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Long-Term Manuring and Fertilization Effects on Soil Physical Properties after Forty Two Cycles under Rice-Wheat System in North Indian Mollisols

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A B S T R A C T

An investigation was carried out at Norman E. Borlaug Crop Research Centre of G. B. Pant Univ. Agric. & Tech. Pantnagar, U. S. Nagar, Uttarakhand, India in order to study the influence of long-term applications of fertilizers and manures on different soil physical properties after forty two cycles in silty clay loam textured Typic Haplustept under rice-wheat cropping sequence during 2012-13. The field was laid out in a randomized block design comprising of ten treatments. Various soil physical properties were measured in surface and sub-surface soil after harvest of rice and wheat crops after 42 cycles and it was found that in 0-60 cm soil layers, the bulk density was significantly lower in 100% NPK + FYM over other treatments. The balanced application of NPK decreased the bulk density in all the soil depths. Irrespective of soil depths, the control plot invariably showed higher bulk density. The soil receiving 100% NPK fertilizers with FYM recorded significantly higher hydraulic conductivity, water holding capacity and mean weight diameter in soils of all four depths, respectively as compared to control and all other fertilizer treatments. Application of P in combination with N significantly increased the hydraulic conductivity in comparison to where N was applied alone. Mean weight diameter increased with increasing fertilizer dose from sub optimal 50% NPK to 100% NPK optimal dose of NPK. The present investigation clearly points out the significance of balanced use of nutrients including FYM in rice-wheat cropping system for improving the various physical soil properties over a long period.

Introduction

Rice–wheat cropping system is the world's largest most prominent cropping system occupying around 12.3 M ha in India around 85 percent of this area falls in Indo-Gangetic plains (Ladha *et al.*, 2003). The Indo-Gangetic plains region of India has Rice–wheat cropping sequence spread over a vast area from Punjab in the Northwest to East up to West Bengal (Singh *et al.*, 2005). The deterioration of soil physical heath due to continuous cultivation without acceptable replenishment poses an immediate threat to soil health and environmental securities. Continuous cultivation of crops and excessive use of fertilizers is depleting the soil physical health hence, there is a need to reintroduce the age old practice of application of farmyard manure (FYM) to maintain soil fertility as well as soil health and also to supplement many essential plant nutrients for crop productivity.

Integrated nutrient management practices have come up as effective options in restoring the soil physical properties and chemical fertility as well as improving the organic matter in the soil (Rudrappa *et al.,* 2006; Nayak *et al.,* 2012). Balanced use of fertilizers in combination with manures is one of the best ways to prevent organic matter depletion and rapid deterioration of soil physical properties, specially soil structure (Singh *et al.,* 2007). Addition of organic matter increases soil organic carbon content, which directly or indirectly affects physical properties of soil and processes like aggregation, water-holding capacity (WHC), hydraulic conductivity and bulk density (Zebarth *et al.,* 1999; Celik *et al.,* 2004). While improvement in soil structural condition through the addition of C inputs has been profusely reported, a quantitative evaluation of soil physical properties under integrated nutrient management system.

The physical soil quality parameters like bulk density, water holding capacity, hydraulic conductivity and mean weight diameter of soil were improved in rice-wheat cropping system because of use of inorganic fertilizer in combination with FYM over a period of forty two years. Thus, the balance and imbalanced use of nutrients through and organic manures and chemical fertilizers should be followed for the improvement of physical soil quality for sustainability (Pant *et al.,* 2017). While the consequence of excessive use of mineral fertilizers adversely affected soil physico-chemical properties, which ultimately reduces the productivity as well as physical environment of soil under rice-wheat cropping system (Kakraliya *et al.,* 2017). Organic manure along with mineral fertilizer also helps to build up soil organic matter, which increases organic carbon which improves soil aggregation and its stability, reduce soil compaction, increase porosity and water holding capacity. Therefore, Long-term fertilizer experiments running on a Typic Haplustept with rice–wheat cropping sequence in G. B. Pant Univ. Agric & Tech. Pantnagar, since 1971 become a useful study material for soil physical properties under mollisols.

