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Dissimilar improvement of soil organic carbon pools with different manures in a subtropical dryland

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Abstract

The present field study was conducted to investigate the influence of different organic manures on pools of soil organic carbon during 2011 to 2013 at two locations (Rawalpindi and Chakwal sites) in subtropical dryland of Pothwar, Pakistan. Organic manures applied were: municipal solid waste, farm yard manure and poultry litter at the concentrations of 0.25%, 0.50% and 1% of soil organic carbon. The highest total soil organic carbon content of 22.2 Mg ha^{-1} and HCl insoluble carbon pool of 19.9 Mg ha^{-1} was achieved with the application of municipal solid waste compost. Particulate organic carbon was highest (3.9 Mg ha^{-1}) with farmyard manure while microbial biomass carbon and mineralizable organic carbon pools differed non-significantly. The present study reveals dissimilar improvement of SOC pools under different organic manures. Therefore farm yard manure should be preferred for short term benefits while MSW compost should be used for rapid carbon sequestration.

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Introduction

The quality of soil organic carbon (SOC) is usually defined by its different pools i.e. active, slow and passive. Microbial biomass and other easily decomposable compounds such as polysaccharides and non humic substances are components of active pool. The active fractions consist of microbial biomass carbon (MBC), glycoprotein, amino compounds, phospholipids, mineralizable C and N, substrate induced activity, non aggregate protected particulate organic carbon (POC), polysaccharides and carbohydrates. The active pool is very small percentage of the total carbon (10-20%) however it performs very important functions such as nutrient cycling and micronutrient chelation.

Passive pool is second major (60-90%) component of SOC which may persist in soil for centuries and is considered as inert biologically but it plays a major role in water holding capacities, structural stability and cation exchange. Passive pool fractions consist of aliphatic macro molecules, sporopollenins, lignin, charcoal, humin, fine silt and course clay associated SOC, HCl insoluble organic carbon (HOC), and high molecular weight condensed SOC etc. This pool sequesters carbon for many decades or even centuries. The slow pool has intermediate properties between passive and active fractions. Very high amount of lignin, slowly decomposable chemically resistant components and finely divided plant residues are the components of the slow fraction. Slow pool consists of particulate organic carbon (POC), amino compound, glycoprotein, aggregate protected POC, acid base hydrolysable and mobile humic acid. This fraction provides plant nutrients such as mineralizable nitrogen.

Improvement in SOC content with the application of organic manures is well established. However we hypothesize that different organic manures improve different SOC pools because of their variable composition and decomposability. Such information will provide basis for the choice of various manures for particular purposes such as improvement of nutrient supply or carbon sequestration etc. Therefore, the following study was carried out with the objective to record changes in pools of SOC with the application of different organic manures.

Materials & methods

Treatments and Locations

The field experiment was conducted during 2011 to 2013 at two locations in dryland Potowar, Pakistan, namely Soil Science Research Farm, PMAS-Arid Agriculture University Rawalpindi (Rawalpindi site) and University Research Farm Chakwal Road (Chakwal site). The cropping sequence was fallow-wheat system, which involved intensively plowed six-month summer-fallow starting in July and ending in October at the plantation of winter-wheat each year. The following treatments were applied during first experimental year at the time of wheat sowing: T_1) control, T_2) municipal solid waste (MSW) compost @ 0.25 % SOC, T_3) MSW compost @ 0.50 % SOC, T_4) MSW compost @1.0 % SOC, T_5) poultry litter @ 0.25 % SOC, T_6) poultry litter @ 0.50 % SOC, T_7) poultry litter @ 1.0 % SOC, T_8) farm yard manure (FYM) @ 0.25 % SOC, T_9) FYM @ 0.50 % SOC, T_{10}) FYM @ 1.0 % SOC. Soil samples were collected at the end of summer-fallow during the second experimental year. Sampling from each subplot was carried out at 0-15 cm depth with core sampler. Each sample was composite of three sub-samples.

