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Effect of long-term nutrient management practices on soil physical properties under rice-wheat cropping system

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ABSTRACT

Studies on soil test crop response (STCR) based integrated nutrient management (INM) practices were conducted after *rabi* season of 2018-19 to assess the impact of long-term nutrient management and soil depth on soil physical properties. The experiment was on a vertisol in central India under an ongoing experiment of AICRP on STCR initiated in *kharif* 2008 at a research farm of JNKVV, Jabalpur ($23^0$10' N latitude, $79^0$57' E longitudes and at elevation 393.0 m above mean sea level (MSL). The study was framed in split plot design with four main treatments of nutrient management (T_1 - control, T_2 - GRD, T_3 - soil test based NPK application for yield of 6.0 t ha^{-1} for each crop, and T_4-T_3 + 10 t ha^{-1} yr^{-1} FYM) and four sub-treatments of soil depth (0-15, 15-30, 30-45 and 45-60 cm) replicated three times. The data on soil physical properties revealed a significant effect of nutrient management and soil depth, *viz.,* large macroaggregates (>2 mm) and small macro-aggregate (2-0.25 mm), MWD and penetration resistance (PR), WHC and bulk density (BD) of soil. The combination of soil test - based NPK and FYM @10.0 t $ha^{-1}yr^{-1}$ for a targeted yield of 6.0 t ha^{-1} improved macroaggregates, MWD (1.52 mm), PR (342.6 MPa), water holding capacity (WHC) (40.2%) and BD (1.33 Mg m^{-3}) of soil. INM had no influence on soil texture, moisture content or particle density. The soil depths were found to influence the proportion of sand (40.2 %), clay (43.5%) and moisture content (35.2%) with maximum percentages at 0-15 cm and 45-60 cm, respectively. The interaction effects of INM and soil depths were found to have no impact on soil physical properties.

1. INTRODUCTION

Rice and wheat are the world's most important cereal crops, budgeting for more than 20% of the global food supply (Memon *et al.,* 2018), 45% of digestible energy and 30% of total protein for an average human being's diet, as well as a substantial contribution to feeding livestock (Timsina and Connor, 2001). In South Asia, this cropping system is a significant source of livelihood for millions of people and occupies approximately 13.5 M ha of land (Nawaz *et al.,* 2019), extending across Indo-Gangetic Plains (IGP) covering Pakistan (2.2 M ha), India (10.5 M ha), Bangladesh (0.8 M ha) and Nepal (0.5 M ha) (Timsina and Connor 2001; Bhatt *et al.,* 2020). During the 1960s and 1970s agricultural policies emphasized food security through introduction of high-yielding cultivars. This enabled rice (*Oryza sativa* L.)-wheat (*Triticum aestivum L.* and *T. durum Desf.*) cropping system to emerge as dominant system in the IGP, ushering in the green revolution (GR).

Recently, the stagnation and, in some cases, a decline in the productivity and sustainability of this system in several long-term experiments have been reported, (Ladha *et al.,* 2003; Kataki *et al.,* 2001) raised the concern of threatening food security. Evaluation of yield trends in long-term trials among different parts found wheat yields more stable that declined rice yields with time (Duxbury *et al.,* 2001). The researchers evidenced that rice-wheat cropping system has fatigued the natural resource base (Gupta *et al.,* 2003; Aggarwal *et al.,* 2000). This could be further aggravated by the deterioration of soil structure, declining underground water and lesser land and water productivity, to which ultimately are threats of sustainable and profitable RWCS in the region (Bhatt *et al.,* 2016).

Rice-wheat (R-W) cropping system requires energy, capital, water and labour intensively. The system is upsetting the ecological balance and over-exploiting the groundwater resources (Mohanty *et al.,* 2007). This system conveys collectively differing and balancing practices as the repeated changeover from aerobic to anaerobic soil conditions which change the physical, chemical and biological surroundings of soils and, most importantly, soil structure and nutrient relations (Timsina and Connor, 2001). The further adverse consequences of there systems are the decline of soil organic carbon (SOC) and effects on soil physicochemical properties (Bhatt and Singh, 2018; Srinivasrao *et al.,* 2019). Nonetheless, the scale of future demand requires more productive and environmentally sustainable cereal farming systems and achieving cereal yield increases will, however, be more difficult than in the past. The extent of nutrient management, either from inorganic or organic sources not only alters crop productivity but also soil properties (Verma *et al.,* 2005).

