Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 8 (4): 642-647, 2008
ISSN 1812-5654

Impact of Organic Amendments with and Without Mineral Fertilizers on Soil Microbial Respiration

S.S. Gilani and M.A. Bahmanyar
Department of Soil Science, Faculty of Agronomy Science,
Sari Agricultural Science and Natural Resources University, University of Mazandaran, Sari, Iran

Abstract: A field experiment was conducted to study the effects of Sewage Sludge (SS), Municipal Waste Compost (MWC) and Vermicompost (VC) with and without chemical fertilizer (Urea, 50 kg ha^{-1} + Potassium sulfate, 100 kg ha^{-1} + Triple super phosphate, 127.5 kg ha^{-1}) on Soil Microbial Respiration (SMR) and Total Organic Carbon (TOC) in a soil cropped to soybean. Experiment was arranged in a complete block design with three replications. Organic amendments were added to soil at rate of 0 (control treatment), 20 and 40 Mg ha^{-1}. Furthermore each level of organic fertilizers with ½ normal of chemical fertilizer was also enriched. Soil samples were taken after one year of fertilization. Results illustrated that application of organic amendments increased TOC and SMR and soybean yield compared to control and chemical fertilizer treatments. Sewage sludge amended soils showed higher SMR, TOC and soybean yield than that of other organic amendment treatments. An increasing trend was observed in all studied parameters, as rates of application increased. All parameters were greater in treatments receiving a combination of chemical fertilizers and organic amendments (enriched treatments) compared to soils receiving organic amendments alone. Results obtained by discriminate analysis indicated that rates of application were more effective to create discriminating among treatments. This study showed that TOC was significantly correlated with SMR. Significant correlation was also observed between SMR and soybean yield.

Key words: Organic amendment, soil microbial respiration, discriminate analysis

INTRODUCTION

Mazandaran province in North of Iran has temperate and humid climate, but its agricultural soils are characterized by low soil organic matter contents, mainly due to cultivation system, intensive cultivation and continuous use of chemical fertilizers. There is increased emphasis on the impact on environmental quality due to continuous use of chemical fertilizers (Doran *et al*., 1996). Integrated plant nutrient-management system is one of the alternatives and is characterized by reduced input of chemical fertilizers and combined use of inorganic fertilizers and organic wastes (Oberson *et al*., 1996; Gunapala *et al*., 1998). The application of organic wastes such as Sewage Sludge (SS) and Compost (C) to agricultural soils has received considerable attention in recent years (Adedrian *et al*., 2003). Thus, use of these amendments in these agro-ecosystems can increase soil organic matter and nutrient contents and also helps to solve environmental and economic problems related to the disposal of these waste materials (Plaza *et al*., 2007). The knowledge of short-term effects of these organic amendments becomes essential when considering, for example, the conservation of soil quality. In recent years, soil microbiological parameters, as microbial activity have been seen to be early and sensitive indicators of soil stress and can be used to predict long-term trends in soil quality (Saviozzi *et al*., 2002).

Brooks *et al*. (1987) suggested that it is more important to obtain information regarding microbial activity. Together with the microbial biomass C, the following microbiological parameters have been proposed in order to achieve this objective (Pascual *et al*., 1997): microbial respiration, microbial biomass C/total organic C (TOC) ratio and metabolic quotient (qCO_2). Among these factors, soil respiration is one of the oldest and still the most frequently used parameter for quantifying microbial activities in soils (Anderson and Domsch, 1990; Kieft and Rosacker, 1991; Alef, 1995) and have been suggested as potential indicator of soil quality because of its relationship to soil biology, ease of measurement and rapid response to changes in soil management (Doran and Parkin, 1994).

Corresponding Author: S.S. Gilani, Department of Soil Science, Faculty of Agronomy Science, Sari Agricultural Science and Natural Resources University, Khazar Abad Road, P.O. Box 578, Sari, Iran Tel: +98-151-3822574-6, +989111120625 Fax: +98-151-3822577

The effects of organic amendments (especially combination of organic amendment and chemical fertilizers) on soil microbial respiration compared to soil physical and chemical parameters and also these effects in field conditions (Quemada and Menacho, 2001) compared to laboratory conditions (Pascual *et al*., 1997; Saviozzi *et al*., 2002; Kara *et al*., 2006; Plaza *et al*., 2007) have been poorly studied.

