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Soil Aggregation and Aggregate Associated Carbon in a Vertisol under Conventional, Organic and Biodynamic Agriculture in Semi-Arid Tropics of Central India

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A field experiment was conducted at Indian Institute of Soil Science, Bhopal on a clayey soil (Typic Haplusterts) under soybean (*Glycine max*) - wheat (*Triticum durum*) cropping system to study the changes in soil physical properties under organic, biodynamic and conventional agriculture. The results revealed that application of organic manures either alone or in combination with liquid organic formulations increased soil organic carbon (13-16%), yield (9-13%), MWD (20-21%) and GMD (11-12%) over inorganic fertilizer addition (RDF). The content of organic carbon in different size water stable aggregates was found higher under the organic nutrition. The treatments receiving organic manure showed 5-9, 5-8 and 4-6 per cent lower bulk density in 0-7.5, 7.5-15.0 and 0-30 cm soil depths, respectively over RDF. No significant difference was observed under biodynamic agriculture.

Key words: Bulk density, water stable aggregates, mean weight diameter, geometric mean diameter, organic carbon, organic nutrient management

No system of farming will be sustainable unless the soil is managed scientifically to maintain its productivity and quality continuously. The health and sustainability of soil lies in the organic carbon management. Besides, the soil chemical and microbial properties, important soil physical properties *viz*., bulk density (BD), aggregate distribution, aggregate stability, mean weight diameter (MWD), geometric mean diameter (GMD), particle size distribution, *etc*. are significantly influenced by management of organic carbon (Karami *et al*. 2012). Many factors that contribute to loss of soil organic matter (SOM) include lower allocation of carbon to the soil, removal or burning of crop residues, tillage induced aggregates disruption, more favorable condition for decomposition and losses of surface soil by water erosion (Manna *et al.* 2012). Increasing SOM inputs *via* agricultural management is the key to increase soil organic carbon (OC) content. The organic nutrient management by application of manures either alone or in combination with the inorganic fertilizers has been reported to increase crop yields and improve soil physical, chemical and biological properties.

Organic farming is an environmentally viable approach to agriculture through use of compost and green manures to provide nutrients and cultural practices to manage weeds, insects, and pathogens. Organic farming reduces runoff, erosion and nitrate leaching when compared to conventional practices and increases nutrient concentrations and biological activity in soil (Williams *et al.* 2017). Similar to organic farming, biodynamic farming also uses no synthetic chemical fertilizers and pesticides. The effects of organic and biodynamic farming on crop yields and environmental quality have been widely reported, but the impacts on soil physical properties have not been documented. Similarly, the effect of allocation of organic carbon towards aggregate associated organic carbon in a Vertisol is not completely understood. Therefore, present study was undertaken with the hypothesis that organic nutrient management results in better soil aggregation and physical environment than conventional nutrient management practices.

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Materials and Methods

The study was conducted during 2011-12 and 2012-13 in an ongoing experiment under Network Project on Organic Farming (NPOF) initiated since 2009 at Research Farm of the Indian Institute of Soil Science, Bhopal under soybean (*Glycine max*) - wheat (*Triticum durum*) cropping system. The soil of the experimental site is classified as Vertisols (Typic Haplustert) with smectite as the dominant clay mineral. It is clayey in texture with 25.2, 18 and 56.8% of sand, silt and clay, respectively. Initially, the soil (0-15 cm depth) was medium in soil OC (5.3 g kg^{-1}), low in available N (68.8 mg kg^{-1}), medium in available P (12.8 mg kg^{-1}), high in available K (237 mg kg^{-1}) and neutral to slightly alkaline in reaction (pH 7.76). Geographically, the Indian Institute of Soil Science, Bhopal lies between 23°18′ N latitude and 77°24′ E longitudes, at 427 m above mean sea level and falls under sub-humid tropics with an average annual rainfall of 1208 mm and a mean annual air temperature of 25 °C. Out of the total annual rainfall, about 80% is received from South-West monsoon (June to September), while the rest from North-East monsoon (October and November). Agro-ecologically, the study region lies in Vindhya plateau region (Zone No. IV), in a sub-humid climate. The meteorological parameters recorded during the present investigation are presented in fig. 1. The annual mean maximum temperature was 31.2 °C (22.3-42.2 °C) and minimum temperature was 18.2 °C (6.9 and 27.3 °C). Total rainfall received during the crop growth period was 687.4 and 945.9 mm in 2011-12 and 2012-13, respectively.

