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Effect of Long Term Nutrients Management on Physical Properties of Soil During Pearl Millet-Fallow Cropping System Under Dry Land Conditions

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Abstract: The present investigation was carried out on the on-going long term experiment started in 2014 to study the yield sustainability and maintenance of soil fertility at Research Farm of Department of Agronomy, CCS, HAU, Hisar. The experiment was planned in a randomized block design (RBD) with four replications and five treatments *viz.* T_1-control, T_2- RDF(Recommended Dose of Fertilizer *i.e.* N 40 Kg ha^{-1} and $P_2 0_5$20 kg ha^{-1}), T_3- FYM (Farm Yard Manure) @ 6.7 t ha^{-1}, T_4-Vermi-compost @ 2.5 t ha^{-1}, T_5-Integrated (50 % N through FYM + 50 % N through Urea) which were applied during *kharif* season in pearl millet crop. The physical properties of the soil such as bulk density, infiltration rate, saturated hydraulic conductivity (Ks), mean weight diameter, water stable aggregate, soil moisture retention and penetration resistance of the soil improved with addition of organic matter either alone or in combination with fertilizer. The increase in infiltration rate was significant over control. Bulk density of the soil was negatively and linearly correlated with volumetric water content at field capacity and permanent wilting point while was found to be positively and linearly correlated with K_s.

Keywords: RDF, FYM, Vermin-compost, Pearl millet, Saturated hydraulic conductivity, Organic matter

Pearl millet crop is well known for its ability to produce consistent grain and forage yields despite crop production constraints such as low productive sandy soils, hot and dry climatic conditions (Jukanti et al 2016). Pearl millet excels all other cereals due to its unique features-C_4 plant with high photosynthetic efficiency, high dry matter production capacity and is grown under the most adverse agro-climatic conditions where other crops like sorghum and maize fail to produce economic yields. Pearl millet [*Pennisetum glaucum* (L.)], the world's hardiest warm-season cereal crop (Reddy et al 2012), ranks sixth in terms of region after rice, wheat, maize, barley, and sorghum (Khairwal et al 2007) and contributes 42 % of total global production with an average productivity of 1156 kg ha^{-1}. India is the world's leading producer of pearl millet (10.05 MT) (Bhardwaj et al 2014). It is usually grown in climates with annual rainfall ranging from 150 to 700 millimeters (Khairwal and Yadav, 2005). It is a grain that is primarily grown in Eastern Uttar Pradesh and Haryana where rainfall is scarce.Pearl millet-wheat cropping system is the second most important after rice-wheat cropping system in the Indo-Gangetic plains of India. Pearl millet can extract a high yield in arid and semi-arid regions due to its ability to withstand high temperatures and dry climatic conditions, compared to other crops that would have performed poorly. Pearl millet is an exhaustive crop which needs heavy dose of fertilizer to meet its nutrient requirement. Inorganic fertilizers increase crop yield by providing immediate plant nutrients, but long-term usage can reduce macro and micro aggregate stability, moisture retention, and bulk density, lowering productivity (Sarkar et al 2003). Inorganic fertilizer consumption increased from 0.07 Mt in 1950-1951 to over 25.0 Mt in 2009-2010 as a result of haphazard application. Aside from that, there is a significant gap between inorganic fertilizer production and consumption in the region, forcing farmers to supplement plant nutrients with organic manures and composts. Organic manures provide nutrients to plants in limited amounts, and their release pattern is slower than chemical fertilizers, but the presence of growth hormones and enzymes helps to sustain soil quality, increasing development and efficiency, and therefore soil fertility. It is thought that long-term use of chemical fertilizers would degrade the physical, chemical, and biological properties of the soil (Singh et al 1999). Using an integrated nutrient strategy and balanced fertilization, such degraded soils can be brought back to life (Gudadhe et al 2015).Bhatt et al (2017) observed that applying fertilizers combined with FYM reduced bulk density for surface and sub-surface soil.Mubarak et al (2014) reported an increase in infiltration rate when organic manure and fertilizer were used together.Kumar et al (2012) reported the maximum saturated hydraulic conductivity at 0-10, 10-20, and 20-30 cm soil depth when comparing plots where FYM was applied continuously for 22 years to control plots. Higher values of soil saturated hydraulic conductivity due to increased organic carbon content and decreased soil bulk density, the long-term application of organic materials with fertilizers improved the soil structure.In order to sustain productivity, use of organic source of nutrients in combination with inorganic fertilizers is necessary not only to maintain soil fertility but also to improve the efficacy of chemical fertilizers (Bagla et al 2008). Hence, nutrient supply through organic source such as bio-fertilizers and vermicompost in conjunction with chemical fertilizers is necessary to meet the crop nutrient requirement and for sustaining agricultural productivity, without detracting from the fact that chemical fertilizer will continue to be main production input for quickening the pace for agricultural production (Kumar et al 2014). Therefore, use of both organic manure and chemical fertilizers in appropriate proportion assumes special significance as complementary and supplementary to each other in crop production and sustainability of soil health.

