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INTERNATIONAL
Agrophysics
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Int. Agrophys., 2014, 28, 169-176
doi: 10.2478/intag-2014-0005

Sequestration of organic carbon influenced by the application of straw residue and farmyard manure in two different soils

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Received September 20, 2012; accepted December 2, 2012

Abstract. Soil organic carbon is one of the most important soil components, which acts as a sink for atmospheric CO_2. This study focuses on the effect of different methods of organic matter application on the soil organic carbon sequestration in a 4-month experiment under controlled greenhouse conditions. Three rates of straw residue and farmyard manure were added to uncultivated and cropland soils. Two treatments of straw residue and farmyard manure incorporation were used into: a soil surface layer and 0-20 cm soil depth. The result showed that the application of organic matter, especially the farmyard manure incorporation led to a significant increase in the final soil organic carbon content. Higher amounts of soil organic carbon were stored in the cropland soil than in the uncultivated soil. On average, the soil surface layer treatment caused a higher sequestration of soil organic carbon compared to the whole soil depth treatment. If higher rates of organic matter were added to the soils, lower carbon sequestration was observed and *vice versa*. The result indicated that the carbon sequestration ranged farmyard manure > straw residue and cropland soil > uncultivated soil. The findings of this research revealed the necessity of paying more attention to the role of organic residue management in carbon sequestration and prevention of increasing global warming.

Keywords: carbon sequestration, farmyard manure, straw residue, rates and methods of organic matter incorporation

INTRODUCTION

It has been recognized in recent decades that the quantity of carbon stored in soils is important on a global scale. Therefore, land management practices affecting the soil organic carbon (SOC) content may have a global impact, if they are applied over large areas (Bronick and Lal, 2005). Global warming concerns have led to a surge of interest in evaluating the effect of management practices on carbon sequestration in soils (Adesodun and Odejimi, 2010). This interest is justified because soils as a sink for atmospheric CO_2 play a key role in the global carbon budget as well as in the global carbon cycle (Eshel *et al*., 2007). Soils are the third largest active carbon pool after the hydrosphere and the lithosphere (Eshel *et al*., 2007). The role of soils as either a source or a sink for greenhouse gases, in general, and that of CO_2, in particular, has been a focus of recent studies (Bhattacharyya *et al*., 2009; Majumder *et al*., 2008).

Since the largest terrestrial pool of carbon is located in the soils (Bhattacharyya *et al*., 2009), factors that affect its retention and release also influence its exchange between soil and atmosphere (Borkowska and Stępniewska, 2011). Storage of SOC in agricultural systems is a balance between carbon additions from non-harvested portions of crops (Wu *et al*., 2008), organic sources (Thelen *et al*., 2010), and carbon losses, primarily through organic matter decomposition and release of respired CO_2 to the atmosphere (Bird *et al*., 2002). For centuries, organic matter has been applied to agricultural soils as a means of supplying the crops with nutrients and maintaining the required SOC content with benefits to soil structure (Balashov *et al*., 2010). Organic substances improve soil aggregation, reduce soil compaction and surface crusting, increase carbon sequestration and nutrient availability, and enhance infiltration and water holding capacity (Ohu *et al*., 2009).

The relationships between soil organic matter, microbial activity, and chemical and physical properties have been evidenced by numerous studies (Fernandez *et al*., 2010; Khan *et al*., 2007). Increased microbial activity and SOC content in manured soils contributed to increasing soil aggregate stability (Balashov *et al*., 2010). Bronick and Lal, (2005) found an increase in the SOC concentration after application of poultry manure and, as a result, higher formation of soil aggregates.

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The incorporation of organic matter into arable arid soils with a low content of SOC is likely to have benefits for soil physical properties and nutrient recycling with relevant economic benefits for farmers (Bronick and Lal, 2005). From another point of view, the application of organic substances may lead to higher greenhouse gas emissions. Both recycling of crop residues and application of farmyard manure (FYM) were suggested to improve soil fertility and to support sustainable production. In some studies, the effects of application of organic sources on soil physical, chemical, and biological properties (Adesodun and Odejimi, 2010; Głąb *et al*., 2009) and CO_2 emissions from soils (Fernandez *et al*., 2010) have been investigated. SOC sequestration is mainly influenced by such key factors as the amounts of C input (Borzecka-Walker *et al*., 2008), plant residue management (Thelen e*t al*., 2010), soil depth (Blanco-Conquie and Lal, 2007), and soil texture (Gami *et al*., 2009). In agro-ecosystems, various organic matter management practices can have different impacts on SOC sequestration.

