Soil & Tillage Research 140 (2014) 40–47

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Reduced tillage as an alternative to no-tillage under Mediterranean conditions: A case study

R. López-Garrido [a,*], E. Madejón [a], M. León-Camacho [b], I. Girón [a], F. Moreno [a], J.M. Murillo [a]

[a] Protection of the Soil, Plant and Water System Department, Instituto de Recursos Naturales y Agrobiología de Sevilla, IRNAS (CSIC), Avda. Reina Mercedes 10, E 41012 Sevilla, Spain

[b] Lipid Characterization and Quality Department, Instituto de la Grasa (CSIC), Avda. Padre García Tejero 4, E 41012 Sevilla, Spain

ARTICLE INFO

Article history:
Received 25 November 2013
Received in revised form 28 January 2014
Accepted 11 February 2014

Keywords:
Tillage systems
Soil conditions
Crop performance
Seed quality
Sunflower

ABSTRACT

Most farmers in SW Spain usually apply traditional tillage (TT) with soil inversion to avoid potential problems of soil compaction after repeated application of no tillage (NT). NT might cause some difficulties for soil workability and crop development derived from the original soil conditions, and, consequently, other tillage options are evaluated. However, less aggressive tillage practices, such as reduced tillage (RT), could solve the problem without losing the advantages of conservation agriculture. We show that despite the chemical (slight increases of soil organic carbon, N, P and K at soil surface) and biochemical (increases of dehydrogenase and β-glucosidase activities) improvements derived from NT, this treatment greatly worsened physical soil conditions after five years of establishment on a Xerofluvent soil cropped with a wheat-sunflower-fodder pea crop rotation. This deterioration was mainly reflected by the penetration resistance at the time of seedling emergence (6.04 MPa under NT versus 0.65 in RT and 0.40 in TT at surface), which contributed to an extreme reduction of the seeds yield of the sunflower crop (about 100 Mg ha^{-1} in NT versus more than 3000 Mg ha^{-1} in RT and TT) and seed quality (33.6% of oil in NT versus 48.0% in TT and 49.6% in RT). In general, the best seed quality related to lipid composition was recorded under RT with a slight, but significant, increase of the oil content, the oleic acid and the unsaturated/saturated fatty acid ratio; very positive features considering their dietary and industrial importance.

1. Introduction

Inadequate agricultural practices may negatively affect soil quality, contributing to soil erosion and degradation. This may include excessive deep ploughing in intensive agriculture, which has caused huge losses of soil organic carbon (SOC) (Lal, 2004) accompanied by soil erosion and degradation in many cases. Although the historic loss of the SOC pool, caused by conversion from natural to agricultural ecosystems, is difficult to estimate, it could be close to 80 Pg C (Lal, 1999). In order to prevent such eventualities, there is a growing trend worldwide for the adoption of conservation tillage (CT) systems, which do not use mouldboard ploughing and leave an adequate amount of residues covering the soil after harvesting (Bradford and Peterson, 2000; Gajri et al., 2002; Lahmar, 2010; Lal and Pimentel, 2007). CT has numerous advantages related to soil quality and biodiversity, such as SOC increase at the surface (with the benefits this entails), gas efflux decrease, reduction of soil erosion and less costs because of the lower fuel and labour inputs (Álvaro-Fuentes et al., 2007; Franzluebbers, 2002; Jemai et al., 2012; Kladivko, 2001; López et al., 2012; Madejón et al., 2007).

Among the different modalities of CT, NT is frequently preferred by many farmers as saving operations and fuel. However, there can be some biophysical constraints which indicate that NT is not a panacea, and does not always produce equivalent crop yields in climates with cold springs, sub-optimal soil temperatures, and poorly drained and heavy-textured soils (Lal, 2007). These constraints are frequent in humid temperate regions, where excessive crop residues and wet soils lead to difficulties in soil workability, soil compaction, cooler soil temperatures at seeding and adverse effects on plant growth from residues (Gajri et al., 2002; Hammel, 1995). These constraints, frequently based on inadequate physical properties, can also arise in less humid climates under particular conditions (rainy years, excess of residues, extreme texture), such as that of many Mediterranean areas.

* Corresponding author. Tel.: +34 954624711; fax: +34 954624002.
E-mail addresses: rlopez@irnase.csic.es, rosalopezma@gmail.com (R. López-Garrido).

http://dx.doi.org/10.1016/j.still.2014.02.008

It has frequently been suggested that biological and biochemical variables are the most appropriate indices for detecting soil quality deterioration or improvement (Visser and Parkinson, 1992). In fact, in a long-term experiment conducted by López-Garrido et al. (2012) it was shown that the improvement of the SOC management proxies in a modality of CT (RT) compared to TT over 16 years had very little impact on soil physical properties. The impact of SOC management was better correlated with soil microbial than with the physical properties at the surface. However, when inadequately controlled by a particular management practice, physical properties are absolutely decisive for plant growth and yield, their influence being much more pronounced than that exerted by chemical and biochemical properties.

Thus, the effects of CT systems, NT in particular, can vary consistently over a wide range of soils and climatic conditions (Franzluebbers, 2002; Lal, 1989; Moreno et al., 1997). The dependence of CT on the soil and climatic conditions makes the study of its effects on soil and crop responses necessary for different sites, considering climatic variations between years for a particular scenario (Wilhelm et al., 2004). This is a very important topic from an agronomic point of view where the adoption of NT has led to difficulties in soil workability, forcing farmers to switch to other systems. Taking into account the negative consequences that could result from a very aggressive tillage, in these cases it would be desirable that farmers opt for other modalities of CT that are different from NT, such as ridge tillage or RT (López-Garrido et al., 2011; Melero et al., 2009b; Panettieri et al., 2013). The suitability of some tillage in arable lands under particular conditions has been considered recently by Kirkegaard et al. (2013).