The objective of this study was to ascertain changes in soil respiration in response to applications of Sewage Sludge (SS), Municipal Waste Compost (MWC) and Vermicompost (VC) and combination of these amendments with chemical fertilizer, in different level under field conditions over one year.

MATERIALS AND METHODS

A field experiment was conducted on a silty clay soil (Typic haploxerept: clay, 44%; silt, 46% and sand, 10%) in Research Farm of the Sari Agricultural Sciences and Natural Resources University located in North of Iran (36° 39′ N, 53° 4′ E), during 2006 and 2007. Three organic fertilizers including Sewage Sludge (SS), Municipal Waste Compost (MWC) and Vermicompost (VC), at two levels of application (20 and 40 Mg ha^{-1}), a control (CT) and a Chemical Fertilizer (CF) (Urea, 50 kg ha^{-1} + Potassium sulfate, 100 kg ha^{-1} + Triple super phosphate, 127.5 = 277.5 kg ha^{-1}) were arranged in a complete block design with three replication. Furthermore each level of organic fertilizers, with ½ normal of chemical fertilizer was also enriched (The whole of treatments were 42). Start of organic fertilization was May 2006. Composite soil samples were collected from surface soils (0-20 cm) in May 2007, after Soybean (*Glycine max* L.) harvesting (14 samples in each replicate). Soil particle size distribution, pH and EC of soil and organic fertilizers using standard procedures were determined (ISRIC, 1986). The relevant characteristics of the studied soil and organic amendments have been shown in Table 1.

Total Organic Carbon (TOC) content was determined by oxidation with potassium dichromate in a sulfuric medium and titration the excess of dichromate with ferrous sulfate (Nelson and Sommers, 1986).

Soil Microbial Respiration (SMR) was determined by measuring the CO_2 evolved in 3 days incubation experiment at 25°C, in which 50 g of each soil samples (remoistened to 55% its water holding capacity) were placed in a 1-l glass jar. Glass vial holding 10 mL of 0.5 M NaOH was placed in the glass jar to trap the evolved CO_2. The excess alkali, after precipitating the CO_3^{2-} with 0.5 M $BaCl_2$ solution, was titrated with standard 0.5 M HCl to a phenolphthalein end point (Alef, 1995).

Analysis of variance (ANOVA) and Least Significant Difference (LSD) was determined by SAS 8.2 software. Discriminate Analysis (DA), linear regression and correlation coefficient were calculated using SYSTAT 8.0 software.

Table 1: Characteristics of the studied soil and organic amendments

Parameters	Soil	Vermicompost	Sewage sludge	Municipal waste compost
pH	7.52	8.05	7.44	7.41
[a]$EC_{e\ 25°C}$ (dS m^{-1})	1.17	2.05	18.22	10.07
TOC (g kg^{-1})	9.00	156.60	179.80	131.80

[a]: $EC_{e\ 25°C}$ (electrical conductivity)

RESULTS

Total organic carbon: Results illustrated that TOC was greater in soils amended with organic amendments as compared to chemical fertilizer and control. It was observed that sewage sludge application increased TOC (16.21 g kg^{-1}) to higher levels than vermicompost (12.37 g kg^{-1}) and municipal waste compost (11.59 g kg^{-1}), respectively (Table 2). Increasing levels of organic amendments increased TOC in organic fertilizer amended soils (8.32, 10.48 and 12.68 g kg^{-1} for 0, 20 and 40 Mg ha^{-1}, respectively) (Table 3). TOC was greater in treatments receiving a combination of chemical fertilizers and organic amendments compared to soils receiving organic amendment alone (13.94 and 16.45 g kg^{-1} for 20 and 40 Mg ha^{-1} + ½ CF, respectively).