Materials and Methods

Experimental design

A field experiment was carried out during 2012-13 in an ongoing Long-Term Fertilizer Experiment conducted with a rice- wheat cropping sequence that have been operative since 1971 at Norman E. Borlaug Crop Research Centre of G.B. Pant Univ. Agric. & tech. Pantnagar, U. S. Nagar, Uttarakhand (29^0 N latitude, $79^0$29' E longitude and an altitude of 243.8 m above the mean sea level), consisted of 12 fertilizer treatments, out of which 10 treatments have been selected for the study (Table 1).

The fertilizer N, P and K were applied through urea/diammonium phosphate, Single Super Phosphate and muriate of potash, respectively. Farmyard manure applied once in a cropping cycle, each year before the sowing of wheat crop. The fertilizer dose was selected based on the soil tests for available N, P and K in the year 1971. Each treatment was replicated three times (plot size 25 m x 12.5 m) in a randomized block design.

Climate and weather conditions during experimental seasons

The Climate of Pantnagar falls under the sub-humid and sub-tropical climatic zones with hot dry summers and cool winters. Generally, southwest monsoon sets in third or fourth week of June and continues upto end of September with its peak in July. Weekly mean maximum and minimum temperature ranged from 34.5 to 11.9 ºC during rice crop in 2012 and 35.6 to 2.5 ºc during wheat crop in 2012-13. The mean weekly relative humidity during rice crop ranged from 94 to 35 percent and 99.6 to 12.9 percent during wheat crop. Total rainfall received during the cropping period of rice was 873.8 mm and 173.5 mm during wheat crop.

Crop cultivation

Rice variety 'PR113' was used for this study. Seedlings of rice were raised by wet bed method of nursery. Seed beds were prepared in dry condition. A day before sowing, the beds were flooded with irrigation water. Sprouted seeds were broadcasted to raise seedlings. Twenty-one days old seedlings were transplanted on first week of July during 2012 at a distance of 20 cm row to row and 10 cm plant to plant. Half dose of N and full dose of P and K as per treatment were applied as basal dressing before rice transplanting. The remaining half dose of N was top dressed in two equal splits, after 3 and 6 weeks of transplanting. The crop was harvested in the month of November after recording the observations.

After harvesting of rice crop, experimental plots were ploughed by tractor drawn disc plough. After one ploughing and 3-4 harrowing the field got leveled by plank and wheat (variety PBW 502) was sown on last week of November during 2012, at a row distance of 23 cm. Half dose of N and full dose of P and K were applied just before sowing. The remaining half dose of N was applied in two equal splits at first and second irrigation. In T8 treatment, FYM was applied @ 15 t ha^{-1}, before the preparation of field for wheat. Irrigation was done as and when required up to crop maturity.

Soil sampling and processing

Representative soil samples were collected separately from each treatment in triplicate from the depth increments of 0–15, 15–30 30–45 cm and 45-60 cm with the help of core sampler and auger to collect undisturbed soil sample for bulk density, soil hydraulic conductivity, Mean weight diameter whereas 2 mm sieved soil samples were used for water holding capacity (WHC). The initial soil pH (1:2.5) was 7.30, electrical conductivity 0.35 dS m^{-1}, Walkley–Black carbon 1.48 %, available N 392.0 kg ha^{-1}, $NaHCO_3$–extractable P 18 kg ha^{-1} and NH_4OAc–extractable K 125 kg ha^{-1} soil. The soil is of alluvial origin, silty clay loam in texture.

Soil physical properties measurements

The soil bulk density at desired depths (0-15, 15-30, 30-45 and 45-60 cm) was determined by core sampler method (Blake and Hartge 1986). Water holding capacity of soil was determined by the method enlisted by Piper (1950). The undisturbed soil samples of desired depths were taken by core, and used for determination of hydraulic conductivity by constant head method (Klute, 1965). Air dried solid clods were used for aggregate analysis employing modified Yoder's wet sieving method (Van-Bavel, 1949).

