Applied Soil Ecology 109 (2017) 69–74

Contents lists available at ScienceDirect

Applied Soil Ecology

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

No tillage and sugar beet foam amendment enhanced microbial activity of degraded acidic soils in South West Spain

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ARTICLE INFO

Article history:
Received 6 June 2016
Received in revised form 13 September 2016
Accepted 14 September 2016
Available online xxx

Keywords:
Acid soil
Ca-amendment
No tillage
Microbial activity
Soil enzyme activity

ABSTRACT

Ca-amendments are commonly applied to improve acid soils, whilst no-tillage (NT) has been widely recommended in soils where conventional tillage (CT) has led to losses of organic matter. However, the potential interactions between the two treatments are only partially known. Our study was conducted on a degraded soil located in SW Spain, in order to assess if the combination of Ca-amendment plus crop-tillage provides long term soil amelioration on microbial activity. To this end the effects of four different combinations of Ca-amendment and crop-tillage on selected key soil microbial properties were analyzed. The experimental design was a split-plot with four replicates. The main factor was the application or not of a Ca-amendment, sugar foam (SF) and control (C), and the second factor was crop-tillage, no tilled improved pasture (no tilled-IP) and conventional tillage forage crop (tilled-FC). Soil samples were collected from 2 soil depths after 7 years since the first SF application and after 1 year from a repeated SF application. The use of the Ca-amendment meant a higher pH although this effect was not found in the combination Ca-amendment plus no-tilled. Total organic carbon (TOC) was highly influenced by tillage, being higher for no tilled plots. The interaction found between tillage and amendment suggested that the beneficial effect of the Ca-amendment on organic carbon is lost after tillage practices. A positive effect on microbial biomass carbon (MBC) was found after a second SF application for the no tilled plots in the upper layer however the effect was opposite in the deepest layer where no differences in TOC were found. After a year from a repeated SF application, a clear positive effect of no-tilled was observed on β-glucosidase, β-glucosaminidase and urease activities at the superficial layer. This fact was not found in these enzymatic activities when the amendment application effect was studied but an interaction between tillage and amendment showed that the Ca-amendment plus no-tilled combination was the most favorable option to increase the activities of these enzymes. Values of dehydrogenase were higher in amended plots than in control for both soil depths regardless of the sampling date, showing a pH effect on its activity. From our findings, no tillage plus a Ca-amendment appears to be the most suitable choice for ensuring suitable production, through the accumulation of soil organic matter (SOM) and the improvement of biological properties.

1. Introduction

Soil degradation caused by intensive agriculture leads to reduction of soil fertility due to changes in physical and chemical soil properties, as well as in microbial activity. In acidic soils, where the main constraints for crop production are Al toxicity and Ca^{2+} deficiency (Kochian et al., 2005), with the most apparent effects being reduced root and shoot growth (Menzies, 2003), traditional tillage and reduced SOM can further aggravate the limiting conditions for plant growth through reduced nutrient content and microbial activity, and also reduced soil buffering capacity.

Abbreviations: SF, sugar foam; C, control; No tilled-IP, no tilled Improved pasture; Tilled-FC, forage crop; OM, organic matter; RF, rock fragments (>2 mm, mainly 2–30 cm); nd, not determined; ND, not detected; TOC, total organic carbon; TN, total nitrogen; MBC/TOC, microbial biomass carbon/TOC; Gls, β-glucosidase activity; DHA, dehydrogenase activity; Glm, β-glucosaminidase activity; Ure, urease activity; U, soil use; A, soil amendment; ***, correlation is significant at the 0.001 level; **, correlation is significant at the 0.01 level; *, correlation is significant at the 0.05 level; ns, not significant.

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http://dx.doi.org/10.1016/j.apsoil.2016.09.012
0929-1393/

This is the case of the ancient Ultisols in the Cañamero's raña surface, located in SW Spain, where land use change from natural vegetation to intensive rye, vetch, cereal vineyards and olive cultivation, has caused SOM depletion, accelerated acidification and increased Al solubilisation. In a study conducted by Gómez-Paccard et al. (2013), the combination of no tillage (NT) with a Ca-rich soil amendment has proven to be a suitable management to recover soil quality of the Cañamero's raña soil, with SOM accumulation playing a major role in improving soil chemical properties. In particular, the amendment induced neutralization of the soil pH value and reduced the Al toxicity and NT allowed to increase the particulate organic carbon (POC), TOC and glomalin content in the soil surface layer. Concomitantly, lime provides Ca^{2+} and generates OH^- ions that neutralize the acidity, leading to precipitation of Al and Fe as insoluble Al^- or Fe hydroxides. Buffering capacity is one of the most important soil properties that can be changed by incorporation of various organic and inorganic amendments, including crop residues, compost, manures, sludge or lime. Traditionally, lime has been used to buffer excessive soil acidity, but the pressing need to reduce the environmental impact of agronomic practices and to maximize waste recycling in the perspective of a circular economy in the agro-ecosystems, has encouraged scientists and farmers to test different industrial by-products as alternative liming agents. Sugar beet foam (SF) results from the purification-flocculation of colloid matter from the liquor extracted from sugar beet. In this process, slaked lime and carbon dioxide are used to purify the liquors and after filtering, a by-product rich in CaCO3 and organic matter is obtained. The annual production of SF in Spain is around 300.000 T on average (Peregrina-Alonso, 2005). This by-product is considered free of pathogens because the temperature reaches 90 °C during the process. SF acts preferentially on the surface horizons when applied to soil and it has been proven to be effective in neutralizing the excessive acidity of soils in several studies (Garrido et al., 2003; Vanderlinden et al., 2006; Gómez-Paccard et al., 2013).

