Solid Earth, 7, 105–114, 2016
www.solid-earth.net/7/105/2016/
doi:10.5194/se-7-105-2016

CO_2 emission and structural characteristics of two calcareous soils amended with municipal solid waste and plant residue

N. Yazdanpanah

Department of Water Engineering, Kerman Branch, Islamic Azad University, Kerman, Iran

Correspondence to: N. Yazdanpanah (najmeyazdanpanah@yahoo.com)

Received: 24 October 2015 – Published in Solid Earth Discuss.: 9 November 2015
Revised: 1 January 2016 – Accepted: 13 January 2016 – Published: 26 January 2016

Abstract. This investigation examines the effect of different amendments on selected soil physical and biological properties over a 24-month period in two cropland fields. Urban municipal solid waste (MSW) compost and alfalfa residue (AR) were used as different organic amendments at the rates of 0 (control), 10 and 30 $\mathrm{Mg\,ha^{-1}}$ to a clay loam soil and a loamy sand soil in a semiarid region. Results showed that the soil improvement was controlled by the application rate and decomposability of amendments and soil type. The addition of organic amendments to the soils improved aggregate stability and consequently enhanced total porosity, especially macropore fraction. The increased soil organic carbon (SOC) and total porosity values as compared to the control treatment were greater in the loamy sand soil than in the clay loam soil. Moreover, compared to the microbial respiration of control plots, the application of MSW resulted in higher values of microbial respiration in the clay loam soil than in the loamy sand soil, whereas the reverse was found for AR. Linear and power functions were provided for the relationships between microbial respiration and SOC in the loamy sand and clay loam soils, respectively. Also, CO_2 emission was stimulated significantly as power functions of the total porosity and the ratio of macroporosity to microporosity. However, the soil microbial respiration and carbon storage improved aggregate stability and pore size distribution, and as a response, soil porosity, especially the macropore fraction, controlled CO_2 flux.

1 Introduction

The maintenance of soil organic carbon (SOC) is important for the sustainable productivity of agroecosystems (González et al., 2010). In this issue, the carbon sequestration is of importance for the earth system (Jaiarree et al., 2014; Parras-Alcántara and Lozano-García, 2014; Brevik et al., 2015; Bruun et al., 2015; de Graaff et al., 2015). Because most soils of arid and semiarid regions are poor in organic carbon (Tejada and González, 2003), the application of organic amendments is a management strategy to improve soil properties with relevant economic benefits for farmers (Bronick and Lal, 2005; González et al., 2010; Alexander et al., 2015). Therefore, organic amendment has been widely used to increase the content of SOC (Fernández et al., 2009; Benbouali et al., 2013; Mahmoodabadi et al., 2013). In this regard, the application of crop residues and manure has been suggested to improve soil quality and to support the sustainable production in agricultural land (Yu and Jia, 2014; Kaleeem Abbasi et al., 2015; Musinguzi et al., 2015; Turgut, 2015). Because the amount of livestock manure as a traditional organic product is limited, crop residue, as an exogenous source of organic matter, has been widely used for the remediation of soil (Benbouali et al., 2013; Mahmoodabadi and Heydarpour, 2014; Novara et al., 2015). The application of organic municipal solid waste (MSW) compost is an alternative approach in agricultural land (Aggelides and Londra, 2000; Ferreras et al., 2006). Exponential growth of population and urbanization, coupled with the improvement of living standards, have resulted in an increase in the amount of urban MSW generation throughout the world (Karak et al., 2012), so that the global generation of MSW exceeds 2 billion Mg per year. Therefore, in recent years, the composted urban MSW has been added to agricultural soils for waste disposal and to im-

Published by Copernicus Publications on behalf of the European Geosciences Union.

prove soil quality (Garcıá-Gil et al., 2000). Soil application of organic amendments, such as animal manure, crop residue and MSW compost provides management strategies to compensate the removal of organic carbon from the soils. Besides, the use of organic amendments in the soils reduces the serious environmental problems caused by residue accumulation (Tejada and González, 2003; Ferreras et al., 2006).

The addition of organic amendments can improve soil physical, chemical and biological properties (Yazdanpanah et al., 2013; Zornoza et al., 2015). Soil organic matter plays an important role in improving soil structure through maintaining aggregate stability (Cerdà, 1998a; Benbouali et al., 2013). In arid and semiarid regions, an increase in SOC results in the formation of more stable aggregates (Bronick and Lal, 2005) and in the reduction of soil erosion (Mahmoodabadi et al., 2014a, b; Mahmoodabadi and Arjmand Sajjadi, 2016). Therefore, the organic sources have been used in these areas to reduce soil degradation (Yazdanpanah et al., 2011; Hueso-González et al., 2014; Srivastava et al., 2014). On the other hand, soil aggregate stability influences several aspects related to the soil behavior, such as pore size distribution, water infiltration and runoff generation (Cerdà, 2000; Mazaheri and Mahmoodabadi, 2012; Sirjani and Mahmoodabadi, 2014; Arjmand Sajjadi and Mahmoodabadi, 2015a, b). In fact, there is an interaction between soil physical and biological properties following the application of an organic amendment. For instance, a positive relationship was found between soil porosity and microbial respiration (Marinari et al., 2000). In general, the application of organic amendments can stimulate soil microbial respiration (Ferreras et al., 2006; Thomas et al., 2015), in order that a higher respiration occurs in those treatments applied at a higher rate (Marinari et al., 2000; González et al., 2010). An increase in the microbial respiration of an amended soil may cause the improvement of soil aggregate stability and porosity (Balashov et al., 2010). Also, the influence of organic amendments on improving soil aggregate stability not only depends on the quantity but also on the quality of adding organic materials, especially their rate of decomposability and their capacity to induce soil microbial activity (Benbouali et al., 2013). Apart from the type and application rate of organic inputs, soil texture plays an important role in carbon stock. Mahmoodabadi and Heydarpour (2014) found that the level of CO_2 emission to the atmosphere is much more in a coarse-textured soil compared to a fine-textured soil. Furthermore, cover and also vegetation are some other parameters controlling the content of soil organic carbon (Cerdà, 1998b; Cerdà and Doerr, 2005; Jiménez et al., 2013; Mahmoodabadi and Cerdà, 2013; Cerdà et al., 2014, 2016).

In most previous studies carried out about the effect of organic amendments on soil properties under field conditions, only one agricultural field (soil type) has been examined. In the present study, two contrasting agricultural fields (two soils with different textures) were examined. Furthermore, little is known about the interaction between microbial respiration and structural porosity in soils with different degrees of aggregate stability, especially in semiarid region soils. Therefore, the aims of the present work were (1) to attribute soil microbial respiration to aggregate stability and porosity fractions (i.e., macropores and micropores) in response to the type and application rate of organic amendments under field conditions, and (2) to compare the effect of two types of organic sources including alfalfa residue (AR) and urban MSW compost on soil CO_2 emission from two different cropland soils. The findings of the present experiment should therefore enhance our understanding of the interrelationship between the microbial respiration and soil structural characteristics in contrasting soils.