The main objectives of this study were to evaluate: the effects of different methods of organic matter application on SOC sequestration, and the effects of soil texture and depth, and the type and application rates of organic matter on SOC sequestration in two different soils.

MATERIALS AND METHODS

In this research, two soils were studied from an arid area in Kerman province, central Iran. A sample of the first soil was taken from an uncultivated land located on Aeolian deposits, whereas that of the second soil was collected from an adjacent agricultural field, which was under fallow for 2 years at the moment of soil sampling. These soils were called 'uncultivated soil' and 'cropland soil', respectively. The uncultivated soil is classified as Torripsamments and the cropland soil is classified as Haplocalcids. The long-term mean precipitation of the area is 140 mm per annum, which mainly occurs in winter. During the last 25 years, the maximum and minimum amounts of rainfall were recorded for 1992 and 1998 – 307.2 and 56.3 mm y^{-1}, respectively. The average annual temperature for this region is 16.5°C and varies from 1.9 to 28.9°C.

Soil samples were taken from a 0-20 cm depth, air-dried, crushed to pass through a 2 mm sieve and, finally, selected physical and chemical properties were measured (Table 1). Soil texture was determined by the hydrometer method (Gee and Or, 2002) and total porosity of the soils was calculated on the basis of their saturated moisture content and bulk density. Soil pH and EC were measured in the saturated paste and the saturated paste extract, respectively (Page *et al.*, 1992). The content of SOC was determined as described by Walkley and Black (1934), and the percent of $CaCO_3$ equivalent was measured using the titration method (Pansu and Gautheyrou, 2006).

The measured physical and chemical properties of the soils are presented in Table 1. Compared to the uncultivated soil with a loamy sand texture, the cropland soil is a silty loam containing higher silt and lower sand contents, while the percent of clay is nearly similar in both soils. As it is expected from the soils of arid and semiarid regions of Iran, these two soils have considerable amounts of $CaCO_3$ equivalent (16.5-17%). As a key parameter, the SOC content was higher in the cropland soil (6.0 g C kg^{-1} soil) than in the uncultivated soil (3.4 g C kg^{-1} soil). However, based on these values of the SOC content, both soils can be classified as poor in native organic matter.

Farmyard manure (FYM) and wheat straw residue were chosen as animal and plant organic sources, respectively. Chemical composition of the FYM and straw residue was measured and their EC and pH values were measured 24 h after 1 h shaking of 1 g samples in vials with 5 ml distilled water. The amounts of SOC and total nitrogen were measured by the Walkley and Black (1934) and Kjeldahl methods, respectively (Pansu and Gautheyrou, 2006).

The applied organic matter had different chemical composition (Table 2). The EC of the FYM was 10 times greater than that of the straw residue. Although the SOC content was similar, the total nitrogen concentration in the FYM was 65 times higher than that in the straw residue. The C:N ratios obtained for the FYM and straw residue were 10.9 and 707.5, respectively.

The experiment was carried out as factorial based on a completely randomized design under controlled greenhouse conditions. As indicated above, the applied treatments included two soils, two types of organic matter incorporated at three rates by two different methods, and three replications. Accordingly, the experiment was performed in pots containing 10 kg of air-dried soil to simulate a 20 cm soil depth. The straw residue and FYM were crushed to pass through a 2 mm sieve. Afterwards, the straw residue and

T a b l e 1. Some physical and chemical properties of uncultivated and cropland soils

Soil	Sand	Silt	Clay	Native OC	$CaCO_3$	Porosity	pH	EC ($dS\ m^{-1}$)
	(%)							
Uncultivated	79.91	7.78	12.31	0.34	17.0	28.61	7.83	0.67
Cropland	35.13	52.86	12.01	0.60	16.5	57.37	7.70	1.06

OC – organic carbon, EC – electrical conductivity.