INM practices have come up as effective options for restoring the soil's physical properties and chemical fertility of the soil (Rudrappa *et al.,* 2006; Nayak *et al.,* 2012; Kumari *et al.,* 2022). The addition of manures increases SOC content, which directly or indirectly affects physical properties of soil and processes like aggregation, WHC, hydraulic conductivity and BD in rice-wheat cropping system due to balance use of inorganic fertilizer along with FYM in a long-term (Celik *et al.,* 2004; Singh *et al.,* 2007; Pant *et al.,* 2017). So, the present investigation was planned to examine the impact of chemical fertilizers alone and in combination with organic manure.

2. MATERIALS AND METHODS

The present investigation was conducted under an on-going long-term experiment of AICRP on STCR initiated in 2008 during 2018-2019 in the experimental field of Department of Soil Science and Agricultural Chemistry, the JNKVV, Jabalpur, India (Fig. 1). It is located at 23°10' N latitude and 79°57'E longitude and an elevation of 393 m above MSL with medium to deep black soil belongs to the *Kheri* series of fine montmorillonitic hyperthermic family of *Typic Haplustert*. The study area falls in a sub-tropical climate with a rice-wheat cropping system as one of the dominant cropping sequences of the region, lies under the *Kymore* plateau and Satpura hills agro-climatic zone of Madhya Pradesh characterized by hot dry summers and cool winters. The average annual rainfall, average humidity and average evaporation are 1274 mm, 73% and 3.93 mm day^{-1}, respectively.

The experiment was arranged in a split plot design with nutrient management practices as the main plot (5×5 m^2) and soil depths (0-15, 15-30, 30-45 and 45-60 cm) as sub-plots tried in triplicate. The soil depths were selected considering the commonly preferred practices and rooting behavior of the rice-wheat cropping system. There are four treatment combinations consisting of inorganic fertilizers and organic manure (FYM), the details of which are given below: T_1: control, T_2: general recommended dose (GRD) of NPK, T_3: soil test-based NPK + targeted yield of 6.0 t ha^{-1}, T_4: soil test based NPK + targeted yield of 6.0 t ha^{-1} + FYM @10.0 t ha^{-1} yr^{-1}. The fertilizer nitrogen, phosphorus and potassium were applied as per the doses selected on the basis of soil tests for available NPK in the year 2008 through

