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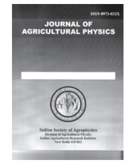

Research Article

Stability and Mechanical Properties of Soil Aggregates under Tillage, Residue and Nitrogen Management in Maize-Wheat Cropping System

SONIYA DAGAR[1], K.K. BANDYOPADHYAY[1]*, DEBASHIS CHAKRABORTY[1], PRAGATI PRAMANIK MAITY[1] AND T.J. PURAKAYASTHA[2]

[1]*Division of Agricultural Physics, ICAR-Indian Agricultural Research Institute, New Delhi-110012*
[2]*Division of Soil Science and Agricultural Chemistry, ICAR-Indian Agricultural Research Institute, New Delhi-110012*

ABSTRACT

The study was conducted from a long term ongoing field experiment on tillage, residue and nitrogen management in maize-wheat cropping system on a Typic Haplustept of the Research Farm of Indian Agricultural Research Institute, New Delhi to evaluate the stability and mechanical properties of soil aggregates.The field experiment was conducted under a split split plot design with three replications.The treatment comprised of two tillage types viz., conventional tillage (CT) and no-tillage (NT)) as main plot factor; two mulching levels i.e. crop residue mulch @ 5t/ha (R+) and without residue (R0) as subplot factor and 3 nitrogen levels i.e. 50% recommended nitrogen dose (RDN), 100% RDN and 150% RDN as sub sub plot factor. The results showed that NT could significantly increase the water stable aggregates (WSA) and mean weight diameter (MWD) of aggregates by 17.8 and 1.9%, respectively over CT at 0-5 cm soil depth. Crop residue mulching also significantly increased the WSA and MWD of aggregates at 0-5 cm soil depth. The ratio of macro-aggregates to micro-aggregates increased under NT with crop residue mulching and 150% of the recommended dose of N. The study revealed that NT practice along with residue retention enhanced the structural stability of soil when the N was applied more than the recommended dose to the maize-wheat cropping system.

Key words: Water stable aggregates, Mean weight diameter, Macro-aggregates, Micro-aggregates, Maize-wheat, Nitrogen

Introduction

Tillage practices involve physical manipulation of soil for improving crop productivity and make the soil either porous or compact and alters the mass and volume relationship of soil, clod-size distribution, increase surface roughness and soil porosity (Allmaras, 1966). The principal aim of tillage practices is to provide congenial soil physical environment for plant growth and production. Degradation of soil structure and losses of soil organic carbon (SOC) as potential adverse effect of conventional (CT) system can be reduced by using conservation tillage practices (Lal, 2008; He *et al*., 2009). Soil aggregate size distribution and stability are important indicators of soil physical quality, reflecting the impact of land use and soil management practices (Castro Filho *et al*., 2002) on aggradation or degradation (Boix-Fayos *et al*., 2001; Barthes and Roose, 2002) of soil health (Herrick *et al*., 2001).

*Corresponding author,
Email: kk.bandyopadhyay@gmail.com

Aggregate sizes are closely related to the amount of SOC and their turnover. Soil organic carbon dynamics are linked to soil aggregate formation and stabilization (Balesdent *et al.*, 2000) and are strongly affected by agricultural management practices (Six *et al.*, 2002), and thus play crucial roles in sustaining soil quality, promoting crop production and protecting the environment (Bauer and Black, 1994; Doran and Parkin, 1994; Robinson *et al.*, 1996). Six *et al.* (1999) reported that a faster turnover rate of macro-aggregates in CT compared to NT leads to a slower rate of micro-aggregate formation within macro-aggregates and less stabilization of new soil organic matter (SOM) in free micro-aggregates under CT. Thus, CT leads to the formation of carbon depleted micro-aggregates at the cost of carbon rich macro-aggregates. NT can have a positive effect on SOM storage and, therefore it can contribute to mitigation of CO_2 emissions from agricultural soils (Lal *et al.*,1999; Bandyopadhyay and Lal, 2015).

It is being hypothesized that NT with crop residue mulching and higher dose of N improve the soil aggregation. With this background, the objective of this study was to evaluate the effect of NT and CT in the presence and absence of crop residue mulch on stability and mechanical properties of soil aggregates.

Materials and Methods

Soil and climate of experimental site

The experiment was conducted on a long term (5 years old) ongoing field experiment on tillage, residue and N management on maize-wheat cropping system on a Typic Haplustept of the Research Farm of Indian Agricultural Research Institute, New Delhi. The experimental site (28°N, 77°E, and 250 m above mean sea level) located in the Trans-Gangetic Plain (TGP) zone represented an irrigated, mechanized and input-intensive cropping area.

Climate of New Delhi is sub-tropical semi-arid with hot and dry summer and cool winter. The summer season is scorching hot whereas winter is brief varying between mild to severe. The soil of experimental site was sandy loam (Typic Haplustept) of Gangatic alluvial origin, very deep (greater than 2m), flat and well drained. The soil of the field is mildly alkaline, non-saline, low in organic carbon (Walkey and Black C) and available N and medium in available P and K content. Bulk density of the surface soil (0-15 cm) is 1.58 Mg/m^3; hydraulic conductivity (saturated) 1.01 cm/h, saturated water content 0.41 m^3/m^3, EC (1:2.5 soil/water suspension) 0.36 dS/m; organic C 4.2 g/kg; total N 0.032%; available (Olsen) P 7.1 kg/ha; available K 281 kg/ha; sand, silt and clay, 64.0, 16.8 and 19.2%, respectively. The bulk density in the profile varied from 1.58 Mg m^{-3} in the 0-15 cm layer to 1.72 Mg m^{-3} in the 90-120 cm layer. Available soil moisture ranged from 24.6-28.3% (0.033 MPa) to 9.7-12.9 % (1.5 MPa) in different layers of for 0-120 cm depth.