Statistical analysis

The data were analyzed using Randomized Block Design using SPSS-16. To compare treatment means, least significant difference was worked out at 5% level of probability.

Results and Discussion

Bulk density

The soil bulk density was lower in treatments where balanced fertilization with FYM amended treatment was practiced (Fig. 1a and 1b). In 0-60 cm soil layers, the bulk density was significantly lower in 100% NPK + FYM over other treatments (Fig. 1a and 1b). The balanced use of NPK decreased the bulk density in all the soil depths. Irrespective of soil depths, the control plot showed higher bulk density.

Bulk density after rice crop ranged from 1.53 to 1.26 g cc^{-1} soil in surface soil and 1.61 to 1.34 g cc^{-1} in15-30 cm, 1.63 to 1.44 g cc^{-1} in 30-45 cm and 1.73 to 1.54 g cc^{-1} in 45-60 cm in sub-surface soil, respectively. Treatments 100% NPK +FYM, 100% NPK, 100% NPK+H.W, and 100% NPK + Zn recorded significantly less bulk density than the control.

The bulk density exhibited an increasing trend with increase in soil depth (0-60 cm) in respective treatments. The decrease in bulk density over the years could be due to the addition of root and plant biomass and to the conversion of some micro-pores into macro-pores because of cementing action of organic acids and polysaccharides which are formed during the decomposition of organic residues by higher microbial activities. The decrease in soil BD under 100% NPK with organic manure (FYM) mainly contributed to higher organic matter content of the soil because of higher microbial activities which leads to better aggregation of soil. Tripathi *et al.,* (2014) and Pant *et al.,* (2017) also observed that application of FYM along with fertilizers decreases the BD of soil.

Hydraulic conductivity

A perusal of data in Table 2 indicated that hydraulic conductivity after rice crop ranged from 0.63 to 0.84 mm hr^{-1} soil in surface soil and 0.49 to 0.70 mm hr^{-1} in 15-30 cm, 0.28 to 0.55 mm hr^{-1} in 30-45 cm and 0.13 to 0.31 mm hr^{-1} in 45-60 cm depth, respectively. Alike after wheat crop, surface soil recorded highest hydraulic conductivity than sub-surface soil. In top soil of 0-15 cm the hydraulic conductivity ranged from 0.65 to 0.91 mm hr^{-1} after wheat crop. However, in deeper soil depth hydraulic conductivity ranged from 0.51 to 0.74 mm hr^{-1} in 15-30 cm, 0.31 to 0.63 mm hr^{-1} in 30-45 cm and 0.15 to 0.38 mm hr^{-1} 45-60 cm, respectively.

Maximum value of hydraulic conductivity in surface as well as sub-surface soil was observed with 100% NPK+FYM treatment followed by 100% NPK+Zn treatment and the lowest was under control treatment. Application of P in combination with N and Zn improved the hydraulic conductivity in comparison to N alone treatment. Data indicated that treatments balanced fertilization with FYM markedly improved the hydraulic conductivity due to more organic matter content which increased biological activity, improved soil aggregation, and optimum pore volume as well as the effective connectivity of the pores. Overall hydraulic conductivity showed decreasing trend with increase in soil depth (0-60 cm) in respective treatments.

As compared to control, hydraulic conductivity increased with the application of fertilizers and improved further by addition of FYM, indicating the beneficial effect on soil properties and the similar findings were also observed by Kaje *et al.*, (2018) and Nandapure *et al.,* (2014).

Water holding capacity

Data from figure 2a and 2b.indicated that soil WHC was maximum in treatments where balanced fertilization with FYM amended treatment was practiced. WHC after harvest of rice crop ranged from 58.35 to 74.97% in surface soil and 56.57 to 73.19% in 15-30 cm, 51.73 to 70.09% in 30-45 cm and 45.64 to 64.13% in 45-60 cm depths, respectively.

