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Emission of Greenhouse Gases from Soil in a Semi-arid Area Applied with Organic Matter in South-western Iran

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ABSTRACT

One of the problems of the modern world is global warming. Agriculture, after industry, is a source of production of greenhouse gases (GHGs). However, suitable agricultural management practices will enable the reduction in emission of GHGs from fields. The objective of this research was to determine the effect of organic matter such as filter mud, bagasse, manure, poultry and biochar on the production of GHGs in a wheat-corn-wheat rotation semi-arid area of south-western Iran from December 2011 to May 2013. The results from this study show there is a fluctuation in production of CH_4, CO_2 and N_2O with the change in seasons, with this behaviour being related to temperature and moisture changes of the season. There were significant differences between treatments and control with more emission from soil after adding organic matter. A comparison of the treated soils showed that biochar had the lowest emissions of CO_2 and N_2O besides experiencing increased immobilisation of CH_4 by the soil for eighteen months.

Keywords: Wheat-corn-wheat rotation, filter mud, bagasse, manure, biochar

INTRODUCTION

Global warming has been described as an increase in surface temperature of the earth. Global warming can lead to environmental imbalance. Agriculture is a major contributor of GHG to the environment and agricultural emissions (60 % of N_2O and 50 % of CH_4) represented 10–12 % of the total global anthropogenic emissions in 2005 (Smith *et al.*, 2007). In semi-arid regions characterised by low rainfall that is restricted to several months in winter and high temperatures in the summer, soils are typically poor in organic matter. Normally, these soils contribute little to global GHG emissions (McLain and Martens, 2006). However, with irrigation and the addition of fertilisers and organic waste, these soils can contribute to net CO_2 losses to the atmosphere (Schlesinger, 1999).

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Soil temperature, soil moisture, soil type, vegetation type, organic substrate type and quantity, and the addition of organic waste can affect the production of GHG (Buyanovsky and Wagner, 1983; Johnson *et al*., 2007). The cumulative effects of a rapid accumulation of GHG in the atmosphere have led to changes in the earth's energy balance and the concern is that ''most of the warming observed over the last 50 years is attributable to human activities'' (Houghton *et al.*, 2001). Methane and nitrous oxide are both produced as a result of microbial processes in the soil (Conrad, 1996). In soils, methane can be formed under anaerobic conditions by methanogens. Under aerobic conditions, both methane that has been produced in anaerobic parts of the soil and atmospheric methane diffusing into the topsoil can be oxidised by methanotrophs (Le Mer and Roger, 2001). Nitrous oxide is naturally produced in soils by microbial processes of nitrification and denitrification (Bleakley and Tiedje, 1982; Bowden, 1986). Impaired aeration in moist soils reduces oxygen availability and promotes the development of partial anaerobic conditions, which, coupled with low redox potential, provide ideal conditions for N_2O production (Ciarlo *et al.*, 2007). Therefore, interactions between soil water content and organic soil amendments will have a profound influence on N_2O emissions. Manure from poultry and livestock contain proteins, amino acids, and carbohydrates and provide a source of energy for bacteria, which, upon decomposition, can release GHGs such as CO_2 and CH_4 (Nyakatawa *et al.*, 2011). While agriculture releases significant amounts of CH_4 and N_2O to the atmosphere, the net GHGs emission in CO_2 equivalent from farming activities can potentially be decreased by increasing soil organic carbon storage and/or decreasing CH_4 and N_2O emissions through improving crop management (Mosier *et al.*, 2006; Smith *et al*., 2008). Increased soil porosity, associated with soil biochar amendment results in improved soil aeration, which ultimately suppresses N_2O emissions (Richardson *et al*., 2009; Clough *et al*., 2013). Therefore, the extent of N_2O emissions from biochar-amended soils is greatly affected by fertiliser type (Nelissen *et al*., 2014), biochar C/N ratio and the amount of organic carbon in soil (Troy *et al*., 2013; Zhu *et al*., 2014), biochar porosity, surface area and particle size (Jeong *et al*., 2015; Martin *et al*., 2015) and the response of denitrifiers (Van Zwietenet *et al.*, 2014). Agricultural lands also remove CH_4 from the atmosphere by oxidation, but this effect is small when compared with other GHG fluxes (Smith and Conen, 2004). Moreover, biochar can promote indirect carbon-sequestration by increasing crop yield, while potentially reducing carbon mineralisation (Kerré *et al.*, 2016).