Experiment details

The field experiment was conducted under a split split plot statistical layout with three replications.The treatments comprised of two tillage regimes i.e. CT and NT as main plot factor, crop residue mulch (@ 5t/ha (R+) and without residue (R0)) as subplot factor and 3 levels of N (50% recommended N dose (RDN); 100% RDN and 150% RDN) as sub sub plot factor. The recommended fertilizer dose for maize was 150-75-75 (N; P_2O_5; K_2O) and that of wheat was 120-60-60 (N; P_2O_5; K_2O) for this region. The same treatment structure was followed both for maize (cv PMH1) in *kharif* season and wheat (cv HD2926) in *rabi* season. The size of sub-sub plot was 4.5m × 5 m.

The plots under CT treatment, were ploughed one time with disc plough and then once with duck-foot tine cultivator followed by land levelling and finally the seeds were sown by seed drill. Under NT treatments, the seeds were sown directly using an inverted T type no-till seed drill. Spray of Glyphosate @ 10 mL/L was used to check the growth of weeds before sowing of wheat. In the Residue treatments (R+), wheat residue was applied to maize crop and maize residue was applied to wheat crop at the rate of 5 t/ha, which correspond to 50% of field cover. Phosphorus and potassium were applied uniformly as basal during sowing in all the plots as single super phosphate and as muriate of potash, respectively. Nitrogen was supplied through urea as split dose in both the crops. In maize crop it was applied at four splits i.e. 20% at sowing, 20% at four leaf stage, 30% at eight leaf stage and rest 30% at flowering stage whereas in wheat it was applied in three splits *i.e.*, 50%, 25% and 25% at sowing, crown root initiation and flowering stage, respectively. Irrigation of 6 cm depth water was applied uniformly to all the plots at critical growth stages of maize (seedling, knee height, flowering and grain filling stages) and wheat (CRI, Tillering, Jointing, and Flowering) in the absence of rainfall in this location. Manual weeding was done 2-3 times in all the plots to ensure weed free situations during crop growth stages.

Soil sampling and Processing

Soil samples were collected in bucket type core samplers after 5 years of maize-wheat cropping cycle in April, 2019 and analysed for bulk density, soil aggregate stability, tensile strength and friability of aggregates following the procedures as given below.

Bulk density and Porosity

The core sampler was inserted into the soil to the desired depth (0-5, 5-15 and 15-30 cm) in such a way that soil core (5 cm internal diameter and 5 cm length) is collected from the centre of the given depth. Soil core samples were dried in oven at 105°C for 48 hrs. Bulk density was calculated by dividing weight of dried soil by the volume of core used (Veihmeyer and Hendrickson, 1948).

Porosity of soil was determined using the formula

$$P = (1\text{-}BD/PD) \quad \ldots(1)$$

Where BD in bulk density and PD is particle density of soil, which was assumed to be 2.65 Mg/m^3.

Aggregate stability

Large clods were broken by hand into smaller segments along natural cleavage prior to air-drying and was sieved to obtain aggregates that passed through 8 mm and retained on 4 mm sieve. These aggregates were separated using wet-sieving technique through a set of sieves (Yoder, 1936). The MWD was calculated as an index of aggregation (Van Bavel, 1950; Kemper and Roseneau, 1986) using following formula:

$$MWD = \Sigma x_i w_i \quad \ldots(2)$$

Where, w_i is the proportion of each aggregate class in relation to whole soil, and x_i the mean diameter of the class (mm).

The WSA was computed by adding the aggregates of different size fractions (0.25-8 mm), and expressing them as percentage of the total weight of soil taken for analysis.

The WSA for each size class was determined as,

$$WSAi= [(Wa – Wc)/W_0]*100 \quad \ldots(3)$$

Where, Wa = weight of material on the sieve after wet sieving of size i; Wc = weight of coarse material in size i; Wo = weight of aggregates placed on the sieve prior to wet sieving of size i

To obtain macro-aggregates and micro-aggregates, the aggregates (4.0-8.0 mm size) were wet sieved manually as per Eliott *et al*. (1986). This resulted in four aggregate size fractions i.e. Large macro- aggregates (>2000 μm), small macro-aggregates (250-2000 μm), micro-aggregates (53-250 μm) and mineral fraction (<53 μm).

The ratio of macro-aggregates to micro-aggregates was expressed as Aggregate ratio.

Aggregate tensile strength

The tensile strength (TS) and friability (F) of aggregates was measured following the procedure of Horn and Dexter, 1989. The test consisted of placing an individual aggregate between two round plates of an apparatus based on a design by Horn and Dexter (1989), and the force P (N) needed to crush the aggregate was recorded. The

TS of aggregates was calculated by using the equation:

$$TS = 0.576 \times \left(\frac{P}{d^2}\right) \qquad \ldots(4)$$

Where, d was the mean aggregate diameter (mm), which was taken as the average of upper (8-mm) and lower (5-mm) sieve sizes (Dexter and Kroesbergen, 1985).

The friability (F) of the soil aggregates was estimated following Watts and Dexter (1998) from the coefficient of variation (σ_Y) and mean ($\bar{Y}$) of the measured values of TS of aggregates for each treatment as:

$$F = \frac{\sigma y}{\bar{Y}} \qquad \ldots(5)$$

Statistical analysis

The analysis of variance (ANOVA) test was performed using the GLM procedure of SAS (SAS Institute, 2003) to determine the effect of tillage, residues and nitrogen on soil aggregate stability as applicable to split-split plot design. The means were compared using least significant difference and Duncan's Multiple Range Test (DMRT).