Soil microbial respiration: Organic fertilizer application increased SMR compared to control and chemical fertilizer treatments, except municipal waste compost and chemical fertilizer treatments that there was no significant differences between them. Results showed that sewage sludge treatment increased SMR (262.4 mg CO_2 kg^{-1} day^{-1}) greater than other organic fertilizers. The lowest amount of SMR was observed in control treatment (Table 2). Soil microbial respiration similar to TOC, increased in amended soils with increasing levels of application (96.88, 183.18 and 212.32 mg CO_2 kg^{-1} day^{-1} for 0, 20 and 40 Mg ha^{-1}, respectively) and also

Table 2: Total Organic Carbon (TOC), Soil Microbial Respiration (SMR) and soybean yield as affected by organic and chemical fertilizers

Type of amendment	TOC (g kg^{-1})	SMR (mg CO_2-C kg^{-1} day^{-1})	Yield (kg ha^{-1})
SS	16.21[a*]	262.40[a]	3487.56[a]
VC	12.37[b]	210.58[b]	2782.35[b]
MWC	11.59[c]	199.27[c]	2633.74[b]
CF	11.43[d]	199.31[c]	2635.66[b]
CT	8.32[e]	96.88[d]	1923.53[c]

SS = Sewage Sludge, VC = Vermicompost, MWC = Municipal Waste Compost, CF = Chemical Fertilizer and CT = Control, *: Different letter(s) in each column shown significant difference between treatments according to Duncan test ($p<0.05$)

Table 3: Total Organic Carbon (TOC), Soil Microbial Respiration (SMR) and soybean yield as affected by application rates

Parameters	(0 Mg ha^{-1})	(20 Mg ha^{-1})	(40 Mg ha^{-1})	(20 Mg ha^{-1} + ½ CF)	(40 Mg ha^{-1} + ½ CF)	CF
TOC (g kg^{-1})	8.32^{f*}	10.48^{e}	12.68^{c}	13.94^{b}	16.45^{a}	11.43^{d}
SMR (mg CO_2-C kg^{-1} day^{-1})	96.88^{f}	183.18^{e}	212.32^{c}	235.88^{b}	264.85^{a}	199.31^{d}
Yield (kg ha^{-1})	1923.53^{e}	2424.25^{de}	2816.03^{bc}	3119.16^{b}	3511.53^{a}	2635.66^{dc}

*: Different letter(s) in each row shown significant difference between treatments according to Duncan test (p<0.05)

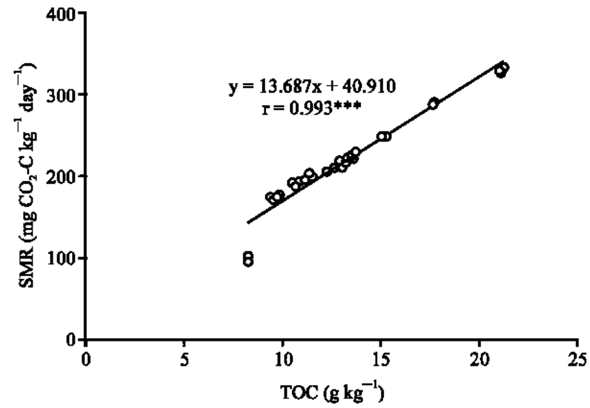

Fig. 1: Relationships of total organic carbon with soil microbial respiration. ***: Significant at (p<0.001)

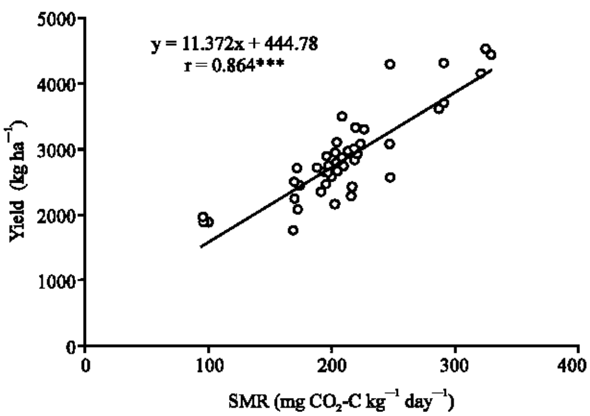

Fig. 2: Relationships of yield of soybean with soil microbial respiration. ***: Significant at (p<0.001)

treatments that receiving a combination of chemical fertilizers and organic amendments showed greater levels of SMR (235.88 and 264.85 mg CO_2 kg^{-1} day^{-1} for 20 and 40 Mg ha^{-1} + ½ CF, respectively) compared to soils receiving organic amendment alone (Table 3). Total organic carbon was significantly correlated with SMR (r = 0.993***) (Fig. 1). There was also significant correlation between SMR and soybean yield (r = 0.864***) (Fig. 2).