Since air temperature in south-western Iran is high and rainfall has recently decreased, using organic matter can have a positive effect on crops but the use of suitable organic matter can play a positive role in reducing GHGs. The net emission of CO_2 equivalents from farming activities can potentially be decreased by land management changes to increase soil organic matter content (Follett, 2001). Studies have shown that biochar addition to soil may also influence methane (CH_4) emissions. Soil CH_4 emissions have also been reported to decrease following biochar addition to soil as it reduces anaerobic conditions and increases soil aeration (Rondon *et al*., 2005). In this study, the amount of GHGs emission from different sources of organic matter was compared with each other to find out which of these materials would have a more effective role in preventing GHG emissions.

MATERIALS AND METHODS

This study was conducted at the Shavoor farm area (32°02’58.3”_N, 48°17’36.4”_E). The site has an arid climate and is 65 m above sea level. Mean annual precipitation and temperature are 213 mm and 23° C, respectively. The soil (fine-clayey, mixed, hyperthermic, ustifluvents based on Keys to Soil Taxonomy (2006)), formed on the alluvial sediments of the Shavoor river, was initially low in organic matter (<0.5%). The experimental setup was a randomised complete block design with different rates of five sources of organic matter (filter mud and bagasse from sugarcane waste, manure from livestock, poultry manure from chicken, biochar from citrus) and control (without organic matter) with three replications conducted over two years. Then, farmyard manure at rates of 0 for control and 20 t/ha of a different type of OM were applied as soil amendment on the surface and mixed to 15 cm depth. The distance between blocks was 4 m and blocks size was 100 m × 10 m. Wheat (cultivar D79) was cultivated using flood-irrigation method and corn (cultivar 704) was cultivated using furrow irrigation method. Planting of wheat and corn was mechanically done using a tractor. At the beginning of wheat cultivation, 150 kg ha^{-1} urea was added to prevent the immobilisation process, followed by the application of 50 kg ha^{-1} triple superphosphate and 100 kg ha^{-1} potassium sulfate in order to increase fertility in December 2011. For corn cultivation, 50 kg ha^{-1} urea was added to prevent the immobilisation process, followed by the application of 50 kg ha^{-1} triple superphosphate and 50 kg ha^{-1} potassium sulfate in order to increase fertility. In the second wheat season, no fertiliser was added. This study was conducted in three-crop cycles (wheat-corn-wheat rotation) and during summer, field moisture was supplied with irrigation at 10- day intervals. Measuring of GHGs was carried out from December 2011 to May 2013.

In this study, sampling of gas emissions from soil was performed using static chambers. This method has already been used by many researchers. Chambers were made of polyethylene pipe (20 cm in diameter, 1mm thick and of 1 m height) and sealed by adhesive tape. In the middle of the chamber body, three-way pipes for sampling and a thermometer were installed. Each month, 36 chambers were installed in the field for 2 days per month at 15-day intervals, from December 2011 to May 2013. The chambers were placed about 5 to 7 cm deep in the soil and after ensuring no gas leakage, samples were taken by a 60 ml syringe in a closed chamber for a duration of 5 h. In order to calculate the differences and the presence of gas within the chamber, concurrent to the sampling chamber, fresh air samples from a height of 2 m were taken as control. Control reading was subtracted from the gas measurements taken from the chamber, to obtain net gas emission from the soil. In cases where gas was absorbed by the soil and the amount of gas in the chamber was lower than in the air where negative emissions were obtained, it represented gas absorption immobilisation by the soil. After 1h of sampling, the sample gas was transported to the laboratory, where type and amounts of gas in the chamber were read in mg cm^{-3} volume. Gas analysis in this study was done using the GC model UNICAM series 610. Then the readings were corrected based on the temperature of the chamber. Intervention chamber volume and the duration of the installation chambers, and the amount of gas emissions were calculated based on the emission of carbon dioxide gas in the form desired, that is, mass per unit area per unit time using Excel software. Bulk density (BD; g cm^{-3}) was calculated using

$$BD = Ms/V$$

where Ms is the mass of dry soil (g), and V (cm^3) is the total volume of the soil core.