Results and Discussion

Water stable aggregate percentage under tillage, residue and nitrogen management

The percentage of WSA ranged from 64.4 to 78.3% (mean 69.5%), 43.0 to 74.3% (mean 59.1%) and 40.3 to 68.5% (mean 54.7%) at 0-5, 5-15 and 15-30 cm depths, respectively (Table 1). Thus, there was significant decrease ($p<0.05$) in the WSA with increase in soil depth. NT resulted in significant increase in WSA by 1.9% compared to CT at 0-5 cm depth but the effect of tillage on WSA was not significant at 5-15 and 15-30 cm depth. Application of crop residue mulch significantly improved the WSA by 3.9% over no-mulching at 0-5 cm depth but the effect of crop residue mulch on WSA was not significant at 5-15 and 15-30 cm depth. With the increase in N levels, WSA increased significantly at 0-5 and 5-15 cm depths. The interaction of tillage, residue and N management was not significant on water stable aggregate percentage.

Table 1. Water stable aggregates as affected by tillage, residue and nitrogen management

Treatment	Water stable aggregate (%)		
	0-5 cm	5-15 cm	15-30 cm
	Effect of tillage		
CT	68.80^{B}	61.53^{A}	58.36^{A}
NT	70.11^{A}	56.60^{A}	51.09^{A}
	Effect of residue mulch		
R_0	68.11^{B}	58.74^{A}	52.08^{A}
R_+	70.79^{A}	59.38^{A}	57.37^{A}
	Effect of Nitrogen		
$N_{50\%}$	68.41^{B}	62.28^{A}	54.53^{A}
$N_{100\%}$	68.58^{B}	55.28^{B}	57.06^{A}
$N_{150\%}$	71.38^{A}	59.63^{AB}	52.58^{A}
	Effect of Tillage × Residue × Nitrogen		
$CTR_0N_{50\%}$	64.90^{a}	57.73^{a}	53.20^{a}
$CTR_0N_{100\%}$	64.40^{a}	56.70^{a}	57.50^{a}
$CTR_0N_{150\%}$	65.70^{a}	49.50^{a}	48.70^{a}
$CTR_+N_{50\%}$	68.77^{a}	74.27^{a}	68.50^{a}
$CTR_+N_{100\%}$	70.73^{a}	64.00^{a}	59.77^{a}
$CTR_+N_{150\%}$	78.30^{a}	66.97^{a}	62.47^{a}
$NTR_0N_{50\%}$	72.80^{a}	67.40^{a}	56.13^{a}
$NTR_0N_{100\%}$	72.03^{a}	57.40^{a}	51.23^{a}
$NTR_0N_{150\%}$	68.83^{a}	63.73^{a}	45.70^{a}
$NTR_+N_{50\%}$	67.17^{a}	49.73^{a}	40.30^{a}
$NTR_+N_{100\%}$	67.13^{a}	43.03^{a}	59.73^{a}
$NTR_+N_{150\%}$	72.67^{a}	58.30^{a}	53.43^{a}
Mean	69.47^{A}	59.07^{B}	54.73^{C}

#Values in a column followed by same alphabets are not significantly different at $p<0.05$ as per Dunkan's Multiple rage test ;The uppercase alphabets and the lower case alphabets are used for comparing main plot and subplot effects, respectively.

Mean weight diameter (MWD) of the WSA ranged from 1.10 to 2.02 mm (mean 1.6 mm), 1.11 to 2.07 mm (mean 1.4 mm) and 0.97 to 1.55 mm (mean 1.2 mm) at 0-5, 5-15 and 15-30 cm depths, respectively (Table 2). Similar to WSA percentage, the MWD decreased significantly ($p<0.05$) with depth. NT could significantly increase the MWD than that of CT by 17.8% at 0-5 cm depth. However, the effect of tillage was not significant on MWD at 5-15 and 15-30 cm

Table 2. Mean weight diameter of water stable aggregates as affected by tillage, residue and nitrogen management

Treatment	Mean weight diameter (mm)		
	0-5 cm	5-15 cm	15-30 cm
Effect of tillage			
CT	1.50^{B}	1.51^{A}	1.29^{A}
NT	1.77^{A}	1.47^{A}	1.20^{A}
Effect of residue mulch			
R_0	1.53^{B}	1.39^{B}	1.19^{A}
R_+	1.73^{A}	1.59^{A}	1.30^{A}
Effect of Nitrogen			
$N_{50\%}$	1.85^{A}	1.54^{A}	1.21^{A}
$N_{100\%}$	1.62^{B}	1.63^{A}	1.31^{A}
$N_{150\%}$	1.43^{C}	1.30^{B}	1.21^{A}
Effect of Tillage × Residue × Nitrogen			
$CTR_0N_{50\%}$	1.65^{a}	1.26^{a}	1.11^{a}
$CTR_0N_{100\%}$	1.30^{a}	1.39^{a}	1.25^{a}
$CTR_0N_{150\%}$	1.10^{a}	1.10^{a}	1.27^{a}
$CTR_+N_{50\%}$	1.91^{a}	1.93^{a}	1.25^{a}
$CTR_+N_{100\%}$	1.60^{a}	1.97^{a}	1.52^{a}
$CTR_+N_{150\%}$	1.43^{a}	1.42^{a}	1.31^{a}
$NTR_0N_{50\%}$	1.90^{a}	1.92^{a}	1.33^{a}
$NTR_0N_{100\%}$	1.56^{a}	1.39^{a}	1.06^{a}
$NTR_0N_{150\%}$	1.67^{a}	1.26^{a}	1.08^{a}
$NTR_+N_{50\%}$	1.94^{a}	1.08^{a}	1.13^{a}
$NTR_+N_{100\%}$	2.02^{a}	1.74^{a}	1.41^{a}
$NTR_+N_{150\%}$	1.51^{a}	1.43^{a}	1.16^{a}
Mean	1.63^{A}	1.44^{B}	1.20^{C}

