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Seasonal variation of microbial activity as affected by tillage practice and sugar beet foam amendment under Mediterranean climate

Eduardo Vazquez[a,*], Nikola Teutscherova[a,b,*], Javier Almorox[a], Mariela Navas[a], Rafael Espejo[a], Marta Benito[a]

[a] Departamento de Producción Agraria, Escuela Técnica Superior de Ingeniería Agronómica, Alimentaria y de Biosistemas, Universidad Politécnica de Madrid, Avda. Puerta de Hierro, E-28040 Madrid, Spain

[b] Department of Crop Sciences and Agroforestry, Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague, Kamýcka 129, Prague 6-Suchdol, 16500, Czech Republic

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ABSTRACT

Enhancement of soil organic matter content by no-tillage practice and alleviation of soil acidity by Ca-amendment application has been recognized as important strategies to combat soil degradation. Based on the limited information about possible interactions between the two commonly used techniques, the aim of this study was (1) to evaluate the long-term effect of no-tillage and Ca-amendment on soil biological activity in a split-plot design established on degraded acid soil in SW Spain, and (2) to analyze the microbial activity fluctuation during a year in a Mediterranean climate with marked seasonality. The studied treatments included traditional tillage without Ca-amendment application (TT), no-tillage without Ca-amendment application (NT), amended traditional tillage (TT-A) and amended no-tillage (NT-A). The used Ca-amendment was the mixture of sugar beet foam (SF) and red gypsum (RG). A refresh dose of Ca-amendment was applied in October 2014 and was incorporated into the soil in the TT plots and let on soil surface in NT. Soil samples were collected in January, April, July and October 2015. The Ca-amendment increased the soil pH and the dehydrogenase, β-glucosidase and acid phosphomonoesterase activity, but decreased microbial biomass carbon (MBC), probably as a result of the neutralizing effect on soil pH. The pH rise was also linked with the increase of microbial biomass nitrogen (MBN) and could be interpreted as a shift in the microbial population. The long-term effect of NT led to a higher organic carbon accumulation in the top soil layer which maintained higher soil moisture content during the water deficient months. The higher availability of organic carbon and the amelioration effect of NT to extreme conditions in the previous months increased the enzymatic activities, MBC, MBN and basal respiration in the NT plots, especially in July when the soil moisture was minimal and temperatures were high. The combination of both treatments did not show any significant synergistic interaction in any biological parameter. Therefore, we can evaluate the application of Ca-amendment on soil surface in NT fields as feasible alternative to lime application and incorporation from the biological point of view. In addition, the less extreme drought conditions in the NT plots and the consequent higher microbial activity during the summer can be considered as a strategy to increase the biological soil resistance against the drought events in the scenery of climate change. The variable response of the different agricultural practices to climate fluctuation should be included in future research in order to evaluate the response of biogeochemical cycling and organic matter dynamics to predicted future climate change.

Abbreviations: ASase, arylsuplhatase; BR, basal respiration; DHase, dehydrogenase; EAs, enzyme activities; Glm, glucosaminidase; Gls, glucosidase; GWC, gravimetric water content; GWC3m, mean gravimetric water content for the three months period prior sampling; RG, red gypsum; MBC, microbial biomass carbon; MBN, microbial biomass nitrogen; NT, no-tillage; PCA, principle components analysis; PHase, phosphatase; POxCp, ermanganate oxidizable carbon; SF, sugar beet foam; SOC, soil organic carbon; SOM, soil organic matter; TT, traditional tillage

* Corresponding authors at: Departamento de Producción Agraria, Escuela Técnica Superior de Ingeniería Agronómica, Alimentaria y de Biosistemas, Universidad Politécnica de Madrid, Avda. Puerta de Hierro, Madrid, E-28040, Spain.

E-mail addresses: eduardo.vazquez@upm.es (E. Vazquez), nikola.teutscherova@upm.es (N. Teutscherova).

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1. Introduction

Unsuitable agricultural practices during the last decades aggravated the risks of soil degradation and soil erosion in many Mediterranean areas (García-Ruiz, 2010). The continuous and intensive tillage of agricultural soil has caused great losses of soil organic carbon (SOC), degradation of the physical properties and decrease of soil biological activity and soil fertility (Moreno et al., 2010). Soil degradation and the variability in distribution of the precipitations during the cropping season is the main cause of the low profitability of rainfed cereal cultivation under Mediterranean climate. The adoption of no tillage (NT) instead of the traditional tillage (TT) practices has been demonstrated to be an efficient alternative capable to increase SOC, restore soil physical, chemical and biogeochemical properties and enhance the water use efficiency (Bescansa et al., 2006; Fernández-Ugalde et al., 2009; Alvaro-Fuentes et al., 2014; López-Garrido et al., 2014).