Table 1. Some physical and chemical properties of the soils with different textures.

Soil property	Loamy sand	Clay loam
Clay (< 0.002 mm; %)	5.8	31.0
Silt (0.05–0.002 mm; %)	10.0	40.8
Sand (2–0.05 mm; %)	84.2	28.2
MWD[a] (mm)	0.18	0.27
Bulk density ($Mg\,m^{-3}$)	1.76	1.53
EC[b] ($dS\,m^{-1}$)	0.28	2.45
pH	6.8	7.2
OC[c] ($g\,kg^{-1}$)	1.33	2.9
$CaCO_3$ (%)	16.2	21.5

[a] MWD: mean weight diameter; [b] EC: electrical conductivity; [c] OC: organic carbon.

2 Materials and methods

2.1 Experimental sites description

This research was conducted in two different agricultural fields both located in the same semiarid climate conditions in Kerman province, central Iran (30°14′ N, 57°06′ E). The first experimental field is placed on a clay loam soil and the second is located on a loamy sand soil established on Aeolian deposits, hereafter called "clay loam soil" and "loamy sand soil", respectively. According to the Keys to Soil Taxonomy, the clay loam and loamy sand soils were classified as Haplocalcids and Torripsamments (Soil Survey Staff, 2010). Long-term mean precipitation of the area is 140 mm per annum, which mainly occurs in winter, and the average annual temperature is 16.5 °C. Both the experimental fields had been under agricultural cropping for more than 10 years, with a conventional management. Prior to the experiment, the dominant crops that had been cultivated in these fields were wheat (*Tritium aestivum* L.) and corn (*Zea mays* L.). Irrigation had been performed as flood irrigation with water that has an electrical conductivity of 1.1 $dS\,m^{-1}$ and sodium adsorption ratio of 0.73. Prior to the start of the experiment, the fields had been under fallow for 2 years and had not been fertilized to make them more homogeneous. In 2 years of fallow before the experiment, weeds were controlled by tillage. Some selected properties of the soils before the amendments' incorporation are presented in Table 1. Particle size distribution of the soils as primary (soil texture) and secondary (i.e., MWD) is different (Table 1), in order that the loamy sand soil contains many more sand particles; nevertheless it has less value of mean weight diameter (MWD) of aggregates.

2.2 Organic amendments

In this study, two organic inputs from different sources, as well as C : N ratios including urban MSW compost and alfalfa residue (AR), were applied. The urban MSW compost was obtained from the organic solid waste of Kerman municipality. Alfalfa residue was used as a green manure, which is commonly associated with organic farming and can play an important role in sustainable cropping systems. Chemical composition of the organic amendments was measured. Electrical conductivity (EC) and pH were measured 24 h after 1 h shaking of 1 g samples in vials with 5 mL distilled water. The amounts of organic carbon and total nitrogen were measured by the Walkley and Black (1934) and Kjeldahl methods, respectively (Pansu and Gautheyrou, 2006). The measured chemical composition of amendments is presented in Table 2. As it is observed, AR has higher organic carbon and a lower amount of total nitrogen compared to MSW. The obtained C : N ratio of AR and MSW is 22.3 and 13.6, respectively (Table 2).

2.3 Experimental design

The experiment was established in a randomized complete block design with five treatments each at three replicates on two separate agricultural fields. For each field (soil texture), 15 experimental plots of 3 m × 5 m were established, so that a total of 30 plots were prepared. The applied treatments were (1) control, without any amendment application (C); (2) municipal solid waste at a rate of 10 Mg ha^{-1} (MSW10); (3) municipal solid waste at a rate of 30 Mg ha^{-1} (MSW30); (4) alfalfa residue at a rate of 10 Mg ha^{-1} (AR10) and (5) alfalfa residue at a rate of 30 Mg ha^{-1} (AR30). The rates of organic amendments were based on dry matter. The cured amendments were passed through a 5 mm mesh screen before soil incorporation (Aggelides and Londra, 2000). Then, the organic amendments were manually spread uniformly on the surface of the specified plots and they were incorporated into the top 15 cm of the soil profile. Similar procedures were followed for the two fields. During the experiment, no crop was planted and no fertilizer was applied.

2.4 Measurement of soil properties

Twenty-four months after the application of amendments, soil samples were taken after mixing four subsamples from each plot at depths of 0–15 cm. All samples were immediately stored in sealed plastic bags in a cooler and transported to a laboratory. The air-dried soil samples were crushed to pass through a 2 mm sieve, and some physical and chemical properties were measured. Soil microbial respiration was measured on fresh soil samples (Benbouali et al., 2013).

To study the effects of applied organic amendments on biological properties, soil microbial respiration was measured by an incubation-alkaline absorption method (Yazdanpanah et al., 2013). The production of CO_2 was measured as an indicator of soil microbial activity. Soil samples (100 g) at 75 % of water-holding capacity were incubated at 25 °C for 7 days in hermetic flasks; the CO_2 evolved was trapped in excess of 0.5 N NaOH. The alkali was titrated to the phenolphthalein with HCl in the presence of $BaCl_2$ to precipitate the carbonate. The CO_2 evolved was calculated by difference between samples and blanks without soil (Ferreras et al., 2006; Yazdanpanah et al., 2013).

Soil organic carbon was measured as described by Walkley and Black (1934). Briefly, organic matter from the soil (1 g) was oxidized with $K_2Cr_2O_7$ 1 N (10 mL) in concentrated sulfuric acid for 30 min, followed by titration of the excess of $K_2Cr_2O_7$ with ferrous ammonium sulfate 0.5 N and N-phenyl anthranilic acid to indicate the end point (González et al., 2010).

A portion of the soil samples (three samples from each treatment) was used to determine aggregate stability as the proportion of aggregates that were stable to water. For this purpose, each soil sample was initially pre-wetted with distilled water. After the soil sample was saturated, it was placed on a 0.25 mm mesh sieve, and was sieved in distilled water at 30 oscillations per min for 2 min. The remaining soil on each sieve was oven-dried (105 °C), and then sand and aggregates were separated. After sand content correction, the fraction of aggregates larger than 0.25 mm was expressed as water-stable aggregates(WSA) > 0.25 mm (Six et al., 2001; Mahmoodabadi and Ahmadbeygi, 2013). Sample pre-treatments with water allow the evaluation of the main factors involved in structural stability. The pre-treatment with water, since it does not allow air expulsion from the aggregate, indicated that aggregate disruption due to the wetting process occurred (Ferreras et al., 2006).

Total porosity and included components (i.e., macroporosity and microporosity) were calculated according to Celik et al. (2004). At first, soil bulk density (BD) was determined on undisturbed samples using a cylinder method made of 100 cm^3 cylinders, after drying 24 h in 105 °C ovens. Then, total porosity (F) was calculated based on $F = 1-$ (BD/2.65). The macroporosity fraction was determined from the volumetric water content using a pressure membrane apparatus at field capacity. Microporosity was calculated as the difference between total porosity and macroporosity values (Celik et al., 2004).