Statistical analysis was performed based on the data obtained from the gas reading software. Data analysis was performed with SPSS 20 and Tukey's test was used for overall comparison of data using one-way ANOVA and means of treatments.

RESULTS AND DISCUSSION

Effects of Soil Temperature and Moisture on Carbon Dioxide and Nitrous Oxide Fluxes

The statistical analyses of the results (Tables 1 and 2) shows significant differences ($p<0.01$) between treatment mean values for CH_4, CO_2 and N_2O parameters. The bulk density for treatments is shown in Table 3 while percentage of soil moisture and soil temperature is shown in Figure 1. The maximum and minimum daily temperature and mean monthly rainfall are shown in Figure 3. In April 2012, there was high soil moisture and temperature and this case was repeated in the following year (Figure 1). Based on the figures and tables in this study, the emission of N_2O and CO_2 increased in treatments compared to control after adding different types of organic matter to the soil. The increase in N_2O and CO_2 is due to increased microorganism activity in decomposing organic matter. Some studies show that increased microbial biomass and root biomass are responsible for the greater CO_2 emission in organic matter amended soils (Qingyan *et al.*, 2015). In addition, N_2O emission rate was found to increase due to urea fertiliser being added in order to prevent the immobilisation process. Some findings show that the addition of organic matter to soil increases N_2O emissions (Qingyan *et al*., 2015). Organic wastes, including animal manure and municipal wastes and their composts, and crop residues enhance CO_2 and N_2O emissions to the air compared with inorganic fertilisers (Hadas *et al.*, 2004; Jones *et al.*, 2005; Ding *et al*., 2007; Johnson *et al.*, 2007). During the wheat planting season that started from December 2011, 150 kg ha^{-1} of urea fertiliser were added to the soil during the first three months in order to prevent immobilisation, leading to the emission of N_2O (Figure 4). Nitrous oxide emissions from agriculture are largely the result of N fertiliser additions (Morgan *et al.*, 2010). Most of the N_2O emission is for bagasse treatment with 1.56 mg N_2O-N $m^{-2}.day^{-1}$ (Figure 4). Biochar has the lowest N_2O emission in the wheat season with 0.474 mg N_2O-N $m^{-2}.day^{-1}$. Also, among the treatments, biochar had the minimum emission of N_2O for the three cycles of crop rotation (Table 1). Various studied soils indicate that the use of biochar significantly reduces the N_2O emissions (Singh *et al*., 2010; Taghizadeh-Toosi *et al*., 2011; Wang *et al*., 2011a; Zhang *et al*., 2010, 2011). For example, the incorporation of biochar into pasture soil that contained ruminant urine reduced N_2O emissions up to 70% (Taghizadeh-Toosi *et al.*, 2011). Zhang *et al.* (2010, 2011) also reported that biochar additions significantly lower the N_2O emissions from both paddy and upland soils. The difference between biochar and soil matrix in physical properties leads to an overall change in soil density and aggregation, hydraulic conductivity and gas transportation, which in turn impacts chemical properties and microbial activity in soil (Lehmann *et al.*, 2011).

TABLE 1
The effect of different types of organic matter on (GHGs) emission (mg CH_4-C m^{-2} day^{-1},mg CO_2-C m^{-2} day^{-1}, mg N_2O-N m^{-2} day^{-1}) in wheat-corn-wheat rotation from December 2011 to May-2013.

		Wheat			Corn			Wheat		
	C/N	CH_4	CO_2	N_2O	CH_4	CO_2	N_2O	CH_4	CO_2	N_2O
Filter Mud	31	-0.011^{C}	332.62^{B}	1.37^{E}	-0.057^{CD}	375.44^{B}	0.844^{B}	-0.028^{B}	341.83^{B}	0.608^{D}
Bagasse	52	-0.008^{C}	387.19^{C}	1.52^{F}	-0.042^{E}	465.75^{D}	1.385^{E}	-0.0108^{C}	435.36^{C}	0.927^{F}
Manure	32	-0.005^{C}	458.44^{D}	1.15^{C}	-0.049^{DE}	596.08^{E}	1.22^{D}	-0.002^{D}	351.44^{B}	0.506^{C}
Poultry M	11	-0.037^{B}	566.16^{E}	1.27^{D}	-0.064^{BC}	769.08^{F}	1.526^{F}	-0.01^{E}	361.41^{B}	0.695^{E}
Biochar	10	-0.055^{A}	180.9^{A}	0.474^{A}	-0.089^{A}	248.3^{A}	0.298^{A}	-0.032^{A}	238.72^{A}	0.131^{A}
Control		-0.043^{B}	347.08^{B}	0.926^{B}	-0.07^{B}	423.94^{C}	1.11^{C}	-0.01^{E}	262.5^{A}	0.19^{B}
CV %		-1.33	0.45	0.41	-0.51	0.50	0.71	-3.73	0.27	0.62

