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Characterization of physical properties of vertisols under long-term fertilizer experiment in soybean-wheat cropping system

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Abstract
An experiment was conducted at the field of Department of Soil Science and Agril. Chemistry, JNKVV, Jabalpur (M.P) during *kharif* and *rabi* season of 2015-2016 under All India Co-ordinate Research Project on “Long term Fertilizer Experiment” in simple randomized block design with eight treatments and four replications comprising viz., T_1 (Control) T_2 (50 % NPK), T_3 (100 % NPK), T_4 150% NPK), T_5 (100%NP), T_6 (100%N), T_7 (100%NPK+FYM), T_8 (100%NPK-S). The results obtained from the present investigation clearly indicated that physical properties (bulk density, infiltration rate, moisture content, fractions of different sized aggregates and mean weight diameter) of soil were significantly affected by long-term application of integrated nutrients under soybean-wheat cropping system. It was found that integration of FYM increased the beneficial effect on physical properties over the treatments of inorganic nutrients application alone in both surface (0-15 cm) and sub-surface (15-30cm) soil under soybean-wheat cropping system.

Keywords: physical properties (bulk density, infiltration rate, moisture content, fractions of different sized aggregates and mean weight diameter), farmyard manure, soybean-wheat sequence, integrated nutrient management

Introduction
Soybean-wheat system is one of the most important legume-cereal cropping systems with wide adaptability to diverse agro-climatic conditions across the world and India as well. Both crops in this system have differential edaphic and nutrient requirement and supposes to have the potential for food and nutritional security to the present and future generations. Soybean-wheat is the most dominant cropping systems on the Vertisols of Madhya Pradesh in Central India where cultivation of wheat in winter season has a considerable potential due to pleasant climate, while soybean in rainy season has witnessed a phenomenal growth in the last two decades in the region (Behera *et al.,* 2007) [3]. Long-term application of fertilizers and organic manure influence SOC content (Benbi *et al.,* 1998; Shirani *et al.,* 2002) [4, 17]. Integration of inorganic fertilizers with organic manures will not only sustain the crop production but also improve the physical, chemical and biological properties as well as nutrient use efficiency in Vertisols (Verma *et al.,* 2005) [23]. Poor soil quality (physical and chemical properties and fertility) of soil is the major cause for the low productivity of soybean-wheat system in Vertisols (Tomar and Dwivedi, 2007 and Dakshinamurthy *et al.,* 2005) [22, 6].

Materials and Methods
Field experiments were conducted during *Kharif* and *Rabi* seasons of 2015-16 at the AICRP on LTFE research field of Department of Soil Science and Agricultural Chemistry, JNKVV, Jabalpur, situated at $23^0 10'$ N latitude, $79^0 57'$ E longitudes and at elevation 393.0 meter above mean sea level in the South-Eastern part of the Madhya Pradesh**.** The physical characteristics of the soil were: Kheri series of fine montmorillonitic hyperthermic family of T*ypic Haplustert* and known as medium deep black soil. Eight treatments were imposed with four replications in simple randomized block design in both soybean and wheat crops. The treatments were T_1 (Control) T_2 (50% NPK), T_3 (100% NPK), T_4 150% NPK), T_5 (100% NP), T_6 (100% N), T_7 (100% NPK+FYM), T_8 (100% NPK-S). Where 100% NPK stands for 20:80:20 kg ha^{-1} and 120:80:40 kg ha^{-1} N: P_2O_5: K_2O in a randomized block design with four replications. Respectively for soybean and wheat crops and NPK-S stated that phosphorus was supplied through DAP. Crops were raised with all the standard recommended agronomic practices other than those under treatments. For the present study two sets of soil samples each for physical analysis were collected with the help of core sampler from selected sites from each plot as per