Table 2. The chemical composition of two types of amendments used in the experiment.

Amendment	OC[a] ($g\,kg^{-1}$)	Total N[b] ($g\,kg^{-1}$)	C : N	Ash ($g\,kg^{-1}$)	EC (1 : 5)[c] ($dS\,m^{-1}$)	pH (1 : 5)
Alfalfa residue	468	21	22.3	320	4.8	7.6
Municipal solid waste	394	29	13.6	540	4.0	6.9

[a] OC: organic carbon; [b] Total N: total nitrogen (Kjeldahl); [c] EC: electrical conductivity.

2.5 Statistical analysis

To study the effects of applied treatments on the selected soil properties, the obtained data were subjected to an analysis of variances (ANOVA) procedure for a randomized complete block design with three replications. Comparison of means was performed by the Duncan multiple range test at the 95 % level of probability. The soil microbial respiration was related to SOC, total porosity, as well as to macro/microporosity ratio by regression functions. All the statistical analyses were performed in the SAS (Statistical Analysis System; SAS Institute, 1990).

3 Results

3.1 Soil organic carbon

The effect of treatments on SOC was significant ($p < 0.05$) in loamy sand and clay loam soils (Table 3). The addition of AR and MSW caused significant increments ($p < 0.05$) in SOC compared to the control plots, with larger increases at higher rates of application (i.e., 30 $Mg\,ha^{-1}$). Also, the soils amended with AR exhibited significantly ($p < 0.05$) higher levels of SOC than those amended with MSW. The SOC concentration under the application rate of 10 $Mg\,ha^{-1}$ MSW and AR was about 1.5 and 1.7 times higher in the loamy sand soil and about 1.1 and 1.3 times higher in the clay loam soil than those obtained for unamended soils, respectively. The comparison with the control plots demonstrated that the addition of 30 $Mg\,ha^{-1}$ MSW and AR resulted in 2.6 and 3.0 times higher SOC in the loamy sand soil and 1.5 and 1.7 times higher SOC in the clay loam soil, respectively. This means that as compared with the control plots, the increased SOC concentrations due to AR incorporation into both soils were more than the values resulted from MSW application. Also, with respect to control, SOC was enhanced following the application of organic amendments in the loamy sand soil more than it was in the clay loam soil.

3.2 Soil microbial respiration

The effect of treatments on the microbial respiration of soils with different textures is provided in Table 3. As is clear, the application of alfalfa residue (AR) and municipal solid waste (MSW) led to significant ($p < 0.05$) increases in the soil microbial respiration compared to the control plots. Also, there were significant ($p < 0.05$) differences in the microbial respiration between MSW and AR for each soil. The maximum CO_2 flux was found in plots amended with 30 $Mg\,ha^{-1}$ MSW; the highest values for loamy sand and clay loam soils were, respectively, 182.1 and 261.5 $\mu g\,CO_2\,g^{-1}$ soil. The values of microbial respiration for 10 and 30 $Mg\,ha^{-1}$ application rates of MSW were 2 and 3 times higher in the loamy sand soil, and 2.1 and 3.3 times higher in the clay loam soil, respectively, than those values obtained for unamended soils. The addition of 10 and 30 $Mg\,ha^{-1}$ AR stimulated the CO_2 emission by 1.5 and 2.5 times higher in the loamy sand soil, and by 1.2 and 1.9 times higher in the clay loam soil with respect to the control plots, respectively. In fact, comparison between the amendment treatments suggests that for both the soils, those plots amended with MSW, showed significantly ($p < 0.05$) higher values of microbial respiration than those amended with AR. Also, compared to the soil microbial respiration of control plots, the application of MSW caused greater increments in the microbial respiration in the clay loam soil than in the loamy sand soil, whereas the reverse was found for AR. On the other hand, when a higher rate of organic amendments was added to the soils (i.e., 30 $Mg\,ha^{-1}$), a greater increase in CO_2 production in relation to the control was observed.

3.3 Soil aggregate stability

The applied treatments showed significant influences ($p < 0.05$) on the percentage of water-stable aggregates of both the soils (Table 3). In the loamy sand soil, the addition of organic amendments, especially MSW, increased the aggregate stability values compared to the control plots. For the 10 and 30 $Mg\,ha^{-1}$ application rates of MSW, the aggregate stability levels were 1.6 and 1.9 times higher, respectively, than those that were found for the control plots, while for the corresponding application rates of AR, a moderate increase was observed. In the clay loam soil, plots amended with both rates of MSW and those amended with 30 $Mg\,ha^{-1}$ AR showed a significant increment ($p < 0.05$) in aggregate stability. In this soil, the aggregate stability values for 10 and 30 $Mg\,ha^{-1}$ application rates of MSW was 1.1 and 1.2 times higher, respectively, than those for unamended soil. Furthermore, the values of aggregate stability for the clay loam soil were, in general, much more than those for the loamy sand

Table 3. Mean ± standard deviation values of the selected soil properties for each soil texture treated with different rates of organic amendments ($n = 3$).

Soil texture	Treatment	OC[a] $(\mathrm{g\,kg^{-1}})$	WSA[b] (%)	Total porosity $(\mathrm{cm^3\,cm^{-3}})$	Microporosity $(\mathrm{cm^3\,cm^{-3}})$	Macroporosity $(\mathrm{cm^3\,cm^{-3}})$	Respiration $(\mathrm{\mu g\ CO_2\ g^{-1}\ Soil})$
Loamy sand	C	1.32 ± 0.21e	9.4 ± 0.37d	0.32 ± 0.032c	0.21 ± 0.021b	0.11 ± 0.011e	61.5 ± 9.1e
	MSW 10	1.95 ± 0.44d	15.2 ± 0.42b	0.40 ± 0.061b	0.22 ± 0.005b	0.19 ± 0.063c	122.9 ± 50.0c
	MSW 30	3.46 ± 0.09b	18.1 ± 0.64a	0.47 ± 0.017a	0.22 ± 0.006b	0.25 ± 0.015a	182.1 ± 17.0a
	AR 10	2.27 ± 0.27c	10.3 ± 0.39cd	0.37 ± 0.042b	0.21 ± 0.014b	0.15 ± 0.054d	93.7 ± 37.7d
	AR 30	3.98 ± 0.41a	11.6 ± 0.92c	0.47 ± 0.009a	0.25 ± 0.003a	0.22 ± 0.009b	154.1 ± 9.1b
Clay loam	C	2.92 ± 0.18e	44.4 ± 0.44c	0.41 ± 0.025d	0.28 ± 0.023b	0.12 ± 0.001e	78.6 ± 4.2e
	MSW 10	3.31 ± 0.24d	50.6 ± 0.30b	0.50 ± 0.051bc	0.29 ± 0.016b	0.21 ± 0.067b	163.3 ± 67.4b
	MSW 30	4.29 ± 0.03b	52.9 ± 0.28a	0.59 ± 0.040a	0.31 ± 0.003b	0.28 ± 0.041a	261.5 ± 65.9a
	AR 10	3.88 ± 0.06c	45.8 ± 1.70c	0.44 ± 0.027c	0.30 ± 0.006b	0.14 ± 0.028d	96.0 ± 23.9d
	AR 30	4.96 ± 0.12a	51.5 ± 0.95ab	0.53 ± 0.061b	0.35 ± 0.041a	0.18 ± 0.027c	151.4 ± 37.7c