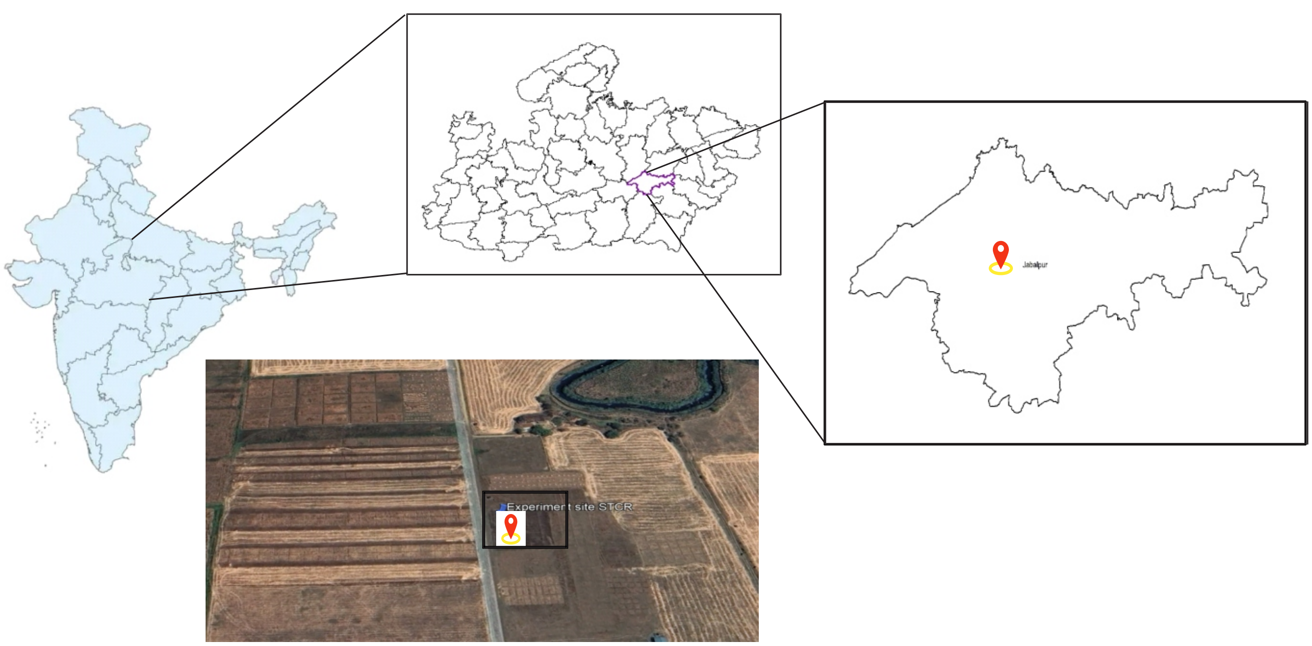

Fig. 1. Location map of study area

Urea/diammonium phosphate, single super phosphate and muriate of potash, respectively. FYM was applied twice in a cropping cycle, each year before the sowing of wheat and rice crops.

Soil samples from 0-15, 15-30, 30-45 and 45-60 cm depth were collected randomly after the harvest of *rabi* season of 2018-19 with tube auger and core sampler. A total of 48 soil samples (4 nutrient management × 4 soil depth × 3 replication) were collected. The samples were air-dried in the shade and passed through a set of sieves 8 mm, 4 mm, and 2 mm. After removing stones and large plant materials, soil sample retained on a 4 mm sieve were kept for aggregate analysis. The sample was crushed and then passed through a 2 mm sieve for analysis as per the methods.

Soil aggregation, BD, PR, soil moisture content and WHC are some of such soil properties that show profound impact of management practices particularly, nutrient management practices. The aggregate size analysis of soil was determined by wet sieving (modified Yoder's sieving method, 1936) and MWD was calculated using the formula of van Bavel (1949). The soil retained on an array of sieves after wet sieving and later dried at 105ºC in an oven were grouped into large macroaggregates (>2 mm), small macro-aggregates (2- 0.25 mm), micro aggregates (0.25-0.10 mm) and silt + clay (<0.10 mm). The BD was estimated using soil samples collected with core sampler through dividing the dry weight of soil material by the volume of soil or inner volume of core samples. Moisture content and WHC of soil was calculated following gravimetric method and keen box. Particle size analysis, particle density and PR was done using hydrometer method described by Bouyoucos (1927), pycnometer and cone penetrometer (Eijelkamp Agrisearch equipment), respectively.

The data generated from investigation was subjected to statistical analysis by applying the split plot analysis of variance (ANOVA) using MS excel and OPSTAT software package. The valid conclusions were drawn as described by Gomez and Gomez (1984). Means of the treatments were compared with Fisher's critical difference (CD) at $p < 0.05$.

3. RESULTS AND DISCUSSION

Proportion of Soil Particles (%)

The soil texture, plays a crucial role in determining various soil properties and its suitability for different uses. It directly affects the ability of soil to retain water, nutrient, erosion rates, root growth and crop productivity. There was clear indication that soil texture was not altered by nutrient management practices while sand and clay had significant variation at depth levels (Table 1). At upper 0-15 cm depth soil recorded significantly higher sand (40.2%) compared to other treatments. At 15-30 cm sand content was statistically higher than at 30-45 cm and 45-60 cm depths which were statistically at par among themselves. Clay content in soil at 45-60 cm depth was statistically on par with that found at 30-45 cm but both were significantly higher than those obtained at 0-15 cm and 15-30 cm depths. Saha *et al.* (2010) also reported that nutrient management has no impact on particle size distribution.

Bulk Density (BD)

BD is a primary indicator of soil compaction. Soil compaction restricts root growth, water infiltration, and air movement, negatively impacting plant health and crop productivity. INM and soil depth had significant effect (< 0.05) on soil bulk density (Table 1).

Table: 1
Effect of long term INM and soil depths on distribution of primary soil particles, bulk density and particle density in rice-wheat cropping system

Nutrient management	Proportion of soil particles (%)			Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})
	Sand	Silt	Clay		
T_1	37.3	21.1	41.6	1.38	2.67
T_2	37.3	21.1	41.6	1.37	2.64
T_3	37.2	20.2	42.6	1.35	2.65
T_4	37.4	20.6	42.0	1.33	2.66
CD (p = 0.05)	NS	NS	NS	0.014	NS
Soil depth, cm					
D_1	40.2	20.4	39.4	1.31	2.66
D_2	37.6	20.9	41.5	1.35	2.65
D_3	35.4	21.2	43.4	1.39	2.64
D_4	36.1	20.4	43.5	1.41	2.65
CD (p = 0.05)	1.56	NS	1.81	0.016	NS
M × S					
CD (p = 0.05)	NS	NS	NS	NS	NS

