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

Najme Yazdanpanah[a*]

[a] Department of Water Engineering, Kerman Branch, Islamic Azad University, Kerman,
Iran. P.O. Box: 31587-11167
Tel: +98 34 31321037; Fax: +98 34 31321010

[*]Corresponding author: Najme Yazdanpanah
E.mail: najmeyazdanpanah@yahoo.com

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Abstract

This investigation examines the effect of different amendments on selected soil physical and biological properties over a twenty four 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 Mg ha^{-1} and 30 Mg ha^{-1} to a clay loam soil and a loamy sand soil in a semiarid region. Result 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 macro pore 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, as a response, soil porosity especially macro pore fraction controlled CO_2 flux.

Key words: Aggregate stability, Microbial respiration, Pore size, Semiarid regions, Soil organic carbon.

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 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 improve 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 specially 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 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; Cerdà et al., 2015).

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. macro pores and micro pores) 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.

2. Materials and Methods

2.1. Experimental sites description

This research was conducted in two different agricultural fields both located in a same semiarid climate conditions in Kerman province, central Iran (30° 14' N and 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 ºC. 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 has been cultivated in these fields were wheat (*Tritium aestivum* L.) and corn (*Zea mays* L.). Irrigation has 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 were under fallow for 2 years and were not fertilized to make them more homogeneous. In two 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 much 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 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 totally 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 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 indicator of soil microbial activity. Soil samples (100 g) at 75% of water holding capacity were incubated at 25º C 7 d 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 sulphuric 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 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 cylinder method, being made of 100 cm^3 cylinders, after drying 24 hr 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).

2.5. Statistical analysis

To study the effects of applied treatments on the selected soil properties, the obtained data were subjected to 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 macro/micro porosity ratio by regression functions. All the statistical analyses were performed in the SAS 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 rate 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 did 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, so that the highest values for loamy sand and clay loam soils were respectively 182.1 and 261.5 µg CO_2 g^{-1} soil. The values of microbial respiration for 10 Mg ha^{-1} and 30 Mg ha^{-1} application rates of MSW, were respectively 2 and 3 times higher in the loamy sand soil, and 2.1 and 3.3 times higher in the clay loam soil than those values obtained for unamended soils. The addition of 10 Mg ha^{-1} 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 higher rate of organic amendments added to the soils (i.e. 30 Mg ha^{-1}), 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 Mg ha^{-1} and 30 Mg ha^{-1} application rates of MSW, the aggregate stability levels were respectively 1.6 and 1.9 times higher than those 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 Mg ha^{-1} and 30 Mg ha^{-1} application rates of MSW was respectively 1.1 and 1.2 times higher 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 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 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 cm^3 cm^{-3} to 0.47 cm^3 cm^{-3} and in the clay loam soil it ranged from 0.41 cm^3 cm^{-3} to 0.59 cm^3 cm^{-3}. The total porosity values produced by 10 Mg ha^{-1} and 30 Mg ha^{-1} application rates of MSW were respectively 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 than those observed in the control plots. The addition of 10 Mg ha^{-1} 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 significantly ($p<0.05$) by the organic amendment treatments (Table 3). The incorporation of amendments into the soils, especially at the higher rate (30 Mg ha^{-1}), enhanced significantly ($p<0.05$) the fraction of soil volume allocated to macro pore fraction. In general, due to different treatments studied, the macro pore fraction varied from 11 cm^3 cm^{-3} to 25 cm^3 cm^{-3} in the loamy sand soil and from 12 cm^3 cm^{-3} 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 be partly 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, higher ratio of C:N can be associated with 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 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. Fig. 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 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, resultsing in more resistant against the microbial decomposition (Majumder et al., 2008; Mahmoodabadi and Heydarpour, 2014). Therefore, AR shows slower microbial decomposition as well as 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).

At the beginning of 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 greater percentage of clay particles and much less 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) in two contrasting soil textures found that both texture and aggregate size significantly influenced CO_2 emission. 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 CO_2 emitted from micro aggregates (<0.25 mm) compared to macro aggregate (>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 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).