The climate of Rawalpindi site (33° 36' 21.56" N and the longitude is 730° 02' 33.45" E) was humid subtropical with long and very hot summers, a monsoon period and short, mild and wet winter with a variable weather. The average annual rainfall is 1,100 mm, most of which falls in the summer monsoon season and remaining rainfall occurring in winter. In summer, the record maximum temperature has soared to 46.5 °C while it dropped to a minimum −3.9 °C in the winter. The Chakwal site (32° 55' 49.00" N, 72° 51' 20.00" E) is located near the Salt Range of Pakistan. The district Chakwal is mainly a rainfed district and its terrain is hilly. The major hills are located in southwest of Chakwal district and are covered with the scrub forest, intercepted with leveled plains and rocky patches. Chakwal lies in the subtropical region and its climate is typical of the area, with the exception that it varies a little on the cooler side, owing to its elevation. Winter temperatures normally range between −4 °C and 25 °C, and summer temperatures average between 15 °C and 40 °C and may go up to a maximum of 15 °C. The physic-chemical properties of the experimental soils are given in table 1.

Table 1. Physico-chemical characteristics of experimental soils.

Characteristic	Rawalpindi site	Chakwal site
Texture	Silty clay loam	Sandy clay loam
Sand (%)	10	49
Silt (%)	53	24
Clay (%)	37	27
pH	7.9	8.1
EC (dSm^{-1})	1.23	1.57
Bulk Density (g/cm^3)	1.44	1.42
Field Capacity (%)	25	27
Available Phosphorus ($mg\ kg^{-1}$)	5.33	4.78
Extractable Potassium ($mg\ kg^{-1}$)	67.9	61.4
Nitrate Nitrogen ($mg\ kg^{-1}$)	4.53	4.13
Total Soil Organic Carbon ($Mg\ ha^{-1}$)	13.9	13.1

Measurement of soil organic carbon pools

Total soil organic carbon (SOC) was determined by titrating 0.2 M solution of ferrous ammonium sulphate against potassium di-chromate (oxidizing agent) with N-phenylanthranillic acid as an indicator (Nelson and Sommers, 2005). Microbial biomass carbon (MBC) was estimated using chloroform fumigation extraction method (Anderson and Ingram, 1993). The evolution of CO_2 by incubating the soil samples in closed jars and CO_2 was trapped with NaOH solution. Using phenophthaline as an indicator, this solution was titrated against standard HCl solution (Kassel and Nannipieri, 1995). Particulate organic carbon (POC) was measured by dispersing the soil in Sodium hexametaphosphate solution. After sieving, the sand and POC was dried at 50 °C. It was ground and passed through 18 µm screen (Cambaradella and Elliot, 1992) and was analyzed for carbon (Nelson and Sommers, 2005). HCl-Insoluble organic carbon (HOC) was determined by digestion method. Soil was digested at 115 °C for 16 hours in a block digester, sieved these samples through 180 µm screen (Robertson *et al.,* 1999). The determination of carbon was performed by Nelson and Sommers (2005) method.

Results & discussion

Total soil organic carbon

The data on total SOC given in table 2 showed that at Rawalpindi site the poultry litter application at the rate of 0.50% SOC, and MSW compost at the rate of 1% SOC significantly enhanced total SOC than other treatments. At Chakwal site, the application of poultry litter at the rate of 0.25% SOC improved the SOC more than all other treatments, followed by MSW compost at the rate of 0.25 % SOC and FYM at the rate of 0.50 % SOC.

Table 2. Total organic carbon in dryland soil as affected by different manures.

Total soil organic carbon ($Mg\ ha^{-1}$)			
Manures	Levels	Rawalpindi site	Chakwal site
Control		13.9^{d}	13.09^{e}
MSW Compost	0.25% of SOC	14.9^{d}	20.6^{ab}
	0.50% of SOC	20.3^{b}	17.09^{cd}
	1% of SOC	20.9^{a}	19.23^{bc}
Farm yard manure	0.25% of SOC	20.1^{b}	15.06^{de}
	0.50% of SOC	14.0^{d}	18.74^{bc}
	1% of SOC	15.8^{cd}	17.11^{cd}
Poultry litter	0.25% of SOC	17.8^{c}	21.62^{a}
	0.50% of SOC	21.02^{ab}	14.91^{de}
	1% of SOC	17.3^{c}	18.63^{bc}

Values sharing the same letters are statistically similar according to least significant difference test ($P \geq 0.05$).