T_1: control, T_2: general recommended dose (GRD) of NPK, T_3: soil test-based NPK + targeted yield of 6.0 t ha^{-1}, T_4: soil test based NPK + targeted yield of 6.0 t ha^{-1} + FYM @10.0 t ha^{-1} yr^{-1}

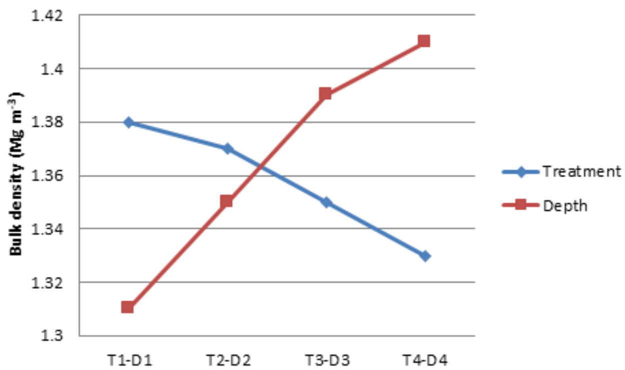

Fig. 2. Effect of INM and soil depth on soil bulk density

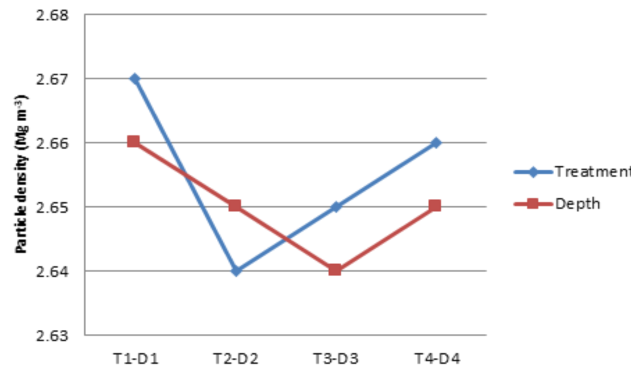

Fig. 3. Effect of INM and soil depth on particle density

Soil test based NPK in combination with FYM @10.0 t ha^{-1} yr^{-1} to achieve the targeted yield of 6.0 t ha^{-1} recorded lowest (1.33 Mg m^{-3}) bulk density which was found statistically significant with other treatments. BD exhibited an increasing trend with every 15 cm increase in soil depth varied from 1.31 to 1.41 Mg m^{-3}. The interaction effect of INM and depth were found non-significant (Fig. 2). Rucknagel *et al.* (2004) and Yaduvanshi *et al.* (2013) observed that addition of organic manure increased the organic carbon content of soil which helped to reduce the mass of soil per unit volume. Reddy *et al.* (2017) and Ejigu *et al.* (2021) also reported significant ($p < 0.05$) decrease in soil bulk density through combined application of compost and mineral fertilizer. The cumulative load of upper horizons and low organic matter can be the reason for higher density at increasing depth (Singh and Khera, 2007; Gathala *et al.,* 2007).

Particle Density

The particle density helps characterize the composition of soil and its ability to hold and transport water and nutrients. Particle density can vary depending on the type of soil and its mineral composition. The data presented in Table 1 showed that different treatments under study were not found impactful in influencing the particle density of soil. Interaction effects were also proved non-significant (Fig. 3). Nandapure *et al.* (2011) also reported no significant change in particle density through practicing long-term integration of chemical fertilizers and manures. While, Kannan *et al.* (2013) found higher particle density of soil under FYM applied treatments.

Soil Aggregates of Different Size (%)

The soil aggregates are groups of soil particles that are bound together to form larger, more stable structures within the soil. The combinations of inorganic fertilizers and organic manures significantly improved the water-stable aggregates of different size fractions cited in Table 2. Soil depth and interaction with nutrient management were found non-significant. Among all size fractions the percentage of small macroaggregates (SM) was the largest, followed by microaggregates (Mi), silt + clay (S+C) and large aggregates (LM). The mean values for WSA among different nutrient management practices showed that T_4 (73.63) and T_3 (72.95) had significantly larger small macroaggregates (2.0-0.5 mm) than T_2 and control. Decreased stability with a

Table: 2
Effect of long term INM and soil depths on soil aggregates of different size (mm) and MWD under rice-wheat cropping system