Means for treatments in the same soil texture followed by the same letter are not significantly different (Duncan $p < 0.05$), $n = 3$. C: control; MSW: municipal solid waste, AR: alfalfa residue. Suffixes 10 and 30 represent the application rates of 10 and 30 Mg ha^{-1}, respectively. [a] OC: organic carbon; [b] WSA: water-stable aggregates.

soil, although as compared to the control plots, the loamy sand soil experienced higher increases in aggregate stability.

3.4 Soil porosity components

At the end of the field experiment, the applied treatments showed significant effects ($p < 0.05$) on the total porosity of soils (Table 3). In the loamy sand soil, MSW and AR had similar effects on total porosity, whereas a different pattern was observed in the clay loam soil. Depending on the type and application rates of amendments added to the soils, the total porosity of loamy sand soil varied from 0.32 to 0.47 cm^3 cm^{-3}, and in the clay loam soil it ranged from 0.41 to 0.59 cm^3 cm^{-3}. The total porosity values produced by 10 and 30 Mg ha^{-1} application rates of MSW were 1.3 and 1.5 times higher in the loamy sand soil and 1.2 and 1.4 times higher in the clay loam soil, respectively, than those observed in the control plots. The addition of 10 and 30 Mg ha^{-1} AR resulted in increases in the total porosity by 1.2 and 1.5 times in the loamy sand soil and by 1.1 and 1.3 times in the clay loam soil as compared to the control plots, respectively. This result indicates that the increased total porosity with respect to the control plots was more pronounced in the loamy sand soil than in the clay loam soil.

In addition to the total porosity, the macroporosity of soils was influenced by the organic amendment treatments significantly ($p < 0.05$) (Table 3). The incorporation of amendments into the soils, especially at a higher rate (30 Mg ha^{-1}), enhanced the fraction of soil volume allocated to macropore fraction significantly ($p < 0.05$). In general, due to different treatments studied, the macropore fraction varied from 11 to 25 cm^3 cm^{-3} in the loamy sand soil and from 12 to 28 cm^3 cm^{-3} in the clay loam soil. The soils amended with MSW gave significantly ($p < 0.05$) higher levels of macroporosity than those treated with AR. On the other hand, the maximum value of macroporosity in both soils was found under the 30 Mg ha^{-1} application rate of MSW. Considering the different texture of soils, due to MSW application, the increased macroporosity in relation to the control plots was similar in both the soils, whereas the application of AR led to higher increments in the macroporosity in the loamy sand soil than that in the clay loam soil.

The result also indicated that all the treatments except AR, at the application rate of 30 Mg ha^{-1}, did not show any significant effect on the soil microporosity (Table 3). In other words, only the application of 30 Mg ha^{-1} AR caused a significant increase ($p < 0.05$) in the soil microporosity compared to the control plots. In all cases, the microporosity of clay loam soil was in general greater than that of the loamy sand soil.

4 Discussion

Results of this study indicated that, in general, application of MSW and AR had positive effects on structural and biological properties of the soils with different textures. The use of organic amendments increased the SOC concentration with larger increments at the higher application rate. This result is consistent with the findings of other researchers (e.g., Ferreras et al., 2006; González et al., 2010), who found increases in the final SOC content after the application of organic sources. It is seen that at the end of experiment, soils amended with AR showed higher SOC concentrations than those amended with MSW. This can partly be attributed to the chemical composition and C : N ratio of organic amendments. As compared to MSW, the AR amendment had higher organic carbon content (468 g kg^{-1} compared to 394 g kg^{-1}). In addition, the C : N ratio for AR-treated soils was greater than that for the MSW-treated soils (Table 2). In general, a higher ratio of C : N can be associated with a lower decomposition rate of organic sources (Majumder et al., 2008).

On the other hand, an increase in the application rate of amendments stimulated the soils microbial respiration, which is in agreement with what is reported by others (e.g., Marinari et al., 2000; Ferreras et al., 2006; Yazdanpanah et al., 2013). The use of organic amendments has been reported previously to increase SOC and improve microbial activity (Marinari et al., 2000). As the soil microbial respiration was measured through CO_2 production, it is a direct indicator of microbial activity and indirectly reflects the availability of organic substrates (Ferreras et al., 2006). This investigation aimed to provide the relationship between microbial respiration and SOC of soils. Figure 1 shows the relationship between SOC concentration and CO_2 emission from loamy sand and clay loam soils, treated with the two types of organic amendments. As is obvious, the soil microbial respiration increases significantly with increasing SOC as linear (Fig. 1a) and power (Fig. 1b) relationships for loamy sand and clay loam soils, respectively. Higher values of microbial respiration were found in plots amended with MSW compared to those treated with AR. Moreover, MSW compost caused higher increases in CO_2 emission as a function of SOC than did AR. This can be partly attributed to the fact that most of the carbon supplied by MSW comprises easily degradable material to be used as an energy and nutrient source for soil microorganisms, resulting in the increased soil microbial respiration (Ferreras et al., 2006; Mahmoodabadi and Heydarpour, 2014). It is well known that the microbial decomposition processes are controlled by the substrate quality (e.g., lignin and polyphenol content) and the availability of labile carbon (Koranda et al., 2013; Smith et al., 2015). In some studies, the C : N ratio has been attributed to the rate of decomposability of organic inputs; i.e., the lower ratio can be associated with the higher rate of carbon mineralization and CO_2 emission (Majumder et al., 2008). It can be assumed that compared to MSW, the application of AR with less easily degradable components may cause the formation of more stable soil organic complexes, resulting in more resistance against the microbial decomposition (Majumder et al., 2008; Mahmoodabadi and Heydarpour, 2014). Therefore, AR shows slower microbial decomposition as well as a lower mineralization rate (Liu et al., 2010; Cely et al., 2014). In other words, the different levels of organic carbon added to the soils are likely to be influenced by the biochemical composition and the decomposability of amendments (Yazdanpanah et al., 2013).

