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Soil Physical Properties and Wheat Yield as Influenced by Varying Levels of Different Organic Materials

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Authors' contributions

This work was carried out in collaboration between all authors. Authors SA, SSI and MAM help designed the study. Authors KB and IA wrote the first draft of the manuscript, managed the literature searches, analyses of the study and managed the experimental process. All authors read and approved the final manuscript.

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ABSTRACT

The quantity and quality of organic amendments play vital role in changing or amending the soil physical properties and crop yield. The improvement in soil physical properties and crop growth is well correlated with the organic carbon status of soil. The behavior of carbon supplied through different materials may vary in the soil. This study was designed with an objective to observe the variation in the response to the different manures applied in the soil with respect to differences in physical properties and crop yield. To accomplish this objective a field trial was executed in September, 2011 at two different sites i.e. Research Farm, PMAS Arid Agriculture University, Rawalpindi and Koont Farm, Chakwal, using wheat as a test crop for two years (2012 and 2013). Three organic amendments *i.e.* Municipal solid waste compost (MSWC), Farmyard manure (FYM) and Poultry litter (PL) each at four levels *i.e.* 0, 0.25, 0.50 and 1% of soil organic carbon were applied in a two factorial randomized complete block design with four replications. The manures

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were characterized on the basis of humic (Humic acid and Fulvic acid) and non humic (Total polysaccharides and Microbial biomass carbon). Soil samples were analyzed for field saturated hydraulic conductivity, total organic carbon, bulk density, moisture content and wheat crop yield. The results showed clear differences in physical properties with respect to the different applied materials. These results suggest that the variation among the organic amendments depends upon the humic composition of materials rather than total organic carbon.

Keywords: Soil organic matter; organic amendments; physical properties; wheat; humic substances.

1. INTRODUCTION

Northern parts of Pothwar plateau situated at the bottom of Himalayas mountain receive higher degree of precipitation. As the distance from the Himalayas increases, rainfall pattern changes and it decreases steadily. Therefore, the climate of the plateau varies from sub-humid to semi-arid, moving from Northeastern parts to the Southern parts [1]. Even though, the total rainfall of the area is adequate for cropping, but the seasonal rainfall pattern does not correspond with the requirements of crop at different growth stages [2]. During winters, wheat is the major crop grown on most of the cultivable land of Pothwar, while most of the total annual rainfall is usually received during summer monsoon. Consequently, the average yields of the major crop of Pothwar plateau are far below its acknowledged potential due to less soil moisture levels. Soil moisture can be conserved by the presence of good soil physical health.

Wheat (*Triticum aestivum* L.) is a staple food of Pakistan. It is cultivated over an area of 8.22 million hectares with annual production of 19.5 million tones with an average yield of 2.37 tonnes per hectare [3]. This average yield is far less than the potential of cultivars and soils, which is due to many factors. Among these factors soil organic matter is an important factor affecting soil physical properties and crop yield. Due to harsh climatic conditions of Pothwar plateau, the rate of organic matter decomposition in the soil system is higher, which is the main cause of many soil physical problems in this area.

Organic matter has multiple functions in soil. The primary role of organic matter is in reducing soil erodibility by stabilizing the surface aggregates through reduced crust formation and surface sealing, which increases infiltration [4]. Soil organic carbon, in its totality, includes soil organisms (e.g. microbial biomass), simple organic compounds (e.g. polysaccharides), large and complex humic substances, as well as relatively fresh residue in various stages of decomposition [5]. Humic substances account for the largest and most decomposed proportion of organic matter with chemically complex and ill-defined structure. For simplification of their study, humic substances are fractionated into fulvic acid, humic acid and humin [6].

Different manures vary in their humic and non humic contents, and these compositional differences may play different roles in determining their benefits upon soil physical properties and eventually the crop yield. This study was designed upon the hypothesis that, "the addition of organic manures at equivalent levels will improve the physical properties and crop yield differently due to the differences of humic contents within the organic manures".