In the present work we have compared crop development and physical, chemical, and biochemical properties in soils under different tillage systems: TT, RT and NT, in a mid-term experiment (over five years) after a period of continuous rains. Under this condition, NT might cause some difficulties for soil workability and crop development derived from the original soil conditions, and, consequently, other tillage options are evaluated.

2. Materials and methods

2.1. Localisation of the experimental area and description of tillage systems

The experiment was carried out under different tillage treatments on a sandy clay loam soil, Entisol (Xerofluvent, Soil Survey Staff, 1999) at the experimental farm "La Hampa" of the "Instituto de Recursos Naturales y Agrobiología de Sevilla (IRNAS-CSIC)" (37°17′ N, 6°3′ W), 13 km southwest of the city of Seville (Spain). Some characteristics of the soil are: pH of around 7.8 (calcareous), alkaline-earth carbonates 280 g kg^{-1}, particle fractions of about 540 g kg^{-1} sand, 210 g kg^{-1} silt, and 250 g kg^{-1} clay, 10 g kg^{-1} SOC and 950 mg kg^{-1} Kjeldahl Nitrogen.

The climate is typically Mediterranean, with mild rainy winters (484 mm mean annual rainfall) and very hot, dry summers. The mean annual daily temperature is 17 °C, with maximum and minimum temperatures of 33.5 °C in July and 5.2 °C in January. The site has an annual average of around 2900 h of sunshine with maximum values of solar radiation exceeding 1000 W/m^2. Environmental data were obtained from the weather station at the experimental farm.

The experiment was established in 2008. Three different tillage treatments were established in a completely randomised experimental design. Three replicates per treatment were established (6 m × 33.5 m, 200 m^2 plots): traditional tillage (TT), reduced tillage (RT) and no-tillage (NT). A tractor with 1.17 m of wheel internal separation was used for field operations in all the treatments. The seed drill had a wheel internal separation of 2.73 m. Traditional tillage consisted of mouldboard ploughing (ca. 25–30 cm deep) and two chisel operations at 25 cm depth (0.57 m separation between chisels) followed by a disc harrowing of 12 cm depth; RT was characterised by a lack of mouldboard ploughing, a reduction in the number of tillage operations (only one chisel operation at 25 cm depth followed by a disc harrowing of 5 cm depth), spraying the plot with pre-emergence herbicides and leaving the crop residues on the surface. NT was characterised by the absence of tillage (only direct drilling), spraying also the plot with pre-emergence herbicides and leaving the crop residues on the surface (Moreno et al., 1997).

CT has been defined as any tillage system that maintains >30% of the soil surface covered with residues from the preceding crops (Gajri et al., 2002). The soil surface area covered by residues in the CT treatments was determined by placing a 10 m cord (marked every 10 cm) diagonally across several rows (Plaster, 1992) and counting the number of marks coincident with some crop residue. This percentage (calculated by the method of Plaster, 1992) was always >30% (in most cases, it was >60%).

All the plots were cultivated under a *Triticum aestivum* L. – *Helianthus annuus* L. – *Pisum arvense* L. crop rotation. Sunflower and pea crops were not fertilised, as is traditional in this area, while wheat received 200 kg ha^{-1} of a compound fertiliser (15N–15P_2O_5–15 K_2O: 60 kg N ha^{-1}, 26.4 P kg ha^{-1}, 49.8 kg K ha^{-1}). NT and RT practices involved leaving crop residues on the surface and spraying the plots with preemergence herbicide (glyphosate at a rate of 4 L ha^{-1}).

The results of this work correspond to the years 2012 and 2013. Sunflower was cropped in 2013. The period from September 2012–April 2013 was very rainy, 526 mm, with a lower total potential evapotranspiration (PET: 455 mm) (Table 1) forcing substantially delayed sunflower planting (early May; the normal period in this area is late February). A hybrid sunflower (cv. Es Topic) was sown in early May with a density of ca. 50,000 seeds ha^{-1}, and harvested in early September 2013.

2.2. Soil sampling

The first soil sampling was conducted in October 2012, five months after the wheat harvest (sown in late 2011). Soil samples were taken at three sites of each individual plot at three depths 0–5, 5–10 and 10–25 cm (a total of three composite samples per treatment and depth). The moist field soil was sieved (2 mm) and divided into two subsamples. One was immediately stored at 4 °C in plastic bags loosely tied to ensure sufficient aeration and to prevent moisture loss before assaying for enzymatic activities. The other was air-dried for chemical analysis.

2.3. Plant sampling

Seedling emergence and plant height were periodically monitored in each treatment. To estimate yields, 16 sunflower heads per treatment were covered with a plastic mesh (5 mm light) to prevent the action of birds. The heads were threshed by hand at 9% seed moisture and the total seeds per head weighed. The seeds were then dried at 70 °C for 24 h to calculate the 1000 seed weight and the oil, fatty acid and nutrient contents.

2.4. Soil chemical and biochemical analysis

The SOC was analysed by dichromate oxidation and titration with ferrous ammonium sulphate (Walkley and Black, 1934). The permanganate oxidisable C (POC), also known as active C (AC), was determined by oxidation with 0.2 M $KMnO_4$ in 1 M $CaCl_2$ (pH 7.2), and non-reduced Mn^{7+} was colorimetrically determined at 550 nm