#Values in a column followed by same alphabets are not significantly different at $p<0.05$ as per Duncan's Multiple rage test ;The uppercase alphabets and the lower case alphabets are used for comparing main plot and subplot effects, respectively.

depths. Application of crop residue mulch significantly improved the MWD by 13.1% at 0-5 cm depth compared to no mulch application. However the effect of mulching on MWD was not significant at 5-15 and 15-30 cm depth. With the increase in N levels the MWD increased significantly only at 0-5 cm depth. The interaction of tillage, residue and N was not significant on MWD at 0-5, 5-15 and 15-30 cm depths.

The increase in WSA and MWD of aggregates under NT than CT at 0-5 cm depth was attributed to the fact that soil aggregates were disrupted due to intensive tillage operations under CT, which resulted in lower percentage of WSA and lower MWD under CT compared to NT. This finding is in agreement with Mikha and Rice (2004) and Six *et al.* (2000a). The disturbance related SOM losses in CT vs NT is attributed to reduced aggregation in CT in comparison with NT and increased organic matter decomposition due to aggregate disruption in CT (Beare *et al.*, 1994). Acar *et al.* (2018) reported that MWD of aggregates was higher in NT as compared to CT in 0-15 cm depth. Similar results were also reported from other studies (Abid and Lal, 2008; Pagliai *et al.,* 2004; Celik *et al.,* 2012; and Abdollahi and Munkholm, 2014). Percentage of WSA and MWD increased significantly due to crop residue mulching at 0-5 cm depth. This was mainly attributed to the addition of SOM though crop residues, which served as binding agent for formation of soil aggregates. Acharya *et al.* (2005) reported that crop residue mulching improved the MWD due to decomposition of residues by microorganism which adds organic matter to soil. With the increase in N level, the percentage of WSA and MWD increased, which was due to more shoot and root biomass, which contributed organic matter to soil for formation of water stable aggregates.

Distribution of water stable aggregates as influenced by tillage, residues and nitrogen management

Distribution of WSA mass at 0-5, 5-15 and 15-30 cm depths as influenced by tillage, residue and N management is presented in Tables 3, 4 and 5, respectively. The contribution of large macro-aggregates ranged from 4.2-6.1% (mean 5.11%), 4.40-5.97% (mean 5.35%) and 4.5-6.17% (mean 5.32%) at 0-5, 5-15 and 15-30 cm depths, respectively. Effect of tillage and residue on large macro-aggregates was not significant in all the three soil depths. However, with the increase in N level the large macro-aggregate stability increased only at 0-5 cm depth. The small macro-aggregates ranged from 5.4-13.85% (mean 8.38%), 3.80-8.43% (mean 7.11%) and 5.67-10% (mean 7.3%) at 0-5, 5-15 and 15-30 cm depths, respectively. NT could significantly increase the

Table 3. Distribution of water stable aggregates at 0-5 cm soil depth as influenced by tillage, residues and nitrogen management

Treatment	Large macro-aggregates (>2000 µm) (g/100g)	Small macro-aggregates (250-2000 µm) (g/100 g)	Micro-aggregates (53-250 µm) (g/100g)	Mineral fraction (<53 µm) (g/100 g)	Aggregation ratio
			Effect of tillage		
CT	5.05^A	8.34^A	64.48^A	18.47^B	0.209
NT	5.17^A	8.41^A	56.77^B	28.17^A	0.240
			Effect of residues		
R_0	4.84^A	6.59^B	62.02^A	22.02^B	0.185
R_+	5.38^A	10.17^A	59.23^B	24.62^A	0.264
			Effect of Nitrogen		
$N_{50\%}$	4.63^B	7.49^B	59.47^A	24.22^A	0.205
$N_{100\%}$	5.27^A	7.82B	60.58^A	23.67^A	0.217
$N_{150\%}$	5.44^A	9.83^A	61.83^A	22.07^A	0.251
			Effect of Tillage ×Residue × Nitrogen		
$CTR_0N_{50\%}$	4.20^a	6.77^a	66.90^a	13.47^a	0.164
$CTR_0N_{100\%}$	5.20^a	5.87^a	65.83^a	16.47^a	0.168
$CTR_0N_{150\%}$	5.33^a	8.30^a	67.90^a	16.33^a	0.201
$CTR_+N_{50\%}$	4.83^a	9.40^a	59.80^a	24.17^a	0.238
$CTR_+N_{100\%}$	4.67^a	9.67^a	62.10^a	21.37^a	0.231
$CTR_+N_{150\%}$	6.07^a	10.07^a	64.33^a	19.00^a	0.251
$NTR_0N_{50\%}$	4.77^a	5.40^a	54.30^a	29.00^a	0.187
$NTR_0N_{100\%}$	5.30^a	6.13^a	56.90^a	29.43^a	0.201
$NTR_0N_{150\%}$	4.27^a	7.07^a	60.30^a	27.40^a	0.188
$NTR_+N_{50\%}$	4.70^a	8.40^a	56.87^a	30.23^a	0.230
$NTR_+N_{100\%}$	5.90^a	9.60^a	57.47^a	27.40^a	0.270
$NTR_+N_{150\%}$	6.10^a	13.87^a	54.80^a	25.53^a	0.364
Mean	5.11	8.38	60.63	23.32	0.224