Discrimination among treatment according to their properties: Discriminate Analysis (DA) was used to determine the most useful variables for discriminating among groups and to test for differences or similarities between groups. Discriminate analysis indicated that the studied parameters could be separated according to the type of fertilizers and application rates (Fig. 3, 4). Results also represented that between rates of application

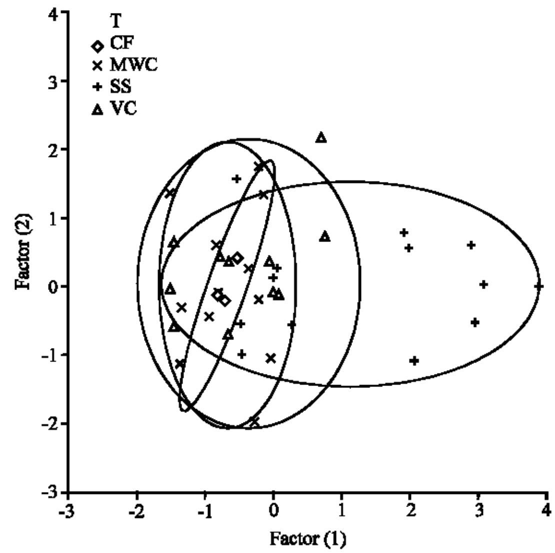

Fig. 3: Two-dimensional plots of the discriminate analysis for the determined parameters and grouped by type of fertilizers

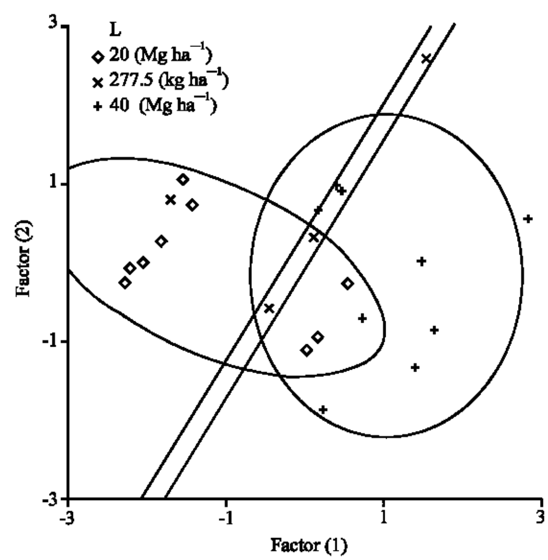

Fig. 4: Two-dimensional plots of the discriminate analysis for the determined parameters and grouped by level of application

and type of fertilizers, rates of application was more effective to create discrimination among treatments (Fig. 4).

DISCUSSION

Total organic carbon: Total organic carbon content provides a measurement of soil organic matter status (Goyal *et al*., 1992). Soil organic matter plays an important role in maintaining soil fertility. The decrease in soil organic matter is paralleled by declines in soil fertility (Tate, 1987). An enhance in TOC content under organic fertilizer application is possibly due to high loading of organic C in this organic materials (SS > VC > MWC) (Table 1), efficient metabolic activity of microorganisms and physico-chemical protection of organic C in soil (Oades, 1984). In this study, the aboveground crop biomass was removed and not incorporated into the soil. The increase in soil organic matter with the application of chemical fertilizers is because of greater input of root biomass due to better crop growth (Goyal *et al*., 1992; Goyal *et al*., 1999) and organic C that presence in urea fertilizer of chemical fertilizer treatment.