Means in the same column followed by the same letters (A, B, C, D, E, F) are not significantly different at 1% level of significance; CV: coefficient of variation; C/N: Carbon/ Nitrogen ratio; M: manure.

TABLE 2
Combined analysis of variance for emission of GHGs in different type of organic matter treatments

	Df	Sum of square			Mean Square		
		CH_4	CO_2	N_2O	CH_4	CO_2	N_2O
Intercept	1	0.691	102027176	524.32	0.691	102027176	524.32
Rotation (R)	2	0.316	2467646	49.49	0.158**	1233823**	24.74**
Month (M)	5	0.05	965218	17.133	0.01**	193043**	3.42**
Treatments (T)	5	0.112	7555339	65.10	0.022**	1511067**	13.02**
R*M	10	0.297	4671351	47.33	0.030**	467135**	4.73**
R*T	10	0.08	2321319	12.46	0.008**	232131**	1.24**
M*T	25	0.029	943406	13.31	0.001**	37736**	0.533**
R*M*T	50	0.057	2428094	20.34	0.001**	48561**	10.76**

*significant at *P*<0.01

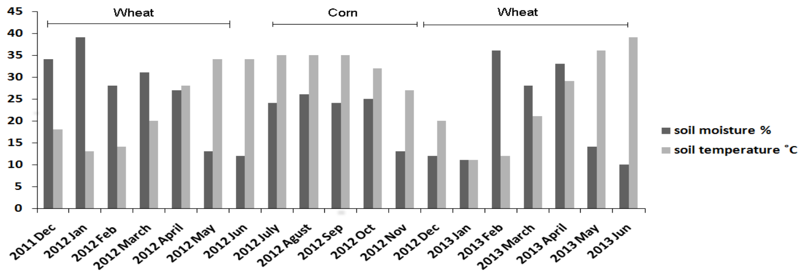

Figure 1: Soil moisture (%) and soil temperature (˚C) measured in wheat-corn- wheat rotation.

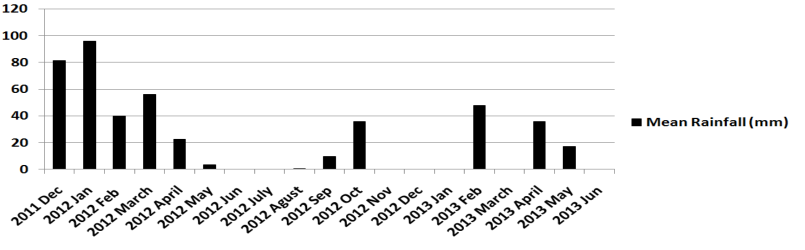

Figure 2: Mean rainfall (mm) from Safi-Abad meteorology station from December 2011 to June 2013 in 5 cm of soil.

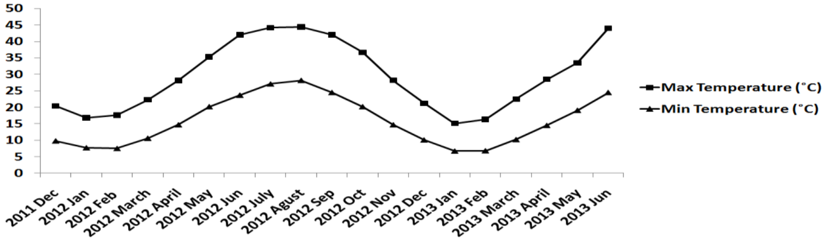

Figure 3. Maximum and minimum temperature (˚C) from Safi-Abad meteorology station from December 2011 to June 2013 in 5 cm of soil.