2. MATERIALS AND METHODS

2.1 Description of Experimental Sites

The Pothwar plateau (Latitude 32°10' to 34°9' N and Longitude 71°10' to 73°55' E) located in the Northern Punjab province, Pakistan, is a large area where agriculture depends solely upon rainfall, hence called rainfed tract. The study was carried out under field conditions in dry land fallow-wheat rotation for two years (2012-13). Three organic amendments *i.e.* Municipal solid waste compost (MSWC), Farmyard manure (FYM) and Poultry litter (PL) each at four levels *i.e.* 0, 0.25, 0.50 and 1% of soil organic carbon were applied in a randomized complete block design with four replications (Table 2). The plot size was 25 m^2. The different amounts of each organic material in accordance with the treatment were added to soil during the fallow period of the first experimental year on the basis of their organic carbon content. The experimental soils (Table 1) were silty clay loam (AAUR site) and sandy clay loam (Koont site). Wheat cultivar Chakwal 50, was sown as a test crop each year during November using a seeding rate of 150 kg ha^{-1}. The fertilization of wheat was carried out with urea and diamonium phosphate (DAP) as sources of N and P respectively. The rainfall and

climate data (Table 3) showed that AAUR site received more rainfall as compared to the Koont site, other climatic variables were almost similar.

2.2 Characteristics of Manures

The poultry litter had higher contents of almost all types of humic and non-humic substances as compared to other manures (Table 4). But due to the heterogeneity in the transformation rates of different compounds within manures, it is quite impossible to predict the best source suitable for the rehabilitation of physical properties. But on the basis of the initial status of the manures, it is evident that poultry litter and MSW compost had higher contents of stable forms of carbon like humic and fulvic acids. And such humic substances can act as persistent organic materials for the improvement of other physical properties.

2.3 Analytical Procedures

2.3.1 Analyses of manures

The three organic materials *viz.* municipal solid waste compost (MSWC), poultry litter (PL) and farm yard manure (FYM), were subjected for different analyses of humic and non humic substances. Total organic carbon (TOC) in samples was measured by wet digestion method [7] with a little modification of reducing the sample weight to 0.25 g instead of 1 g, due to high amount of carbon present in the manure samples. Total polysaccharide contents (TPC) were extracted from a 1g dried and ground samples by adding 20 mL distilled water at 80℃ for 24 hours. The supernatant solution was collected after centrifugation at ambient temperature for 25 minutes and the total polysaccharide contents were measured colorimetrically [8]. Microbial biomass carbon (MBC) was measured by the fumigation extraction method using a 0.025 M solution of K_2SO_4 to extract relatively labile organic C from the fumigated and non-fumigated samples [9] and then carbon in the samples was analyzed by titrating them against acidified ferrous ammonium sulphate. Organic matter fractionation was carried out by extracting humic acid and fulvic acid using NaOH and HCl [6].

Table 1. Characteristics of the experimental soils

Characteristics	AAUR Site	Koont site
Texture	Silty clay loam	Sandy clay loam
Sand (%)	19	56.0
Silt (%)	55	22.8
Clay (%)	26	21.2
EC (dS m^{-1})	0.31	0.53
Soil pH	7.7	7.87
Bulk density (Mg m^{-3})	1.40	1.45
Total organic carbon (g $100g^{-1}$)	0.60	0.59

Table 2. Calculated levels of manures applied at experimental sites

Levels of SOC (%)	MSW compost	Farmyard manure	Poultry litter
	t ha^{-1}		
0	0	0	0
0.25	62	50	30
0.5	124	100	60
1.0	248	200	120

Table 3. Meteorological comparison of experimental sites

Characteristics	AAUR site		Koont site	
	2011-12	2012-13	2011-12	2012-13
Total rainfall (mm)	949	1118	465	604
Mean yearly temperature (℃)	21.3	21.4	19.4	21.11
Mean evaporation (mm day^{-1})	110	122	102	115