Treatments and agronomic practices

The field experiment was conducted with seven treatments and four replications in a randomized block design having 6 m × 7 m plot size. The treatments were: T_1: Organic manure (on N equivalent basis); T_2: Biodynamic preparation [BD 500 (cow horn manure) as soil application @ 75 g ha^{-1} + BD 501 (cow horn silica) as foliar application @ 2.5 g ha^{-1}]; T_3: T_1 + foliar spray of 3% Panchagavya; T_4: T_1+T_2; T_5: T_2+T_3; T_6: Control, and T_7: Recommended dose of NPK fertilizers (RDF). The RDF for soybean (var HI 8498) and wheat (var JS-335) was 30:26.2:16.6 and 80:17.5:33.2 kg of N:P:K supplied through urea, single superphosphate (SSP) and muriate of potash (MOP), respectively. In case of soybean, organic manure was supplied through cattle dung manure (CDM), while to wheat it was supplied through CDM+vermicompost+poultry manure in 1:1:1 ratio on N equivalent basis with due adjustment of moisture. The soybean was sown with the seed rate of 75 kg ha^{-1} and spacing 45 cm × 5 cm, while wheat was sown with the seed rate of 100 kg ha^{-1} and spacing 22.5 cm × 5 cm.

The panchagavya was prepared by mixing of cow dung, cow urine, milk, curd and ghee in 5:3:2:2:1 proportion in 3 L of water in a wide mouth plastic container. In addition, jaggery (500 g), ripened banana (12 nos.) and water of tender coconut (3 L) were also added to improve the fermentation process. The mixture was incubated for 10 days and stirred daily clockwise and anti-clockwise in morning and evening. The mixture was filtered using a cloth and the filtrate was called panchagavya. It was used for foliar spray @ 3%. The biodynamic preparation BD 500 (cow horn manure) and BD 501 (cow horn silica) were commercially procured from Kurinji Organic Food (I) Pvt. Ltd., Theni, Tamil Nadu. The mean nutrients content of the organic inputs used in this experiment are presented in table 1.

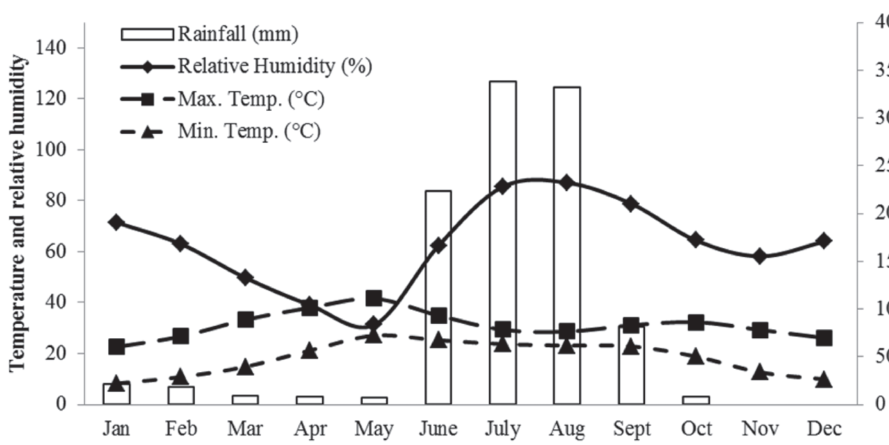

Fig. 1. Meteorological observations during the experimental period

Table 1. Mean nutrient composition of organics used in the experiment

Nutrient (g kg^{-1})	Cattle dung manure	Vermicompost	Poultry manure	Panchagavya	BD 500 (Cow horn manure)
Nitrogen (N)	8.6 ± 0.63	10.9 ± 1.79	16.3 ± 0.75	7.8 ± 0.11	21.1± 1.29
Phosphorus (P)	4.4 ± 0.11	7.3 ± 0.85	11.7 ± 0.25	1.9± 0.05	8.1± 0.16
Potassium (K)	10.7 ± 0.74	8.2 ± 0.60	12.9 ± 0.31	3.5± 0.15	8.2± 0.03

*In BD 501 (cow horn silica) no nutritional element was detected.

The organic manures *viz*., CDM, vermicompost, poultry manure and BD 500 were supplied as basal before last ploughing. Recommended dose of chemical fertilizers were applied as basal dose at the time of sowing. The panchagavya (3%) and BD 501 were sprayed at 30 and 45 days after sowing. Soybean was raised under rainfed conditions, while 4 irrigations were applied to wheat crop. Neem oil *(Azadiractin* 3% from Pest Control (I) Pvt. Ltd) and Hostathion (Trizophos 40 EC @ 0.75 L ha^{-1}; Bayer Crop Science Ltd.) were used to control the pests in organic and fertilizer treatments, respectively. Pheromone traps were also used in organic plots in order to control the crop specific pest *Helicoverpa armigera* and *Spodoptera litura* of soybean.

Soil sampling, processing and analyses

The soil samples were collected at the end of cropping cycle from 0-15 cm depth at three randomly selected spots in each replication and composite samples were prepared. The gently hammered soil samples were passed through 8 mm sieve but retained on 4-mm sieve and were used for estimating water stable aggregate. The bulk soil was gently ground, well mixed and sieved through 2-mm mesh and utilized for laboratory analysis for chemical properties. Soil chemical parameters were determined by following standard methods outlined by Jackson (1973). Soil pH and EC were determined in soil:water (1:2.5) suspension. Soil OC was determined by dichromate oxidation method (Walkley and Black 1934). Soil bulk density (0-7.5, 7.5-15.0, 15.0-22.5 and 22.5-30.0 cm) was determined by core method as described by Blake and Hartge (1986). The bulk density in 0-30 cm soil depth was determined as a weighted mean of the bulk densities of four depths. Water stable soil aggregates were determined as per procedure outlined by Yoder (1936). The MWD and GMD were calculated using following equations (Kemper and Rosenau 1986).