Table.1 Treatment details of long-term field experiment

Treatment	Details
T_1	50% NPK
T_2	100% optimum NPK
T_3	150% NPK
T_4	100% NPK + Hand Weeding
T_5	100% NPK + Zn
T_6	100% NP
T_7	100% N
T_8	100% NPK + FYM
T_9	100% NPK (-S)
T_{10}	control—no NPK or manure

Table.2 Effect of fertilizer treatments on soil hydraulic conductivity (mm hr^{-1}) after rice-wheat cropping system

Treatments	Soil hydraulic conductivity (mm hr^{-1})							
	Rice crop				Wheat crop			
	0-15 cm	**15-30 cm**	**30-45 cm**	**45-60 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**	45-60 cm
50% NPK	0.74	0.60	0.45	0.21	0.75	0.64	0.47	**0.28**
100% NPK	0.76	0.62	0.47	0.23	0.78	0.67	0.52	**0.31**
150% NPK	0.77	0.63	0.48	0.24	0.79	0.68	0.54	**0.32**
100% NPK+H.W.	0.78	0.64	0.49	0.25	0.79	0.67	0.54	**0.31**
100% NPK +Zn	0.79	0.65	0.50	0.26	0.81	0.69	0.56	**0.33**
100% NP	0.77	0.63	0.48	0.24	0.80	0.68	0.57	**0.32**
100% N	0.71	0.57	0.42	0.18	0.73	0.63	0.49	**0.27**
100% NPK+FYM	0.84	0.70	0.55	0.31	0.91	0.74	0.63	**0.38**
100% NPK(-S)	0.74	0.60	0.45	0.21	0.76	0.63	0.46	**0.27**
Control	0.63	0.49	0.28	0.13	0.65	0.51	0.31	**0.15**
SEm±	**0.01**	**0.008**	**0.005**	**0.003**	**0.01**	**0.01**	**0.006**	0.005
CD (5%)	0.03	0.02	0.02	0.009	0.03	0.03	0.02	0.02

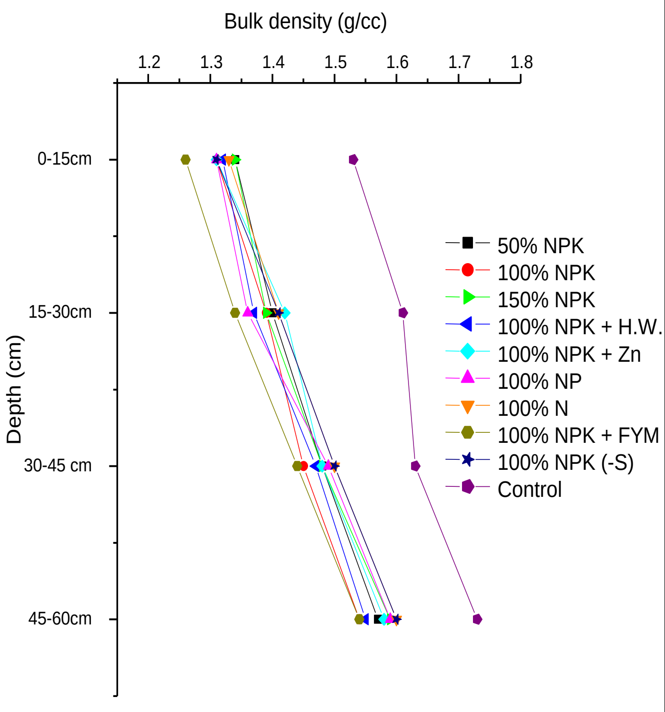

Fig. 1a: Effect of organic and inorganic fertilizers on bulk density (g cc^{-1}) after rice crop