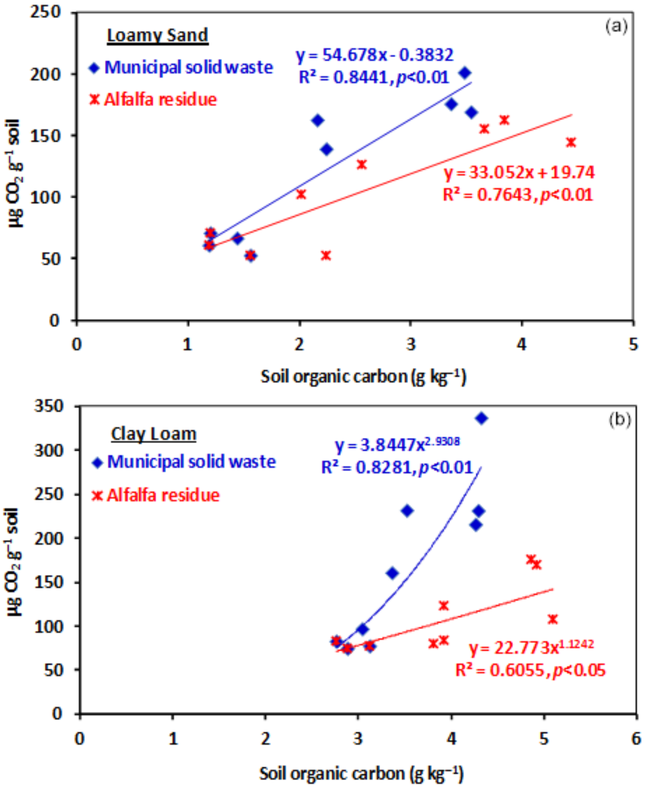

Figure 1. Relationship between the soil organic carbon and microbial respiration of loamy sand **(a)** and clay loam **(b)** soils, treated with different levels of municipal solid waste (MSW) and alfalfa residue (AR).

At the beginning of the experiment, the clay loam soil used in this study had higher content of organic carbon than the loamy sand soil (Table 1). In spite of a greater percentage of clay particles and far fewer sand particles in the clay loam soil, the mean weight diameter (MWD) of clay loam soil (0.27 mm) was more than that of the loamy sand soil (0.18 mm). When the soil microbial respiration was assessed in relation to control, MSW caused higher increases in the CO_2 emission from clay loam soil than from loamy sand soil, whereas the reverse was observed for AR. Alternatively, as compared to control, the increased SOC concentration in the loamy sand soil was higher than in the clay loam soil. This means that apart from soil texture, the aggregate size distribution plays an important role in the carbon stock and microbial activity. It can be assumed that the decomposition rate of organic matter can vary in soils among different aggregate size classes (Mangalassery et al., 2013). Mangalassery et al. (2013) found that both texture and aggregate size significantly influenced CO_2 emission in two contrasting soil textures. Mahmoodabadi and Heydarpour (2014) found that CO_2 emission from a coarse-textured soil is relatively higher than a fine-textured soil. Sey et al. (2008) reported that higher levels of CO_2 were emitted from microaggregates (< 0.25 mm) compared to macroaggregates (> 0.25 mm). In a clay loam soil, Drury et al. (2004) found a decrease in CO_2 production with increasing aggregate size. In contrast, Strong et al. (2004) found a faster decomposition rate of carbon in a soil with relatively larger pore sizes. Overall, our result are conditioned by the chemical composition of amendment, the rate of application and the soil texture and aggregate size distribution, which have been supported by other studies (Tejada and González, 2003; Ferreras et al., 2006; Mahmoodabadi and Heydarpour, 2014).

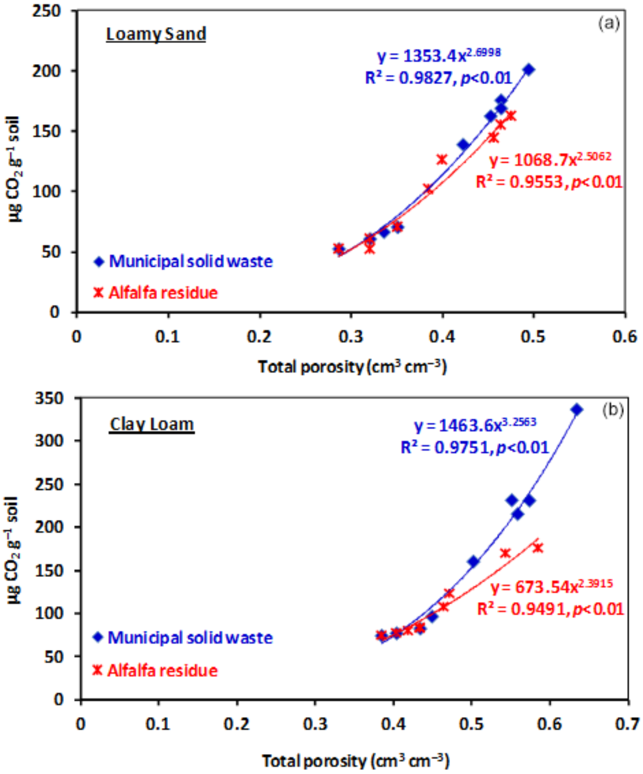

Figure 2. Relationship between the total porosity and soil microbial respiration of loamy sand **(a)** and clay loam **(b)** soils, treated with different levels of municipal solid waste (MSW) and alfalfa residue (AR).

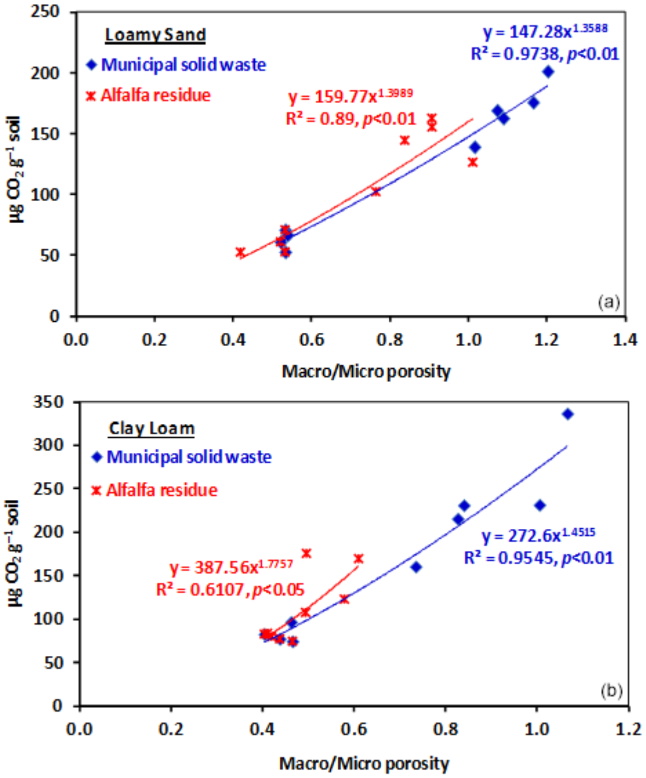

Figure 3. Relationship between the ratio of macroporosity to microporosity and soil microbial respiration of loamy sand **(a)** and clay loam **(b)** soils, treated with different levels of municipal solid waste (MSW) and alfalfa residue (AR).