the treatments for surface (0-15 cm) and sub-surface (15-30 cm) soils after harvest of soybean and wheat crops grown during 2015-16. To determine the bulk density (BD), manually operated core sampler method (Richards *et al.,* 1954) [12]. The soil samples collected for determination of the bulk density were used for estimation of soil moisture content. For the purpose weight of the fresh and oven dried soil samples were recorded and gravimetric soil moisture content was computed using the following relationship: Penetration resistance was recorded using Cone Penetrometer (Eijelkamp Agrisearch Equipment). Infiltration rate of soil at initial and equilibrium stages were measured using double ring infiltrometer (Haise *et al.,* 1956) [9]. The procedure used for aggregate size analysis was modified Yoder's sieving method Yoder, 1936 [26]. It gives an estimate of weighted percentage of average sizes of all aggregates. The mean diameter of any particular size range of aggregates (X_i) is multiplied by the weight of the aggregates in that size range as a fraction of the total dry weight of the sample analyzed (W_i). The sum of the products gives the MWD in mm.

$$\text{MWD (mm)} = \sum X_i W_i$$

Results and Discussion

Effect of long-term application of integrated nutrients on physical properties of soil after harvest of soybean and wheat crop in soybean-wheat cropping system:

Bulk density

Data on bulk density of surface and sub-surface soils after harvest of soybean and wheat crops as affected by long-term application of integrated nutrients are given in Table 1. The data clearly indicated that bulk density of soil in both the depths was significantly affected by different treatments of integrated nutrient application. Data further showed that bulk density of surface and sub-surface soil was maximum in control (T_1) and minimum under T_7 (100% NPK with FYM) followed by T_3 and T_4 (100 % NPK and 150% NPK) treatments. It is evident from the data that bulk density of sub-surface soil was higher as compared to surface soil in all the treatments. The results also showed that integration of organic source (FYM) with inorganic nutrients significantly reduced the bulk density of soil and it was increased with soil depth irrespective of the nutrients application treatments. Results showed that bulk density of soil was significantly affected by different treatments of long-term application integrated nutrients. Maximum bulk density was obtained under control, while it was minimum under T_7 (100% NPK+ FYM) treatment. It might be because of addition of FYM and more root biomass in T_7 treatment which resulted in lower bulk density in both after harvest of soybean and wheat crops. The findings are in good agreement of those reported by Singh *et al.,* (2000), Sharma *et al.,* (2001) and Walia and Dhaliwal, (2010) [18, 16, 14]. They also reported that integrated nutrient application decreased the bulk density of soil as compared to the treatments of using inorganic nutrients alone and control treatment as well. The results further showed that bulk density of sub-surface (15-30 cm) soil was higher as compared to the surface (0-15 cm) soil under all the treatments may be due to fine aggregates and low organic carbon content in sub-surface soil. Gathala *et al.,* 2007 and Yaduvanshi *et al.,* 2013 [7, 25]. Also reported that bulk density of surface soil is lower than sub-surface soil irrespective of the treatments under long-term integrated nutrient application experiment.

Penetration resistance

Penetration resistance indicates the degree of compactness in soil. Significant effect of long-term integrated nutrients application on penetration resistance of surface and sub-surface soil after harvest of soybean and wheat crops is presented in Table 1.Data also indicated that integration of FYM with inorganic fertilizers significantly reduce the penetration resistance. Highest penetration resistance was observed under control for surface and sub-surface soils, respectively. It was also evident from the data that sub-surface soil layer exert more resistance to penetration as compared to surface layer. Data further showed that penetration resistance of surface and subsurface soils varied from 0.36 M Pa (T_7) to 0.42 M Pa (T_1) and 0.38 M Pa (T_7) to 0.44 M Pa in control (T_1) treatments in soybean crop and Penetration resistance of surface and sub-surface soils was varied from 0.34 - 0.40 M Pa and 0.36-0.41 M Pa in wheat crop, respectively. Integration long-term nutrients application on penetration resistance of surface (0-15 cm) and sub-surface (15-30 cm) soils depth was significantly affected. Result showed that integration of FYM with inorganic nutrients decreased the penetration resistance of soil over same levels of inorganic nutrient application for targeted yield treatments and other treatments as well, while maximum penetration resistance in surface and sub-surface soils after harvest of soybean and wheat crops was recorded under control treatment. It was might be due to addition of FYM along with inorganic nutrient which decreases the degree of compactness and resulted in lower penetration resistance in soil. Similar findings were also reported by Ghuman and Sur, (2001); Zeleke (2004) [8, 27]. They also found that integrated nutrient application (inorganic + organic) significantly reduced the penetration resistance of soils. Results further showed that penetration resistance of soil after harvest of soybean and wheat crops was lower in surface (0-15 cm) soil as compared to sub-surface (15-30 cm) soil may be due to higher bulk density and lower organic carbon content in sub-surface soil. The finding of the present study is well supported by those reported by Bandyopadhyay *et al.,* (2010) [2] which also stated that penetration resistance of surface soil is lower than sub-surface soil under all the treatments of long-term integrated nutrient management with lowest and highest values in treatments of 100% NPK + FYM application and control, respectively.