Table 4. Concentration of different humic and non-humic substances in the manures

Manures	Farmyard manure	Municipal solid waste compost	Poultry litter
Humic acid (g kg^{-1})	8.67	14.08	14.97
Fulvic acid (g kg^{-1})	9.96	4.9	25.22
Total polysaccharides (mg kg^{-1})	1.58	2.06	3.28
Total organic carbon (g kg^{-1})	100.7	80.6	158.6
Microbial biomass carbon (g kg^{-1})	1.71	3.07	37.2

2.3.2 Soil analyses

The textural analysis of soil was carried out using hydrometer method [10]. Bulk density was measured using the cylinder method [11]. Soil moisture content was measured gravimetrically [12]. Total organic carbon (TOC) in samples was measured by wet digestion method [7]. Saturated hydraulic conductivity was measured by constant head method [13] using Guelph permeameter.

2.3.3 Crop parameters

The crop was harvested from $1m^2$ quadrate randomly selected in each plot. The plants were oven dried, weighed and total biomass was recorded. Then, the crop was threshed and the grains were weighed to determine the grain yield. Both biomass and grain yields were then converted to t ha^{-1}.

2.4 Statistical Analysis

The data collected for various characteristics was subjected to Analysis of Variance and the means obtained were compared by LSD at 5% level of significance [14].

3. RESULTS AND DISCUSSION

3.1 Variation in Field Saturated Hydraulic Conductivity by the Application of the Manures and Their Levels

The results of field saturated hydraulic conductivity (Fig. 1) at AAUR site, showed that the application of MSW compost at 1% and 0.25% levels, in 2012 and 2013, respectively, improved the conductivity rates. While application of poultry litter and farmyard manure at 0.25% level has significantly improved conductivity rates as compared to all other treatments at Koont site, in 2012 and 2013 respectively. Overall the hydraulic conductivity at AAUR site was significantly high as compared to the Koont site, and also the amendments affected significantly in the first year of application.

As compost and farm yard manure are degraded products, their activity in soil is somehow different as compared to the un composted materials like poultry litter. MSW compost application affects the macro porosity of soil, which is the main reason of higher conductivity rates [15], and this improvement in macro porosity may be due to the improvement in stable macro aggregate formation of 2-4 mm aggregates. The textural porosity is mainly due to the aggregates ranging in the size of 2-3 mm diameter [16]. This kind of pore space is mainly affected by the arrangement of basic soil particles, by the soil water content and the nature and proportions of clay, organic matter, and Fe and Al oxides, so, mechanical strength of 2-3 mm aggregates only depends on the packing and cementing of such particles [17].

These results clearly showed that higher levels of manures decreased the hydraulic conductivity or increased the water holding capacity of the soil over a period of two years of application. Such changes to soil hydraulic conductivity, particularly in the rhizosphere have been related to changes in soil structure [18].

3.2 Total Organic Carbon (TOC) in Soil as Affected by the Application of the Manures and Their Levels

The results regarding total organic carbon (TOC) were non-significant in all the years of both experimental sites (Fig. 2), only the main effects were statistically significant. Overall the manures were non-significant for their potential to improve the TOC level of soil. The different levels manure treatment means exhibited significant differences in TOC content of the soil in all tested years at both experimental sites. At AAUR site, in 2012 all manure treatments were significantly higher for soil TOC content in comparison with the control but non-significantly different from each other. In

2013, the 0.5% manure treatments showed significantly improved soil TOC content in comparison with the control. At Koont site, in 2012 the manures applied at 0.25% and 1% level significantly shown an increase in TOC contents as compared to control. While in 2013, the 0.5% and 1% manure treatments has shown higher concentration of TOC in soil.