$$MWD = \sum_{i=1}^{n} wi\bar{X}i$$

$$GMD = \left\{ \sum\nolimits_{i=1}^{n} wi \log \bar{xi} \Big/ \sum\nolimits_{i=1}^{n} wi \right\}$$

where, MWD and GMD are mean weight diameter and geometric mean weight diameter; $\bar{X}i$ is mean diameter $\bar{X}i$ of each size fraction; *wi* is the proportional of the total sample mass occurring in the corresponding size fraction, and *n* is number of size fractions.

The data generated through observations and laboratory analysis during the investigation was statistically analyzed and the differences among the treatment means were tested for their significance *(P<0.05)* as per the standard methods (Gomez and Gomez 1984) using Web Agri Stat Package (WASP 2.0) developed by ICAR-Central Coastal Agricultural Research Institute, Goa. Significant differences among the treatments were indicated by different alphabets using Duncan's Multiple Range Test *(P<0.05)*.

Results and Discussion

Soil pH, EC and OC

The pH of the soil was neutral to slightly alkaline in nature across all the treatments (Table 3). It has been observed that the organic farming practice or application of fertilizers had no significant difference on soil pH over the brief period of study which may be attributed to the fact that the soil pH is mainly affected by the parent material involved in soil formation and the climatic conditions. The EC of soil ranged from 0.20 to 0.29 dS cm^{-1} with highest value in treatment receiving recommended dose of fertilizers (T_7). Significant decrease in EC of T_1, T_3, T_4 and T_5 over other treatments was observed while these treatments were statistically at par with each other. Treatment T_7 was statistically significant over all other treatments whereas T_2 and T_6 were found statistically at par. It has been observed that the treatments receiving organic manure alone or in combination showed slight but significant reduction in EC (Table 3). Application of organic manures does

Table 2. Soil properties and crop yield under various treatments

Treatments	pH	EC (dS m^{-1})	Organic C (g kg^{-1})	Soybean yield (kg ha^{-1})	Wheat yield (kg ha^{-1})
T_1	7.84 ^{a}	0.20 ^{c}	7.62 ^{a}	441 ^{b}	3673 ^{b}
T_2	8.01 ^{a}	0.26 ^{b}	6.29 ^{c}	352 ^{c}	1914 ^{c}
T_3	7.94 ^{a}	0.20 ^{c}	7.82 ^{a}	497 ^{a}	3770 ^{ab}
T_4	7.92 ^{a}	0.21 ^{c}	7.66 ^{a}	441 ^{b}	3676 ^{b}
T_5	7.92 ^{a}	0.20 ^{c}	8.73 ^{a}	480 ^{a}	3875 ^{a}
T_6	8.02 ^{a}	0.25 ^{b}	6.34 ^{c}	344 ^{c}	1896 ^{c}
T_7	7.96 ^{a}	0.29 ^{a}	6.74 ^{b}	440 ^{b}	3768 ^{ab}

not increase soil salinity due to the slow release of N (Clark *et al.* 1998) indicating that organic manure applications do not increase salinity.

Data on soil organic carbon (OC) revealed that, the treatments T_3 (7.82 g kg^{-1}), T_5 (7.73 g kg^{-1}), T_4 (7.66 g kg^{-1}) and T_1 (7.62 g kg^{-1}) were found statistically at par but significantly superior over T_2 (6.29 g kg^{-1}), T_6 (6.34 g kg^{-1}) and T_7 (6.74 g kg^{-1}). The treatments receiving organic manures either alone or in combinations (T_5, T_3, T_4 and T_1) recorded 13% to 16% increase in OC over the treatment receiving recommended dose of chemical fertilizers (T_7) (Table 3). The OC showed highest accumulation under the treatments receiving organic manures alone or in combination with liquid organic nutrient sources. The observed increase in OC was mainly due to the continuous build-up of carbon in soil through external carbon inputs such as cattle dung manure, vermicompost and poultry manure. Besides the regular applications of different organic manures, the root biomass and left over stubbles also contribute to the increment in OC. An increment of 49% (Jha *et al.* 2014) and 71% (Lakaria *et al.* 2012a) in soil organic carbon over sole application of fertilizers in Vertisols upon application of FYM alone or in combination with fertilizers had already been reported. The results of present study are similar with those reported earlier (Lakaria *et al.* 2012b). The higher C accumulation in the Vertisols is attributed to their high silt+clay content which increase the C stabilization capacity (Six *et al.* 2002; Jha *et al.* 2012).