Mean weight diameter

Mean weight diameter of soil aggregates is very crucial for movement of air, water and temperature and ultimately for flourishing the root system of crops. Data on mean weight diameter of soil aggregates after harvest of soybean and wheat crops (Table 2) clearly data showed a significant effect of long-term application of integrated nutrients on mean weight diameter of soil aggregates at 0-15 and 15-30 cm soil depths. Mean weight diameter of soil aggregates under the treatments received only inorganic and/or imbalanced nutrients were significantly lower than those supplied with FYM in surface sub-surface soil except in T_4 treatment of sub-surface soil. The results of the present study are well supported by findings of Samahadthai *et al.,* (2010) [13]. They stated that MWD of soil aggregates has increased due to application of inorganic fertilizers along with organic source (FYM and VC) under soybean-wheat cropping system. The results further showed that mean weight diameter of soil aggregates after harvest of wheat was more than those obtained harvest of soybean crop which may be due to decomposition of FYM and plant biomass of soybean. Results clearly indicated that long-term application of balanced and integrated nutrients significantly increased the mean weight diameter of aggregates in surface and sub-surface soils as compared to the treatments of only inorganic nutrients application. Significantly smaller mean weight diameter of soil aggregates were obtained in control at both the soil depths. This was might be because of binding ability of organic carbon which facilitated the formation of larger soil aggregates. The mean weight diameter of soil aggregate in surface soil was greater than those in sub-surface soil in respective treatments after harvest of soybean and wheat crop as well. It may be due to higher organic content and organic acid secretion in surface soil. This finding is well supported by the results reported by Aulakh *et al.,* (2013) [1].

Soil moisture content

Data on soil moisture content in 0-15 cm and 15-30 cm soil depths as affected by long-term application of integrated nutrients after harvest of crops has also presented in Table 2. It is clear from data that soil moisture content was significantly affected by treatments of long-term application of integrated nutrients. Soil moisture content in sub-surface soil was higher than those of surface soils of respective treatments. Results clearly indicated that addition of organic manure significantly increased the soil moisture content and also the moisture content is directly related to the soil depth. The results showed a significant effect of long-term application of integrated nutrients on soil moisture content after harvest of soybean and wheat crops. Results clearly indicated that addition of FYM along with inorganic nutrients significantly increased the soil moisture content and also the moisture content is directly related to the soil depth. It was might be because of buildup of organic carbon, good aggregation and better porosity which promoted the adhesive force of soil matrix that enhanced the moisture holding capacity of soil. Findings of Selvakumari *et al.,* (2000), Pattanayak *et al.,* (2001), Smiciklas *et al.,* (2002), Sarwar *et al.,* (2003) and Chesti *et al.,* (2013) [15,11,20,14,5] have also emphasized that continuous application of organic manures along with inorganic fertilizers increases the soil moisture content with soil depth under soybean-wheat cropping system.