The non-significant differences among manures strongly prove that the application of all three manures was on equivalent basis of carbon, and the role of manures' compositional differences is negligible in determining the overall organic carbon status of soil. On the other hand the differences among the levels suggest that higher levels like 0.5% and 1% found to be successful for maintaining the soil TOC levels at both sites up to second year of application. Higher carbon content in the amended soils leads to questions regarding the location of carbon in the soil [19]. The bulk soil carbon or TOC affect the carbon concentration into the different sized soil aggregates, and TOC contents vary in soil by different organic inputs applied at variable rates [20].

3.3 Variation in Soil Bulk Density as Affected by the Application of Manures and Their Levels

At AAUR site, the results of bulk density (Fig. 3) were significant in 2013, and the application of poultry litter at 0.25% and 0.5% levels significantly decreased the bulk density. While at Koont site in 2012, the application of MSW compost at 0.5% and 1% levels resulted in a significant decrease in bulk density, and in 2013, in addition to the previous application rates the addition of MSW compost at 0.5% level significantly reduced the bulk density values.

The difference in the behavior of manures varied with the change in locations suggests that the textural properties are also taking part in determining the effects of application of the manures. At AAUR site, the reduction in bulk density values were significant in the second year of application and poultry litter application had significantly reduced the bulk density which is due to the stabilization of carbon contents of poultry litter in two years duration. The application of MSW compost showed significant reduction in bulk density at Koont site, because of the composting process. The applications of mature products significantly reduce the bulk density and hence improve the soil physical quality [20,21,22]. The effect of manure accumulation in the soil may take time but it significantly reduces the bulk density of soil [23].

3.4 Gravimetric Moisture Content Variation by the Application of Manures and Their Levels

Results regarding the gravimetric moisture content (Fig. 4) were statistically significant. At both sites, the application of all levels were significantly higher as compared to control in first year of application (2012), on the other hand in 2013, the soils applied with poultry litter at the rate of 0.5% level showed highest moisture content as compared to all other treatments.

The results regarding poultry litter have shown that saturated hydraulic conductivity is being reduced upon its application. And higher results of moisture content in poultry litter amended soils prove that it is a highly porous material as compared to other amendments, thus increasing the water holding capacity of soil. The application of organic materials sometimes reduces the hydraulic conductivity and increase the moisture holding capacity of soil, and it apparently depends upon their individual surface properties like surface area, porosity etc. Application of organic manures and residues improve the soil moisture content and hence helpful in moisture conservation [24,25].

3.5 Wheat Crop Yield of Wheat Crop as Affected by the Application of Manures and Their Levels

At AAUR site, all the levels of manures improved the wheat biomass yield (Fig. 5) significantly as compared to control in both years. The trends of levels, means were similar at Koont site. The manure means were significant in 2013 at Koont site only. And these results showed that the application of poultry litter and farmyard manure at Koont site in 2013 significantly enhanced the biomass yield as compared to MSW compost.

At both sites, in 2012 all the levels of manures improved the wheat grain yield (Fig. 6) significantly as compared to control, and in 2013 the application of manures at 1% significantly increased the grain yield. The manure means were significant in 2013 at Koont site only. And these results showed that the application of poultry litter and farmyard manure at Koont site in 2013 significantly enhanced the grain yield as compared to MSW compost.