Crop yield

The seed yield of soybean ranged between 344 and 497 kg ha^{-1} among the different treatment combinations (Table 3). The soybean seed yield was low during both the years across the treatments due to extraordinary rains in the months of July and August that caused many problems such as incidence of insect pest, disease as well as poor pod formation as evidenced from meteorological data recorded during the study period (Fig. 1). The soybean crop received 20 and 76% higher rainfall in July-August in 2011 and 2012, respectively. The total rainfall received during July-August was 510 mm and 757 mm in 2011 and 2012, respectively against the average 429 mm. Soybean seed yield was the highest in treatment T_3 (497 kg ha^{-1}) followed by T_5 (480 kg ha^{-1}). The organic treatments recorded 28 to 45% increment in seed yield over control (T_6). Similarly, the treatment T_5 and T_3 also proved superior to T_7 (RDF) with an increment of 9 and 13% in seed yield, respectively. The grain yield of wheat ranged from 1896 kg ha^{-1} in T_6 (control) to 3875 kg ha^{-1} in T_5. The treatments receiving organic manure either alone or in combination with *panchagavya* and/or biodynamic preparations *i.e.* T_1, T_3, T_4 and T_5 recorded grain yield of wheat similar to that obtained with the treatment receiving application of recommended dose of chemical fertilizers (T_7) (Table 2).

The yield data of both the crops indicated that application of chemical fertilizers (T_7) resulted in 28 and 99% higher yields of soybean and wheat, respectively over control. The effect of application of sole biodynamic preparations (T_2) with respect to the performance of soybean and wheat crops was not observed as the treatment T_2 was statistically similar with treatment control (T_6). The application of panchagavya along with organic manure significantly improved the performance of soybean and wheat crops as compared to the application of sole organic manures or in combination with biodynamic preparations. Further, performance of both the crops was comparable and even better under organic nutrient management as compared to the application of RDF. In general, application of organics improved the performance of both soybean and wheat in terms of yield. The earlier studies showed that continuous application of FYM and green manure significantly improved crop yield and the OC content under different soils and cropping systems and compared to the recommended dose of fertilizers and hence it was recommended that, under tropical and subtropical climatic conditions, organic matter applications are necessary to obtain good yields. The improved crop performance under the application of organic manures was attributed to the cumulative effects on soil available nutrients (Panwar *et al.* 2010), enhanced organic carbon (Manna *et al.* 2005; Lakaria *et al.* 2012a), higher microbial population, increased enzyme activities, improvement in soil physical properties (Hati *et al.* 2008) and also due to the residual effect on available nutrients (Singh *et al.* 2001). The presence of naturally occurring beneficial and effective microorganisms, plant growth promoters and nutrients in panchagavya helped in improving soil quality, plant growth, metabolic activities, diseases and pest resistance and crop yield (Somasundaram *et al.* 2007). The effect of application of sole biodynamic preparations (T_2) with respect to the performance of soybean and wheat crops was not seen over control. These results are in agreement with Tung and Fernandez (2007) who also reported non-significant effects of biodynamic applications.

Soil bulk density

The soil bulk density in 0-7.5, 7.5-15, 15-22.5 and 22.5-30 cm soil layer showed increasing trend with soil depth in all the treatments (Fig. 2). The data revealed that the treatments receiving organic manure *i.e.* T_1, T_3, T_4 and T_5 significantly decreased bulk density over control and treatment receiving recommended dose of chemical fertilizers (T_7) and biodynamic preparations (T_2) in 0-7.5 and 7.5-15.0 cm soil depth. The soil bulk density in 15.0-22.5 and 22.5-30.0 cm were not affected significantly by different treatments (Fig. 2). In 0-30 cm soil depth, the bulk density value ranged from 1.29 to 1.37 Mg m^{-3} (Fig. 3). The lowest bulk density (1.29 Mg m^{-3}) was recorded in the treatments receiving organic manures either alone or in combination with other formulations *i.e.* treatment T_1, T_3, T_4 and T_5. At 0-30 cm soil depth, highest bulk density (1.37 Mg m^{-3}) was recorded under control and T_2 followed by RDF (1.34 Mg m^{-3}). Significant reduction in bulk density was observed in treatments T_1, T_3, T_4 and T_5 over other treatments (Fig. 3).

Bulk density is an important characteristic for successful root development. The reduction in soil bulk density was mainly attributed to the increase in soil OC content due to application of the organic manures *viz.* CDM, vermicompost and poultry manures. The soil OC content is inversely proportional to bulk density which helps in improving the soil structure, soil aggregation, and an increase in volume of micropores resulting in reduction in bulk density. Similarly, Hati *et al.* (2008) also reported decrease in bulk density of soil from 1.35 to 1.27 Mg m^{-3} at 0–15 cm depth with the application of FYM @ 10 t ha^{-1} under soybean-potato-wheat cropping system in a sandy-loam soil of Ranchi.