The addition of organic amendments to the soils also improved the aggregate stability and consequently increased the soils' total porosity, especially macropore fraction. The result indicated that the capability of different organic amendments in the improvement of soil structural stability depends on the dose of application, the rate of decomposability, the capacity of microbial respiration and the texture of soils, which corresponds to previous observations (Benbouali et al., 2013; Yazdanpanah and Mahmoodabadi, 2013). The added organic carbon, in general, is necessary for the flocculation of soil particles to form more stable aggregates. The incorporation of organic amendments into the soils increased the cohesion of aggregates (Ferreras et al., 2006), with a more significant effect in plots amended with the higher rate (i.e., $30\,\mathrm{Mg\,ha^{-1}}$). Similarly, Bronick and Lal (2005) found parallel increases in SOC concentration and aggregate stability following the poultry manure application. On the contrary, some researchers (e.g., Celik et al., 2004) reported that organic amendments increased the SOC concentration, but did not show any significant effect on the aggregate stability.

The higher aggregate stability observed in amended soils was concurrent with the improvement of total porosity and the remarkable increase in the macropore fraction. Several authors have previously reported that the organic matter from amendment incorporation improved pore size distribution (Marinari et al., 2000; Tejada and González, 2003). Figure 2 shows the relationship between the total porosity and microbial respiration of loamy sand and clay loam soils after the application of different levels of MSW and AR. For both the organic amendments, good relationships were obtained, therefore the CO_2 emission was stimulated significantly ($p < 0.01$) as power functions of the total porosity of soils. A similar result was reported by Marinari et al. (2000), who found positive linear correlations between soil porosity, microbial activity and CO_2 production in organic and mineral treatments. Aggelides and Londra (2000) demonstrated that the organic amendment application considerably improved soil physical properties through increasing of the total porosity and changing the distribution of pore sizes in loamy- and clay-textured soils. In some studies, the effect was significant in the micropore fraction, as Celik et al. (2004) found that the organic treatments had positive effects on microporosity compared to control.

The concurrent improvement in the aggregate stability and soil porosity due to the amendments' addition was more pronounced in the macroporosity than in the microporosity. In other words, the macropore fraction was much more sensitive to the amendments' application than the micropore fraction.

This finding is in agreement with Jarvis (2007), who reported that the macropore fraction had higher temporal variability than micropore fraction. The macropore fraction in general contributes to ease the aeration of soil and consequently affects the soil microbial respiration. Therefore, in the present study, the ratio of macroporosity to microporosity as a soil structural indicator was related to the microbial respiration. As can be seen in Fig. 3, there are significant relationships (power) between the ratio of macroporosity to microporosity and CO_2 production from the soils, treated with different levels of MSW and AR.

Overall, an interrelationship was found between the soil microbial respiration and the structural characteristics such as aggregate stability and porosity fractions. In fact, the microbial respiration and SOC content of soils can be linked to the soils' aggregate stability and pore size distribution. The increased microbial respiration and SOC content in the amended soils can contribute to the improvement of soil aggregate stability (Balashov et al., 2010). Mangalassery et al. (2013) found that CO_2 flux was affected by soil porosity, indicating that the soil pore network plays a major role in driving CO_2 produced by microbial respiration to the soil surface. However, the microbial respiration and carbon storage affect the aggregate stability and pore size distribution, and as a response, the soil porosity, especially the macropore fraction, influences the carbon mineralization and CO_2 flux significantly. In fact, the improved soil macroporosity due to the stimulated microbial activity might as well ease the soil aeration, producing more oxygen that is available to microorganisms for the respiration process.

5 Conclusions

The use of MSW and AR improved the structural stability and biological properties of soils significantly, with a larger influence at higher application rates. At the end of the experiment, those soils amended with AR showed higher SOC concentrations than those amended with MSW, whereas MSW caused greater increases in the soil microbial respiration and macropore fraction. Apart from soil texture, the aggregate size distribution plays an important role in the carbon stock and CO_2 emission. The macropore fraction was much more sensitive to the application of amendments than the micropore fraction. As a result, an interaction was found between the soil microbial respiration and the structural characteristics. However, the microbial respiration and carbon storage affect the aggregate stability and pore size distribution, and as a response, the soil porosity, especially the macropore fraction, influences the soil microbial respiration and carbon mineralization.

Edited by: A. Cerdà

References

Aggelides, S. M. and Londra, P. A.: Effects of compost produced from town wastes and sewage sludge on the physical properties of a loamy and a clay soil, Bioresource Technol., 71, 253–259, 2000.

Alexander, P., Paustian, K., Smith, P., and Moran, D.: The economics of soil C sequestration and agricultural emissions abatement, SOIL, 1, 331–339, doi:10.5194/soil-1-331-2015, 2015.

Arjmand Sajjadi, S. and Mahmoodabadi, M.: Aggregate breakdown and surface seal development influenced by rain intensity, slope gradient and soil particle size, Solid Earth, 6, 311–321, doi:10.5194/se-6-311-2015, 2015a.

Arjmand Sajjadi, S. and Mahmoodabadi, M.: Sediment concentration and hydraulic characteristics of rain-induced overland flows in arid land soils, J. Soil. Sediment., 15, 710–721, doi:10.1007/s11368-015-1072-z, 2015b.

Balashov, E., Kren, J., and Prochazkova, B.: Influence of plant residue management on microbial properties and water-stable aggregates of two agricultural soils, International Agrophysics, 24, 9–13, 2010.

Benbouali, E. H., Hamoudi, S. A. E. A., and Larich, A.: Short- term effect of organic residue incorporation on soil aggregate stability along gradient in salinity in the lower cheliff plain (Algeria), Afr. J. Agric. Res., 8, 2144–2152, 2013.

Brevik, E. C., Cerdà, A., Mataix-Solera, J., Pereg, L., Quinton, J. N., Six, J., and Van Oost, K.: The interdisciplinary nature of SOIL, SOIL, 1, 117–129, doi:10.5194/soil-1-117-2015, 2015.

Bronick, C. J. and Lal, R.: Manuring and rotation effects on soil organic carbon concentration for different aggregate size fraction on two soils in northeastern Ohio, USA, Soil Till. Res., 81, 239–252, 2005.

Bruun, T. B., Elberling, B., de Neergaard, A., and Magid, J.: Organic carbon dynamics in different soil types after conversion of forest to agriculture, Land Degrad. Dev., 26, 272–283, doi:10.1002/ldr.2205, 2015.

Celik, I., Ortas, I., and Kilic, S.: Effects of compost, mycorrhiza, manure and fertilizer on some physical properties of a Chromoxerert soil, Soil Till. Res., 78, 59–67, 2004.

Cely, P., Tarquis, A. M., Paz-Ferreiro, J., Méndez, A., and Gascó, G.: Factors driving the carbon mineralization priming effect in a sandy loam soil amended with different types of biochar, Solid Earth, 5, 585–594, doi:10.5194/se-5-585-2014, 2014.