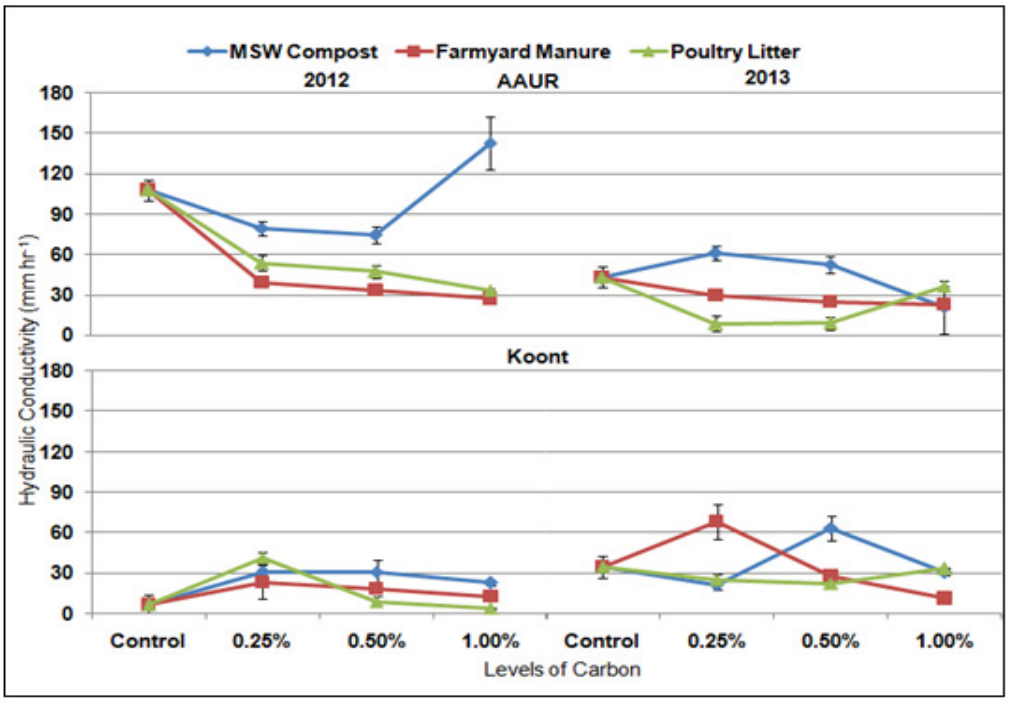

Fig. 1. Effect of different levels of various organic materials on soil hydraulic conductivity (mm hr^{-1})