The addition of organic amendments to the soils also improved the aggregate stability and consequently increased the soils total porosity especially macro pore fraction. The result indicated that the capability of different organic amendments in the improving 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 more significant effect in plots amended with the higher rate (i.e. 30 Mg ha^{-1}). Similarly, Bronick and Lal (2005) found parallel increases in SOC concentration and aggregate stability following the poultry manure application. To 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 increasing in macro pore 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). Fig. 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, so that the CO_2

emission was stimulated significantly ($p<0.01$) as power functions of the total porosity of soils. 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 the total porosity and changing the distribution of pore sizes in loamy and clay textured soils. In some studies, the effect was significant in micro pore 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 macro pore fraction was much more sensitive to the amendments application than the micro pore fraction. This finding is in agreement with Jarvis (2007) who reported that macro pore fraction had higher temporal variability than micro pore fraction. The macro pore fraction in general contributes to ease the aeration of soil and consequently affects on 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, as a response, the soil porosity especially macro pore fraction influences significantly the carbon mineralization and CO_2 flux. In fact, the improved soil macroporosity due to the stimulated microbial activity might as well ease the soil aeration producing more oxygen available to microorganism for the respiration process.

4. Conclusion

The use of MSW and AR improved significantly the structural stability and biological properties of soils with larger influence at higher application rate. At the end of 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 macro pore fraction. Apart from soil texture, the aggregate size distribution plays an important role in the carbon stock and CO_2 emission. The macro pore fraction was much more sensitive to the application of amendments than the micro pore 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, as a response, the soil porosity, especially macro pore fraction, influenced the soil microbial respiration and carbon mineralization.

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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

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

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] **($g\ kg^{-1}$)**	**WSA** [b] **(%)**	**Total porosity ($cm^3\ cm^{-3}$)**	**Microporosity ($cm^3\ cm^{-3}$)**	**Macroporosity ($cm^3\ cm^{-3}$)**	**Respiration (µg 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. Suffixes10 and 30 represent the application rates of 10 Mg ha^{-1} and 30 Mg ha^{-1}, respectively.