Keeping all these facts in consideration, the present study (initiated in 2014) was undertaken in the on-going long term experiment at DLA Research Farm, Department of Agronomy, CCS HAU, Hisar in 2020-21 to explore the long term use of fertilizer with or without organic manures on soil physical properties in pearl millet- fallow cropping system.

MATERIAL AND METHODS

The experiment was started during *Kharif* 2014 and pearl millet-fallow system was followed. The field experiment was conducted during *Kharif* season of 2020 at Dryland Agriculture Research Farm, CCS Haryana Agricultural University, Hisar. The average annual precipitation of the experimental site is estimated to 425.5 mm and most of which is received from South-Western monsoon during July to September. The experiment was planned in a randomized block design (RBD) with four replications and five treatments *viz.* T_1-control, T_2-RDF(Recommended Dose of Fertilizer *i.e.*N 40 Kg ha^{-1} and $P_2 0_5$ 20 kg ha^{-1}), T_3- FYM (Farm Yard Manure) @ 6.7 t ha^{-1}, T_4-Vermi-compost @ 2.5 t ha^{-1}, T_5-Integrated (50 % N through FYM + 50 % N through Urea) which were applied during *kharif* season in pearl millet crop.Pearl millet hybrid 'HHB 67 (Improved)' was used in row spacing at 45 cm. The other agronomic practices were followed as per package of practices during the crop growth period. The FYM and Vermicompost were applied one month prior to the sowing. Soil samples were taken at a depth of 0-15 cm before sowing and after harvest of crop and examined in the laboratory for physical characteristics using the standard techniques. Bulk density was determined using galvanised metal cores from 0–15 and 15–30 cm depth. Undisturbed soil samples were taken from all treatments before seeding of pearl millet 2020. To determine the dry weight of the soil, the soil cores were dried in an oven at 105° C for 24-48 hours. The soil's bulk density (Mg m^{-3}) was calculated as the ratio of the dry weight of the soil to the inner volume of the metallic core (Bodman 1942). At crop harvest, the Infiltration rate (cm hr^{-1}) of water from the surface of each plot was determined using double ring infiltrometer methods (Bertrand 1965). The soil cores used to calculate bulk density were also used to calculate saturated hydraulic conductivity using constant head method in the laboratory (Richards 1954). Soil moisture was determined using undisturbed soil samples obtained at 0-15 cm soil depth for bulk density. Soil moisture was determined in the laboratory by measuring the water content of soil samples at 0.3 and 15.0 bar pressures with a pressure plate apparatus (Richards 1954). The soil core samples were saturated overnight, placed in contact with a saturated pressure plate, and brought to equilibrium using the pressure plate apparatus at 0.3 and 15.0 bar. To determine the soil water content at 15 bar, saturated samples and the saturated pressure plate of the pressure plate equipment were retained. The soil samples were equilibrated at 15 bars. When the water flow through the outflow tube was stopped, the soil water content was calculated gravimetrically at each applied pressure. The volumetric water content was calculated by multiplying the gravimetrical water content by the bulk density of the sample. The wet sieving method was employed to analyse the aggregates (Yodder 1936). After harvest of pearl millet in 2020, soil penetration resistance was evaluated using a digital penetrometer (Davidson, 1965) by inserting it very softly and perpendicular to the soil surface.