Table 2. Chemical composition of FYM and wheat straw residue

Organic sources	$EC_{(1:5)}$ (dS m^{-1})	$pH_{(1:5)}$	OC (%)	TN (%)	C:N
FYM	2.62	8.14	14.2	1.30	10.9
Straw residue	0.25	5.98	14.1	0.02	707.5

EC – electrical conductivity, OC – organic carbon, TN – total nitrogen. EC and pH were measured 24 h after 1 h shaking of a 1 g sample in 5 ml distilled water.

FYM were applied in two arrangements: mixed with the soil surface layer of 0-7 cm (SUR treatment) and homogeneously mixed with the 0-20 cm soil layer (whole soil depth, MIX treatment), each at the rates of 0 (control), 100, and 300 g of dry organic matter per each pot. Correspondingly, different treatments including C (control), S1, S3 (1 and 3% wheat straw residue, respectively), and M1, M3 (1 and 3% FYM, respectively) were examined.

After preparing the treatments, the treated soils were incubated at field water capacity and a constant temperature of 25°C for 4 months to stimulate decomposition of the residues. At the end of the incubation period, the soil samples were collected from two depths of 0-7 cm (upper-layer) and 7-20 cm (sub-layer), separately. Then, they were analyzed to determine the final SOC content.

The content of native SOC in the soils was measured initially. In addition, different amounts of organic matter were added to each soil according to its type and application rate. Therefore, the SOC content in each soil was calculated prior to the incubation (OC_i). Moreover, at the end of the experiment, the amount of final SOC (OC_f) was measured in the treated soils. According to the initial and final content of SOC, carbon sequestration percentage (CSP) was calculated for each treatment as:

$$CSP = \left[\frac{OC_f}{OC_i}\right]100.$$

To study the effects of the applied treatments on selected soil properties, the results obtained were subjected to analysis of variance (ANOVA) tests to assess the treatment differences. Duncan test ($\alpha = 0.01$) was applied to compare the differences between the treatment means. All the statistical analyses were performed in the SAS system.

RESULTS AND DISCUSSION

Table 3 shows the result of analysis of variance for the SOC content and the CSP in the applied treatments. It was found that almost all of the considered treatments significantly affected the final SOC content and the CSP. It is obvious that the resultant property (*eg* SOC) of different soils due to the addition of organic matter is not the same. This is partly because of the differences in the chemical and physical properties of both soils (Table 1). Initially, the studied soils were composed of different levels of native SOC. Moreover, the final values of the SOC content and CSP were significantly (p<0.01) influenced by the type and the application rate of organic matter. This is partly due to the different content of organic carbon (OC) in the FYM and straw residue added to the soils (Table 2). As a result of the process of decomposition of organic sources, different amounts of OC were added to the soils. In some previous studies, a direct relationship between application rates of organic matter and the final SOC content has been reported (Bronick and Lal, 2005).

Table 3. Variance analysis of the final soil organic carbon (SOC) and carbon sequestration percentage (CSP) for the applied treatments (the values are mean square)

Source of variance	Degrees of freedom	Organic carbon	Carbon sequestration percentage
Soil (A)	1	1.07**	180.40**
Type and rate of organic matter (B)	4	0.06**	2870.81**
Method of application (C)	1	0.03**	111.23**
Soil depth (D)	1	0.12**	1059.41**
A×B	4	0.03**	268.19**
A×C	1	0.001ns	882.07**
A×D	1	0.02**	25.67**
B×C	4	0.01**	217.78**
B×D	4	0.001*	25.27**
C×D	1	0.047**	11.47**
A×B×C	4	0.61**	170.58**
A×B×D	4	0.77**	24.56**
A×C×D	1	0.75**	0.02 ns
B×C×D	4	1.07**	14.45**
A×B×C×D	4	1.05**	13.03**
Error	94	0.00004	1.03

Significant at level: *0.05, **0.01, ns – not significant.