During the corn season, irrigation and the addition of nitrogen fertiliser, the highest emission of N_2O was observed at the beginning of the cultivation in July 2012. Meanwhile, in March 2012, the highest soil temperature was observed, and because of irrigation, soil moisture was also high. As a result, the emission of N_2O was significantly high (Figure 4).

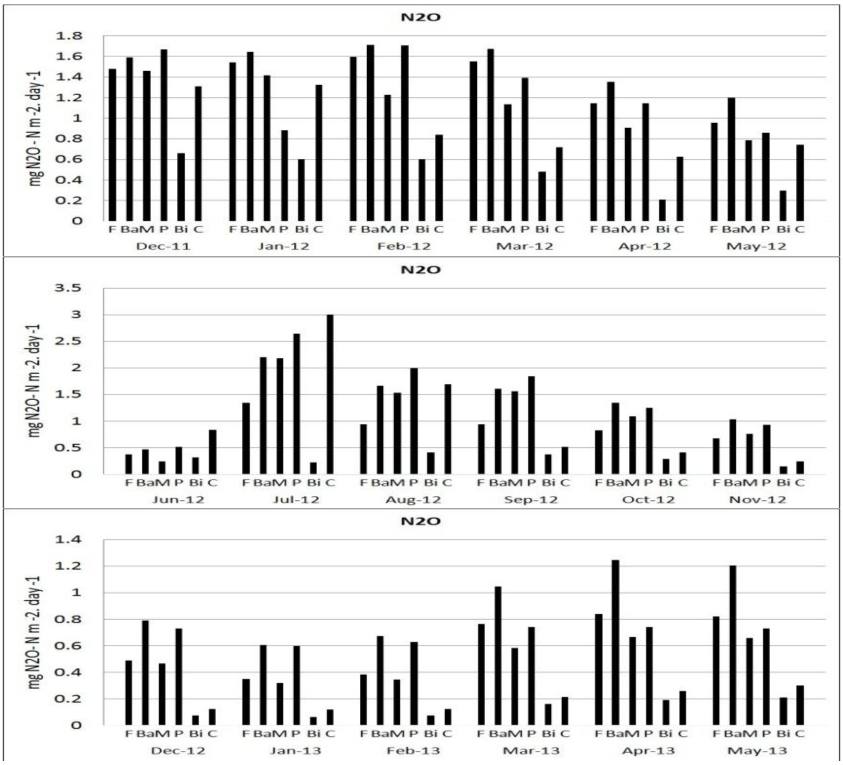

Figure 4. N_2O emission (mg N_2O- N m^{-2}. day^{-1}) from soil in different months from different treatments. F: filter mud; Ba: bagasse; M: manure; P: poultry; Bi: biochar; C: control.

Friedl *et al*., (2016) showed that the effect of fertiliser application on N_2O emission is more than the natural soil nitrogen pool and that greater denitrification rates are exhibited at higher soil moisture content. In addition, Dhadli *et al*., (2016) showed that in wheat and maize seasons, peaks in N_2O fluxes coincided with the rainfall or irrigation and N-fertilisation events.

Poultry treatment has the maximum value with 1.526 mg N_2O-N m^{-2} day^{-1} but is not significantly different from other treatments except for biochar with 0.298 mg N_2O-N m^{-2} day^{-1}. In the second season of wheat, biochar had the lowest N_2O emission with 0.131 mg N_2O-N m^{-2} day^{-1}, but was not significantly different from control which had a mean value of 0.19 mg N_2O-N m^{-2} day^{-1}. However, it was significantly different from other treatments (Table 1). In the second season of wheat, the maximum mean value of N_2O was obtained for bagasse with 0.927 mg N_2O-N m^{-2} day^{-1} (Figure 4).

Due to microorganism activity in decomposing organic matter added to the soil, a high rate of CO_2 emission was observed in January 2012. With the passage of time and the beginning of the spring season (March and April, 2012), microorganism activity increased due to rising soil temperature; CO_2 emission also increased during this time (Figure 5). In July 2012, due to the beginning of maize cultivation and land irrigation, microorganism activity reached its maximum again leading to increased rates of CO_2 emission. But with the passage of time and the beginning of the autumn season, microorganism activity decreased due to the falling soil temperature resulting in decreased CO_2 emission. This trend of reduction continued during the winter of 2013 and with the beginning of the spring season (March and April, 2013), the increasing trend of CO_2 emission was observed again (Figure 5). Brito *et al.,* (2015) found that seasonal variation of soil carbon dioxide emission to be directly related to variations in precipitation and soil temperature. Soil CO_2 emission is found to be higher in summer and lower in winter. Data variability in carbon dioxide emission is higher in rainy, hot summers than in dry, cold winters. A positive linear association between carbon dioxide emission and soil temperature is observed in summer and autumn.

