Agriculture, Ecosystems and Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Rational application of treated sewage sludge with urea increases GHG mitigation opportunities in Mediterranean soils

M.E. Calleja-Cervantes[a,*], P.M. Aparicio-Tejo[a], P.J. Villadas[b], I. Irigoyen[c], J. Irañeta[d], A.J. Fernández-González[b], M. Fernández-López[b], S. Menéndez[e]

[a] Department of Natural Environmental Sciences, Public University of Navarre, Edificio Departamental de los Olivos, Campus Arrosadía, E-31006 Pamplona, Spain
[b] Department of Soil Microbiology and Symbiotic Systems, Estación Experimental del Zaidín, Consejo Superior de Investigaciones Científicas, Granada E-18008, Spain
[c] Department of Agricultural Production, Public University of Navarre, Edificio Departamental de los Olivos, Campus Arrosadía, E-31006 Pamplona, Spain
[d] INTIA, ITG Divison, E-31610 Villava, Spain
[e] University of the Basque Country, UPV/EHU, Department of Plant Biology and Ecology, Apdo. 644, Bilbao, Bizkaia E-48080, Spain

ARTICLE INFO

Article history:
Received 16 February 2016
Received in revised form 29 August 2016
Accepted 19 September 2016
Available online xxx

Keywords:
GHG emissions
Soil enzymes
Bacterial diversity
16s
Fertilization
Mediterranean soils

ABSTRACT

Mediterranean soils, which are carbonate-rich and organic matter-poor, are prone to erosion and important carbon losses due to seasonal changes associated with dry summers and wet winters. The use of thermophilic digested sewage sludge (TSS) in these agricultural systems, as a soil amendment, has been acknowledged as an interesting way to supply organic matter and nutrients. Data on the long-term evaluation of TSS applied to Mediterranean soils are scarce. Moreover, the effect of the application is unpredictable because of the intrinsic variation in the TSS. The scope of this study was to determine whether the continued application of TSS for 20 years leads to increased carbon sequestration in the soil without affecting emissions of greenhouse gases.

To conduct this evaluation, the doses applied since 1992 have been as follows: 40 t ha^{-1} and 80 t ha^{-1} every year, and 40 t ha^{-1} every 3 years, plus annual mineral N fertilization depending on the crop. A control without TSS or mineral fertilization and a treatment with only mineral N fertilizer were also evaluated. In this case, urea was used as the mineral treatment. The TSS doses were applied annually in October, while the mineral was split into one dose around January and another in March. The chemical parameters, greenhouse gas emissions, nitrate and ammonium concentrations of the soil were measured during the crop cycle. The bacterial community and enzymes in the soil were surveyed 15 days after the last annual application and at harvest. Fifteen days after fertilization with TSS and urea, nitrification and denitrification potentials were measured.

The 80 t ha^{-1} yr^{-1} dose yielded the most significant increase in total carbon, organic matter content, P_2O_5, and total nitrogen. This same treatment significantly increased GHG emissions for all gases concerned. Similar results were found in the 40 t ha^{-1} 3yr^{-1} and urea for CO_2 and CO_2eq ha^{-1}. TSS application increased soil enzyme activities. According to the microbial diversity results, 80% of the DNA sequences corresponded to 6 main phyla: (from most to least) Proteobacteria, Acidobacteria, Actinobacteria, Bacteroidetes, Chloroflexi and Verrucomicrobia with unclassified material making up an average 10.94% of the sequences. The soil microbial community structure only altered with the 80 t ha^{-1} yr^{-1} dose. The highest dose of TSS applied in this study resulted in the irreversible lodging of the crop and a concomitant decrease in yield.

In the 40 t ha^{-1} 3yr^{-1} treatment, interesting similarities were found with urea alone. In summary, rational application of TSS, such as 40 t ha^{-1} 3yr^{-1} dose, along with urea, trigger a beneficial increase in

Abbreviations: C, carbon; Ca, calcium; $CaCO_3$, calcium carbonate; CCA, canonical correspondence analysis; CH_4, methane; CO_2, carbon dioxide; d, day; DNA, deoxyribonucleic acid; DW, dry weight; ECD, electron capture detector; FID, flame ionization detector; FW, fresh weight; GC, gas chromatography; GHG, greenhouse gas; H′, Shannon-Weaver index; ha, hectare; K, potassium; kg, kilogram; M, molar; mg, milligram; Mg, magnesium; $MgCl_2$, magnesium chloride; N, nitrogen; N_2O, nitrous oxide; Na, sodium; NH_3, ammonia; NH_4, ammonium; NO_3, nitrate; OM, organic matter; OTUs, operational taxonomic units; P, phosphorus; PCoA, principal component analysis; PCR, polymerase chain reaction; RDP, ribosomal database project; rRNA, ribosomal ribonucleic acid; TSS, treated sewage sludge; UPGMA, unweighted pair group method with arithmetic mean; w/w, weight/weight; yr, year.