The ancient soils of the Cañamero's raña, located in SW Spain, has been degrading rapidly since the elimination of natural vegetation in the 1940s by the action of the unsustainable agricultural practices carried out during the following decades (Mariscal et al., 2007). The continuous tillage decreased the soil organic matter (SOM) content and accelerated soil acidification and Al^{3+} solubilization, which further reduced soil fertility. The restoration of these soils requires the combination of soil conservation techniques to increase the SOM content and the application of amendments rich in calcium (Ca-amendment) to raise the soil pH and reduce the Al toxicity. An experiment on raña surface was established in 2005 aiming to test the combined effect of NT and the application of Ca-amendment on soil properties and crop yield. For the pH increase, the combined application of sugar beet foam (SF), a residue resulting from the purification–-flocculation of colloid matter from the liquor extracted from sugar beet, and red gypsum (RG) were selected. The SF obtained in this process is a pathogen-free material rich in $CaCO_3$ and organic matter (Peregrina-Alonso, 2005) and its management forms an additional costs to the sugar beet producers. The previous results obtained from this field trial showed that the combination of NT and the Ca-amendment increased the SOM content and reduced the Al toxicity (Gómez-Paccard et al., 2013), enhanced soil aggregation (Hontoria et al., 2016) and improved soil-water relationship (Gómez-Paccard et al., 2015), which promoted the improvement of crop yields.

Although the effects of NT and Ca-amendment on soil microbiology have been largely reported individually (Inagaki et al., 2016; Madejón et al., 2009; Mijangos et al., 2010; Martín-Lammerding et al., 2015; Tabatabai, 2000), less attention is paid to the combination and interactions between both agronomic techniques. Generally, the accumulation of SOM and labile fractions of C caused by the NT increase the enzymes activities (EAs) and the microbial biomass of the Mediterranean soils where the semi-arid conditions limit the SOM accumulation under TT (Madejón et al., 2009). Moreover, the application of Ca-amendment to acid soils and the pH raise has shown to increase the activity of most of the enzymes involved in the carbon (C), nitrogen (N), phosphorus (P) and sulfur (S) cycle (Tabatabai, 2000). However, in the studies where both treatments were combined, their potential interaction in the soil microbiology was only partially found and did not show any clear pattern (León et al., 2017; Tabatabai, 2003).

A better understanding of the possible interactions between both practices and their effect on soil biological activity should be considered as fundamental on the scenery of global climate change. More intense, frequent and longer droughts together with heat waves may occur in the future in south-western Spain (Varela-Ortega et al., 2016), which could affect the microbial biomass and the soil EAs involved in the C, N or P cycle (Acosta-Martínez et al., 2014a, 2014b; Bérard et al., 2011; Sardans et al., 2008). Furthermore, this response of the ecosystems to the heat waves and drought will depend on soil management history (Hou et al., 2016). Many studies have shown the positive effect of NT on soil moisture in semiarid conditions maintaining higher soil water contents during dry periods (Bescansa et al., 2006; De Vita, 2016). In the same line, the NT promotes the accumulation of crop residues on the soil surface which reduces soil temperature during the summer months (Dahiya et al., 2007). This amelioration of the extreme conditions could reduce the stress of soil microorganisms and lead to higher EAs during the summer periods. Moreover, the expected increase of the EAs caused by Ca-amendment could lead to the multiplication of the enhancing effects of NT on EAs and alteration of the SOM dynamics and biogeochemical nutrient cycles.

The main objectives of the present study were (1) to evaluate the long-term effect of no-tillage and Ca-amendment on soil biological activity in an experimental plot established in 2005 on degraded acid soil in SW Spain, and (2) to analyze the microbial activity fluctuation during a year in a Mediterranean climate with marked seasonality. We hypothesize that the studied biological parameters will be affected by soil properties changes produced by the different agricultural practices and that those changes will interact with the seasonality of the Mediterranean climate and will vary throughout the year.

2. Materials and methods

2.1. Study site and experimental design

The experimental plots were established in 2005 on detritic formation of Cañamero's raña in SW Spain. The climate in the area is temperate with dry and hot summer (Csa according to Köppen climate classification) and the historical precipitation and mean temperature of the near Guadalupe station are shown in Fig. 1. The soil was formed under subtropical climate in middle Pleistocene (Espejo, 1987) and is classified by Soil Taxonomy as Typic Palexerult. It is characterized by Al-dominated exchange complex, low pH, low content of exchangeable bases and high content of rock fragments (Espejo, 1987).

The experiment was designed as split-plot design with four replicates and two factors giving 16 plots in total, each with the area of 64 m^2 (4 m × 16 m). The studied factors are tillage (traditional tillage vs. no-tillage) and Ca-amendment application (amended vs. not-amended). Therefore, all the treatments included are: traditional tillage without Ca-amendment application (TT), no-tillage without Ca-amendment application (NT), amended traditional tillage (TT-A) and amended no-tillage (NT-A). The Ca-amendment used in the study is the mixture of SF, by-product of sugar beet industry, and RG (Table 1). The co-application of these two products resulted favorable because of

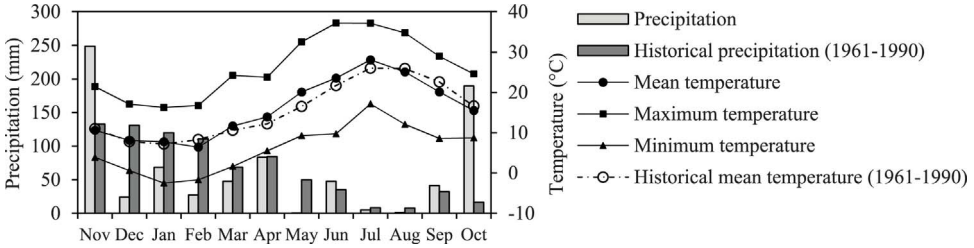

Fig. 1. Precipitation, minimum temperature, maximum temperature and mean temperature for the study period (2014–2015) and the historical data of precipitation and mean temperature for the period 1961–1990. Data obtained from Guadalupe meteorological station.