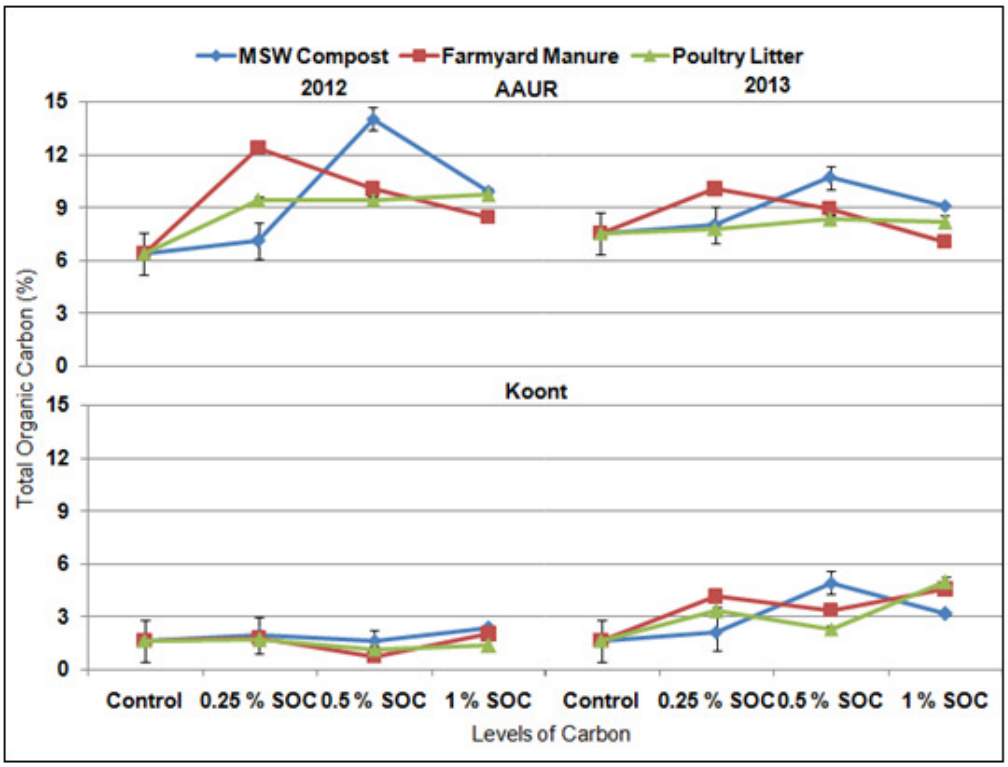

Fig. 2. Effect of different levels of various organic materials on soil total organic carbon (%)

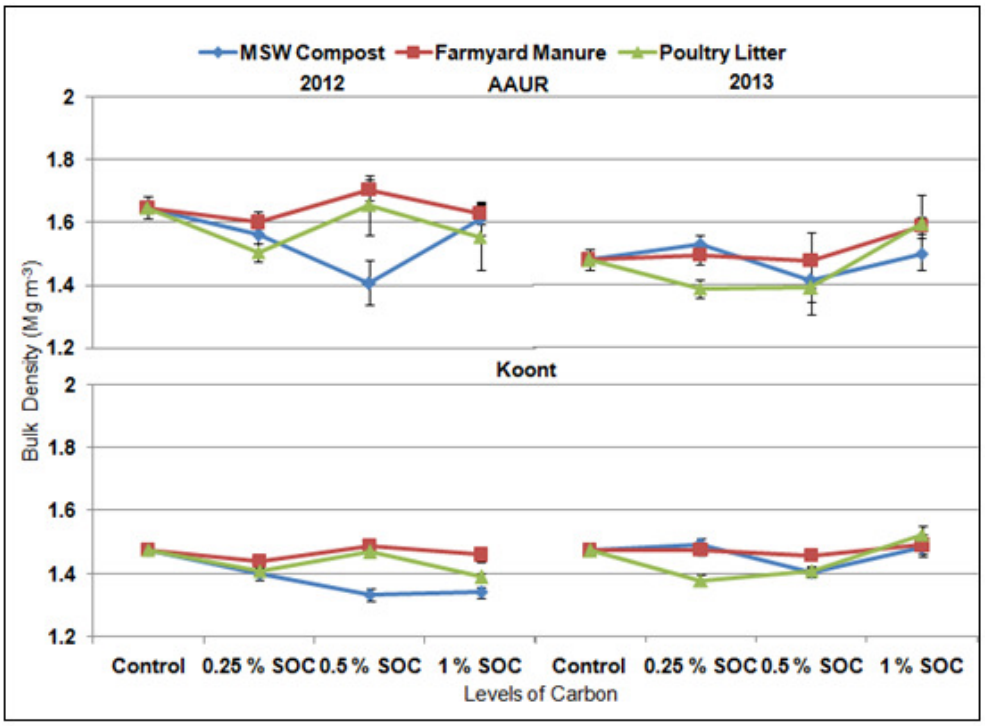

Fig. 3. Effect of different levels of various organic materials on soil bulk density (Mg m^{-3})