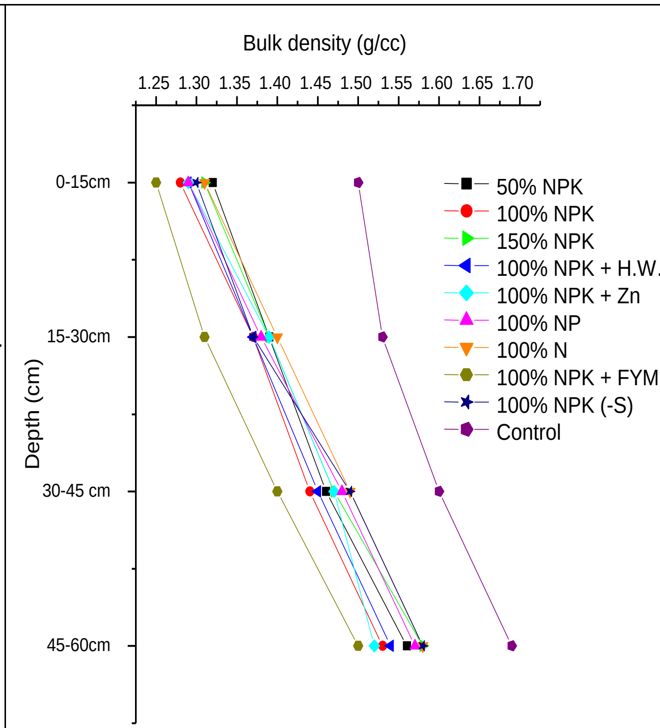

Fig. 1b: Effect of organic and inorganic fertilizers on bulk density (g cc^{-1}) after wheat crop

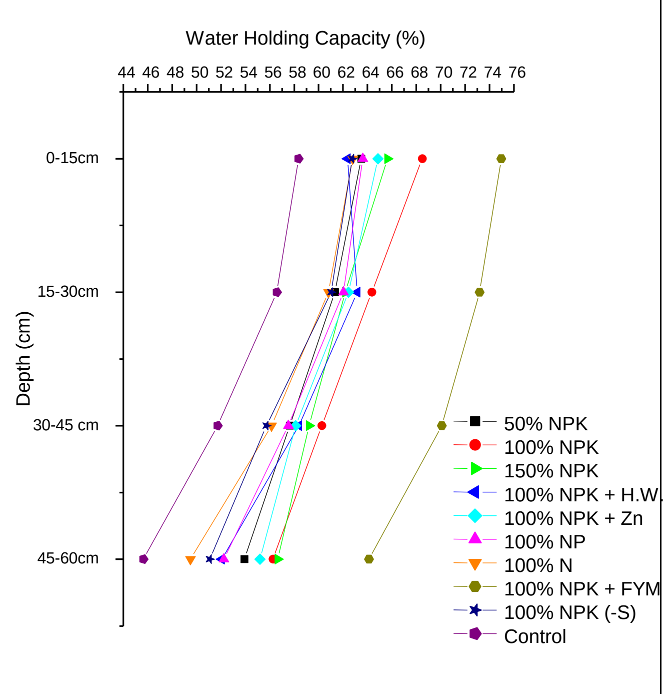

Fig. 2a: Effect of organic and inorganic fertilizers on water holding capacity (%) after rice crop

