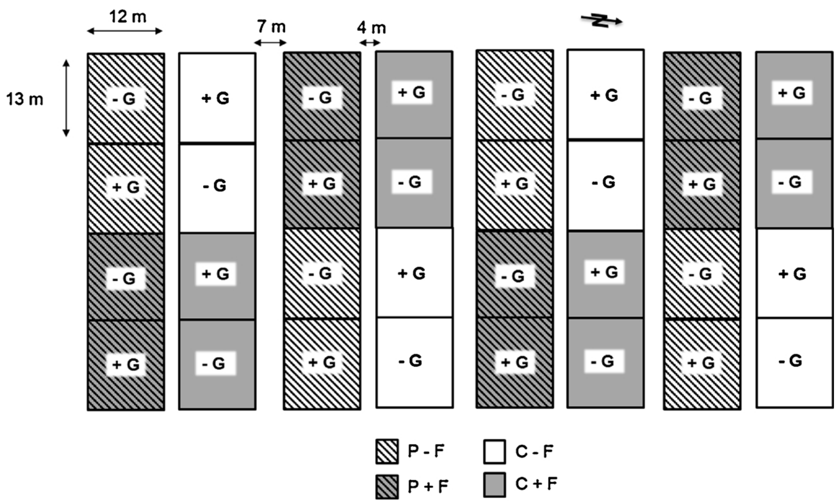

Fig. 1. Experimental design in a strip-split-block with three factors of two levels each. P, mouldboard ploughing; C, chisel ploughing; + F, fertilization with farmyard manure, − F, not fertilized: + G, with green manure, − G, no green manure. Each treatment is replicated four times, totalling 32 plots.

Crop production in organic farms is often limited by the lack of nitrogen. In such farms nitrogen inputs are needed to restore the amount of N depleted by crops (Fließbach et al., 2007). The use of organic fertilizers, in one hand, is an effective way to increase soil organic matter content (Alvarez, 2005) and N availability (Krauss et al., 2010; Lal, 2009; Maltas et al., 2013). On the other hand, suitable crop rotations containing legumes are fundamental to produce surpluses in N budgets (Gadermaier et al., 2012). However, the residue from a cover crop rich in legume species is often mineralised very fast, and nutrients can be released before the demands of the subsequent cash crop (Pang and Letey, 2000) and thus be lost or used by weeds. Therefore, the use of cover crops for supplying N to crops must be adapted to the reduced tillage systems (Peigné et al., 2007). In consequence, it is considered of great interest to gain knowledge on the N dynamics after the introduction of green manures and reduced tillage practices in organic arable cropping systems.

Links between C and N cycling are important to understand N supply in arable systems. The application of organic manures, and reducing tillage intensity can increase the SOC in topsoil, improve soil physical and biological properties and lead to reduced carbon losses or even to increased soil carbon storage in the soil (Cooper et al., 2016; Gattinger et al., 2012). In addition, soil microbiological activity is of primary importance in organic farming because N supply is mainly dependent on the degradation of soil organic matter by soil micro-organisms (Vian et al., 2009). In this case, and because of their high sensitivity, C and N in soil microbial biomass can be used as indicators of changes in soil owing to management in the short term (Fließbach et al., 2007).

Few experiments integrate reduced tillage into organic farming systems, and most of them are performed in temperate climates (Berner et al., 2008; Krauss et al., 2010; Peigné et al., 2007; Pekrun et al., 2003). So far, in Mediterranean climates reduced tillage practices have been studied only in conventional systems (Kassam et al., 2012; López-Garrido et al., 2014; Ward et al., 2012), and thus there is a lack of long term reduced tillage studies in organic systems. The low organic matter content with poor soil structure of the Mediterranean arable soils and the climatic constraints that limit plant growth during summer may constrain the chances to improve soil quality by means of reduced tillage and green manures (Kassam et al., 2012; Romanyà and Rovira, 2011; Hernanz et al., 2009).

Our aims were to study the effects of reduced tillage, farmyard manure and green manure (cover crop) on crop yields, weed abundance and soil organic C stocks and N availability. To address these aims we set in 2011 a mid-term experiment that was monitored during a four-year rotation of spelt (*Triticum spelta* L., 2011–12), chickpea (*Cicer arietinum* L., spring 2013), winter wheat (*Triticum aestivum* L., 2013–14) and lentil (*Lens culinaris* Medik., spring 2015).

We hypothesized that a) the lower disturbance of the soil profile by reduced tillage plus the addition of farmyard and green manures contribute to an increase, or at least maintain SOC and N stocks. These changes, combined with the increased stability of the soil system, b) will increase microbial biomass and N availability; and c) will allow a sustainable crop performance in reduced tillage organic crops.

2. Materials and methods

2.1. Site conditions

In November of 2011, a midterm field experiment was initiated in Gallecs (41°33′31.9″N 2°11′59.5″E), a peri-urban agricultural area of 753 ha situated 15 km north of Barcelona (Catalonia, Spain). Gallecs has a Mediterranean climate; the mean annual temperature and precipitation are 14.9 °C and 647 mm, respectively. At the beginning of the experiment, the soil properties of the field were evaluated. On average, the mineral fraction consisted of 43.3 ± 6.9% sand, 26.9 ± 4.7% loam and 29.7 ± 3.7% clay; the texture was classified as loamy-clay (Soil Survey Staff, 1998); the soil type was Haplic Luvisol (IUSS Working Group WRB, 2015); the average soil organic matter was 1.5 ± 0.1% (Walkley-Black); and the pH (H_2O) was 8.1 ± 0.1.

2.2. Field experiment

The trial consisted of a four-year crop rotation in a strip-split-block design of three factors (with two levels each): tillage system (mouldboard ploughing (P) vs. chisel (C)), fertilization (composted farmyard manure (+F) vs. no fertilizer (−F)) and green manure (with green manure (+G) vs. no green manure (−G)). The factors were arranged with tillage treatments laid out in strips; fertilization was applied in perpendicular strips across the experiment, and the tillage strips were split into subplots for the green manure treatment. In total, 32 plots measuring 13 m × 12 m were established, comprising four replicates of each treatment (Fig. 1). The field had been under organic management for five years prior to the trial establishment, with a typical dryland Mediterranean crop rotation that alternated winter cereals and legumes in spring for human consumption. The crop rotation of this trial consisted of spelt (2011–2012), chickpea (2013), winter wheat (2013–2014) and lentil (2015) (Fig. 2).

Two tillage systems were used: a mouldboard plough (P) (soil