RESULTS AND DISCUSSION

Soil bulk density: It as affected by various nutrient management strategies demonstrated a significant decrease at surface and subsurface soils in the treatments viz. vermicompost (T_4) and FYM (T_3) and integration of FYM with fertilizer (T_5) as compared to control and RDF (T_2) (Table 1). The bulk density decreased up to 5.4, 4.7 & 6 % in surface and 5.9, 6.5 and 4.6 % in sub-surface soil in T_3, T_4 and T_5 treatments, respectively over the control. Organic source of nutrient would have improved the structure of the soil by improving total aggregation which leads to improvement in the porosity of soil. The increase in aggregation and decrease in bulk density may also be attributed to increase in microbial activity that may release polysaccharide which holds the particles together to form stable soil structure. As a result, the soil bulk density reduced, resulting in increased pores space. Application of RDF also significantly decreased the bulk density of the soil as it may promotes more vigorous growth of plant root and may increases the biomass when compared to control. The highest bulk density in control is owing to a lack of fertilizer and organic manure treatment, as well as increased compaction. Furthermore, increase bulk density was observed in subsurface soil, which could be associated with low organic carbon content at 15-30 (Table 1.) cm soil. Furthermore, the weight of the top layer increased the subsurface soil bulk density. Moharana et al (2017) showed a reduction in bulk density of the soil after six years of constant organic matter addition as compared to control and fertilizer treatments at 0-15 cm and 15-30 cm soil depths. These findings showing a reduction in bulk density due to the inclusion or application of FYM are also consistent with the findings of Rudrappa et al(2006),Gong et al (2009) and Narwal et al (2010).Singh et al (2016) carried out to analyzed the effect of long-term FYM and vermicompost treatment on bulk density of sandy loam soil under pearl millet–wheat cropping system and found that bulk density reduced 8.4 and 6.9 % in *rabi* and*kharif* respectively at surface soil. Furthermore, bulk density of the soil was found to be negatively and linearly correlated with volumetric water content at field capacity and permanent wilting point in surface and sub-surface, as evidenced by R^2 values of 0.65 and 0.76 (Fig. 1) and 0.79 and 0.80, (Fig. 2) respectively. A similar correlation was observed for soil bulk density with infiltration rate (R^2 0.76 and 0.74) at the surface and subsurface (Fig. 4). The bulk density of the soil was positively and linearly correlated with saturated hydraulic conductivity (K_s) at 0-15 cm and 15-30 cm depth with R^2values of 0.75 and 0.69, respectively (Fig. 3). This significant correlation of bulk density implies an increase in the soil saturated hydraulic conductivity, field capacity, moisture content, and infiltration rate due to the addition of organic matter, which may have enhanced aggregation and resulted in more pore space (porosity).

Infiltration rate: The rate of infiltration varies according to soil type, organic matter concentration, water stable aggregates, and other factors. The increase in infiltration

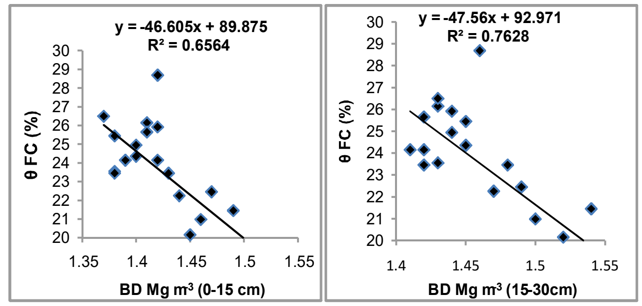

Fig. 1. Relationship of bulk density with volumetric water content at field capacity (Θ_{FC}) at 0-15 cm and 15-30 cm depth

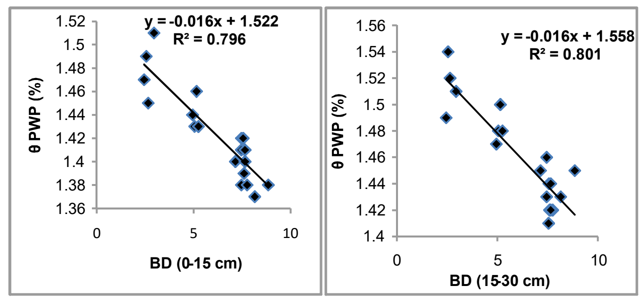

Fig. 2. Relationship of bulk density with volumetric water content at PWP (Θ_{PWP}) at 0-15 cm and 15-30 cm depth

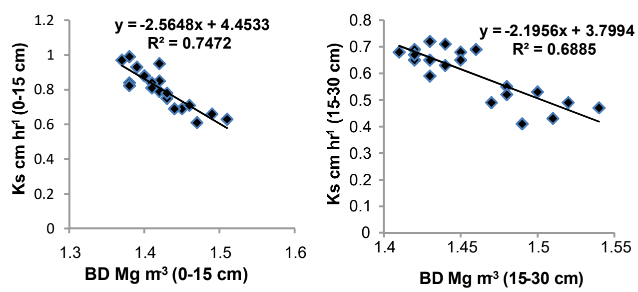

Fig. 3. Relationship of bulk density with saturated hydraulic conductivity (K_s) at 0-15 cm and 15-30 cm depth