Water stable soil aggregates

Data pertaining to size fractions of water stable soil aggregates in surface and sub-surface soils after harvest of soybean and wheat crops as effect by long-term application of integrated nutrients are presented in Table 3 and 4, respectively. Data clearly indicated that different size fractions of water stable soil aggregates were significantly affected. Water stable soil aggregates in surface soil was improved due to integrated use of FYM and inorganic fertilizers as compared to application of inorganic fertilizers alone. However, the fraction of water stable soil aggregates of finer size were more in the treatments received imbalanced and only inorganic fertilizers. Data also showed that per cent fraction of larger aggregates were significantly more in the treatment received FYM along with inorganic fertilizers. While, the per cent of finer aggregates fractions were more in the treatments which received imbalanced inorganic fertilizers only respectively under different treatments. It was also found that integration of FYM with inorganic fertilizers significantly improved the proportion of larger size water stable soil aggregates in both surface and sub-surface soils which have great importance for aeration, infiltration and water holding capacity of soil. Result pertaining to different size fractions of water stable aggregates showed a significant effected of long-term application of integrated nutrients in both surface and sub-surface soils under soybean-wheat cropping system. It is also evident from the results that per cent of larger sized water stable soil aggregates in surface soil were increased due to integrated use of FYM and inorganic fertilizers as compared to application of imbalance inorganic fertilizers alone. However, the effect of treatments of balanced (100% NPK and 150% NPK) use of inorganic nutrients on different size fractions of water stable aggregates was on par to those obtained in 100% NPK+FYM treatment. It was might be because of cementing behavior of organic carbon which promotes the size of soil aggregates. The findings are in good agreement of those reported by Gathala *et al.,* (2007) and Mahmood-ul-Hassan *et al.,* (2013) [7,10]. They have also found higher fraction of water stable aggregates under integrated nutrient management as compared to imbalanced use of chemical fertilizer treatments in the soybean-wheat cropping system.

Infiltration rates of soil after harvest of soybean and wheat crops

Effect of long-term application of integrated nutrients on initial and equilibrium infiltration rates of soil was also studied after harvest of soybean and wheat crops grown in soybean-wheat cropping system and the data thus obtained are given in Table 5. Data showed that initial and equilibrium infiltration rates (mm hr^{-1}) after harvest of soybean and wheat were significantly affected by different treatments of long-term application of integrated nutrients. Maximum initial infiltration rate after harvest of soybean (40.0 mm hr^{-1}) and wheat (43.0 mm hr^{-1}) were recorded in T_7 (100% NPK+FYM) followed by T_4 (37.8 and 40.6 mm hr^{-1}) treatments. However, the minimum initial infiltration rate after harvest of soybean (35.0 mm hr^{-1}) and wheat (37.6 mm hr^{-1}) were recorded in T_6 (100% N) treatment. In general initial infiltration rate of soil after harvest of wheat was higher compared to those after harvest of soybean in respective treatments. Data further revealed that effect long-term application of integrated nutrient on equilibrium infiltration rate (mm hr^{-1}) of soil after harvest of soybean and wheat crops was significantly higher (14.1 and 15.5 mm hr^{-1}) in T_7 treatments over T_1, T_5 and T_6 treatments, while values of equilibrium infiltration rate in the remaining treatment (T_2, T_3, T_4 and T_8) were statistically at par. The lowest values (11.1 and 12.2 mm hr^{-1}) of equilibrium infiltration rate after harvest of soybean and wheat crops were recorded in the control, respectively. Data also revealed infiltration rate was more after harvest of wheat as compared to those after harvest of soybean and also the integration of FYM with inorganic nutrients improve the infiltration rate. The results clearly indicated that infiltration rate (mm hr^{-1}) of soil after harvesting of soybean and wheat crops was significantly increased by the treatments of long-term use of balanced inorganic nutrients (100% NPK and 150% NPK) alone or in combination with FYM as compared to imbalanced use of inorganic fertilizers alone. Infiltration rate of soil after harvest of wheat was higher as compared to those after harvest of soybean in all the treatments. Maximum (40.0 and 43.0 mm hr^{-1}) initial infiltration rate after harvest of soybean and wheat crops were recorded in T_7 treatment, while the lowest values (35.6 and 38.3 mm hr^{-1}) were recorded in the control. It might be due to higher porosity resulted from formation of larger aggregates in treatments of integrated nutrient application. Smiciklas *et al.*, (2002), Sarwar *et al.*, (2003) and Mahmood-ul-Hassan *et al.*, (2013) [20, 14, 10] have also reported 26-49 per cent higher infiltration rate in the treatment of integrated nutrient application as compared to the treatments of inorganic fertilizer application alone.