Soil microbial respiration: Determination of soil microbial respiration is generally used as a rapid indicator for the response of microbial activity to changes in soil management that affect the turnover of organic matter (Nannipieri *et al*., 1990). Garcia *et al*. (1994) suggested that this parameter was related to the fraction of biomass C that is truly active. Results of this study implied that soils amended with SS, VC and MWC increased SMR significantly more than what observed for chemical fertilizer and control treatments (Table 2). A relatively rapid response to organic amendments has been reported for SMR by several researchers, which suggests it could be useful indicator in identifying positive effects of soil management (Dick, 1992). Addition of organic fertilizers by preparing microbial habitats, increasing more food resources (nutrients that exist in organic fertilizers especially carbon, are important food resources for microorganism) and directly addition of soil organisms via incorporation of these organic amendments might enhance SMR. Other authors have reported a similar effect on soil microbial biomass and SMR (Garcia *et al*., 1998). Since the availability of organic C is considered the limiting factor for the SMR (Garcia *et al*., 1994; Min *et al*., 2003), a reduction in SMR in chemical fertilizer compared to organic fertilizer treatments, was presumably due to lower input and availability of C in application of chemical fertilizers into the soils. Others have reported that soils receiving organic amendments have more SMR than in the same soils receiving only chemical fertilizers (Goyal *et al*., 1999; Islam and Weil, 2000; Kaur *et al*., 2005). Soil microbial respiration from soil with sewage sludge application was higher than the other organic treatments, which is probably as a result of the amount of C added soil in these treatments (Table 1). Significance difference between chemical fertilizer and municipal waste compost in TOC (MWC > CF) and no significance difference between these treatments in SMR (Table 2), was probably due to microbial consumption of easily biodegradable compounds during composting processes (Moreno *et al*., 1999) and so presence of resisting biodegradable organic matter in compost (Eghball, 2000). There was more SMR in soils under higher rate of organic fertilizer application (40 Mg ha^{-1}) as compared to soils under chemical fertilizer and control treatments (Table 3). Increasing SMR after application of these amendments at a higher rate of application suggests that this soil is C-limited and that the labile C provided by SS, VC and MWC may have been used as an energy source for microorganisms. As SMR is controlled by availability of C content, greater amount of organic matter in these organic fertilizers could have provided more labile C substrates that lead to the larger SMR in organic fertilizer amended soils (Min *et al*., 2003). The higher amount of TOC and SMR in treatments receiving a combination of chemical fertilizer and organic amendments was probably because of greater input of root biomass due to better crop growth in enriched treatments because of effects of chemical fertilizer (For example, yield of soybean Table 3) and presence of organic C in chemical fertilizer (from urea) that leads to greater level of TOC and then SMR in enriched treatments than treatments receiving organic amendment alone (Table 3).

Strong correlation between SMR and TOC (r = 0.993***) (Fig. 1) confirmed the idea that OC is the main source of microbial activity (especially for heterotrophic microflora) and so soil microbial respiration (Nannipieri *et al*., 1990; Killham, 1994). Significant correlation were also observed between SMR with soybean yield (r = 0.846***) (Fig 2). Strong correlation between SMR and plant productivity in this study adapted to the hypothesis that application of organic fertilizers by supplying essential nutrients for plant uptake through organic fertilizers mineralization can increase crop yields and that organic carbon mineralization (or soil microbial respiration) is the basal reaction for organic forms mineralization of other nutrients (Castellanos and Pratt, 1981; Gilmour *et al*., 1985; Haney *et al*., 2001). It is also suggested that improving soil structure following addition of organic materials could be an effective factor in increasing plant productivity.

Discrimination among treatment according to their properties: Multivariate DA was used to determine the relevance of TOC, SMR and soybean yield for explaining the impact of application rates and fertilizer types on the functionality of microbial communities. Analysis of the TOC, SMR and soybean yield measured implied a high discrimination among 20 Mg ha^{-1}, 40 Mg ha^{-1} and 277.5 kg ha^{-1} (Fig. 4). By comparing results obtained from DA for fertilizer types (Fig. 3) and application rates (Fig. 4), it can be realized that the studied variables are more sensitive to the application rates (minor overlap) than to fertilizer types (major overlap). It was interestingly observed that soils received higher amount of organic materials showed more microbial activities. Therefore, the soil microbiological characteristics (SMR in this study) provided a reliable research tool to estimate early changes in the dynamics of soil microbial processes after improving soil organic matter content (Doran *et al*., 1996; Kaur *et al*., 2005).

CONCLUSION

Addition of organic fertilizers (sewage sludge, municipal waste compost and vermicompost) increased TOC and SMR. The enhanced levels of SMR upon application of SS, MWC and VC to the soils promoted the recycling of nutrients and energy in the soil ecosystem. It was also observed that land application of sewage sludge can return valuable nutrients and organic matter to the land, but its usage should be controlled to cut the risks of heavy metal accumulation in applied soils (data not shown). TOC and SMR improved following integrated use of organic amendments and chemical fertilizers. The study shows that balanced fertilization using both organic and inorganic fertilizers is important for maintenance of soil organic carbon and soil microbial respiration and also soil productivity in the Mazandaran province where soil organic matter levels are low.

ACKNOWLEDGMENT

The authors gratefully acknowledge Sari Agricultural Sciences and Natural Resources University for funding the Project.

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