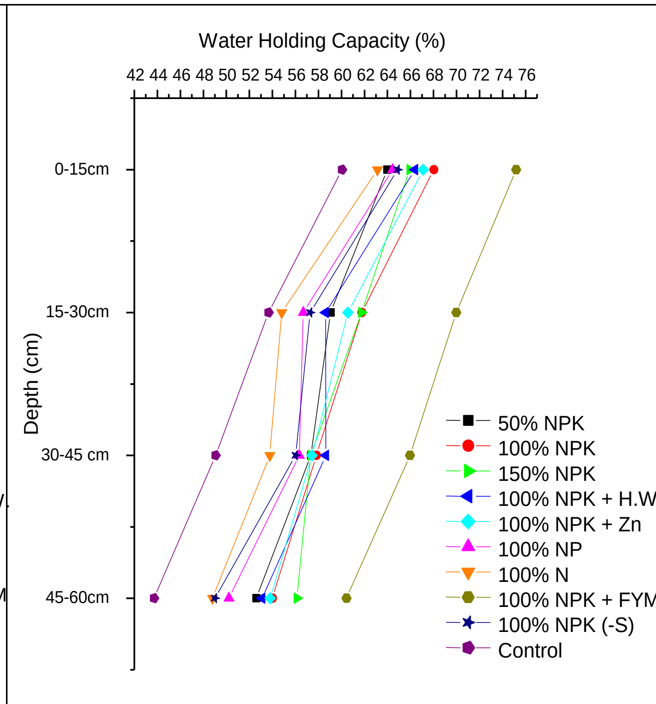

Fig. 2a: Effect of organic and inorganic fertilizers on water holding capacity (%) after Wheat crop

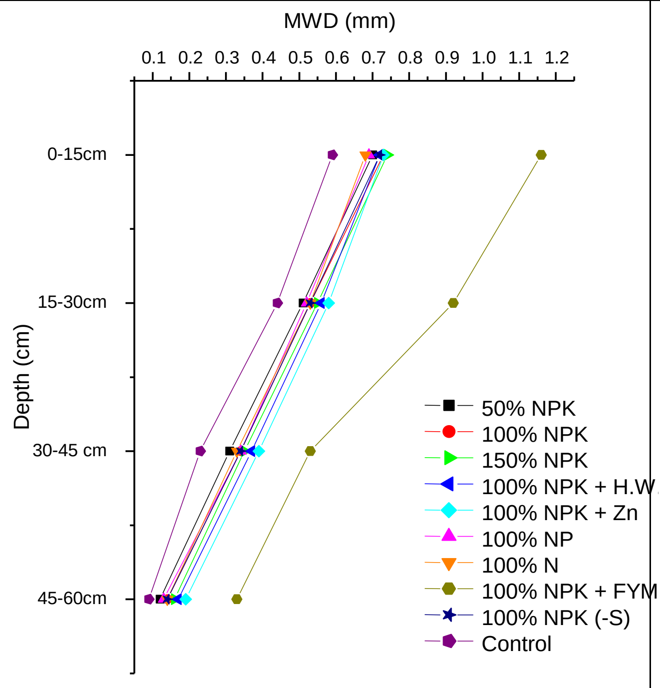

Fig. 3a: Effect of organic and inorganic fertilizers on mean weight diameter (mm) after rice crop

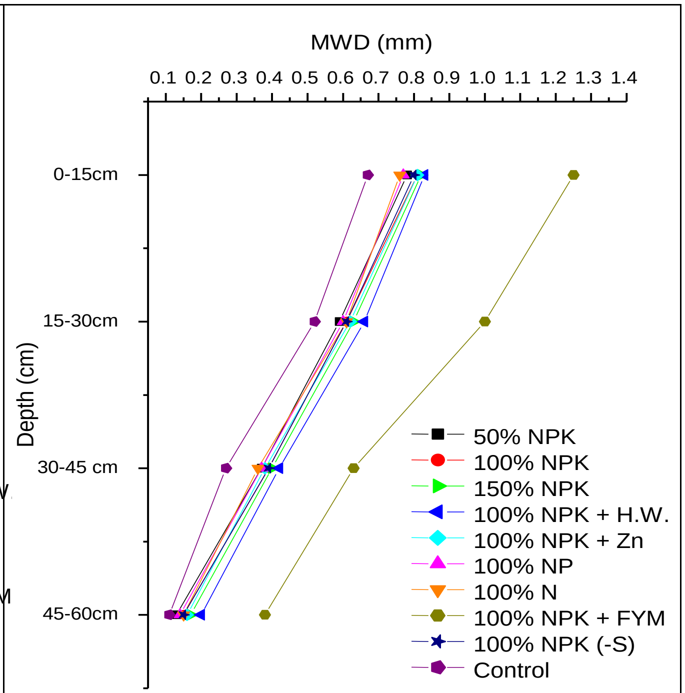

Fig. 3b: Effect of organic and inorganic fertilizers on mean weight diameter (mm) after wheat crop