Table 1: Effect of long-term application of integrated nutrients on bulk density (BD) and penetration resistance (PR) of soil after harvest of soybean and wheat crops.

Treatments	After harvest of soybean crops				After harvest of wheat crops			
	BD (Mg m^{-3})		PR (M Pa)		BD (Mg m^{-3})		PR (M Pa)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1	1.39	1.44	0.42	0.44	1.36	1.41	0.40	0.41
T_2	1.38	1.41	0.39	0.41	1.35	1.40	0.38	0.41
T_3	1.35	1.40	0.37	0.39	1.32	1.38	0.36	0.39
T_4	1.34	1.37	0.37	0.39	1.32	1.38	0.36	0.38
T_5	1.35	1.38	0.38	0.40	1.35	1.39	0.38	0.39
T_6	1.36	1.39	0.39	0.41	1.36	1.40	0.38	0.40
T_7	1.29	1.34	0.36	0.38	1.28	1.33	0.34	0.36
T_8	1.35	1.38	0.37	0.39	1.33	1.38	0.36	0.38
SEm$\pm$	0.019	0.018	0.011	0.009	0.016	0.013	0.011	0.010
CD (*p=0.05*)	0.055	0.052	0.032	0.026	0.047	0.039	0.031	0.028

Table 2: Effect of long-term application of integrated nutrients on Mean weight diameter (MWD) and Soil moisture content of soil after harvest of soybean and wheat crops.

Treatments	After harvest of soybean crops				After harvest of wheat crops			
	MWD (mm)		Soil moisture content		MWD (mm)		Soil moisture content	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1	0.35	0.36	18.8	29.1	0.38	0.36	17.4	22.3
T_2	0.40	0.40	19.7	28.4	0.45	0.41	18.3	24.0
T_3	0.47	0.45	21.5	29.1	0.51	0.45	19.9	24.6
T_4	0.50	0.47	23.8	29.0	0.54	0.47	22.0	24.9
T_5	0.41	0.39	20.1	28.9	0.49	0.40	18.6	24.2
T_6	0.39	0.38	19.1	28.6	0.46	0.40	17.9	24.0
T_7	0.58	0.49	24.9	30.7	0.64	0.51	23.1	25.3
T_8	0.45	0.44	20.7	28.0	0.51	0.45	19.1	24.5
SEm$\pm$	0.015	0.010	1.24	1.78	0.022	0.018	1.15	1.24
CD (*p=0.05*)	0.043	0.029	3.75	NS	0.064	0.052	3.43	NS

Table 3: Effect of long-term application of integrated nutrients on water stable aggregate in sub-surface soil after harvest of soybean crop.

T	Soil aggregates of different size (%) at 0-15 cm soil depth						Soil aggregates of different size (%) at 15-30 cm soil depth					
	>2.0mm	2.0-1.0 mm	1.0-0.5 mm	0.5-0.25 mm	0.2-0.10 mm	< 0.10 mm	>2.0 mm	2.0-1.0 mm	1.0-0.5 mm	0.5-0.25 mm	0.25-0.10 mm	< 0.10 mm
T_1	3.5	5.50	23.0	29.8	24.8	13.5	2.8	4.8	30.0	27.8	22.8	12.0
T_2	4.8	7.00	25.8	27.0	25.0	10.5	4.0	6.3	33.0	24.3	23.5	9.0
T_3	6.8	8.50	32.8	22.3	15.5	14.3	5.5	7.3	38.3	20.3	14.3	14.5
T_4	7.3	9.25	35.0	23.8	16.3	8.5	6.3	7.5	38.0	22.0	15.5	10.8
T_5	4.5	7.50	29.5	28.0	20.0	10.5	3.8	6.5	30.8	25.8	18.5	14.8
T_6	4.0	6.50	27.0	30.8	22.0	9.8	3.8	5.5	31.0	26.5	20.3	13.0
T_7	8.5	15.0	37.8	20.3	14.8	3.8	6.0	10.5	39.8	17.0	14.5	12.3
T_8	7.0	7.75	28.0	21.5	16.0	19.8	5.5	7.0	36.8	19.8	15.5	15.5
SEm$\pm$	0.39	0.60	1.74	1.56	1.83	0.83	0.43	0.51	1.40	1.52	1.27	0.88
CD (*p=0.05*)	1.08	1.76	5.20	4.61	5.39	2.41	1.26	1.50	4.18	4.51	3.79	2.63