#Values in a column followed by same letters are not significantly different at $p<0.05$ as per DMRT; The uppercase letters and the lower case letters are used for comparing main plot and subplot effects, respectively

small macro-aggregate stability compared to CT at 5-15 and 15-30 cm soil depth by 18.1 and 21.3%, respectively. However, effect of tillage on small macro-aggregate stability at 0-5 cm depth was not statistically significant. Application of crop residue mulch could significantly increase the small macro-aggregate stability at 0-5 and 15-30 cm depths by 54.4 and 34.4%, respectively whereas the effect of crop residue mulch on macro-aggregate stability at 5 -15 cm depth was not statistically significant. With the increase in N level the small macro-aggregate stability increased in all the three depths.

The contribution of micro-aggregates ranged from 54.3-67.9% (mean 60.63%), 61.37-75.43% (mean 68.52%) and 71.0-78.93% (mean 74.16%) at 0-5, 5-15 and 15-30 cm depth, respectively. There was an increase in the micro-aggregates with the increase in the soil depth. It was observed that under NT treatment there was significant decrease in the micro-aggregate stability by

Table 4. Distribution of water stable aggregates at 5-15 cm soil depth as influenced by tillage, residues and nitrogen management

Treatment	Large macro-aggregates (>2000 µm) (g/100g)	Small macro-aggregates (250-2000 µm) (g/100 g)	Micro-aggregates (53-250 µm) (g/100g)	Mineral fraction (<53 µm) (g/100 g)	Aggregation ratio
			Effect of tillage		
CT	5.32^{A}	6.53^{B}	68.80^{A}	15.91^{B}	0.173
NT	5.38^{A}	7.70^{A}	68.24^{A}	17.83^{A}	0.192
			Effect of residues		
R_0	5.57^{A}	6.86^{A}	70.38^{A}	14.71^{B}	0.177
R_+	5.13^{A}	7.37^{A}	66.66^{B}	19.03^{A}	0.187
			Effect of Nitrogen		
$N_{50\%}$	5.37^{A}	5.99^{B}	67.23^{B}	16.94^{A}	0.170
$N_{100\%}$	5.38^{A}	7.44^{A}	67.93^{AB}	17.70^{A}	0.189
$N_{150\%}$	5.30^{A}	7.91^{A}	70.40^{A}	15.97^{A}	0.188
			Effect of Tillage ×Residue × Nitrogen		
$CTR_0N_{50\%}$	5.93^{a}	3.80^{a}	72.83^{a}	13.07^{a}	0.134
$CTR_0N_{100\%}$	4.80^{a}	7.50^{a}	70.47^{a}	13.07^{a}	0.175
$CTR_0N_{150\%}$	5.47^{a}	7.47^{a}	75.43^{a}	11.17^{a}	0.171
$CTR_+N_{50\%}$	5.27^{a}	5.07^{a}	61.37^{a}	19.23^{a}	0.168
$CTR_+N_{100\%}$	5.20^{a}	6.90^{a}	65.03^{a}	21.67^{a}	0.186
$CTR_+N_{150\%}$	5.23^{a}	8.43^{a}	67.67^{a}	17.27^{a}	0.202
$NTR_0N_{50\%}$	5.87^{a}	7.50^{a}	65.70^{a}	16.40^{a}	0.203
$NTR_0N_{100\%}$	5.97^{a}	7.40^{a}	68.77^{a}	17.00^{a}	0.194
$NTR_0N_{150\%}$	5.40^{a}	7.50^{a}	69.10^{a}	17.57^{a}	0.187
$NTR_+N_{50\%}$	4.40^{a}	7.60^{a}	69.00^{a}	19.07^{a}	0.174
$NTR_+N_{100\%}$	5.57^{a}	7.97^{a}	67.47^{a}	19.07^{a}	0.200
$NTR_+N_{150\%}$	5.10^{a}	8.23^{a}	69.40^{a}	17.87^{a}	0.192
Mean	5.35	7.11	68.52	16.87	0.182

#Values in a column followed by same letters are not significantly different at $p<0.05$ as per DMRT; The uppercase letters and the lower case letters are used for comparing main plot and subplot effects, respectively

11.9% compared to CT at 0-5 cm depth. In 5-15 and 15-30 cm depth it followed similar trend but the effect was nonsignificant. Application of crop residue mulch significantly decreased the micro-aggregate stability by 4.5 and 5.3% than no mulch treatment at 0-5 and 5-15 cm depth, respectively whereas at 15-30 cm depth, effect crop residue mulch on micro-aggregate stability was not significant. With the increase in N levels, micro-aggregate stability increased significantly at 5-15 cm depth whereas the effect of N levels on micro-aggregate stability was statistically similar at 0-5 and 15-30 cm depth.