Distribution of soil aggregates

The distribution of soil aggregates for different sieve size fractions revealed similar trend of distribution of mass [(2.000-0.125 mm) > (0.125-0.053 mm) > (<0.053 mm) > (>2 mm) *i.e.* small macro-aggregates > micro-aggregates > mineral fraction > large macro-aggregates] in all the treatments during the investigation. The treatments T_1, T_3, T_4 and T_5 and treatments T_2, T_6 and T_7 were found statistically at par during the entire period of

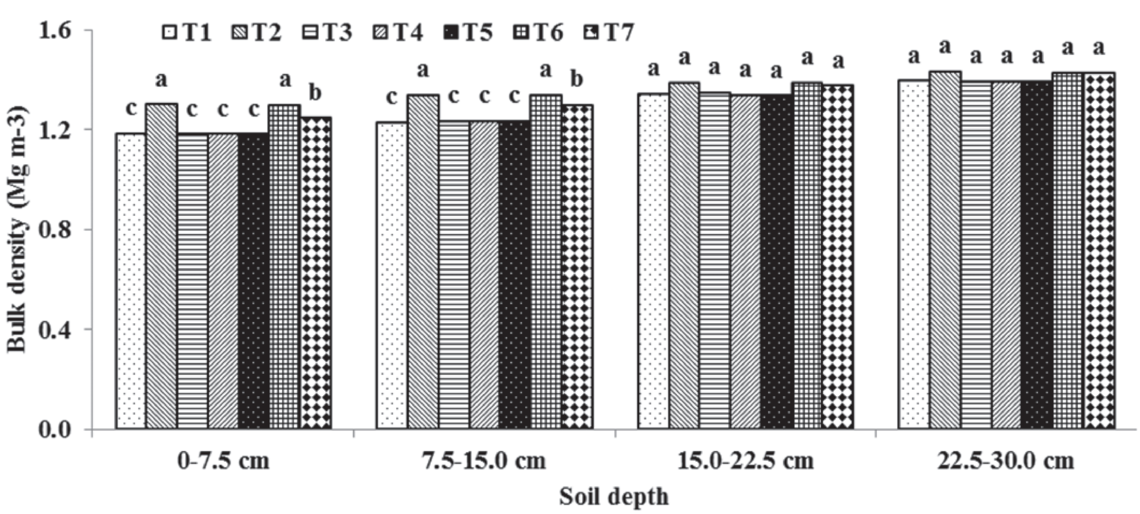

Fig. 2. Depth wise distribution of soil bulk density under different treatments

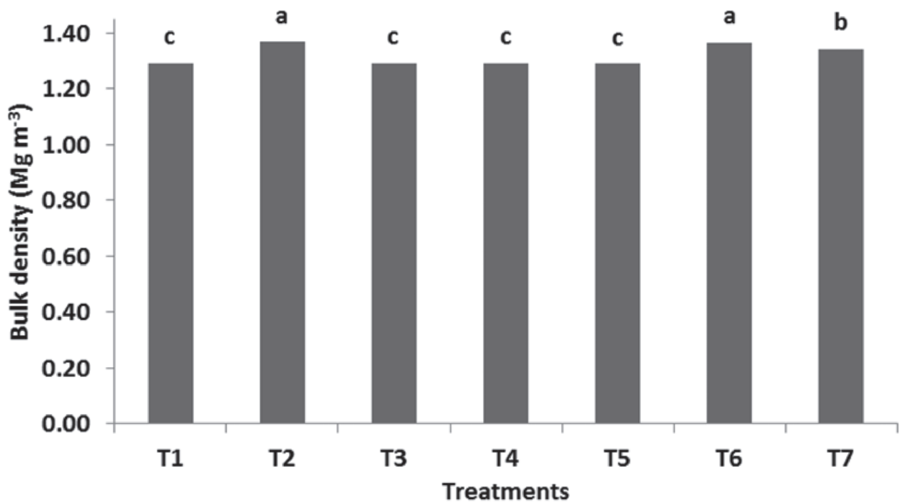

Fig. 3. Effect of organic nutrients on soil bulk density in 0-30 cm soil depth

investigation. The treatments T_1, T_3, T_4 and T_5 recorded significantly higher percentage of large macro-aggregates and small macro-aggregates while significantly lower mass of micro-aggregates and mineral fraction. The aggregates soil mass in different size classes ranged from 3.1 to 4.8%, 50.5 to 57.4%, 25.0 to 31.4% and 11.7 to14.8% in >2 mm, 2-0.125 mm, 0.125-0.053 mm and <0.053 mm size classes, respectively (Table 3).

The distribution of soil aggregates revealed that the treatments receiving organic manures *i.e.* T_1, T_3, T_4 and T_5 recorded significantly higher percentage of large macro-aggregates (>2 mm) and small macro-aggregates (2-0.125 mm) while significantly lower micro-aggregates (0.125-0.053 mm) and mineral fractions (<0.053 mm) during the study period. The aggregates soil mass in different size classes ranged from 3.1 to 4.8% (large macro-aggregates), 50.5 to 57.4% (small macro-aggregates), 25.6 to 31.4% (micro-aggregates) and 11.8 to 14.8% (mineral fraction) under different treatments (Table 3).