Microbial biomass and enzymatic activities are reduced by soil acidification mainly through the negative selection of acid-sensitive microorganisms (Rousk et al., 2010a, 2010b), and by inhibition of enzymes with pH optima in the neutral alkaline pH range (Renella et al., 2007a) which limits SOM decomposition and nutrient mineralization. Significant increase of soil microbial biomass and microbial diversity in acidic soils by organic manure, mineral fertilizers, and man-guided revegetation has been reported (Fuentes et al., 2006; Mabuhay et al., 2006; Deng et al., 2010; Xu et al., 2010).

Remediation of acidification requires the use of amendments capable of raising the soil pH value. Reclamation of acidic infertile soils through different conservation and amendment practices improves soil biological fertility by increasing microbial biomass and enzymatic activity, which are beneficial to plant growth and crop production. Minimum or zero tillage also increase soil microbial biomass and enzymatic activities of degraded soils (Acosta-Martínez et al., 2003; Fuentes et al., 2006), but the potential effectiveness of this conservative practice in combination with liming agents on microbial biomass and enzymatic activities of acidic soils, is still poorly understood. We hypothesized that combination of no tillage and sugar beet foam amendment could have the potential to restore chemical fertility and increase microbial biomass and enzyme activities of a degraded acidic soil. We tested the working hypothesis by analyzing soils from a field trial established in 2002 on soils from the Cañamero's raña, characterized by low SOM content and P availability, and Al toxicity (Espejo and Cox, 1992). Information on the potentials of the adopted management can be useful as a model for soil reclamation of the Spanish 'raña', furthermore considering the large amount of SF produced worldwide, which does not find any sustainable use and must be disposed, with additional expense by the beet industry. Because the neutralization effects of organic amendments on soil pH value depend not only on its alkalinity but also on its N content and N mineralization processes, the positive effects of SF amendment of the Cañamero raña soil, long-term depend on both soil buffering capacity and intensity of N turnover. Inorganic N availability in soil is regulated by the rate of organic N mineralization (e.g. soil organic matter, crop residues, manure, chitin), catalyzed by extracellular enzymatic activities such as urease and glucosaminidase that release inorganic N from urea and amino-sugars, from which N is rapidly mineralized to inorganic N (Gooday 1994). Urease and glucosaminidase activities are influenced by soil physico-chemical properties and soil management and are generally inhibited by acidic soil pH values (Wang et al., 2003). Because an increase of N-mineralizing enzyme activity can result in soil acidification, the importance of the present study relies on the fact that we assessed both the effects of the SF alkalinity and of enzymes involved in N turnover to understand the potentials of long term beneficial effects of SF on pH and fertility of the Cañamero raña soil.

2. Materials and methods

2.1. Experimental site and agronomical management

The study was conducted on an experimental plot established in 2002 in the Cañamero's Raña (39°22′–39°17′, 5°21′ N -5°16′, E) where soils are located 580 m a.s.l. on a longitudinal slope (<1%). Based on Köppen classification, the climate of the area is moist Mediterranean (Csa), with mean annual temperature of 15.0 °C, annual precipitation of 870 mm, and Penman-Monteith evapotranspiration rate of 1248 mm.

Soils of the Cañamero's Raña area are classified as clay-skeletal, kaolinitic, acid, thermic Plinthic Palexerult. Soil pH values are in the range 5.1–5.3 in the top 5 cm and 4.4–4.6 at 15 cm depth. Soils have low content in exchangeable bases, Al-dominated exchange complex, low bioavailable P and high content in rock fragments (Espejo and Cox, 1992; Gómez-Paccard et al., 2013). Main chemical and physical properties are showed in Table 1.

The long term effects of sugar foam (SF) on the properties of the Cañamero's Raña soil was tested with a field experiment established in 2002. The SF amendment was applied at rate of

Table 1
Physico-chemical properties of the soil.

Horizon (cm)	SOM ($g\,kg^{-1}$)	pH H_2O	pH KCl	Al^{3+} ($cmol_c\,kg^{-1}$)	Exchangeable base cations Ca^{2+} ($cmol_c\,kg^{-1}$)	Mg^{2+}	Na^+	K^+	RF[a] (%)	Texture Sand (%)	Silt	Clay
Ap (0–25)	33.8	5.3	4.3	0.76	1.12	0.21	0.05	0.65	52	80.1	6.1	13.8
Ab (25–35)	15.9	5.0	4.0	1.01	0.85	0.16	0.04	0.08	47	69.1	5.6	25.3
Bt (35–90)	2.5	4.9	3.7	1.75	0.82	0.11	0.03	0.07	56	59.9	4.7	35.4
Btv (90–200)	nd	4.6	3.4	2.23	1.12	0.1	0.05	0.06	75	56	5.1	38.9

[a] RF = rock fragments (>2 mm; mainly 2–30 cm).