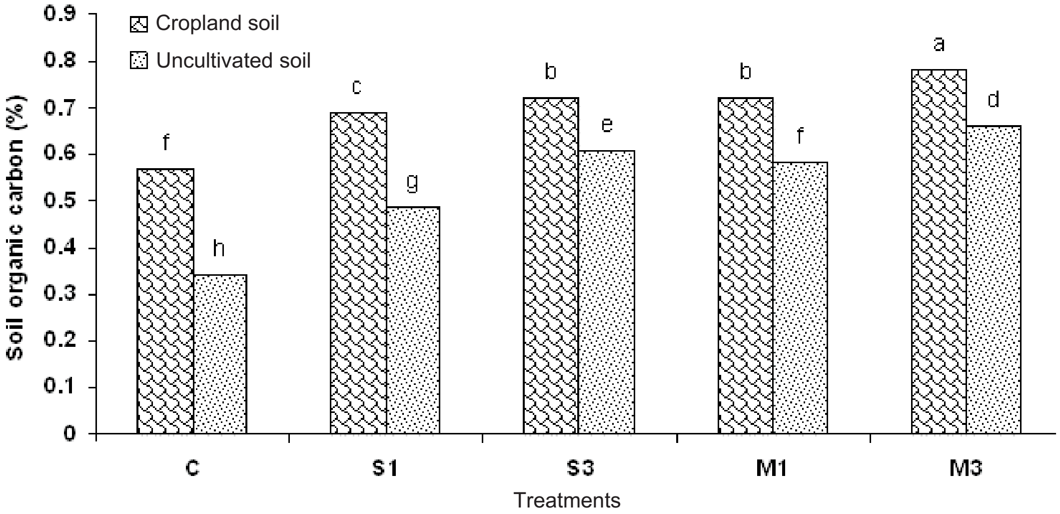

Fig. 1. Comparison between the soil organic carbon contents in cropland and uncultivated soils affected by the type and application rate of organic matters (mean comparison using Duncan test; $p<0.01$). Results of the 4-month pot experiment where: C – control, S1 – 1% wheat straw residue, S3 – 3% wheat straw residue, M1 – 1% FYM, M3 – 3% FYM. Different small letters on the columns indicate treatment means significantly different at $p<0.01$.

As a practical result, the effect of the type and application rates of the straw residue and FYM on the content of SOC at the end of the experiment for both soils is presented in Fig. 1. As shown, the application of the straw residue and FYM into the soils led to a significant increase in the SOC content. The higher the rate of added organic matter was, the higher increase in SOC content was observed. This result is consistent with the findings of Wu *et al.* (2008), who found an increase in the final SOC content after application of organic matter. Similarly, Adesodun and Odejimi (2010) observed that carbon sequestration was enhanced with the application of pig-composted manure.

It is apparent from the result that a higher amount of OC was added to the soils with the FYM application than that with the straw residue application. However, the C:N ratio of straw residue was higher than the C:N ratio of FYM (Table 2). In some studies, this ratio has been attributed to the decomposability of organic matter, *ie* lower values of C:N ratios were associated with higher rates of organic matter decomposition (Majumder *et al.*, 2008). This finding is inconsistent with our results. It can be assumed that the applied organic matter had different amounts of lignin and polyphenol as resistant organic components. It seems that the application of FYM with higher contents of these organic constituents led to formation of stable soil organic complexes, which could be more resistant to the microbial decomposition than the soil organic matter in the straw residue treatment (Majumder *et al.*, 2008). Therefore, the FYM treatment might have slower breakdown as well as lower mineralisation rates (Liu *et al.*, 2010). On the other hand, FYM has a much lower C:N ratio, 10.9 (*ie* it has a very high amount of easily available nitrogen) than that in wheat straw residue, 700.5. Therefore, the application of FYM, compared to the wheat residue, can contribute to a higher increase in the size and functional group diversity of soil microorganisms that may decompose any inherent soil organic complexes and substances, even including humic acids. Besides, the application of wheat straw residue (with a high C:N ratio) into the soils can cause deficiency in available mineral nitrogen. Rasse *et al.* (2005) found that organic substances originating from crop roots were more resistant to decomposition than those of aboveground shoot residues. In general, the accumulation of SOC after inputs of organic matter is likely to be influenced by their biochemical composition and decomposition rates.