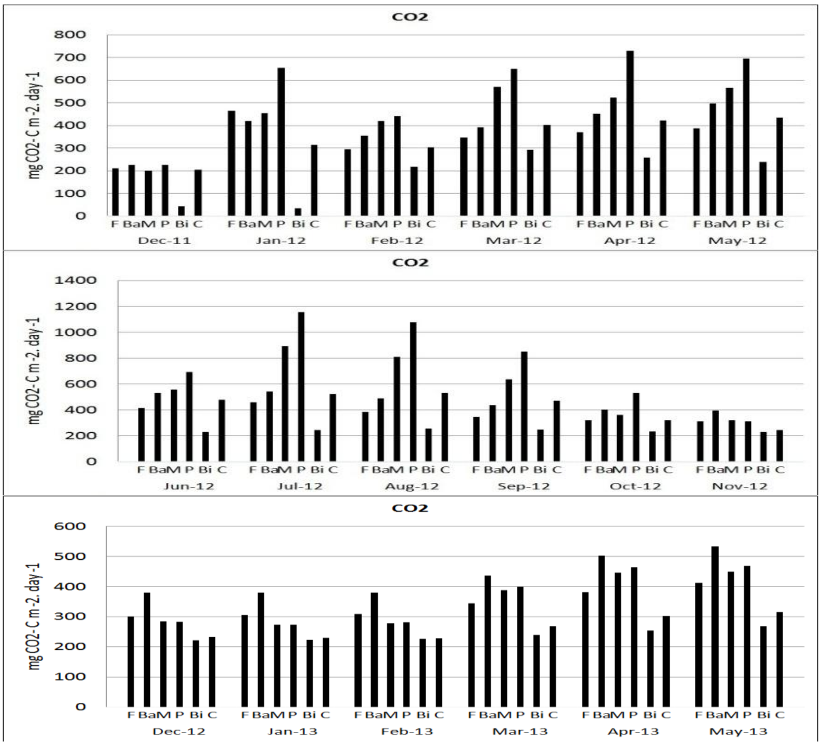

Figure 5: CO_2 emission (mg CO_2- C m^{-2} day^{-1}) from soil in different months from different treatments. F: filter mud; Ba: bagasse; M: manure; P: poultry; Bi: biochar; C: Control.

From Table 1, it can be seen that CO_2 is low in biochar treatment with the mean value being 180.9 mg CO_2-C m^{-2} day^{-1}. In the first season of wheat and corn season, the mean value of CO_2 for biochar is 248.3mg CO_2-C m^{-2} day^{-1}which is significantly different compared to other treatments. In the second season of wheat, the lowest mean value for CO_2 is for biochar with 238.72 mg CO_2-C m^{-2}. day^{-1} which is also significantly different from other treatments with the exception of the control which reads 262.5mg CO_2-C m^{-2} day^{-1} (Table 1). The contour graphs for N_2O and CO_2 (Figures 4 and 5) show that maximum CO_2 fluxes are observed during summer (July 2012) with 1157 mg CO_2-C m^{-2} day^{-1}. For poultry treatment when the soil is hot and wet, and the field is tilled for corn cultivation the minimum level of CO_2 emission at this time was for biochar with 251 mg CO_2-C $m_{-2}day^{-1}$ (Figure 5). In these three cycles of crop rotation, the lowest level of CO_2 emission was from biochar application (Table 1). Thus it can be seen that with increasing temperature and moisture, N_2O and CO_2 production increased as microbial activities increased at high temperature and moisture. Similar results have been reported by other researchers which state that temperature fluctuations and seasonal soil moisture, dominated by rainfall events, affect soil-atmosphere exchange of GHG. Vegetation type (McLain and Martens, 2006) as well as irrigation (Mariko *et al.,* 2007) and other agricultural management practices (Mosier *et al.*, 2006) can be controlled and the extent of GHG emissions determined, particularly in semi-arid regions. Based on Figures 4 and 5, N_2O and CO_2 emissions were highest in spring and lower in winter since precipitation was less in 2013 (Figure 2). As a result, the emission level of N_2O and CO_2 was reduced in 2013 compared to 2012 (Figures 4 and 5). Therefore, the findings show that GHGs emissions change in amounts according to seasons. The high fluxes of CO_2 throughout the corn seasons for the plots with corn plants originated from the contribution of root respiration and root turnover, as shown by Chen *et al.*, (2005). Figure 4 shows that in the first season of wheat cultivation, which began in December 2012, the rate of N_2O emission decreased as spring approached. This is due to the low soil moisture as well as the lowest rate of inorganic nitrogen in the soil compared to the first months of wheat cultivation. This decreasing trend reached its minimum in the months of May and June 2012, during which the soil moisture was also at its minimum level. At the beginning of summer (July 2012), when maize cultivation season began, the high temperature of the soil, the use of fertilisers N: 50 kg ha^{-1}, P: 50 kg ha^{-1} and K: 50 kg ha^{-1} especially nitrogen, and irrigation and land preparation for maize cultivation, resulted in increased N_2O emission. However, the N_2O emission rate in autumn (October 2012) gradually reduced due to reducing irrigation and soil moisture and reduced soil temperature (Figure 4). Ekoungoulou *et al.* (2015) shows that the processes of carbon and nitrogen mineralisation leading to N_2O and CO_2 emissions from soils are affected by variability in moisture, temperature, fertiliser application and organic carbon availability.