In this study, the highest aggregation was found in the treatments receiving organic manures. These trends are mainly attributed to the application of decomposed organic matter to soil which enhanced aggregate stability. Organic matter is considered as one of the main agents favoring soil aggregation. Part of the aggregate size variation and the aggregation indices in tropical soils can be attributed to variations in SOM that enhances aggregates stability by forming and strengthening bonds between clay domains and between quartz particles and clay domains and through binding of the soil mineral particles by polysaccharides (Oades 1984). Positive effects of manure application on aggregate stability have been reported by many researchers in India (Acharya *et al.* 1988; Hati *et al.* 2006; Singh *et al.* 2007). Hati *et al.* (2008) also observed significantly higher water stable macroaggregates under the treatment receiving organic manure along with NPK (58.6%) over sole

Table 3. Distribution of soil aggregates in different sieve size fractions, MWD and GMD in 0-15 cm soil depth under different treatments

Treatment	Soil aggregates distribution (%)				MWD (mm)	GMD (mm)
	Large macro-aggregates (>2.0 mm)	Small macro-aggregates (0.125-2.0 mm)	Micro-aggregates (0.053-0.125 mm)	Silt and clay (<0.053 mm)		
T_1	4.7[a]	57.4[a]	25.6[b]	11.9[b]	0.87[a]	0.69[a]
T_2	3.1[b]	50.9[b]	31.1[a]	14.8[a]	0.73[b]	0.62[b]
T_3	4.8[a]	57.2[a]	25.7[b]	12.0[b]	0.87[a]	0.69[a]
T_4	4.7[a]	57.3[a]	26.0[b]	11.8[b]	0.87[a]	0.69[a]
T_5	4.8[a]	57.3[a]	25.7[b]	11.7[b]	0.88[a]	0.69[a]
T_6	3.1[b]	50.6[b]	31.4[a]	14.6[a]	0.73[b]	0.62[b]
T_7	3.2[b]	50.5[b]	31.4[a]	14.6[a]	0.73[b]	0.62[b]

NPK treatment (49.8%) and unfertilized control (42.7%) in 0-15 cm soil depth. The positive effects of application of organic matter on water stable soil aggregates were also reported by other workers (Manna *et al.* 2005; Benbi and Senapati 2010).

Aggregate MWD and GMD

Soil aggregation was significantly influenced by the organic farming practice. The MWD in 0-15 cm soil layer ranged from 0.73 mm to 0.88 mm among different treatment combinations (Table 5). The treatments T_3, T_4, T_5 and T_1 were statistically at par with each other whereas significantly superior over T_2, T_6 and T_7 with respect to MWD. Similarly, the treatments T_2, T_6 and T_7 were also found statistically at par with each other with respect to MWD. Similarly, the GMD values among the different treatments ranged from 0.62 to 0.69 mm with higher value in treatments T_1, T_3, T_4 and T_5. The GMD followed similar trends as that of MWD in all the treatments during the study. It has been observed that the treatments receiving organic manure alone or in combination showed increased aggregation. Pinheiro *et al.* (2004) found MWD and GMD in the range of 1.7-4.2 mm and 0.9-1.1 mm, respectively in a red Latosols of Brazil in 0-5 cm soil depth under different land management practices. In India, Hati *et al.* (2006) reported significantly higher MWD with application of NPK+FYM (0.50 mm) than sole NPK (0.44 mm). An earlier study in Alfisols by Acharya *et al. (*1988) also reported similar results. The MWD and GMD under organic applications were 20-21 and 11-12 per cent higher than recommended dose of chemical fertilizers, respectively which is attributed to higher organic carbon content in organic treatment plots.

WBC in soil aggregates

The WBC in large macroaggregates was higher than that of small macro-aggregates followed by micro-aggregates and mineral fraction (Table 4). The WBC in large macro-aggregates, small macro-aggregates, micro-aggregates and mineral fraction were in the range of 9.14-21.27, 6.15-9.40, 4.32-5.62 and 2.32-3.08 g kg^{-1}, respectively, among the different treatment combinations. The treatments T_3 and T_5 were statistically at par and proved significantly superior over biodynamic preparation, RDF and control in all size of soil aggregates. The WBC in large macro-aggregate showed significant improvement with application of organic nutrient sources. The application of organic manures under different treatment combinations (T_1, T_3, T_4 and T_5) increased WBC in large macro-aggregate from 125 to 132 per cent whereas the increment in small macroaggregate was 47-53 per cent over T_6 and T_7, respectively. The treatments T_2, T_7 and T_6 were found statistically at par with respect to WBC in micro-aggregates and mineral fraction whereas T_2 and T_6 were found significant over T_7 with respect to large and small macro-aggregates. The WBC concentrations were found greater in large macro-aggregates than in small macro-aggregates and micro-aggregates irrespective of treatments. However, irrespective of aggregates size class, the concentration of WBC was higher in the treatments receiving organic manure with or without liquid organics (Table 4). The lowest C concentration was observed in the mineral fraction (silt + clay) for all treatments. The interactions between aggregate WBC concentration and treatments were statistically significant. Similar results were also reported by Manna *et al.* (2005). In Vertisols, a large part of the total aggregate C could be protected by microbial attack by its physical isolation within macro-aggregates, and high initial SOC in soil (Jha *et al.* 2012). These results are in accordance to the findings of Bossuyt *et al.* (2002), who also reported more recently added C in the 2-4 mm aggregate size class. Earlier, results from continuous application of