Moreover, a comparison of the final SOC content in the soils after the FYM and straw residue application indicated that the cropland soil had higher concentrations of SOC than the uncultivated soil. Nevertheless, the native OC content in the cropland soil was higher than that in the uncultivated soil. This means that, apart from the type and application rate of organic matter, soil texture plays an important role in carbon stock. As a general concept, the release of respired CO_2 to the atmosphere is much easier in coarse-textured soils compared to fine-textured soils.

The effect of different methods of organic matter application on the SOC content measured after the experiment is shown in Fig. 2. In general, significantly higher values of the SOC content were observed in the SUR than in the MIX treatment. This implies that the incorporation of organic matter into the soil surface led to a higher soil carbon stock, but this effect was insignificant in the control treatment. The

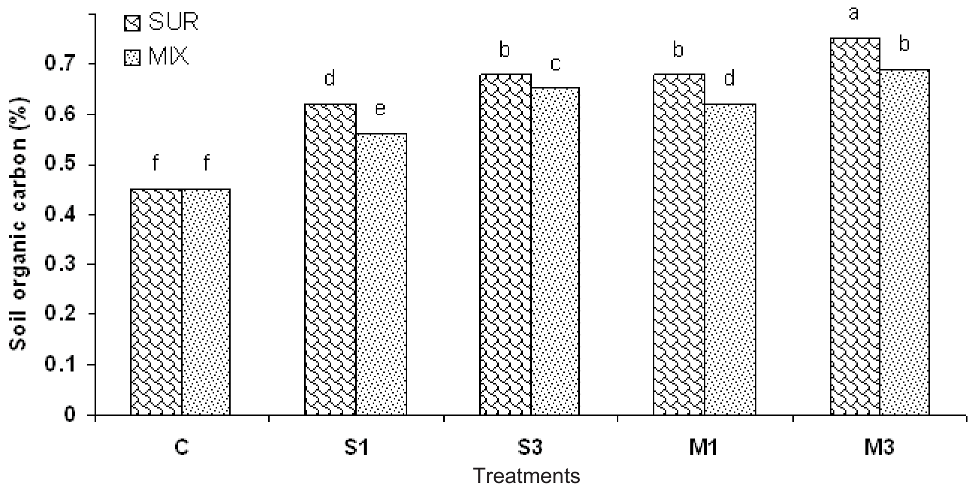

Fig. 2. Comparison between the soil organic carbon content affected by the different methods of organic matter application.Results of the 4-month pot experiment where SUR – mixed with the soil surface layer of 0-7 cm, MIX – homogeneously mixed with the 0-20 cm soil layer, S1 – 1% wheat straw residue, S3 – 3% wheat straw residue, M1 – 1% FYM, M3 – 3% FYM. Other explanations as in Fig. 1.

surface application of straw residue produces a buffer zone between the soil and atmosphere, which protects the soil from direct sunlight. Such surface soil mulching by plant residues may diminish mineralization of organic matter (Thelen *et al*., 2010) and, therefore, higher amounts of SOC can be stored in the soils.

In some cases, researchers reported that the application of organic matter in the soil surface also protects the surface from the direct impact of raindrops and reduces excessive fluctuations of freezing and thawing cycles of surface soil (Thelen *et al*., 2010). However, this process was not dominant in our study. Compared to the MIX treatment, when the straw residue was added to the soil surface, fewer soil aggregates were subjected to slaking (Zinn *et al*., 2005), which led to accumulation of SOC within the soil aggregates. Moreover, due to the accumulation of organic matter in the topsoil layer, hydrophobic properties can be more pronounced and result in lower rewetting of aggregates (Denef *et al*., 2001). Consequently, the hydrophobic behaviour may be due to the presence of humic acids, which act as strong binding agents of soil particles (Bronick and Lal, 2005). Under these circumstances, less organic matter can be decomposed and emitted as CO_2 to the atmosphere.

Our findings have clearly demonstrated that any management practices with organic sources can influence the resultant SOC content. In fact, if the aim of management practices is carbon sequestration, the better choice is to apply organic residues to the surface layer of soil.