The mineral fraction (sand+slit fraction) ranged from 13.46-30.23% (mean 23.32%), 11.15-21.67% (mean 16.87%) and 7.53-14.5% (mean 11.97%) at 0-5, 5-15 and 15-30 cm depths, respectively. Thus mineral fraction decreased with soil depth. NT significantly increased mineral fraction by 52.5 and 12.1% at 0-5 and 5-15 cm depths, respectively whereas at 15-30 cm depth,

Table 5. Distribution of water stable aggregates at 15-30 cm soil depth as influenced by tillage, residues and nitrogen management

Treatment	Large macro-aggregates (>2000 µm) (g/100g)	Small macro-aggregates (250-2000 µm) (g/100 g)	Micro-aggregates (53-250 µm) (g/100g)	Mineral fraction (<53 µm) (g/100 g)	Aggregation ratio
			Effect of tillage		
CT	5.53^{A}	6.60^{B}	74.84^{A}	11.86^{A}	0.162
NT	5.11^{A}	8.00^{A}	73.47^{A}	12.07^{A}	0.179
			Effect of residues		
R_0	5.37^{A}	6.23^{B}	75.19^{A}	11.62^{A}	0.155
R_+	5.27^{A}	8.37^{A}	73.12^{A}	12.31^{A}	0.187
			Effect of Nitrogen		
$N_{50\%}$	5.34^{A}	7.05^{B}	75.02^{A}	8.68^{B}	0.165
$N_{100\%}$	5.19^{A}	7.13^{B}	74.70^{A}	12.96^{A}	0.166
$N_{150\%}$	5.43^{A}	7.72^{A}	72.75^{A}	14.27^{A}	0.181
			Effect of Tillage ×Residue × Nitrogen		
$CTR_0N_{50\%}$	5.53^{a}	5.93^{a}	78.93^{a}	7.53^{a}	0.145
$CTR_0N_{100\%}$	4.80^{a}	5.67^{a}	76.17^{a}	12.30^{a}	0.137
$CTR_0N_{150\%}$	5.23^{a}	6.57^{a}	74.13^{a}	13.97^{a}	0.159
$CTR_+N_{50\%}$	6.17^{a}	6.57^{a}	73.50^{a}	9.40^{a}	0.173
$CTR_+N_{100\%}$	5.90^{a}	6.77^{a}	73.77^{a}	13.63^{a}	0.172
$CTR_+N_{150\%}$	5.57^{a}	8.10^{a}	72.53^{a}	14.33^{a}	0.188
$NTR_0N_{50\%}$	5.50^{a}	6.53^{a}	71.97^{a}	9.10^{a}	0.167
$NTR_0N_{100\%}$	5.10^{a}	6.10^{a}	76.60^{a}	12.57^{a}	0.146
$NTR_0N_{150\%}$	6.07^{a}	6.57^{a}	73.33^{a}	14.27^{a}	0.172
$NTR_+N_{50\%}$	4.17^{a}	9.17^{a}	75.67^{a}	8.67^{a}	0.176
$NTR_+N_{100\%}$	4.97^{a}	10.00^{a}	72.27^{a}	13.33^{a}	0.207
$NTR_+N_{150\%}$	4.83^{a}	9.63^{a}	71.00^{a}	14.50^{a}	0.204
Mean	5.32	7.30	74.16	11.97	0.171

Values in a column followed by same letters are not significantly different at $p<0.05$ as per DMRT; The uppercase letters and the lower case letters are used for comparing main plot and subplot effects, respectively

the effect of tillage on mineral fraction was not significant. Application of crop residue mulch significantly increased mineral fraction by 11.8 and 29.4% at 0-5 and 5-15 cm depths, respectively whereas at 15-30 cm depth, the effect was not significant. Effect of N levels on this fraction was also nonsignificant at 0-5 and 5-15 cm depth but at 15-30 cm depth, there was significant increase in mineral fraction with the increase in N levels. Effect of tillage, residue and N interaction was not significant on aggregate mass distribution in all the three soil depths.

It was observed that in all the soil depths, micro-aggregates (250-2000 µm) contribute maximum towards soil aggregation followed by mineral fraction (<53 µm), small macro-aggregates(250-2000 µm) and large macro-aggregates(>2000 µm).Soil aggregation ratio, which is the ratio of macro-aggregates to micro-aggregate ranged from 0.164-0.364 (mean 0.224), 0.134-0.203 (mean 0.182) and 0.137-0.207 (mean 0.171) at 0-5, 5-15 and 15-30 cm soil depths, respectively. Thus, with increase in soil depth, the contribution of macro aggregates decreased and that of micro-aggregates increased. Soil aggregation ratio under NT was higher than that of CT by 15, 11.2 and 10% at 0-5, 5-15 and 15-30 cm soil depths, respectively. So, NT resulted in increase in macro-aggregates but decrease in the micro-aggregates. This was mainly attributed to the fact that CT resulted in breakdown of macro-aggregates due to intensive tillage operation whereas NT promoted the formation of macroaggregates due to less disturbance of soil. Similar findings were reported in other study (Ma *et al.*, 2007; Hou *et al.*, 2016; Andruschkewitsch *et al.*, 2014). Application of crop residue mulching increased the aggregation ratio by 43.0, 5.5 and 20.7%at 0-5, 5-15 and 15-30 cm soil depths, respectively. Addition of soil organic matter through crop residues served as nucleus for the formation of carbon rich macro-aggregates at the cost of the micro-aggregates. With the increase in N dose, soil aggregation ratio increased in all the three soil depths. Addition of organic matter through root biomass at higher N level might have facilitated formation of macro-aggregates at higher N dose (Rani *et al.*, 2017)

Tensile strength and Friability of aggregates as affected by tillage, residue and nitrogen management

Tensile strength and Friability of aggregates (size 4-8 mm) as influenced by tillage, residue and N management are presented in Tables 6 and 7, respectively. Tensile strength is defined as the force required to break the aggregate and is a very sensitive indicator of structural stability of the soil (Watts and Dexter, 1998). It tells about the strength that the roots have to overcome while growing geostropically (Imhoff *et al.*, 2002). Tensile strength of the aggregates ranged from 338.3-419.2 kPa (mean 371.8 kPa), 399.0-588.2 kPa (mean 512.5 kPa) and 406.3-643.0 kPa (mean 565.5 kPa) at 0-5, 5-15 and 15-30 cm depth, respectively. So the tensile strength of the aggregates increased significantly (p<0.05) with soil depth. Higher tensile strength of soil at lower layers resist mechanical disturbance to greater limit (Perfect and Kay, 1994). However, effect of tillage, residue and N levels or their interactions on tensile strength of the aggregates was not statistically significant. Whereas Abid and Lal (2009) observed significant decrease in the tensile strength of NT compared with CT soil, and also observed an inverse relationship between SOC and the tensile strength of the dry aggregates.

