Soil & Tillage Research 183 (2018) 83–92

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Mid-long term effects of no tillage and Ca-amendment on degraded acid soils under contrasting weather conditions

Chiquinquirá Hontoria[a,*], Clara Gómez-Paccard[a], Eduardo Vázquez[a], Ignacio Mariscal-Sancho[a], Rafaela Ordónez-Fernández[b], Rosa Carbonell-Bojollo[b], Rafael Espejo[a]

[a] *Departamento de Producción Agraria, ETS Ingeniería Agronómica, Alimentaria y de Biosistemas, Universidad Politécnica de Madrid, Avda. Puerta de Hierro, no 2-4, 28040 Madrid, Spain*

[b] *Área de Agricultura y Medio Ambiente, Centro IFAPA "Alameda del Obispo", Apdo. 3092, Córdoba 14080, Spain*

A R T I C L E I N F O

Keywords:
Conservation agriculture
Soil quality
Degraded ultisols
Mediterranean climate

A B S T R A C T

Inadequate soil management such as excessive ploughing is one of the main problems affecting the sustainability of agroecosystems and may exacerbate problems in acid soils. The application of Ca-amendments to ameliorate acid soils and no tillage practices to recover degraded soils are common management strategies. However, few studies have focused on their interactive effects under conditions of variable rainfall. In this study, we assessed the changes in soil properties over a period of seven years in response to no tillage (NT) and tillage, with or without the application of a Ca-amendment (sugar beet foam and red gypsum). Our split-plot experiment, which started in 2005 was carried out in a degraded Palexerult in Southwestern Spain with an annual rainfed forage crop. The Ca-amendment increased soil pH, Ca content and ameliorated Al-toxicity down to a depth of 50 cm, even under NT, due to the relatively high solubility of the amendment. However, after seven years of experiment, soil organic matter variables were enhanced only to a soil depth of 0–5 cm: NT and the Ca-amendment increased total organic carbon by 31% and 25%, respectively, whereas particulate organic carbon was increased to a larger extent (by a factor of 2.5 and 2, respectively). The positive effect of NT on organic matter variables increased with time, whereas the beneficial effect of the Ca-amendment was stronger in the early years of the experiment. Adverse weather conditions, with either excessive precipitation in autumn-winter or scarce precipitation in spring, favoured biomass production under NT. Given that NT mitigated the adverse effects of both water excess and deficit on biomass, it constitutes a valuable tool to combine with Ca-amendment to maintain crop productivity and recover degraded acid soils. This is especially the case under the changing weather conditions of a Mediterranean climate or other climates with increasing occurrences of periods of drought and/or water excess.

1. Introduction

The degradation of soil quality due to intensive ploughing is one of the main problems affecting the sustainability of rainfed agriculture. In the case of acid soils, the use of traditional tillage (TT) increases the soil degradation due to: i) the extraction of bases from the soil and the corresponding increase in acidity and Al^{3+} toxicity as a result of harvesting crops without leaving crop residues in the field (Tang and Rengel, 2003); and ii) the decrease of soil organic matter (OM) by tillage (Six et al., 1999). Given that OM tends to form stable non-toxic complexes with Al^{3+}, the reduction of OM aggravates the problems of excessive acidity (Brown et al., 2008). In addition, the reduction of OM content adversely affects many soil properties that contribute to soil quality (Doran and Parkin, 1996).

Ca-amendments, through the enhancement of biomass production as a result of reduced Al^{3+} toxicity and increased nutrient supply (Haynes and Naidu, 1998), generally promote higher soil C inputs resulting in OM accumulation (Briedis et al., 2012; Da Costa and Crusciol, 2016). This effect, however, may be offset by microbial enhancement and increased respiration rates leading to increased mineralization (Ekeuler and Tabatabai, 2003; Leifeld et al., 2013) and OM depletion after liming (Chan and Heenan, 1999; Kowalenko and Ihnat, 2013). However, some studies have found no variation in OM with the Ca-amendment (Garbuio et al., 2011; Manna et al., 2007). These contradictory results demonstrate the need for more field research under different environmental conditions to clarify the net effect of Ca-amendments on OM (Paradelo et al., 2015).