Nutrient management	Soil aggregates of different size (%)						MWD (mm)
	> 2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	< 0.10	
T_1	1.87	9.71	28.12	26.22	18.43	15.65	1.19
T_2	1.95	12.73	32.61	24.37	8.21	20.13	1.43
T_3	2.43	16.86	37.58	18.51	7.93	16.69	1.45
T_4	3.65	21.48	36.37	15.78	6.06	16.66	1.52
CD (p = 0.05)	0.219	4.317	4.175	2.473	2.193	3.529	0.089
Soil depth, cm							
D_1	4.06	23.62	31.45	17.92	11.68	11.27	1.51
D_2	3.13	18.74	26.19	24.76	16.34	10.84	1.42
D_3	1.29	11.28	16.23	27.12	27.86	16.22	1.33
D_4	1.17	8.31	11.41	29.13	34.06	15.92	1.21
CD (p = 0.05)	0.836	2.174	4.339	2.342	4.337	1.857	0.176

similar trend was noticed in deeper soil layers. Prakash *et al.* (2002), Selvi *et al.* (2005) and Manna *et al.* (2007) also reported the aggregates with better water stability under INM practices.

Mean Weight Diameter (MWD)

Balanced nutrient management help maintain good soil structure. Adding organic matter, such as compost or manure, to the soil can increase aggregate stability and MWD by promoting the formation of stable organic matter-rich aggregates. The findings demonstrate that different treatments had variable impact on MWD with maximum value (1.52) under treatment T_4 shown in Table 2. MWD under treatment T_4 was statistically at par with T_3. It was noted that MWD of soil aggregates were decreased significantly with increasing soil depth (Fig. 4). Largest (1.51 mm) MWD were obtained at 0-15 cm soil depth Bandyopadhyay *et al.* (2010); Pant and Ram (2018) and Guo *et al.* (2019) also reported that integrated use of organic manure and inorganic fertilizers improved the mean aggregate size.

Penetration Resistance (PR)

Soil PR is an important indicator of soil compaction and resistance to root penetration. The results in Table 3 show that the integration of FYM with inorganic fertilizers significantly reduced the PR. Significantly higher PR (403.6 kPa) was recorded under control. At 0-15 cm and 15-30 cm PR values were statistically at par but significantly lower mean PR values 356.2 kPa and 366.8 kPa were recorded than at 30-45 cm (382.4 kPa) and 45-60 cm (403.6 kPa), respectively (Fig. 5). Walia *et al.* (2010) and Sandhu *et al.* (2020) reported a decrease in soil strength with the application of FYM in conjunction with chemical fertilizers as compared to chemical fertilizers alone.

Moisture Content (%)

The moisture content of the soil plays a vital role in the hydrological cycle and growth of vegetation. The soil moisture content in the root zone fluctuates both temporally and geographically across the agricultural field. Understanding the variability and dynamics of soil moisture at the root zone is crucial for the best irrigation and crop management practices, as moisture is a prerequisite for plant growth and health. Numerically higher soil moisture content was reported under treatment T_4 but no significant improvement was observed under integrated application of organic manure and inorganic fertilizers from Table 3. However, soil depths had a profound impact on moisture content (Fig. 6). Soil moisture content significantly increased with soil depth upto 30-45 cm. The interactions were also non significant for all treatment combinations. Numerically higher water content was also reported by Khan *et al.* (2017). Similar results were also reported by Tedesse *et al.* (2013).

Table: 3
Effect of long term INM and soil depths on penetration resistance, moisture content and WHC of soil particles in rice-wheat cropping system

Nutrient management	PR (kPa)	Moisture content (%)	WHC (%)
T_1	391.8	29.5	37.9
T_2	364.3	30.4	37.7
T_3	370.2	34.2	39.3
T_4	342.6	34.6	40.2
CD (p = 0.05)	6.89	NS	0.92
Soil depth / cm			
D_1	356.2	29.8	37.4
D_2	366.8	30.8	36.9
D_3	382.4	32.8	39.3
D_4	403.6	35.2	40.8
CD (p = 0.05)	11.43	2.92	1.79
M × S			
CD (p = 0.05)	NS	NS	NS