After wheat crop, surface soil recorded highest WHC than sub-surface soil. In top soil of 0-15 cm the WHC ranged from 60.05 to 75.18% after wheat crop. However, in deeper soil depth WHC ranged from 53.66 to 69.97% in 15-30 cm, 49.06 to 65.95% in 30-45 cm and 43.71 to 60.43% in 45-60 cm, respectively.

The lowest WHC values were under control and highest with 100% NPK+FYM. Treatments of 50% NPK, 100% NPK, 150% NPK, 100% NPK+H.W, 100% NPK + Zn, 100% NP and 100% N recorded significantly higher WHC than the control.

The higher SOC content in FYM treated plots could be responsible for increasing the WHC of the soil, the increase was more in the surface soil layers as compare to lower layers. The higher WHC in the surface layers was due to surface application of FYM which increased the organic carbon level in soil, whereas in the subsurface layers the increase in WHC could be due to the increased root biomass with FYM or inorganic fertilizers (Rasool *et al.*, 2008 and Bhatt *et. al*, 2017).

Mean weight diameter (mm)

Application of NPK fertilizers @ i.e.50, 100 and 150% significantly enhanced MWD of soils of surface as well as sub-surface compared to control. Data from figure 3a and 3b indicated that soil MWD was maximum in treatments where balanced fertilization with FYM amended treatment was practiced. The lowest MWD values were under control and highest with 100% NPK+FYM.

MWD after rice crop ranged from 0.59 to 1.16 mm in surface soil and 0.44 to 0.92 mm in 15-30 cm, 0.23 to 0.53 mm in 30-45 cm and 0.09 to 0.33 mm in 45-60 cm soil depths, respectively. Alike after wheat crop, surface soil recorded highest MWD than sub-surface soil.

In top soil of 0-15 cm the MWD ranged from 0.67 to 1.25 mm after wheat crop. However, in deeper soil depth MWD ranged from 0.52 to 1.00 mm in 15-30 cm, 0.27 to 0.63 mm in 30-45 cm and 0.16 to 0.38 mm in 45-60 cm soil depth, respectively. Treatments of 50% NPK, 100% NPK, 150% NPK, 100% NPK+H.W, 100% NPK + Zn, 100% NP, 100% N and 100% NPK(-S) recorded significantly higher MWD than the control.

The positive effect of FYM in increasing MWD upto the deeper layers indicates that apart from direct effect of FYM as a binding agent it indirectly might have increased MWD through increased root biomass leading to higher organic matter content. Rasool *et al.*, (2008) and Tripathi *et al.*, (2014) also observed that application of FYM improved the MWD. The increase in organic carbon content might be responsible for stabilization of aggregates and hence higher MWD with the application of FYM and inorganic fertilizers which improves the physical condition of soil.

In conclusion, the application of optimal dose of NPK (100%) along with FYM in rice-wheat cropping system improved the soil physical properties of soil in comparison to application of NPK fertilizers alone. The physical properties play a vital role for the nutrient turnover and long-term productivity of the soil which are enhanced by balanced application of nutrients and manure. Continuous cropping of rice-wheat with imbalanced nutrient management declined the physical properties of soil. Compared with fertilizer NPK alone, use of Organic manure along with Mineral fertilizers improved soil physical properties through increased soil aggregation, improved aggregate stability, decrease in bulk density, increased saturated hydraulic conductivity and improved soil water-holding capacity for sustaining soil quality. In the light of above, it can be concluded that continuous cropping with integrated use of fertilizer and organic manure improving soil physical conditions and having positive impact of these practices on ecosystems and environment.

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