Table 4. Soil aggregates associated Walkley and Black carbon (WBC) in 0-15 cm soil depth for different sieve size fractions under different treatments

Treatments	Soil aggregate size (mm)			
	Large macro-aggregates (>2.0 mm)	Small macro-aggregates (0.125-2.0 mm)	Micro-aggregates (0.053-0.125 mm)	Silt and clay (<0.053 mm)
T_1	20.61[a]	9.07[b]	5.54[b]	2.97[a]
T_2	9.61[bc]	7.13[c]	4.50[c]	2.43[b]
T_3	21.27[a]	9.40[a]	5.55[a]	3.08[a]
T_4	20.63[a]	9.13[b]	5.51[ab]	3.02[a]
T_5	20.73[a]	9.20[ab]	5.62[a]	3.02[a]
T_6	9.14[c]	6.88[c]	4.32[c]	2.32[b]
T_7	9.98[b]	6.15[d]	4.40[c]	2.35[b]

rice straw and FYM either alone or in conjunction with inorganic fertilizers also improved macro-aggregate associated C in rice-wheat cropping on a sandy loam soil after 7 years of cropping in India (Benbi and Senapati 2010) with higher C concentration in macro-aggregates as compared to micro-aggregates. Similarly, Wright and Hons (2005) also observed that majority of SOC storage at 0-5 cm depth was in 0.25-2 mm aggregates, and at 5-15 cm depth, in the >2 mm and 0.25-2 mm aggregate size fractions. The greater amount of TOC within macro-aggregates results in a proportionately higher amount of mineralizable C and suggests that macro-aggregates contribute more to short-term nutrient cycling than micro-aggregates (Mikha and Rice 2004) which is evident from the WBC content (Table 4).

Conclusions

The application of organic manures either alone or in combination with liquid organic formulations increased soil organic carbon (13-16%), yield (9-13%), MWD (20-21%) and GMD (11-12%) over RDF. The biodynamic preparations involving BD 500 and 501 did not show encouraging results over control in terms of crop yields as well as soil properties. Panchgavya application alongwith with organic manures showed improvement in crop yields but no effect was observed on soil properties. Soil organic carbon content in different size water stable aggregates was found higher under the organic nutrient management. The treatments receiving organic manure showed significant decrease in bulk density in 0-7.5, 7.5-15.0 and 0-30 cm soil depths, respectively over chemical fertilizers. Thus, application of organic matter is essential for improving the physical properties of Vertisols and enhancing crop yields on sustainable basis.

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References

Acharya, C.L., Bisnoi, S.K. and Yaduvanshi, H.S. (1988) Effect of long-term application of fertilizers and organic and inorganic amendments under continuous cropping on soil physical and chemical properties in an Alfisol. *Indian Journal of Agricultural Sciences* **58**, 509-516.

Benbi, D.K. and Senapati, N. (2010) Soil aggregation and carbon and nitrogen stabilization in relation to residue and manure application in rice-wheat systems in northwest India. *Nutrient Cycling in Agroecosystems* **87**, 233-247.

Blake, G.R. and Hartge, K.H. (1986) Bulk density. In *Method of Soil Analysis,* Part-I *Physical and Mineralogical Methods* (A. Klute, Ed.), 2nd edition, American Society of Agronomy Inc. and Soil Science Society of America, Madison, Wisconsin, USA, pp. 371-373.

Bossuyt, H., Six, J. and Hendrix, P.F. (2002) Aggregate-protected carbon in no-tillage and conventional tillage agro-ecosystems using carbon-14 labeled plant residue. *Soil Science Society of America Journal* **66**, 1965-1973.

Clark, M.S., Horwath, W.R., Shennan, C. and Scow, K.M. (1998) Changes in soil chemical properties resulting from organic and low-input farming practices. *Agronomy Journal* **90**, 662-671.

Gomez, K.A. and Gomez, A. (1984) *Statistical Procedures for Agricultural Research* (2nd edition), John Willey and Sons, New York, 1-680.

Hati, K.M., Mandal, K.G., Mishra, A.K., Ghosh, P.K. and Bandyopadhyay, K.K. (2006) Effect of inorganic fertilizer and farmyard manure on soil physical properties, root distribution, water-use efficiency and seed yield of soybean in Vertisols of central India. *Bioresource Technology* **97**, 2182-2188.

Hati, K.M., Swarup, A., Mishra, B., Manna, M.C., Wanjari, R.H., Mandal, K.G. and Mishra, A.K. (2008) Impact of long-term manure, fertilizer and lime under intensive cropping on physical properties and organic carbon content of an Alfisol. *Geoderma* **148**, 173-179.

Jackson, M.L. (1973) *Soil Chemical Analysis*. Prentice Hall of India (Pvt.), Ltd., New Delhi.

Jha, P., Garg, N., Lakaria, B.L., Biswas, A.K. and Subba Rao, A. (2012) Soil and residue carbon mineralization as affected by soil aggregate size. *Soil and Tillage Research* **121**, 57-62.