[a] OC: organic carbon

[b] WSA: water stable aggregates

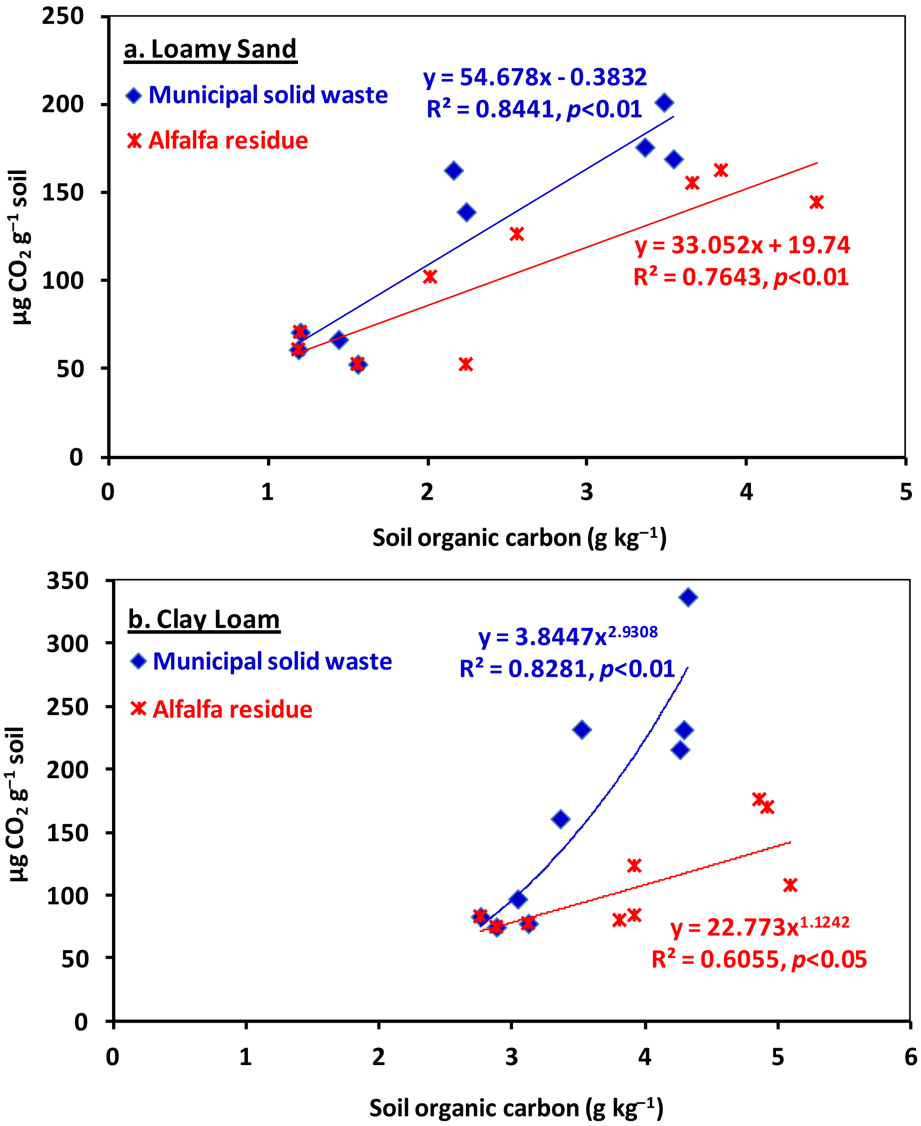

Fig. 1. Relationship between the soil organic carbon and microbial respiration of loamy sand (a) and clay loam (b) soils treated with different levels of municipal solid waste (MSW) and alfalfa residue (AR).

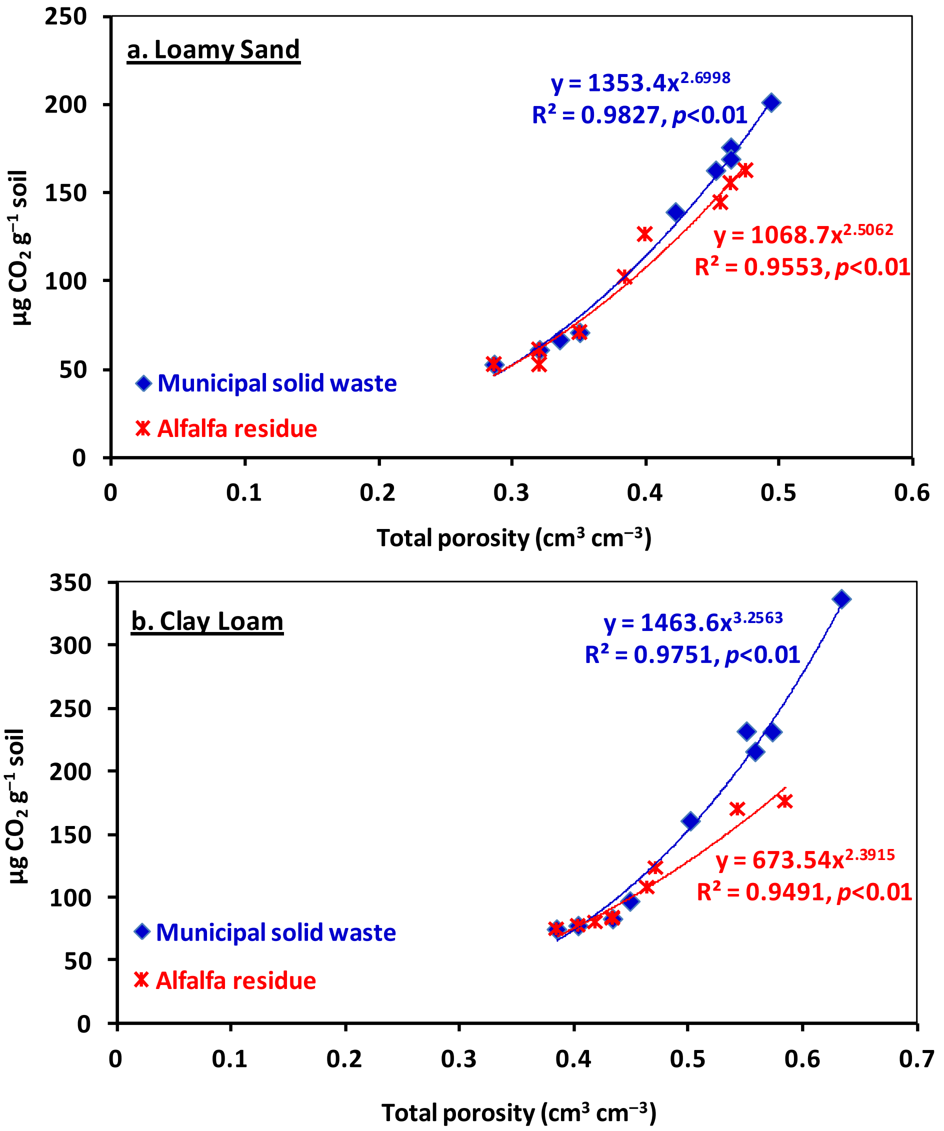

Fig. 2. Relationship between the total porosity and soil microbial respiration of loamy sand (a) and clay loam (b) soils treated with different levels of municipal solid waste (MSW) and alfalfa residue (AR).