Table 1. Effect of long term nutrients management on soils bulk density, saturated hydraulic conductivity andinfiltration rate during pearl millet-fallow cropping system under dryland condition

Treatments	Bulk density (Mg cm^{-1})		Saturated hydraulic conductivity (cm hr^{-1})		Infiltration rate (cm hr^{-1})
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	
T1	1.48	1.52	0.65	0.45	0.70
T2	1.44	1.48	0.73	0.52	0.94
T3	1.40	1.43	0.88	0.67	1.32
T4	1.41	1.42	0.82	0.65	1.27
T5	1.39	1.45	0.95	0.69	1.40
CD (p = 0.05)	0.032	0.02	0.06	0.06	0.05

rate was significant over control which recorded maximum for integrated treatment followed by, FYM and vermicompost sole treatment, RDF, and the lowest for control. The infiltration rate increased up to 88.5, 81.5 and 100 % in T_3, T_4 and T_5 treatments over control. The high infiltration rate was caused by higher organic matter, which was thought to promote pore size distribution and consequently soil structure and soil health. Singh et al (2007) observed that treatments with organic manures have higher infiltration rate than controls. Reddy et al (2017) and Chauhan et al (2018) demonstrated significant findings on infiltration rate due to long-term application of nutrient management.

Infiltration rate was positively significant and linearly connected with water stable aggregates and mean weight diameter of aggregates, with R^2 values of 0.96 and 0.92, respectively (Fig. 5). A rise in soil aggregation may results in an increase in pore size distribution, resulting in increased water infiltration over time.

Saturated hydraulic conductivity (K_s): Saturated hydraulic conductivity is affected by soil pore size distribution and total porosity soil, which are controlled by soil structure, texture, and organic carbon content. The Ks increased up to 35, 26 and 46 % in surface and 48.8, 44.4 and 53 % in sub-surface soil in T_3, T_4 and T_5 treatments respectively, over control. The higher saturated hydraulic conductivity in surface and subsurface soils with the addition of vermicompost, FYM individually or in combination with RDF treatments was attributable to improved soil aggregation, which enhanced porosity and hence hydraulic conductivity. The reduced hydraulic conductivity of subsurface soil compared to surface soil was owing to a lower amount of organic carbon at lower depths. Verma et al (2010) investigated the long-term use of various nutrient management strategies and observed higher hydraulic conductivity in *Typic Haplustept* in a maize-wheat cropping system. Singh et al (2016) also showed an increase in hydraulic conductivity of 15.7, 26 and 31 % and 12, 26 and 31 % in 15, 30 and 45 t FYM ha^{-1} in the *rabi* and *kharif* seasons, respectively. They also obtained the higher Ks in surface 0-5 cm, as opposed to 5-10 and 10-15 cm plots in FYM treatment. Katkar et al (2012) reported a similar pattern in hydraulic conductivity when organic matter was present. Earlier workers also observed similar findings(Bhattacharyya et al (2006), Mosaddeghi et al (2009) and Shwetha and Varija (2015).

Water stable aggregates (WSA) and mean weight diameter (MWD): Long-term nutrient management strategies had a significant impact on the water stable

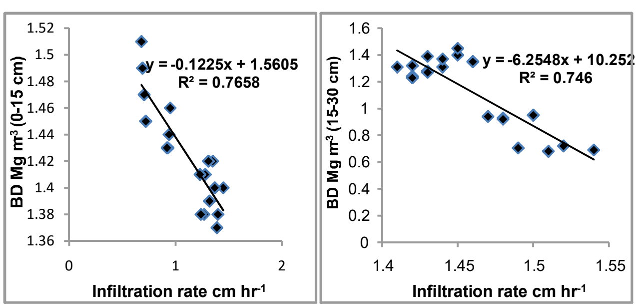

Fig. 4. Relationship of bulk density with infiltration rate at 0-15 cm and 15-30 cm