Several studies have reported significant increase in total SOC with the application of organic manures (Gosh *et al.,* 2012). Depletion of total SOC has been observed when continuous cultivation is done without application of organic manures. However total SOC is not a sensitive indicator of short-term changes of soil quality with soil and crop management practices due to high background levels and natural soil variability (Rustad *et al.,* 2000).

Particulate organic carbon

The data pertaining to particulate organic carbon (POC) presented in table 3 reveals that at Rawalpindi site significant increase in POC was observed over other treatments by the addition of MSW compost at the rate of 0.25 % SOC and FYM at the rate of 1% SOC. At Chakwal site, FYM applied at the rate of 0.50 % SOC significantly increased POC content than other treatments.

Table 3. Particulate organic carbon in dryland soil as affected by different manures.

Particulate organic carbon (Mg ha^{-1})			
Manures	**Levels**	**Rawalpindi site**	**Chakwal site**
Control		2.6^{e}	2.1^{g}
MSW Compost	0.25% of SOC	3.4^{abc}	3.8^{bc}
	0.50% of SOC	3.3^{bcd}	3.6^{cde}
	1% of SOC	2.7^{de}	3.3^{def}
Farm yard manure	0.25% of SOC	3.9^{a}	3.9^{bc}
	0.50% of SOC	2.8^{de}	4.8^{a}
	1% of SOC	3.5^{abc}	3.2^{ef}
Poultry litter	0.25% of SOC	2.9^{cde}	3.6^{cd}
	0.50% of SOC	2.7^{de}	4.1^{b}
	1% of SOC	3.8^{ab}	2.9^{f}

Values sharing the same letters are statistically similar according to least significant difference test (P≥0.05).

As the FYM is easily decomposable organic manure, it gave higher values of POC indicating that the application of FYM should be recommended for short term benefits such as nutrient release. Liu *et al.* (2013) also observed an increase of 65–92% in POC when organic manures were applied in combination with the inorganic fertilizers.

HCl-insoluble organic carbon

The data regarding the effect of various organic manures on HCl-insoluble organic carbon (HOC) is shown in the table 4. It is evident from the data that the HOC was significantly affected by various treatments. At Rawalpindi site MSW compost at the rate of 0.50 % SOC caused maximum increase over other treatments closely followed by application of MSW compost at the rate of 0.25%, poultry litter at the rate of 0.50 % SOC and poultry litter at the rate of 1.0 % SOC. At Chakwal site the application of MSW compost at the rate of1.0 % SOC, FYM at the rate of 1.0 % SOC, poultry litter at the rate of 0.25 % SOC, 0.50 % SOC, and 1.0 % SOC gave increase in HOC over other treatments.

Table 4. HCl-Insoluble carbon in dryland soil as affected by different manures.

HCl- Insoluble organic carbon (Mg ha^{-1})			
Manures	**Levels**	**Rawalpindi Site**	**Chakwal Site**
Control		10.4^{e}	11.6^{b}
MSW Compost	0.25% of SOC	16.3^{b}	11.8^{b}
	0.50% of SOC	19.9^{a}	11.7^{b}
	1% of SOC	12.7^{d}	17.0^{a}
Farm yard manure	0.25% of SOC	13.7^{cd}	13.3^{b}
	0.50% of SOC	12.7^{d}	13.7^{b}
	1% of SOC	15.1^{bc}	17.2^{a}
Poultry litter	0.25% of SOC	13.7^{cd}	18.2^{a}
	0.50% of SOC	15.8^{b}	18.1^{a}
	1% of SOC	15.6^{b}	16.5^{a}

Values sharing the same letters are statistically similar according to least significant difference test (P≥0.05).