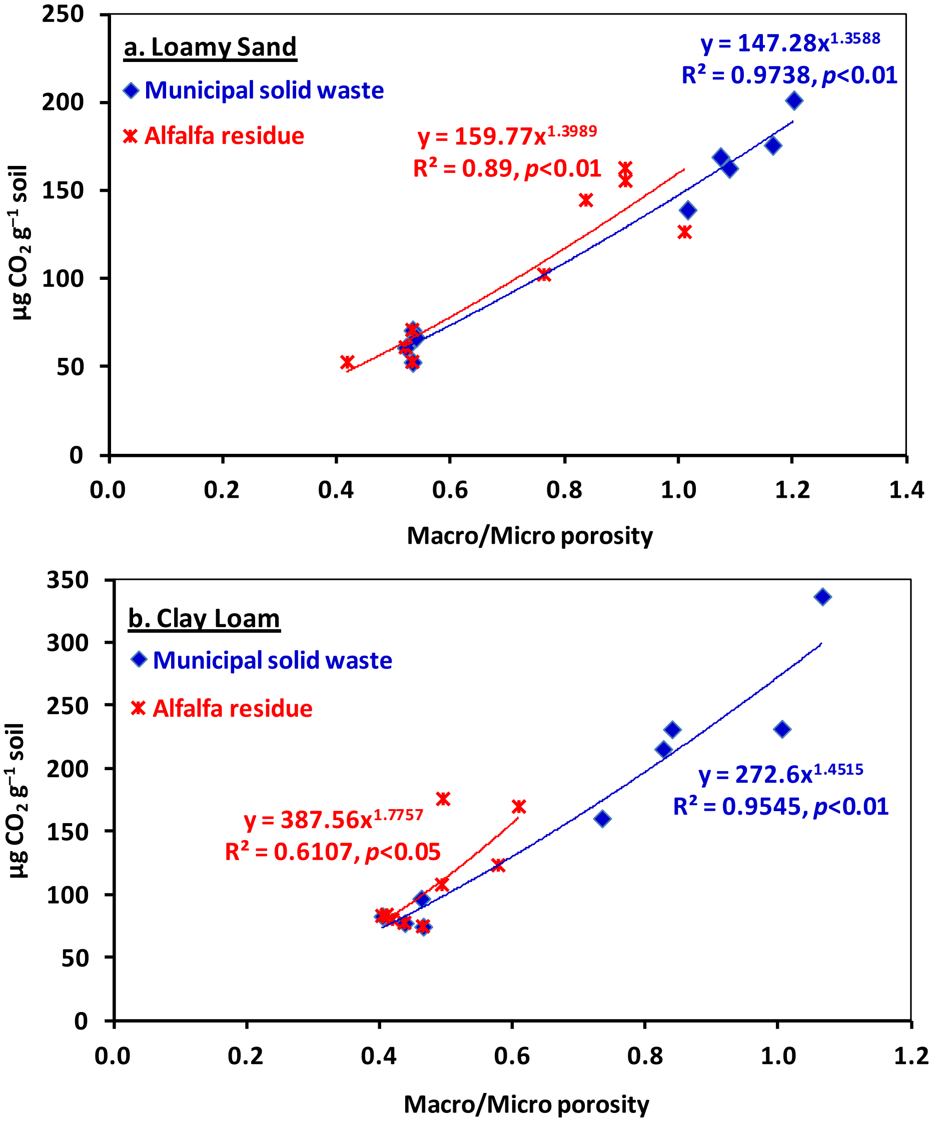

Fig. 3. Relationship between the ratio of macroporosity to microporosity and soil microbial respiration of loamy sand (a) and clay loam (b) soils treated with different levels of municipal solid waste (MSW) and alfalfa residue (AR).