Cerdà, A. and Doerr, S. H.: Influence of vegetation recovery on soil hydrology and erodibility following fire: An 11-year investigation, Int. J. Wild. Fire, 14, 423–437, doi:10.1071/WF05044, 2005.

Cerdà, A., Giménez Morera, A., García Orenes, F., Morugán, A., González Pelayo, Ó., Pereira, P., Novara, A., and Brevik, E. C.: The impact of abandonment of traditional flood irrigated citrus orchards on soil infiltration and organic matter, in: Geoecología, Cambio Ambiental y Paisaje: Homenaje al Profesor José María García Ruiz, edited by: Arnáez, J., González-Sampériz, P., Lasanta, T., and Valero-Garcés, B. L., Instituto Pirenaico de Ecología, Zaragoza, 267–276, 2014.

Cerdà, A., González-Pelayo, O., Giménez-Morera, A., Jordán, A., Pereira, P., Novara, A., Brevik, E. C., Prosdocimi, M., Mahmoodabadi, M., Keesstra, S., García Orenes, F., and Ritsema, C.: The use of barley straw residues to avoid high erosion and runoff rates on persimmon plantations in Eastern Spain under low frequency

– high magnitude simulated rainfall events, Soil Res., in press, 2016.

Cerdà, A.: Aggregate stability against water forces under different climates on agriculture land and scrubland in southern Bolivia, Soil Till. Res., 36, 1–8, 2000.

Cerdà, A.: Soil aggregate stability under different Mediterranean vegetation types, Catena, 32, 73–86, 1998a.

Cerdà, A.: The influence of aspect and vegetation on seasonal changes in erosion under rainfall simulation on a clay soil in Spain, Can. J. Soil Sci., 78, 321–330, doi:10.4141/S97-060, 1998b.

de Graaff, M.-A., Adkins, J., Kardol, P., and Throop, H. L.: A meta-analysis of soil biodiversity impacts on the carbon cycle, SOIL, 1, 257–271, doi:10.5194/soil-1-257-2015, 2015.

Drury, C. F., Yang, X. M., Reynolds, W. D., and Tan, C. S.: Influence of crop rotation and aggregate size on carbon dioxide production and denitrification, Soil Till. Res., 79, 87–100, 2004.

Fernández, J. M., Plaza, C., García-Gil, J. C., and Polo, A.: Biochemical properties and barley yield in a semiarid Mediterranean soil amended with two kinds of sewage sludge, Appl. Soil Ecol., 42, 18–24, 2009.

Ferreras, L., Gomez, E., Toresani, S., Firpo, I., and Rotondo, R.: Effect of organic amendments on some physical, chemicals and biological properties in a horticultural soil, Bioresource Technol., 97, 635–640, 2006.

Garcıá-Gil, J. C., Plaza, C. Soler-Rovira, P., and Polo, A.: Long-term effects of municipal solid waste compost application on soil enzyme activities and microbial biomass, Soil Biol. Biochem., 32, 1907–1913, 2000.

González, M., Gomez, E., Comese, R., Quesada, M., and Conti, M.: Influence of organic amendments on soil quality potential indicators in an urban horticultural system, Bioresource Technol., 101, 8897–8901, 2010.

Hueso-González, P., Martínez-Murillo, J. F., and Ruiz-Sinoga, J. D.: The impact of organic amendments on forest soil properties under Mediterranean climatic conditions, Land Degrad. Dev., 25, 604–612, doi:10.1002/ldr.2296, 2014.

Jaiarree, S., Chidthaisong, A., Tangtham, N., Polprasert, C., Sarobol, E., and Tyler, S. C.: Carbon budget and sequestration potential in a sandy soil treated with compost, Land Degrad. Dev., 25, 120–129, doi:10.1002/ldr.1152, 2014.

Jarvis, N. J.: A review of non-equilibrium water flow and solute transport in soil macropores: principles, controlling factors and consequences for water quality, Eur. J. Soil Sci., 58, 523–546, 2007.

Jiménez, M. N., Fernández-Ondoño, E., Ripoll, M. Á., Castro-Rodríguez, J., Huntsinger, L., and Navarro, F. B.: Stones and organic mulches improve the Quercus ilex L. afforestation success under Mediterranean climatic conditions, Land Degrad. Dev., doi:10.1002/ldr.2250, 2013.

Kaleeem Abbasi, M., Mahmood Tahir, M., Sabir, N., and Khurshid, M.: Impact of the addition of different plant residues on nitrogen mineralization-immobilization turnover and carbon content of a soil incubated under laboratory conditions, Solid Earth, 6, 197–205, doi:10.5194/se-6-197-2015, 2015.

Karak, T., Bhagat R. M., and Bhattacharyya, P.: Municipal solid waste generation, composition, and management: the world scenario, Crit. Rev. Env. Sci. Tec., 42, 1509–1630, 2012.

Koranda, M., Kaiser, C., Fuchslueger, L., Kitzler, B., Sessitsch, A., Zechmeister-Boltenstern, S., and Richter A.: Seasonal variation in functional properties of microbial communities in beech forest soil, Soil Biol. Biochem., 60, 95–104, 2013.

Liu, E., Yan, C., Mei, X., He, W., Bing, S. H., Ding, L., Liu, S., and Fan, T.: Long-term effect of chemical fertilizer effects on soil organic matter fraction and microbes under a wheat-maize cropping system in northern China, Geoderma, 149, 318–324, 2010.

Mahmoodabadi, M. and Ahmadbeygi, B.: Dry and water-stable aggregates in different cultivation systems of arid region soils, Arabian Journal of Geosciences, 6, 2997–3002, doi:10.1007/s12517-012-0566-x, 2013.

Mahmoodabadi, M. and Arjmand Sajjadi, S.: Effects of rain intensity, slope gradient and particle size distribution on the relative contributions of splash and wash loads to rain-induced erosion, Geomorphology, 253, 159–167, doi:10.1016/j.geomorph.2015.10.010, 2016.

Mahmoodabadi, M. and Cerdà, A.: WEPP calibration for improved predictions of interrill erosion in semi-arid to arid environments, Geoderma, 204–205, 75–83, doi:10.1016/j.geoderma.2013.04.013, 2013.

Mahmoodabadi, M. and Heydarpour, E.: Sequestration of organic carbon influenced by the application of straw residue and farmyard manure in two different soils, Int. Agrophys., 28, 169–176, doi:10.2478/intag-2014-0005, 2014.

Mahmoodabadi, M., Ghadiri, H., Rose, C., Yu, B., Rafahi, H., and Rouhipour, H.: Evaluation of GUEST and WEPP with a new approach for the determination of sediment transport capacity, J. Hydrol., 513, 413–421, doi:10.1016/j.jhydrol.2014.03.060, 2014a.

Mahmoodabadi, M., Ghadiri, H., Yu, B., and Rose, C.: Morphodynamic quantification of flow-driven rill erosion parameters based on physical principles, J. Hydrol., 514, 328–336, doi:10.1016/j.jhydrol.2014.04.041, 2014b.