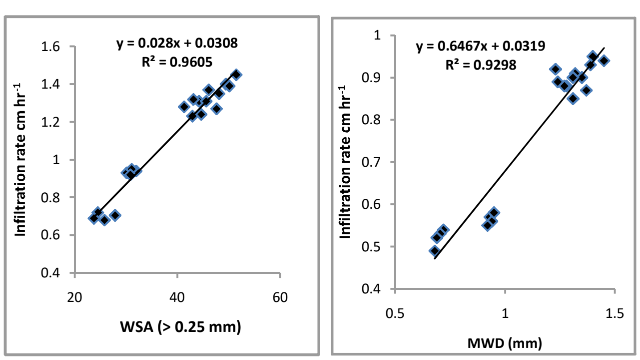

Fig. 5. Relationship of infiltration rate with water stable aggregates (WSA) and mean weight diameter (MWD)

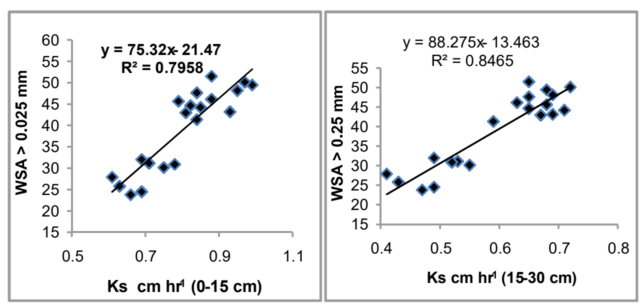

Fig. 6. Relationship of water stable aggregates with saturated hydraulic conductivity (Ks) at 0-15 cm and 15-30 cm soil depth

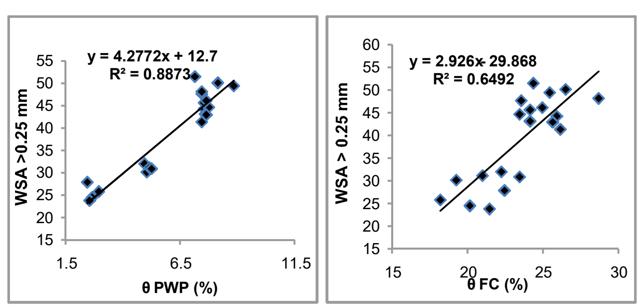

Fig. 7. Relationship of water stable aggregates with volumetric water content at field capacity and permanent wilting point at surface soil depth

aggregates (>0.25 mm) and mean weight diameter in the pearl millet crop. Mean weight diameter increased up to 9.6, 69, 73 & 77.3 % while water stable aggregates enhanced up to 21.7, 77.6, 71.6 and 95.3 % in T_2, T_3, T_4 and T_5 treatments over control, respectively. Addition of organic matter in the form of FYM or vermicompost either single or in integration with fertilizer significantly increased aggregate stability against water, due to more strong bonding of soil particles with each other or with organic matter, thus preventing its dispersion against disruptive action of water. Also FYM and vermicompost would increase the microorganism activity that might be responsible for formation of stable aggregates. Water stable aggregates has a significant and positive association with saturated hydraulic conductivity (Fig. 6), volumetric water content volumetric water content at field capacity and permanent wilting point (PWP) (Fig. 7), with R^2 values of 0.84 and 0.79 at 0-15 and 15-30 cm, respectively, while with FC and PWP having R^2 values of 0.64 and 0.88, respectively. The correlation coefficient was observed between WSA, θ_{FC} and θ_{PWP} which further showed the impact of organic matter in increasing the WSA & MWD of aggregates. Infiltration rate was shown to be highly significant and associated to WSA and mean weight diameter with $R^2$0.96 and 0.92, respectively (Fig. 8).

Chakraborty et al (2010) reported an improvement in water stable aggregates in integrated nutrient management of 100 % NPK + FYM. Furthermore, they observed a considerable positive association between aggregation indices and soil organic carbon in aggregates with sizes ranging from 8 to 4 mm. Similarly, increasing aggregate MWD significantly increased volumetric water content at field capacity and permanent wilting point (Fig. 9 and 10) with R^2 values of 0.65 and 0.87, respectively, and saturated hydraulic conductivity with R^2 values of 0.77 and 0.87 for 0-15 and 15-30 cm soil depth, respectively.

Bhatt et al (2017) evaluated the effect of vermicompost and fertilizers individually and in combination with FYM (Integrated) for 29 years experiment and found that the integrated treatment increased MWD and WSA by 31.74 and 53.35 and 21.45 & 27.16 percent in surface and sub-surface over the control.