On the other hand, no tillage (NT) soil management favours the

* Corresponding author.
E-mail address: c.hontoria@upm.es (C. Hontoria).

https://doi.org/10.1016/j.still.2018.06.002
Received 21 December 2017; Received in revised form 11 June 2018; Accepted 12 June 2018
0167-1987/

accumulation of OM (West and Post, 2002; Aguilera et al., 2013), especially in certain fractions, such as particulate organic matter (POM) (Bayer et al., 2002), which is closely related to soil fertility (Salas et al., 2003). However, the beneficial effect of NT on OM content depends on time, climate, soil, crop and other environmental factors (Soane et al., 2012), as well as the management and amount of crop residues (Imaz et al., 2010).

In the Mediterranean area, the weather conditions are very variable with alternating periods of drought and excessive rainfall affecting biomass production. This variability may hinder the assessment of the effects of management factors, but at the same time offers the opportunity to evaluate treatments under a variety of contrasting weather conditions that may occur during a long term study. Thus, mid and long-term studies are necessary in order to evaluate how Ca-amendment and the tillage system are influenced by weather conditions as well as their evolution over time.

Ultisols from old surfaces ("Raña") of SW Spain that were formed in the Middle-Upper Pliocene with a subtropical climate (Espejo, 1987) are representative of degraded acid soils resulting from excessive ploughing. Following the clearing of the natural vegetation during the first thirty years of the 20th century, the use of TT led to major losses of OM and soil degradation. The uptake by crops of Ca in the exchange complex increased the Al/Ca ratio in soil, worsening the problems caused by excessive acidity and toxicity (Noble et al., 1988), thereby reducing productivity and finally leading to abandonment (Mariscal-Sancho et al., 2009). Reclaiming these degraded acid soils requires the use of a liming amendment to raise pH and alleviate Al toxicity, as well as the application of conservation practices such as NT in order to build OM stocks.

The objectives of this study were to assess: i) the evolution in the mid-long term of selected indicators related to soil acidity as well as OM variables as a result of the tillage system (NT vs. TT) and Ca-amendment, and ii) the effect of treatments on the biomass production under variable Mediterranean weather conditions. Tillage systems with and without a Ca-amendment were applied for seven years and soil variables were measured every other year. Biomass production together with weather conditions were assessed each year. Our hypotheses are that: i) the combination NT + Ca-amendment will increase soil OM and alleviate soil acidity; ii) the enhanced soil properties will lead to an overall increase in the biomass production; and iii) the effectiveness of the treatments increasing biomass production will be affected by the specific weather conditions of each year.

2. Materials and methods

2.1. Experimental site and design

The experimental field (39°19′ 7.1″N, 5°19′ 33.1″ W) was located in the Cañamero's Raña (SW Spain), a glacis–piedmont plateau that occupies a very large flat area. According to Soil Taxonomy (USDA, 2014), the soils are plinthic Palexerults. They have a low pH that decreases with depth, an exchange complex that is dominated by Al and a low content of exchange bases. Kaolinite is the dominant mineral in the clay fraction. Non-porous quartzite rock fragments are frequent to abundant throughout the soil profile (Espejo, 1987). Selected properties of a representative soil profile are showed in Table 1.

According to the Köppen classification, the climate of the area is temperate with dry and hot summer (Csa). Temperature and precipitation data (period 1996–2012) were taken from the meteorological station Cañamero-El Pinar, 2.5 km far from the experimental field (Table 2). Mean annual precipitation is 856 mm, with the lowest mean monthly precipitation during July and August (6.0 and 10.7 mm, respectively) and the highest from October to January (121.6, 108.8, 126.4 and 113.4 mm, respectively). Monthly precipitation had high inter-annual variability during the study. Data for the growing seasons of the seven studied years are presented in Table 3. Mean annual temperature is 15.3 °C, with January having the lowest mean monthly temperature (6.2 °C) and August having the highest (25.2 °C). Evapotranspiration data (Penman–Monteith, period 2007–2017) were taken from the Guadalupe meteorological station located 12 km from the experimental field. Mean annual evapotranspiration is 1365 mm, with the lowest value in December (30.4 mm) and the highest in July (234.2 mm).