Jha, P., Lakaria, B.L., Biswas, A.K., Saha, R., Mahapatra, P., Agrawal, B.K., Sahi, D.K. Wanjari, R.H., Lal, R., Singh, M. and Subba Rao, A. (2014) Effects of carbon input on soil carbon stability and nitrogen dynamics. *Agriculture, Ecosystems and Environment* **189**, 36-42.

Karami, A., Homaee, M., Afzalinia, S., Ruhipour, H. and Basirat, S. (2012) Organic resource management: impacts on soil aggregate stability and other soil physico-chemical properties. *Agriculture, Ecosystems and Environment* **148**, 22-28.

Kemper, W.D. and Rosenau, R.C. (1986) Aggregate stability and size distribution. In *Methods of Soil Analysis* (A. Klute, Ed.), Part I, 2nd Ed., American Society of Agronomy and Soil Science Society of America, Medison, Wisconsin, USA, pp. 445-452.

Lakaria, B.L., Patne, M.K., Jha, P. and Biswas, A.K. (2012b) Soil organic carbon pools and indices under different land use systems in Vertisols of Central India. *Journal of the Indian Society of Soil Science* **60**, 125-131.

Lakaria, B.L., Singh, M., Reddy, K.S., Biswas, A.K., Jha, P., Choudhary, R.S., Singh, A.B. and Rao, A.S. (2012a) Carbon addition and storage under integrated nutrient management in soybean-wheat cropping sequence in a Vertisol of central India. *National Academy of Science Letters* **35**, 131–137.

Manna, M.C., Swarup, A., Wanjari, R.H., Ravankar, H.N., Mishra, B., Saha, M.N., Singh, Y.V., Sahi, D.K. and Sarap, P.A. (2005) Long-term effect of fertilizer and manure application on soil organic carbon storage, soil quality and yield sustainability under sub-humid and semiarid- tropical India. *Field Crops Research* **93**, 264-280.

Manna, M.C., Sahu, A. and Subba Rao, A. (2012) Impact of long-term fertilizers and manure application on C-sequestration efficiency under different cropping systems. *Indian Journal of Soil Conservation* **40**, 70-77.

Mikha, M.M. and Rice, C.W. (2004) Tillage and manure effects on soil and aggregate associated carbon and nitrogen. *Soil Science Society of America Journal* **68**, 809-816.

Oades, J.M. (1984) Soil organic matter and structural stability: Mechanisms and implications for management. *Plant and Soil* **76**, 319-337.

Panwar, N.R., Ramesh, P., Singh, A.B. and Ramana, S. (2010) Influence of organic, chemical and integrated management practices on soil organic carbon and soil nutrient status under semi-arid tropical conditions in central India. *Communications in Soil Science and Plant Analysis* **41**, 1073-1083.

Pinheiro, E.F.M., Pereira, M.G. and Anjos, L.H.C. (2004) Aggregates distribution and soil organic matter under different tillage system for vegetable crops in a Red Latosol from Brasil. *Soil and Tillage Research* **77**, 79-84.

Singh, K.N., Prasad, B. and Sinha, S.K. (2001) Effect of integrated nutrient management on a Typic Haplaquent on yield and nutrient availability in a rice-wheat cropping system. *Australian Journal of Agricultural Research* **52**, 855-858.

Singh, K.P., Suman, A., Singh, P.N. and Lal, M. (2007) Yield and soil nutrient balance of a sugarcane plant ratoon system with convention a land organic nutrient management in sub-tropical India. *Nutrient Cycling in Agroecosystems* **79**, 209-219.

Six, J., Conant, R.T., Paul, E.A. and Pautain, K. (2002) Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. *Plant and Soil* **241**, 155-176.

Somasundaram, E., Amanullah, M., Vaiyapuri, K., Thirukkumaran, K. and Sathyamoorthi, K. (2007) Influence of organic sources of nutrients on the yield and economics of crops under maize based cropping system. *Journal of Applied Sciences Research* **3**, 1774-1777.

Tung, L.D. and Fernandez, P.G. (2007) Yield and seed quality of modern and traditional soybean (*Glycine max*) under organic, biodynamic and chemical production practices in the Mekong delta of Vietnam. *Omonrice* **15**, 75-85.

Walkley, A. and Black, I.A. (1934) An examination of the Degtjareff method for determining soil organic carbon, and proposed modification of the chromic acid titration method. *Soil Science* **63**, 29-38.

Williams, D.M., Blanco-Canqui, H., Francis, C.A. and Galusha, T.D. (2017) Organic farming and soil physical properties: An assessment after 40 years. *Agronomy Journal* **109**, 600-609.

Wright, A.L. and Hons, F.M. (2005) Carbon and nitrogen sequestration and soil aggregation under sorghum cropping sequences. *Biology and Fertility of Soils* **41**, 95-100.

Yoder, R.E. (1936) A direct method of aggregate analysis of soils and a study of the physical nature of soil erosion. *Journal of American Society of Agronomy* **28**, 337-351.

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