From another point of view, each type of organic matter was applied at the rates of 0 (control), 100, and 300 g of dry organic matter per pot. However, for the SUR treatment, all these levels of the added organic matter were concentrated just in the surface layer of 0-7 cm (one third of the pot depth). In fact, in the SUR treatment, all the applied organic matter per pot was mixed with the soil surface layer of 0-7 cm. Therefore, the concentration of organic matter in the surface layer was three times higher than in the MIX treatment within the depth of 0-20 cm. Accordingly, regardless of the method of incorporation (MIX or SUR) for each type of organic matter, four levels of the organic sources were applied at the depth of 0-7 cm (0, 1, 3 and 9% per layer). The SOC content in the 0-7 cm soil layer at different levels of added organic matter is shown in Fig. 3. It is obvious that the content of SOC increased with the increasing rate of organic matter. However, the differences observed in the SOC content were insignificant in some cases. The application of FYM, compared to straw residue, led to a sharper increase in the SOC content, particularly at the higher rates. Besides, the cropland soil exhibited higher values of the SOC content than the uncultivated soil, as discussed earlier.

Based on the initial and final percentages of the SOC content, the parameter of carbon sequestration percentage (CSP) was calculated for each treatment according to equation. The results for uncultivated and cropland soil are presented in Figs 4 and 5, respectively. The order of the CSP values for both soils was nearly similar. In general, the application of 1% FYM mixed with the soil surface layer of 0-7 cm (M1SUR) showed the highest value of CSP, whereas the least CSP values were obtained for the application of 3% straw residue homogeneously mixed with the 0-20 cm soil layer (S3MIX). This means that, at higher rates of organic matter added to the soils, lower values of CSP were obtained and vice versa. This could be partly attributed to the fact that microbial activity in the soil was stimulated in the presence of available organic matter, and may be result of the priming effect (Gajda, 2010; Kuzyakov, 2010). Consequently, at

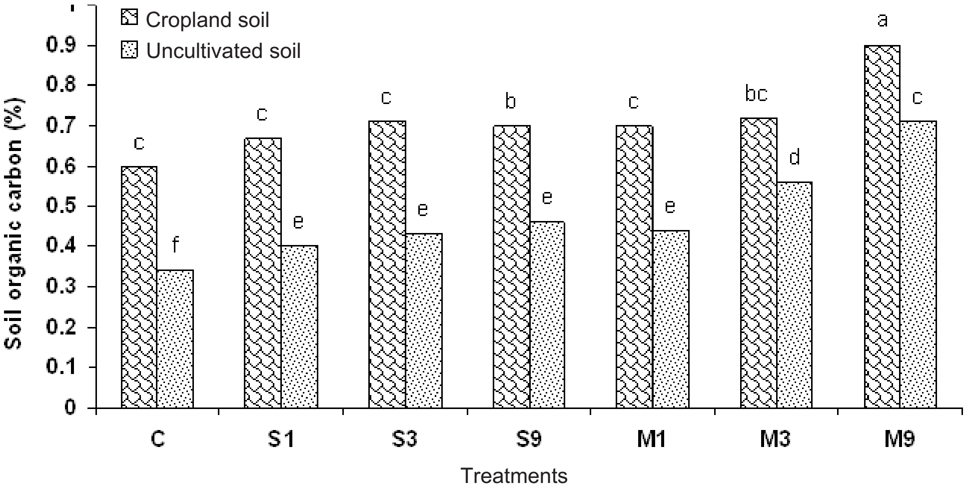

Fig. 3. Comparison between the soil organic carbon content in the 0-7 cm soil layer at the different rates of organic matter added to the soils ($p<0.01$). Results of the 4-month pot experiment where C – control, S1 – 1% wheat straw residue, S3 – 3% wheat straw residue, S9 – 9% wheat straw residue, M1 – 1% FYM, M3 – 3% FYM, M9 – 9% FYM. Other explanations as in Fig. 1.