Fraibility on the other hand, is defined as the tendency of soil mass to disintegrate under

Table 6. Tensile strength of aggregates as affected by tillage, residue and nitrogen management

Treatment	Tensile strength of aggregates (kPa)		
	0-5 cm	5-15 cm	15-30 cm
Effect of tillage			
CT	379.0^A	531.4^A	563.0^A
NT	364.6^A	493.6^A	567.9^A
Effect of residue mulch			
R_0	360.9^A	508.9^A	565.6^A
R_+	382.8^A	516.2^A	565.4^A
Effect of Nitrogen			
$N_{50\%}$	361.9^A	487.1^A	531.1^A
$N_{100\%}$	371.4^A	507.5^A	594.0^A
$N_{150\%}$	382.2^A	542.9^A	571.3^A
Effect of Tillage × Residue × Nitrogen			
$CTR_0N_{50\%}$	373.0^a	521.9^a	518.5^a
$CTR_0N_{100\%}$	378.1^a	527.7^a	597.9^a
$CTR_0N_{150\%}$	356.6^a	472.9^a	406.3^a
$CTR_+N_{50\%}$	377.8^a	546.9^a	592.2^a
$CTR_+N_{100\%}$	369.5^a	536.1^a	616.6^a
$CTR_+N_{150\%}$	419.2^a	583.1^a	646.7^a
$NTR_0N_{50\%}$	338.3^a	480.5^a	600.7^a
$NTR_0N_{100\%}$	372.7^a	462.1^a	621.3^a
$NTR_0N_{150\%}$	346.5^a	588.2^a	649.0^a
$NTR_+N_{50\%}$	358.5^a	399.0^a	412.9^a
$NTR_+N_{100\%}$	365.2^a	504.3^a	540.3^a
$NTR_+N_{150\%}$	406.44^a	527.6^a	583.3^a
Mean	371.8^C	512.5^B	565.5^A

#Values in a column followed by same alphabets are not significantly different at p<0.05 as per Duncan's Multiple rage test; The uppercase alphabets and the lower case alphabets are used for comparing main plot and subplot effects, respectively.

Table 7. Friability of aggregates as affected by tillage, residue and nitrogen management

Treatment	Friability		
	0-5 cm	5-15 cm	15-30 cm
Effect of tillage			
CT	0.52^A	0.46^A	0.46^A
NT	0.42^B	0.44^A	0.43^A
Effect of residue mulch			
R_0	0.45^A	0.44^A	0.41^B
R_+	0.49^A	0.46^A	0.48^A
Effect of Nitrogen			
$N_{50\%}$	0.47^A	0.43^A	0.43^A
$N_{100\%}$	0.44^A	0.46^A	0.46^A
$N_{150\%}$	0.50^A	0.46^A	0.46^A
Effect of Tillage × Residue × Nitrogen			
$CTR_0N_{50\%}$	0.46^a	0.43^a	0.41^a
$CTR_0N_{100\%}$	0.51^a	0.39^a	0.42^a
$CTR_0N_{150\%}$	0.53^a	0.47^a	0.39^a
$CTR_+N_{50\%}$	0.67^a	0.35^a	0.41^a
$CTR_+N_{100\%}$	0.40^a	0.56^a	0.50^a
$CTR_+N_{150\%}$	0.53^a	0.53^a	0.63^a
$NTR_0N_{50\%}$	0.42^a	0.46^a	0.44^a
$NTR_0N_{100\%}$	0.44^a	0.45^a	0.42^a
$NTR_0N_{150\%}$	0.37^a	0.43^a	0.36^a
$NTR_+N_{50\%}$	0.34^a	0.46^a	0.44^a
$NTR_+N_{100\%}$	0.43^a	0.45^a	0.49^a
$NTR_+N_{150\%}$	0.55^a	0.42^a	0.44^a
Mean	0.47^A	0.45^A	0.45^A

#Values in a column followed by same alphabets are not significantly different at $p<0.05$ as per Duncan's Multiple rage test; The uppercase alphabets and the lower case alphabets are used for comparing main plot and subplot effects, respectively.

applied stress (Utomo and Dexter, 1981) and is a useful indicator of soil tilth and is positively correlated with SOC content (Macks *et al*., 1996). The friability of the aggregates ranged from 0.34-0.67 (mean 0.47), 0.35-0.57 (mean 0.45) and 0.36-0.63 (mean 0.45) at 0-5, 5-15 and 15-30 cm depth respectively. Thus friability of aggregates in the sub-surface was less than that of the surface layer but this difference is not significant. Similar to the tensile strength, the effect of tillage, residue and N levels or their interactions on friability of the aggregates was not statistically significant.