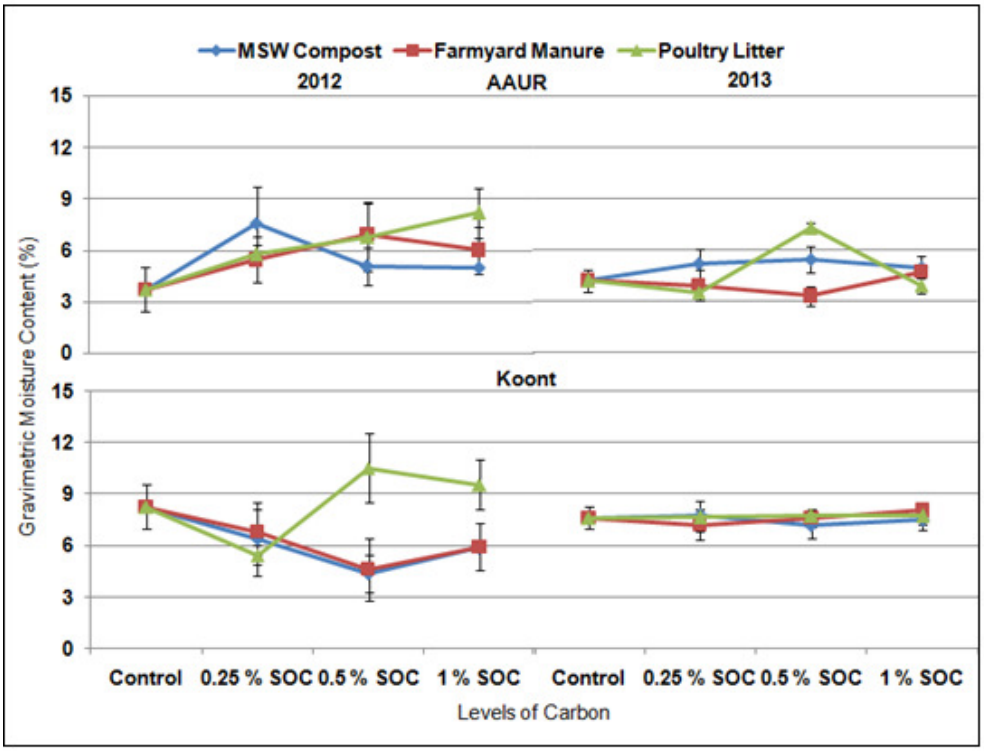

Fig. 4. Effect of different levels of various organic materials on soil gravimetric moisture content (%)

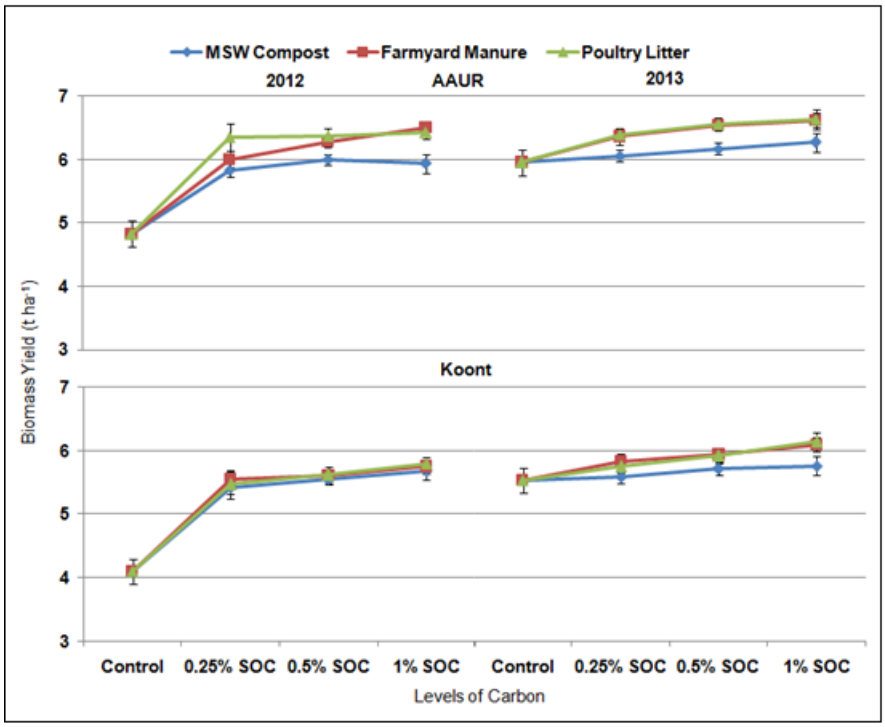

Fig. 5. Effect of different levels of various organic materials on biomass yield of wheat (t ha^{-1})