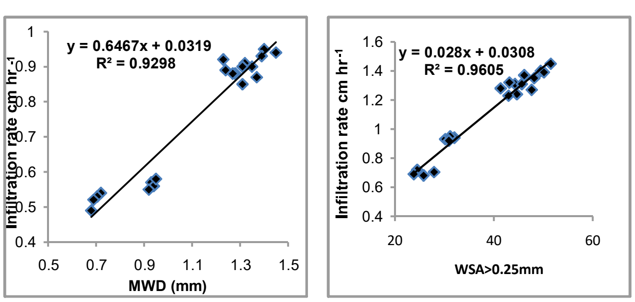

Fig. 8. Relationship of infiltration rate with mean weight diameter and water stable aggregates

Soil moisture retention: The study indicated that soil moisture retention at field capacity & PWP moisture content was found higher in treatment where FYM, vermicompost and FYM along with urea were applied with significant increase in soil retention as compared to control and RDF treatments (Table 1). Moisture retention at field capacity and permanent wilting point increased by the application of organic fertilizer up to 4, 19.8, 20 and 27 % and 92.4, 185.5, 186.8 and 198 % in T_2, T_3, T_4 and T_5 treatments as compared to control, respectively. Among treatments T_3, T_4& T_5 the

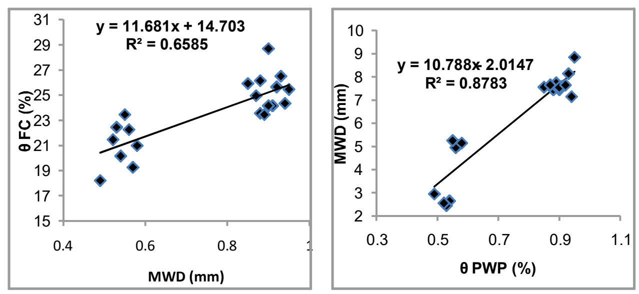

Fig. 9. Relationship of mean weight diameter with volumetric water content at field capacity and permanent wilting point

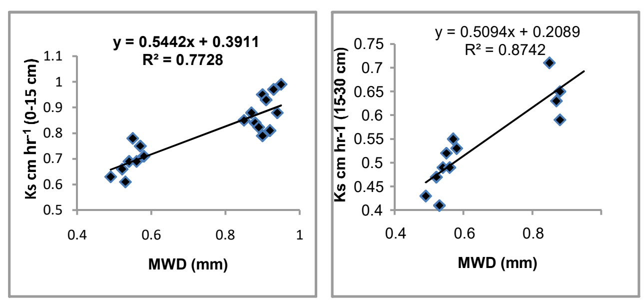

Fig. 10. Relationship of mean weight diameter (MWD) with saturated hydraulic conductivity (Ks) at 0-15 cm and 15-30 cm soil depth

Table 2. Effect of long term nutrient management on WSA (%), MWD (mm) and soil moisture (%) at different suctions of the soils during pearl millet-fallow cropping system under dry land condition

Treatments	Aggregate size analysis		Soil moisture (%)	
	MWD (mm)	WSA (%)	FC	PWP
T1	0.52	25.50	20.56	2.65
T2	0.57	31.05	21.48	5.10
T3	0.88	45.30	24.64	7.57
T4	0.90	43.65	24.85	7.60
T5	0.93	49.80	26.25	7.90
CD (p = 0.05)	0.03	2.55	2.55	0.55

Table 3. Effect of long term nutrient management on penetration resistance (MPa) of the soils at varying depths during pearl millet-fallow cropping system under dry land condition

Treatments	Penetration resistance (Mpa)						
	0 cm	5 cm	15 cm	5 cm	15 cm	30 cm	45 cm
T1	0.280	31.6	30.7	31.2	29.2	1.974	1.030
T2	0.260	32.2	31.3	31.6	30.4	1.959	1.015
T3	0.240	32.8	31.7	32.7	31.2	1.663	0.860
T4	0.240	32.6	31.1	31.6	30.8	1.735	0.805
T5	0.258	34.8	33.5	33.5	32.6	1.878	0.980
CD (P = 0.05)	0.020	1.5	1.3	0.9	1.2	0.02	0.019