Bulk density and Total porosity of soil as influenced by tillage, residue and nitrogen management

Bulk density and porosity of soil as influenced by tillage, residue and N are depicted in Fig. 1. Bulk density of soil ranged from 1.46 to 1.64 Mg m^{-3} (mean 1.53 Mg m^{-3}), 1.52-1.69 Mg m^{-3} (mean 1.61 Mg m^{-3}) and 1.66-1.79 Mg m^{-3} (mean 1.71 Mg m^{-3}) at 0-5, 5-15 and 15-30 cm depth, respectively. It was observed that there was significant ($p<0.05$) increase in the BD with increase in soil depth. Under NT there was significant increase in BD in the 0-5 and 5-15 cm depth by 3.5 and 1.3%, respectively and significant decrease of BD at 15-30 cm depth by 2.4% than that of CT. This indicates that NT has a potential to decrease the subsurface compaction. Abid and Lal (2009) reported significant decrease in the BD and increase in the porosity under NT than CT. With the application of crop residue mulch, BD decreased by 3.5, 0.7 and 3.2% at 0-5, 5-15 and 15-30 cm depth, respectively but the effect of crop residue mulch on BD at 5-15 cm depth was not statistically significant. This was attributed to better soil aggregation because of higher SOC under crop residue mulching. This finding is in agreement with other studies (Celik *et al*., 2004; Leroy *et al*., 2008; Heuscher *et al*., 2005). The effect of N levels on BD of soil was not consistent.

Total porosity of soil ranged from 0.38-0.45 (mean 0.42), 0.36-0.43 (mean 0.39) and 0.33-0.39 (mean 0.35) at 0-5, 5-15 and 15-30 cm depths, respectively. It was observed that with the increase in soil depth porosity decreased significantly ($p<0.05$). Under NT there was significant decrease in porosity at 0-5 cm depth by 4.5% than that of CT. Decrease in average porosity with the increase in soil depth and also under NT in the surface layer is attributed to increase in bulk density. Application of crop residue mulch significantly increased the porosity by 4.9% at 0-5 cm depth. Effect of N levels on porosity of soil was not consistent. Increase in porosity with the crop residue mulching is attributed improvement in soil aggregation due to addition of organic matter in this treatment.

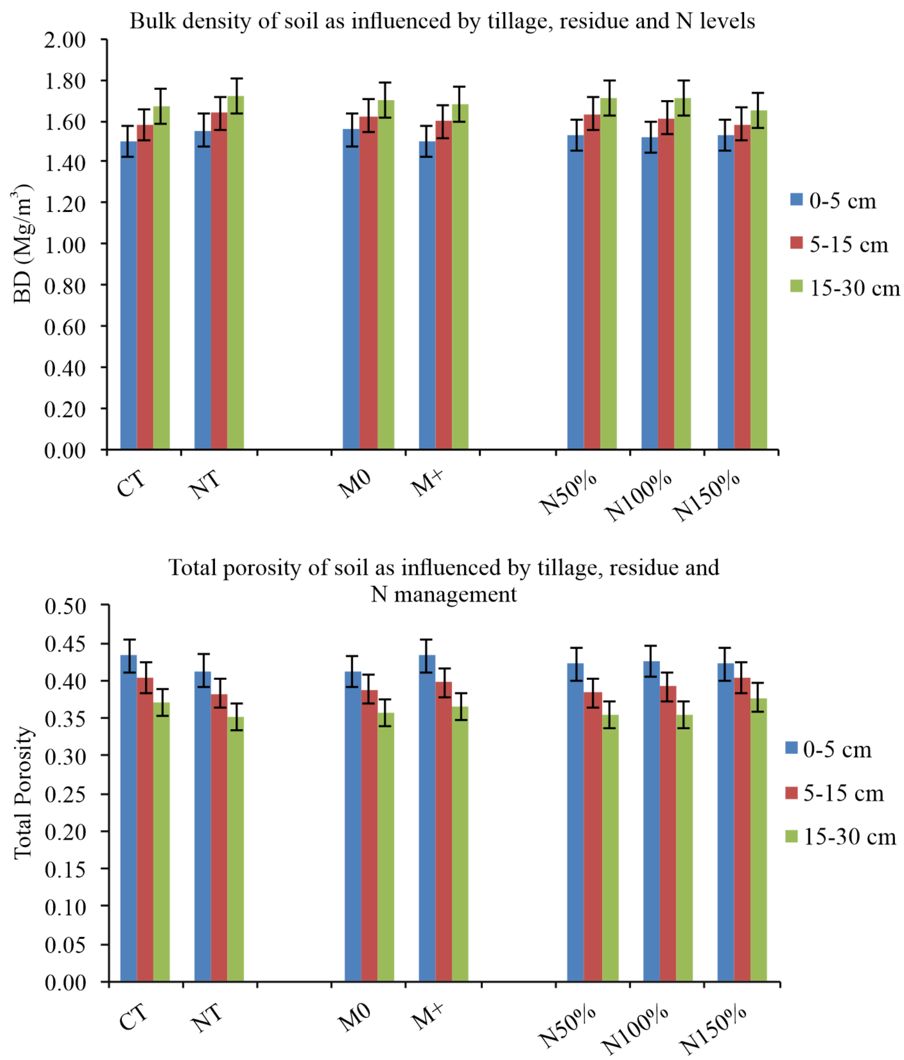

Fig. 1. Bulk density and Total porosity of soil as influenced by tillage, residue and nitrogen management

Conclusions

From this study, it was concluded that NT with crop residue retention as surface mulch promoted soil aggregate stability in maize-wheat cropping system. The ratio of macro-aggregates to micro-aggregates increased under NT with crop residue mulching and with the increase in N dose. There was increase in the formation of macro-aggregate at the cost of micro-aggregates in NT with crop residue retention. This practice also has the potential to alleviate subsurface compaction and hence NT with crop residue retention is the suitable option to be followed under maize-wheat system in the Indo Gangetic plain regions for improving soil aggregation and soil health.

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