As HOC is the most resistant pool of SOC, the higher values of HOC under MSW compost suggest its use for enhancing carbon sequestration in soil.

Microbial biomass carbon

The microbial biomass carbon (MBC) under various organic manures in soil (Table 5) showed that at Rawalpindi site, the MBC was numerically highest with the application of poultry litter at the rate of 1.0 % SOC followed by addition of municipal solid waste compost at the rate of 0.50 % SOC. At Chakwal site, application of MSW compost at the rate of 0.50 % SOC, poultry litter at the rate of 0.50 % SOC and poultry litter at the rate of 1.0 % SOC gave numerically highest MBC. However these differences were statistically non-significant.

Table 5. Microbial biomass carbon in dryland soil as affected by different manures.

Microbial biomass carbon (µg g^{-1} soil)			
Manures	**Levels**	**Rawalpindi site**	**Chakwal site**
Control		239 ns	233 ns
MSW Compost	0.25% of SOC	246	311
	0.50% of SOC	307	330
	1% of SOC	295	302
Farm yard manure	0.25% of SOC	282	291
	0.50% of SOC	276	285
	1% of SOC	276	272
Poultry litter	0.25% of SOC	239	298
	0.50% of SOC	251	323
	1% of SOC	313	334

Values sharing the same letters are statistically similar according to least significant difference test (P≥0.05).

Although use of organic manures such as municipal solid waste (MSW) (Liang *et al.,* 2003; Tejada *et al.,* 2006), compost (Melero, 2006; Dar, 1995), sewage sludge and cop residues have been reported to improve MBC in soil (Kunito *et al.,* 2001; Orenes *et al.,* 2010), the non significant differences in present study are due to longer gap between the application of manures and soil sampling. The manures were applied during the first experimental year while soil samples were collected during the second experimental year (one year later). As the MBC is part of easily decomposable active SOC pool, it could not withstand the decomposition.

Potentially mineralizable carbon

Response of potentially mineralizable carbon (PMC) to organic manures given in the table 6 showed increased CO_2-C evolutions with the application of organic manures however the improvements were statistically non-significant. At Rawalpindi site, CO_2-C evolution was highest with the application of FYM at the rate of 1.0 % SOC. At Chakwal site, highest values of CO_2-C were obtained with the application of MSW compost at the rate of 0.50 % SOC and 1.0 % SOC, FYM at the rate of 0.50 % SOC and 1.0 % SOC, and poultry litter at the rate of 0.25 % SOC. The minimum emission of CO_2-C was observed in control treatment.

As already discussed the active SOC pool including potentially mineralizable carbon has been reported to significantly improve with the application of organic manures (Liang *et al.,* 2003; Melero, 2006; Orenes *et al.,* 2010), however their turnover time ranges between months to years. Therefore non significant differences in present study are due to one year gap between application of manures and collection of soil samples that resulted in decomposition of mineralizable carbon.

Table 6. Mineralizable carbon in dryland soil as affected by different manures.

Mineralizable carbon (µgCO_2-C g soil day^{-1})			
Manures	**Levels**	**Rawalpindi site**	**Chakwal site**
Control		39.8 ns	40.8 ns
MSW Compost	0.25% of SOC	52.8	47.1
	0.50% of SOC	55.1	50.3
	1% of SOC	60.6	49.6
Farm yard manure	0.25% of SOC	51.3	46.3
	0.50% of SOC	46.6	53.6
	1% of SOC	53.8	51.6
Poultry litter	0.25% of SOC	53.3	53.3
	0.50% of SOC	46.8	48.3
	1% of SOC	50.6	49.8

Values sharing the same letters are statistically similar according to least significant difference test (P≥0.05).

Conclusion

The present study reveals dissimilar improvement of SOC pools under different organic manures. The application of farm yard manure improves slow carbon pool (represented by particulate organic carbon) while MSW compost improves passive organic carbon pool (represented by HCl-insoluble carbon). Therefore, farm yard manure should be preferred for short term benefits while MSW compost should be used for rapid carbon sequestration.

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