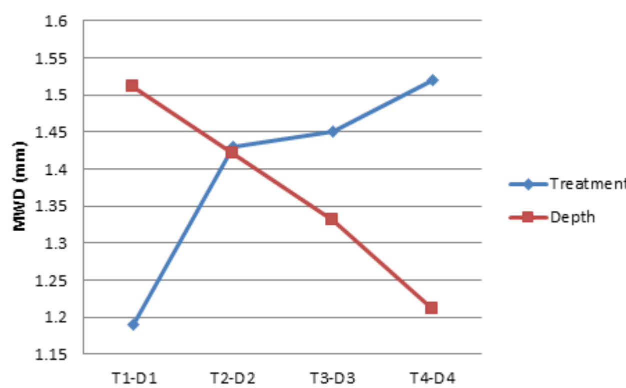

Fig. 4. Effect of INM and soil depth on mean weight diameter

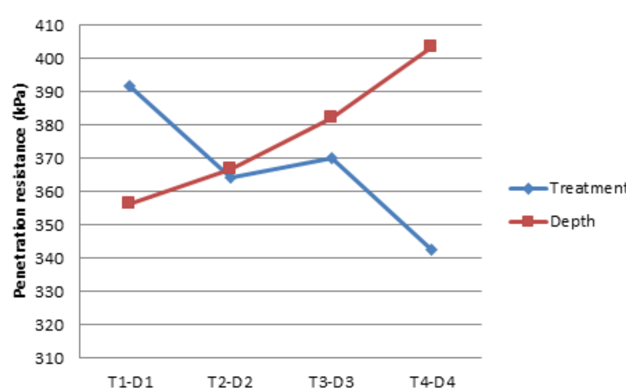

Fig. 5. Effect of INM and soil depth on penetration resistance (kPa)

Water Holding Capacity (WHC)

WHC is the ability of soil to physically retain water against gravity. The cohesive force of soil particles holds water molecules together. The WHC of soil had a significant influence on long-term nutrient management practices and increasing soil depths depicted in Table 3. Addition of NPK

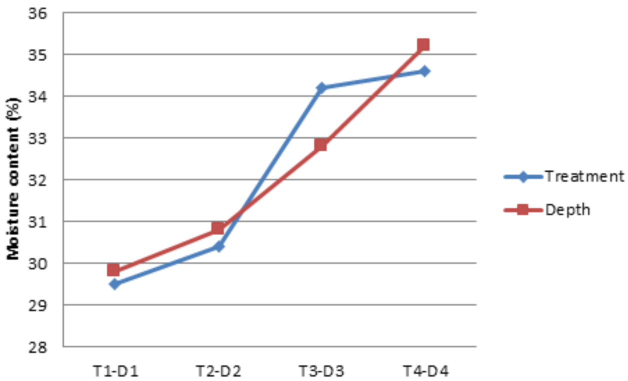

Fig. 6. Effect of INM and soil depth on moisture content (%)

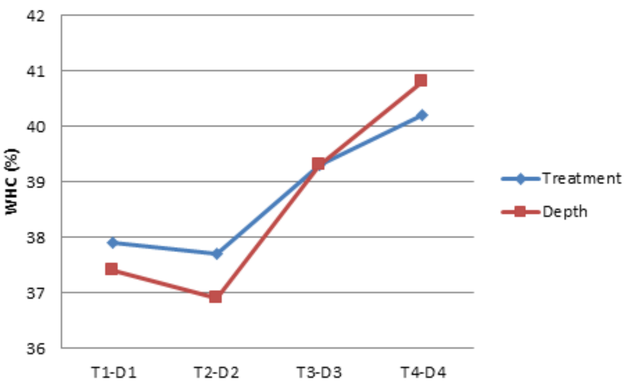

Fig. 7. Effect of INM and soil depth on water holding capacity (%)

fertilizers alongwith FYM (T_4) increased (40.2%) WHC of soil. Treatment T_3 and T_4 were statistically at par (Fig. 7). Saha *et al.* (2010) and Vengadaramana *et al.* (2012) also observed significant improvement in the WHC of soil under integrated application of organic and inorganic fertilizers. FAO (2005) and Senjobi and Ogunkunle (2011) also reported similar trends.

4. CONCLUSIONS

It is concluded from the study that treatment T_4 registered significantly good results of BD, water stable aggregates of different size, MWD, PR and WHC. The data at depth levels performed differently better at 0-15 cm of soil depth compared with increasing depth. It is therefore, concluded that treatment T_4 (soil test based NPK + targeted yield of 6.0 t ha^{-1} + FYM @10.0 t $ha^{-1}yr^{-1}$) is the most suitable nutrient management practice under rice-wheat cropping sequence on sustainable bases. Taking in to consideration the findings of the present study the field experiments need to be conducted to assess the soil quality and sustainability of rice-wheat cropping system.

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