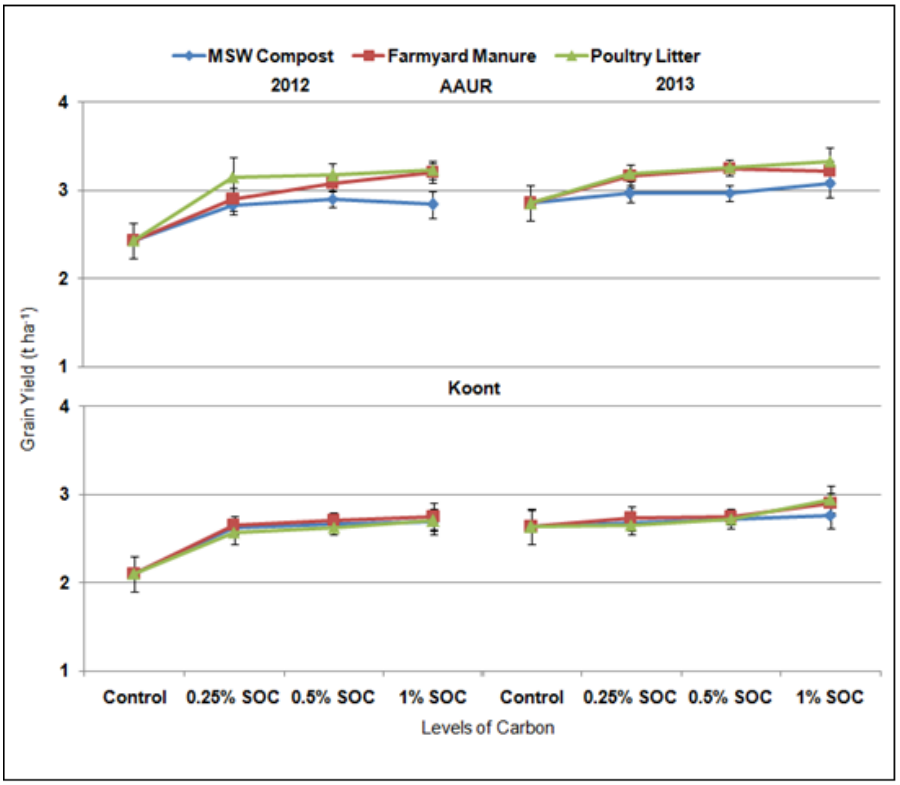

Fig. 6. Effect of different levels of various organic materials on biomass yield of wheat (t ha^{-1})

The interactions were non-significant at both sites in all years, which show that all the manures had similarly improved the biomass and grain yields with increasing levels at all sites in all years. Poultry litter had improved the moisture contents at Koont site in 2013, which is the main cause to improve the wheat crop growth and eventually crop yields. As poultry litter and farmyard manure had higher concentrations of nutrients as compared to the MSW compost, so the nutritionally sufficient levels of these manures is also the driving factor to improve the crop growth and yield [26]. Improvement in hydraulic properties and moisture conservation produces a conducive environment for high crop productivity.

4. CONCLUSION

The organic sources differ in their humic and non-humic composition which can directly affect soil physical properties as poultry litter had higher concentrations of microbial biomass carbon and polysaccharide contents (active carbon pools) and MSW compost had highest content of humic acid (passive carbon). The variation in different physical properties was not uniform in different organic materials. All the applied amendments improved the crop growth similarly with increasing levels, which clearly shows that still these levels have not touched the optimal values. Research efforts should be made to find out those carbonaceous substances (present in organic materials) which can affect directly the physical health of soil and the crop yield. According to our results the recommendations cannot be made on the basis of total organic carbon status of composted or un composted materials, it is very necessary to characterize these materials more profoundly to exactly understand the chemistry of a particular organic source or material prior to its use as soil supplement.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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