The study area was cropped and tilled from 1940 to 1990, and then abandoned due to the declining productivity. A natural pasture, degraded by overgrazing, with isolated specimens of *Halimium ocymoides* (Lam.) Willk. and *Cistus ladanifer* L., became established and the soil remained undisturbed for 15 years (Mariscal-Sancho et al., 2009; Gómez-Paccard et al., 2015).

The experiment was established in autumn 2005 following a block design in a split-plot arrangement consisting of four replicates with individual plots of 4 m × 16 m. The main factor was tillage system: no-tillage (NT) and traditional tillage (TT), with Ca amendment (A) or without Ca-amendment (NA) as the second factor. Soil management in the tilled plots consisted of two passes with a cultivator to 20 cm depth, one after the first rains of September and the other before sowing (October–November), followed by a pass with a power tiller. This replicates the traditional tillage in the area except for the power tiller, which replaces a disc harrow. In the NT plots, glyphosate (36% purity) was applied at a rate of 2.5 L ha^{-1} for weed control prior to seeding. The experimental field was protected from the influence of sheep, deer and wild boar (frequent in the area) by a wire fence.

The Ca-amendment consisted of a mixture of 3.9 Mg ha^{-1} of sugar beet foam plus 7.5 Mg ha^{-1} of red gypsum (RG). In order to balance the Ca/Mg ratio, 100 kg ha^{-1} of MgO from dolomitic converter basic slag (CBS) as well as100 kg $ha^{-1}$of MgO, in the form of $MgSO_4$, were added. The main components of the sugar beet foam were calcium carbonate equivalent (765 g kg^{-1}) and CaO (437 g kg^{-1}), with 213 g kg^{-1} of easily soluble calcium carbonate. The RG mainly contained SO_4^{2-} (465 g kg^{-1}) and CaO (231 g kg^{-1}) whereas the CBS contained 401 g kg^{-1} MgO and 395 g kg^{-1}CaO (detailed compositions can be found in Gomez-Paccard et al., 2013). The Ca-amendment was incorporated into the top 0–7 cm layer with a power tiller in September 2005 once at the beginning of the experiment. All plots were sown with a mixture of *Avena sativa* L. (57%), *Triticosecale* Wit. (17%) and *Vicia sativa* L. (26%) at a rate of 140 kg ha^{-1}. This type of forage mixture is common for animal feed production. In 2009–2010, *Brassica napus* L. was sown to test its viability in the area. Seeding was carried out each autumn using a direct drill seeder. Every year 36 kg N ha^{-1}, 92 kg P $ha^{-1}$and 92 kg K ha^{-1} were added to all plots in autumn, except in 2009–2010 when the N dose was modified and 70 kg N ha^{-1} were added in autumn plus another 70 kg N ha^{-1} in spring. Each year at the beginning of June, the crop was manually harvested at a height of 20 cm above ground.

2.2. Soil and biomass sampling and laboratory methods

Soil sampling was carried out in 2006, 2008, 2010 and 2012 which correspond to the 1st, 3rd, 5th and 7th years of the experiment, respectively. Each September, before the TT plots were ploughed, three disturbed soil samples were collected for soil analysis from 0 to 5, 5–10, 10–25, and 25–50 cm depths from each plot. Bulk samples from each plot and depth were thoroughly mixed, air-dried and passed through a 2 mm sieve. Soil subsamples were analysed for pH, Al^{3+}, extractable bases (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), total organic carbon (TOC) and particulate organic carbon (POC) (the last two were measured up to a depth of 25 cm). Soil pH was determined in de-ionized water (1:2.5 soil/water ratio). The Al^{3+} in samples (denoted Al in the text) were extracted with 1 M KCl and determined by titration (Soon, 1993). Base cations Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} (denoted Ca, Mg, Na and K in the text) were extracted with ammonium acetate at pH 7 and then determined by atomic absorption spectrophotometry. We do not refer to these bases as exchangeable bases because part of the measured Ca and Mg could come