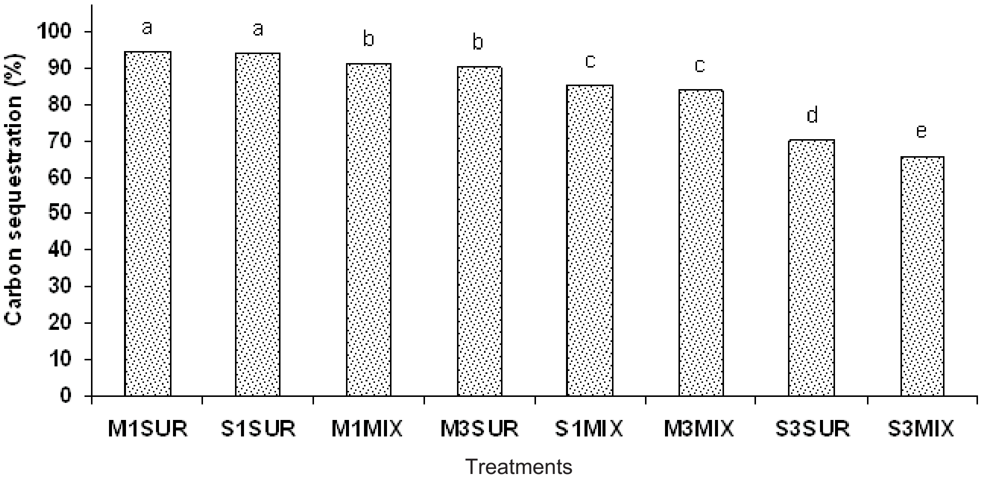

Fig. 4. Comparison of carbon sequestration potentials in the different treatments applied on the uncultivated soil ($p<0.01$). Results of the 4-month pot experiment where SUR – mixed with the soil surface layer of 0-7 cm, MIX – homogeneously mixed with the 0-20 cm soil layer, S1 – 1% wheat straw residue, S3 – 3% wheat straw residue, M1 – 1% FYM, M3 – 3% FYM. Other explanations as in Fig. 1.

higher rates of applied organic matter, carbon mineralization as well as CO_2 emission may be enhanced. Furthermore, it was found that higher amounts of carbon were sequestrated in the SUR than in the MIX treatment. The results also indicated that the application of FYM, in comparison with that of straw residue, contributed to greater carbon sequestration in both soils.

Figure 6 shows comparison of the means of the CSP affected by the different levels of organic matter added to the surface layer (0-7 cm) of the soils. The control treatment showed the highest CSP, since no organic matter was added initially and the soil contained only native SOC. This type of SOC is a relatively stable component and the change in its concentration with time is negligible. For almost all of the cases, the cropland soil showed higher CSP values than the uncultivated soil. However, the content of SOC in the cropland soil was higher than that in the uncultivated soil (Table 1). The texture of soils was different, and, therefore the aeration in the cropland soil was lower than that in the uncultivated soil. In fact, CO_2 produced due to carbon mineralization could be emitted more easily and faster from the uncultivated soil than from the cropland soil, which had a heavier texture and higher ability to protect SOC against microbial decomposition. This result is consistent with the finding of Wu *et al.* (2008), who reported that soil texture is a core determinant of SOC. They concluded that fine-textured