Mahmoodabadi, M., Yazdanpanah, N., Rodríguez Sinobas, L., Pazira, E., and Neshat, A.: Reclamation of calcareous saline sodic soil with different amendments (I): Redistribution of soluble cations within the soil profile, Agr. Water Manage., 120, 30–38, doi:10.1016/j.agwat.2012.08.018, 2013.

Majumder, B., Mandal, B., Bandyopadhyay, P. K., Gangopadhyay, A., Man, P. K., Kuudu, A. L., and Mazumdar, D.: Organic amendments influence soil organic carbon pools and rice-wheat productivity, Soil Sci. Soc. Am. J., 72, 775–685, 2008.

Mangalassery, S., Sjögersten, S., Sparkes, D. L., Sturrock, C. J., and Mooney, S. J.: The effect of soil aggregate size on pore structure and its consequence on emission of greenhouse gases, Soil Till. Res., 132, 39–46, 2013.

Marinari, S., Masciandaro, G., Ceccanti, B., and Grego, S.: Influence of organic and mineral fertilisers on soil biological and physical properties, Bioresource Technol., 72, 9–17, 2000.

Mazaheri, M. R. and Mahmoodabadi, M.: Study on infiltration rate based on primary particle size distribution data in arid and semi-arid region soils, Arabian Journal of Geosciences, 5, 1039–1046, doi:10.1007/s12517-011-0497-y 2012.

Musinguzi, P., Ebanyat, P., Tenywa, J. S., Basamba, T. A., Tenywa, M. M., and Mubiru, D.: Precision of farmer-based fertility ratings and soil organic carbon for crop production on a Ferralsol, Solid Earth, 6, 1063–1073, doi:10.5194/se-6-1063-2015, 2015.

Novara, A., Rühl, J., La Mantia, T., Gristina, L., La Bella, S., and Tuttolomondo, T.: Litter contribution to soil organic carbon in the processes of agriculture abandon, Solid Earth, 6, 425–432, doi:10.5194/se-6-425-2015, 2015.

Pansu, M. and Gautheyrou, J.: Handbook of Soil Analysis, Mineralogical, Organic and Inorganic Methods, Springer, Heidelberg, Germany, 993 pp., 2006.

Parras-Alcántara, L. and Lozano-García, B.: Conventional tillage versus organic farming in relation to soil organic carbon stock in olive groves in Mediterranean rangelands (southern Spain), Solid Earth, 5, 299–311, doi:10.5194/se-5-299-2014, 2014.

SAS Institute.: SAS/STAT Users Guide, Statistics Version, sixth ed., SAS Institute, Cary, NC, 1990.

Sey, B. K., Manceur, A. M., Whalen, J. K., Gregorich, E. G., and Rochette, P.: Small-scale heterogeneity in carbon dioxide, nitrous oxide and methane production from aggregates of a cultivated sandy-loam soil, Soil Biol. Biochem., 40, 2468–2473, 2008.

Sirjani, E. and Mahmoodabadi, M.: Effects of sheet flow rate and slope gradient on sediment load, Arabian Journal of Geosciences, 7, 203–210, doi:10.1007/s12517-012-0728-x, 2014.

Six, J., Guggenberger, G., Paustian, K., Haumaier, L., Elliott, E. T., and Zech, W.: Sources and composition of soil organic matter fractions between and within soil aggregates, Eur. J. Soil Sci., 52, 607–618, 2001.

Smith, P., Cotrufo, M. F., Rumpel, C., Paustian, K., Kuikman, P. J., Elliott, J. A., McDowell, R., Griffiths, R. I., Asakawa, S., Bustamante, M., House, J. I., Sobocká, J., Harper, R., Pan, G., West, P. C., Gerber, J. S., Clark, J. M., Adhya, T., Scholes, R. J., and Scholes, M. C.: Biogeochemical cycles and biodiversity as key drivers of ecosystem services provided by soils, SOIL, 1, 665–685, doi:10.5194/soil-1-665-2015, 2015.

Soil Survey Staff: Keys to Soil Taxonomy (11th Ed.), NRCS, USDA, USA, 2010.

Srivastava, P. K., Gupta, M., Shikha, N., Singh, N., and Tewari, S. K.: Amelioration of sodic soil for wheat cultivation using bioaugmented organic soil amendment, Land Degrad. Dev., in press, doi:10.1002/ldr.2292, 2014.

Strong, D. T., De Wever, H., Merckx, R., and Recous, S.: Spatial location of carbon decomposition in the soil pore system, Eur. J. Soil Sci., 55, 739–750, 2004.

Tejada, M. and González, J. L.: Effects of the application of a compost originating from crushed cotton gin residues on wheat yield under dryland conditions, Eur. J. Agron., 19, 357–368, 2003.

Thomas, C., Sexstone, A., and Skousen, J.: Soil biochemical properties in brown and gray mine soils with and without hydroseeding, SOIL, 1, 621–629, doi:10.5194/soil-1-621-2015, 2015.

Turgut, B.: Comparison of wheat and safflower cultivation areas in terms of total carbon and some soil properties under semi-arid climate conditions, Solid Earth, 6, 719–725, doi:10.5194/se-6-719-2015, 2015.

Walkley, A. and Black, I. A.: An examination of the degtjareff method for determining soil organic matter, and proposed modification of the chromic acid titration method, Soil Sci., 37, 29–38, 1934.

Yazdanpanah, N. and Mahmoodabadi, M.: Reclamation of calcareous saline- sodic soil using different amendments: Time changes of soluble cations in leachate, Arabian Journal of Geosciences, 6, 2519–2528, doi:10.1007/s12517-011-0505-2, 2013.

Yazdanpanah, N., Pazira, E., Neshat, A., Mahmoodabadi, M., and Rodríguez Sinobas, L.: Reclamation of calcareous saline sodic soil with different amendments (II): Impact on nitrogen, phosphorous and potassium redistribution and on microbial respiration, Agr. Water Manage., 120, 39–45, doi:10.1016/j.agwat.2012.08.017, 2013.

Yazdanpanah, N., Pazira, E., Neshat, A., Naghavi, H., Moezi, A. A., and Mahmoodabadi, M.: Effect of some amendments on leachate properties of a calcareous saline- sodic soil, International Agrophysics, 25, 307–310, 2011.

Yu, Y. and Jia, Z. Q.: Changes in soil organic carbon and nitrogen capacities of Salix cheilophila Schneid along a revegetation chronosequence in semi-arid degraded sandy land of the Gonghe Basin, Tibetan Plateau, Solid Earth, 5, 1045–1054, doi:10.5194/se-5-1045-2014, 2014.

Zornoza, R., Acosta, J. A., Bastida, F., Domínguez, S. G., Toledo, D. M., and Faz, A.: Identification of sensitive indicators to assess the interrelationship between soil quality, management practices and human health, SOIL, 1, 173–185, doi:10.5194/soil-1-173-2015, 2015.