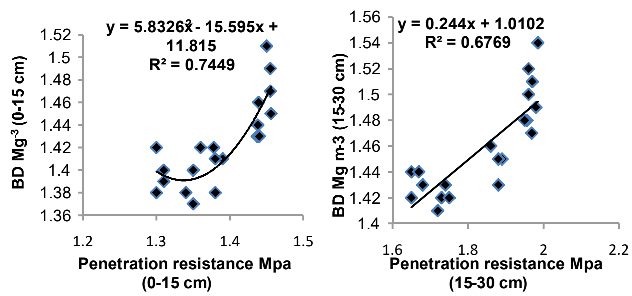

Fig. 11. Relationship of penetration resistance with bulk density at 0-15 cm and 15-30 cm soil depth

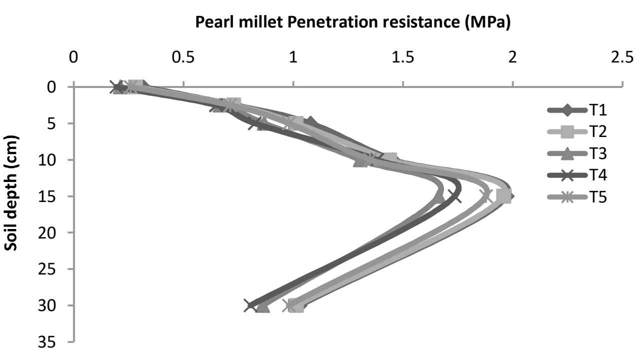

Fig. 12. Soil penetration resistance (MPa) at different depths of soil under long term nutrient management studies during pearl millet

effect was non-significant at both field capacity (-33 Kpa) and permanent wilting point (-1500 Kpa). High water retention due to organic matter was related to the creation of micro pores, which may retain the water more securely than the fertilizer-only treatment and control. Plant available water was high in treatments with Vermicompost and FYM alone or in conjunction with the urea fertilizer. The study findings were in consistent with those of Singh et al (2007), where high soil moisture holding at 0-5, 5-10, and 10-15 cm soil depths with the incorporation of organic matter in the rice crop. Gudadhe et al (2015) investigated the effect of FYM and fertilizers on moisture content at field capacity and permanent wilting point and observed that 10 t FYM ha^{-1} + RDF had the maximum field capacity, which could be attributed to the number of pores, their distribution, and the specific surface area.

Penetration resistance: The influence of different nutrient management strategies on penetration resistance at various depths in pearl millet was observed (Table 3 and Fig. 12). Significantly higher penetration resistance in control and RDF compared to integrated, vermicompost, and FYM alone may be attributable to reduced water retention due to the lower organic matter content in the earlier than to the latter. Greater organic matter content may have higher soil water holding capacity at field capacity and permanent wilting point. The increased moisture may help in reduction of the effect of crust in soil, allowing crop roots to penetrate the soil easily and promote crop growth. The study indicated that increasing the bulk density with increasing the penetration resistance in surface and subsurface soil was positively correlated, with R^2 values of 0.74 and 0.67 (Fig. 11) at 0-15 cm and 15-30 cm, respectively. Bassouny and Chen (2016) observed that the decline in penetration resistance with organic matter and fertilization was more prominent than the control and observed that use of organic and inorganic additives prevents soil compaction, which limits root growth, infiltration rate, and hydraulic conductivity. Celik et al (2010) reported that mycorrhizal anaesthetized compost had the least penetration resistance and the strongest in control and mineral fertilizer applications, which could be ascribed to the conditions imposed of glomalin naturally produced by mycorrhizae, which increased aggregation and thus porosity, lowering penetration resistance. Similarly, Chouhan et al (2018) and Borie et al (2018) reported a decline in penetration resistance due to organic and inorganic fertilization at the surface and subsurface.

CONCLUSION

The physical properties of the soil such as bulk density, infiltration rate, saturated hydraulic conductivity (Ks), mean weight diameter, water stable aggregate, soil moisture retention and penetration resistance of the soil improved with addition of organic matter either alone or in combination with fertilizer in surface soil. Bulk density of the soil was negatively and linearly correlated with volumetric water content at field capacity and permanent wilting point while was positively and linearly correlated with saturated hydraulic conductivity (K_s) and penetration resistance in surface and sub-surface soil. Significantly higher penetration resistance in control and RDF treatment was observed in comparison to left over treatments. Physical properties of the soil were improved by the continuous application of FYM and vermin-compost for 7 years on long term basis.

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