Table 3
Bulk density of organic matter amended soil in the beginning and ending of crop seasons.

		Bulk density ($g.cm^{-3}$)				
Treatments	Source of OM	Jan 2012	May 2012	July 2012	Nov 2012	Jun 2013
Filter mud	Sugarcane W	0.8^{B}	1.28^{D}	0.9^{B}	1^{B}	1.2^{C}
Bagasse	Sugarcane W	0.65^{A}	0.91^{A}	0.77^{A}	0.76^{A}	1^{A}
Manure	Livestock	0.97^{C}	1.01^{B}	1^{C}	0.96^{AB}	1.18^{BC}
Poultry M	Chicken	1.1^{D}	1.45^{E}	1.2^{E}	1.23^{C}	1.54^{E}
Biochar	citrus	0.77^{B}	1.1^{C}	0.84^{AB}	0.90^{AB}	1.13^{B}
Control		1.03^{CD}	1.6^{F}	1.1^{D}	1^{B}	1.4^{D}
CV%		0.18	0.20	0.15	0.15	0.14

Means in the same column followed by the same letters (A, B, C, D, E, F) are not significantly different at 1% level of significance. CV: coefficient of variation; OM: Organic Matter; W: waste; M: manure.

Effects of Soil Temperature and Moisture on Methane Uptake

The mean immobilisation of methane in the first season for wheat under the biochar treatment was -0.055 mg CH_4-C m^{-2} day^{-1}. With the application of organic matter (January 2012), soil bulk density decreased (Table 3) and the process of oxidation with the help of microorganisms occurred leading to CH_4 immobilisation in the soil. Soil pores affect CH_4 emission (Liu *et al*., 2015). However, due to the high rate of rainfall in this season and high moisture of the soil, CH_4 immobilisation by the soil was low. Moreover, in the months of April and May 2012, because of increased soil bulk density (Table 3), rainfall and high temperature (Figures 1 and 2), a revival process occurred leading to an increase in CH_4 emission while at the end of spring (June, 2012), CH_4 immobilisation rate increased again due to a reduction in soil temperature and in July 2012, at the beginning of the maize cultivation season, when land preparation begin, soil bulk density rate decreased again (Table 3). Although soil moisture was high, the revival process had not occurred and therefore CH_4 immobilisation in the soil increased (Figure 6).