* Corresponding author.
E-mail addresses: maren.calleja@unavarra.es, tlallihuacan@gmail.com (M.E. Calleja-Cervantes).

http://dx.doi.org/10.1016/j.agee.2016.09.021
0167-8809/

microbial activity in soil, that ultimately activates soil metabolism and enhances carbon sequestration possibilities, while GHG emissions remain at the same level as with urea alone. The results support the hypothesis that TSS can induce carbon sequestration without increasing GHG emissions. TSS has proven to exert beneficial outcomes under Mediterranean conditions; additionally, its application offers a viable opportunity for converting this by-product into a fertilizer. However, application rates must be adjusted or it should be used together with mineral fertilization.

1. Introduction

Technological developments have led to important waste water sanitization rates, but collateral residues or by-products are still generated. One such by-product is sewage sludge (SS). Supplementary treatments, such as thermophilic anaerobic digestion, ensure that any potential biological hazards are minimized or removed from the SS. Thermophilic anaerobic digestion (TSS) is an adequate way to remove unpleasant smells, sanities SS and, to a lesser extent, stabilize the generated organic matter. Considering that TSS contains high proportions of organic matter and plant nutrients, applying it agriculturally as a soil amendment or fertilizer is a common practice (Wang, 1997). The physical, chemical and biological properties of soils are positively modified after TSS application; plants are provided essential nutrients and waste recycling is promoted (Singh and Agrawal, 2008). However, regional assessments of long-term application and extreme application rates should be conducted (Paramasivam et al., 2008) to explore the limitations of TSS application to soil, as there are important associated environmental risks (Roig et al., 2012).

Applying SS to soil is known to increase GHG fluxes (Paramasivam et al., 2008). As the organic material in the sludge is mineralized, CO_2 emissions from the soil increase. (Sheppard et al., 2005). However, in certain vulnerable ecosystems where TSS has been applied, soil C and N content have been increased between 40% and 60% (Pavan-Fernandes et al., 2005). Thus, appropriate agricultural management has resulted in important opportunities for GHG mitigation: the optimization of fertilization has resulted in a greater potential to reduce GHG fluxes and increased potential carbon sequestration in soil (Loubet et al., 2011).

An important and increasing number of studies are focusing their efforts on the evaluation of heavy metal evolution, accumulation and translocation in soil in response to TSS application (Lake et al., 1984; Smith, 2009). In Mediterranean ecosystems a similar tendency can be seen. However, only a few studies have assessed the environmental performance of TSS application in terms of GHG fluxes. Arguably, the agricultural application of TSS could induce important N imbalances in soil. Nitrification and denitrification processes could theoretically be exacerbated, increasing N_2O emissions and favouring other nutrient losses (Sheppard et al., 2005; Pezzolla et al., 2012). Moreover, there is a general paucity of research work investigating bacterial community dynamics in response to continued applications of TSS to the soil. Undoubtedly, soil biota plays a key role in the functions that control gaseous losses and nutrient cycling. Alterations at community level after TSS application have been recorded by Dennis and Fresquez (1989), Pascual et al. (2008) and Mattana et al. (2014). Their findings stress the importance of evaluating each individual case in detail, as the TSS composition varies importantly, beginning with the stabilizing and sanitizing treatments, but the effect is also influenced by the dose applied (Zaman et al., 2004).

Therefore, the objective of this research was to determine the possible effects of long-term application of TSS on fertility and soil surface GHG emissions at an agricultural field. Soil chemical, environmental and biological characteristics were assessed during the cropping season of the 20th year after continued treatment application to the soil (TSS; mineral N fertilizer and control). Additionally, the bacterial community was surveyed to investigate its structure and the possible correlations between the bacterial communities and soil enzyme activity and GHG emissions from soil.

2. Materials and methods

2.1. Site description

This research was carried out at a long-term experimental site established in 1992 in Arazuri, Navarra, Spain (42° 48′N–1° 43′W).

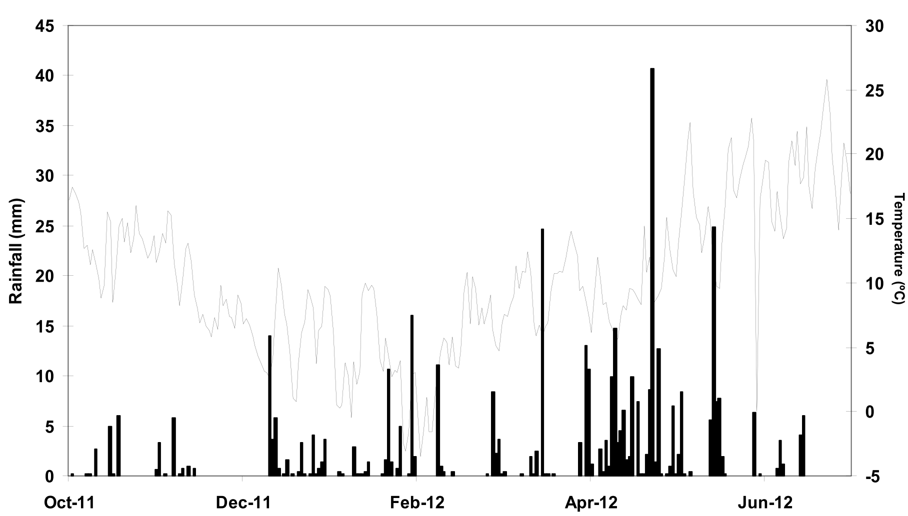

Fig. 1. Daily precipitation (bars) and mean air temperature (line) for 261 days of study in Arazuri.