Table 4: Effect of long-term application of integrated nutrients on water stable aggregate in sub-surface soil after harvest of wheat crop

T	Soil aggregates of different size (%) at 0-15 cm soil depth						Soil aggregates of different size (%) at 15-30 cm soil depth					
	> 2.0 mm	2.0-1.0 mm	1.0-0.5 mm	0.5-0.25 mm	0.25-0.10 mm	< 0.10 mm	> 2.0 mm	2.0-1.0 mm	1.0-0.5 mm	0.5-0.25 mm	0.25-0.10 mm	< 0.10 mm
T_1	5.3	6.8	21.5	26.5	22.7	17.3	3.5	5.5	28.0	24.4	20.6	18.0
T_2	7.5	8.5	24.1	24.1	22.9	12.9	4.8	7.3	30.8	21.3	21.2	14.7
T_3	9.0	9.8	30.7	19.8	14.2	16.6	6.0	8.0	35.7	17.8	12.9	19.6
T_4	9.8	10.5	32.8	21.2	14.9	10.9	6.8	8.5	35.4	19.3	14.0	16.0
T_5	8.5	9.0	27.6	24.9	18.3	11.6	4.5	7.3	28.6	22.6	16.7	20.3
T_6	8.0	7.5	25.3	27.4	20.2	11.7	5.0	6.5	29.0	23.3	18.3	17.9
T_7	12.5	16.5	33.4	17.0	11.7	8.9	7.3	11.5	37.0	14.9	13.1	16.2
T_8	8.8	10.0	29.3	22.3	14.7	15.0	6.3	8.0	34.3	17.2	14.0	20.2
SEm$\pm$	0.86	0.77	1.66	1.44	1.68	0.97	0.78	0.62	1.31	1.34	1.16	1.23
CD (*p=0.05*)	2.51	2.29	5.01	4.30	4.99	2.89	2.30	1.81	3.90	3.99	3.45	3.65

Table 5: Effect of long-term application of integrated nutrients on infiltration rate of soil after harvest of soybean and wheat crops in soybean-wheat cropping system.

Treatments	After harvest of soybean crops		After harvest of wheat crops	
	Initial (0-30 min) infiltration rate (mm hr^{-1})	Equilibrium (30-60 min) infiltration rate (mm hr^{-1})	Initial (0-30 min) infiltration rate (mm hr^{-1})	Equilibrium (30-60 min) infiltration rate (mm hr^{-1})
T_1	35.6	11.1	38.3	12.2
T_2	36.1	12.1	38.8	13.3
T_3	37.2	13.3	40.0	14.6
T_4	37.8	13.6	40.6	15.0
T_5	35.8	11.5	38.4	12.6
T_6	35.0	11.3	37.6	12.4
T_7	40.0	14.1	43.0	15.5
T_8	37.0	12.8	39.8	14.0
SEm$\pm$	0.92	0.71	0.99	0.78
CD (*p=0.05*)	2.71	2.10	2.91	2.29

Conclusions

Physical (bulk density, penetration resistance, infiltration rate, moisture content, fractions of different sized aggregates and mean weight diameter of soil aggregates) properties of surface and sub-surface soil after harvest of soybean and wheat crops were significantly altered by long-term application of integrated nutrients.

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