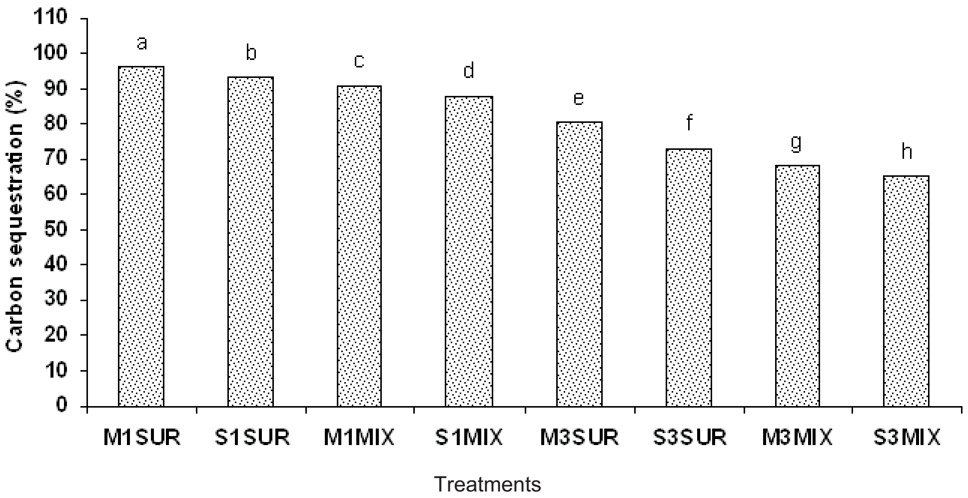

Fig. 5. Comparison of carbon sequestration potentials in the different treatments applied on the cropland soil (p<0.01). Results of the 4-month pot experiment where SUR – mixed with the soil surface layer of 0-7 cm, MIX – homogeneously mixed with the 0-20 cm soil layer, S1 – 1% wheat straw residue, S3 – 3% wheat straw residue, M1 – 1% FYM, M3 – 3% FYM. Other explanations as in Fig. 1.

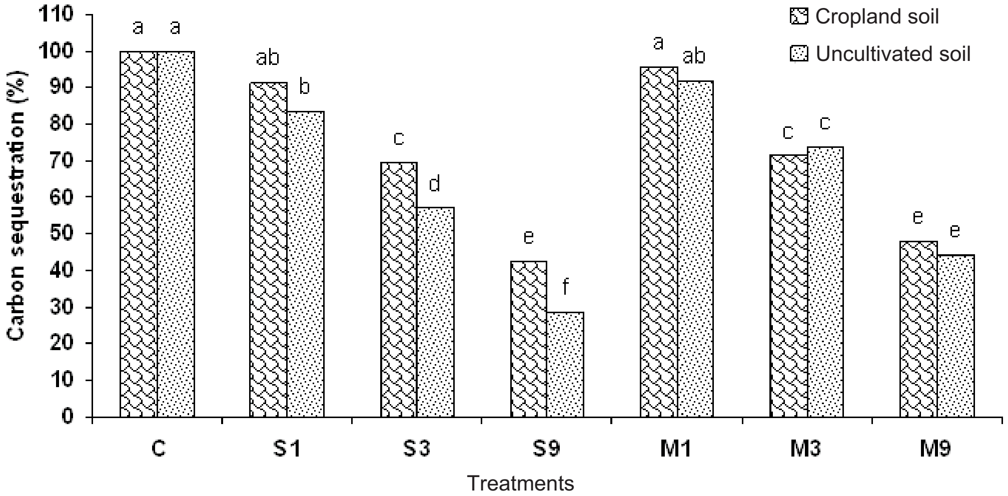

Fig. 6. Comparison of the means of carbon sequestration potentials affected by the different rates of organic matter added to the surface layer (0-7 cm) of the soils (p<0.01). Results of the 4-month pot experiment where C – control, S1 – 1% wheat straw residue, S3 – 3% wheat straw residue, S9 – 9% wheat straw residue, M1 – 1% FYM, M3 – 3% FYM, M9 – 9% FYM. Other explanations as in Fig. 1.

soils have higher rates of organic carbon sequestration during their cultivation compared to coarse-textured ones. This findings support the importance of soil texture in controlling SOC sequestration.

CONCLUSIONS

1. The examination of the different treatments showed that the application of organic matter, especially farmyard manure led to a significant increase in the soil organic carbon content over the 4-month pot experiment. The cropland soil stored higher amounts of soil organic carbon than the uncultivated soil. This means that, apart from the type and application rate of organic matter, soil texture plays an important role in carbon stock change.

2. On average, the soils in the soil surface layer treatment showed a higher soil organic carbon content than those in the whole soil depth treatment. This means that the application of organic matter into the soil surface led to higher carbon sequestration. At the higher rates of added organic matter, lower carbon sequestration values were observed and *vice versa*.

3. The results also indicated that carbon sequestration was farmyard manure > straw residue and also cropland soil > uncultivated soil. The findings of this research revealed the necessity of paying more attention to the role of organic residue management in carbon sequestration.

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