In the corn season, the mean immobilisation of CH_4 was -0.089 mg CH_4-C m^{-2} day^{-1} for the biochar treatment which was significantly different compared to other treatments. The mean immobilisation value of CH_4 was also -0.032 mg CH_4-C m^{-2} day^{-1} for biochar in the second season of wheat. There was no significant difference between treatments in the first and second seasons of wheat for CH_4 emission but there was a significant difference between biochar and other treatments in the corn season. Based on Figure 6, maximum immobilisation of CH_4 occurred in October 2012 with -0.145 mg CH_4-C m^{-2} day^{-1} for biochar treatment; the value of immobilisation of CH_4 in summer was generally maximum for biochar in comparison with other seasons. Other studies have reported that biochar amendment reduces CH_4 emissions or has no significant effect on CH_4 emissions as compared to the control (Castaldi *et al*., 2011; Karhu *et al*., 2011; Rondon *et al*., 2005; Scheer *et al*., 2011; Zhang *et al*., 2011). Biochar addition may increase soil aeration resulting in the oxidation of CH_4 and the high porosity

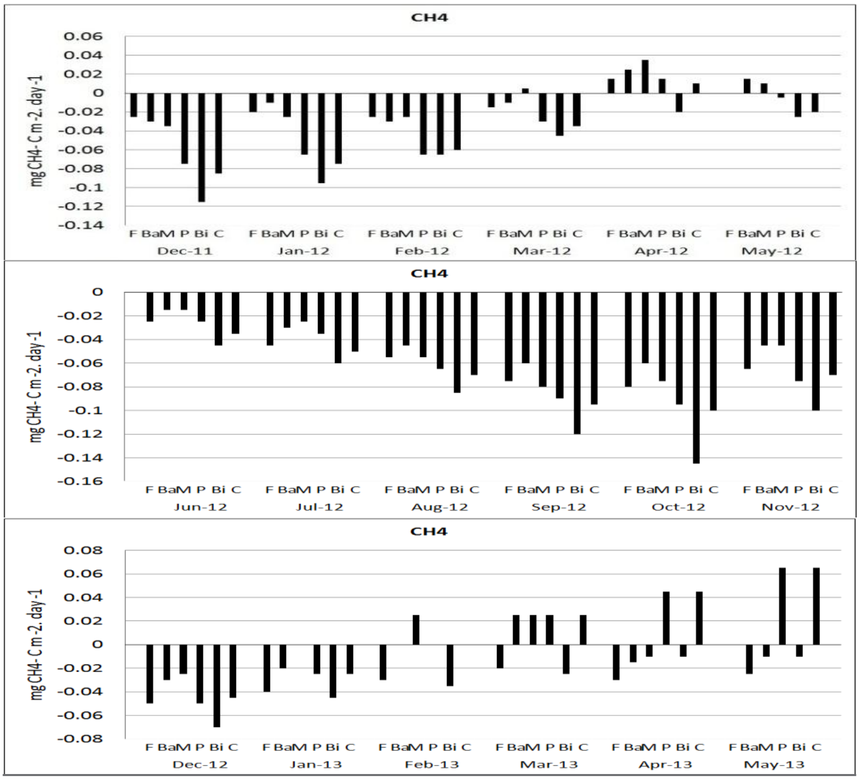

Figure 6: CH_4 emission of mg CO_2- C $m^{-2}.day^{-1}$ from soil in different months for different treatments. F: filter mud; Ba: bagasse; M: manure; P: poultry; Bi: biochar; C: Control.

and large surface area of aerated soil may enhance CH_4 immobilisation (Karhu *et al*., 2011; Rondon *et al*., 2006; Yanai *et al*., 2007; Zhang *et al*., 2011), both leading to a reductions in CH_4 emission from soils.

CONCLUSION

The findings of this research show the significant effect of organic matter in the emission of GHGs from soil in different seasons and crops. The increase in CO_2 emission at the beginning of the wheat season is attributed to the activity of microorganisms in decomposing organic matter added to the soil.

The reduction in N_2O emission at the end of the maize season is due to a reduction in the soil temperature, irrigation rate and soil moisture. The increase in CO_2 emission at the beginning of cultivation is also due to nitrogen fertiliser being added. Moreover, it is observed that the rate of CH_4 absorbed by the soil increases due to the reduced rate of soil bulk density after organic matter is added to the soil as well as to the activity of microorganisms in oxidising CH_4. In some months, the revival process occurred due to high rainfall and weakness in drainage and in such months, CH_4 emission can be observed.

Biochar application appears to have a better role in soil and GHGs emission as the application of biochar results in lower GHGs emission compared to other organic matters. Since global warming is of increasing concern to the world, we recommend biochar application in soils for reducing GHGs emission and improving soil fertility.

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