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Tillage and residue management effect on soil hydro-physical environment under pigeonpea (*Cajanus cajan*)-wheat (*Triticum aestivum*) rotation

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ABSTRACT

A study was conducted in a long-term (6 year) experiment on tillage and residue management on a sandy loam soil (Typic Haplustept) in pigeonpea [*Cajanas cajan* (L.) Millsp]-wheat (*Triticum aestivum* L.) cropping system at IARI research farm, New Delhi for evaluation of the soil hydro-physical environment. Residue application significantly affected soil bulk density (ρ_b) and penetration resistance (PR), which were lowest in conventional tillage with residue incorporation (CTRI) (ρ_b =1.52 Mg/m^3, PR=1.27 MPa). The PR was highest in no-till and bare (NT) (1.77 MPa), while residue retention in no tillage (NTRM) significantly reduced PR (1.65 MPa). A hard pan (PR between 1.72 - 1.80 MPa and ρ_b between 1.66-1.78 Mg/m^3) was detected 0.1- 0.2 m layer. Mean weight diameter of 0-0.10 soil layer under NT and NTRM became 1.5 and 1.3 times that of its value of 0.396 mm and 0.435 mm, respectively, under CT. Soil macro-pores were 30-40% higher in NT and NTRM. Residue incorporation could improve transmission pores in conventional tillage, which might have contributed in better water retention in soils.

Key words: Aggregates, Carbon, Conventional tillage, Infiltration, No-tillage, Penetration resistance, Residue, Soil pores

Conservation tillage practices have received considerable attention over the past few decades due to increasing concern of sustainability of agri-production system *vis-à-vis* food security in near future. In this context, crop residue management becomes important due to its close association with tillage practice *per se*, and potential role in increasing soil C-stocks. There has been ample number of reports on the effect of various tillage and residue management practices in modifying the soil physical environment. All of these are considerably diverse and contradictory owing to their dependence on regional soil and climatic variability and the duration of the experimental study.

No-tillage is usually reported to increase the soil bulk density (ρ_b) in initial years and therefore, makes the soil more compact at surface but lesser in sub-surface (López-Fando *et al.* 2007). But in due course of time, significant increase in soil organic matter and protection of surface layer by cover residue mulch against the action of falling raindrops have usually contributed in improving the soil aggregation under no-tillage (Álvaro-Fuentes *et al.* 2009). Thus in long-term, more stable structure under no tillage improved saturated hydraulic conductivity as compared to conventional methods (Osunbitan *et al.* 2005).

Area under no-tillage in India increased from 400 ha in 1998 to nearly 2.2 Mha in 2005 (Derpsch 2005). However this is very small compared to 105.8 Mha worldwide and only 2.3% of this in Asia (Derpsch and Friedrich 2009). Adoption to resource conserving tillage practices in India is mostly taking place in rice-wheat system and is quite less in other prominent cropping systems. Understanding the modifications in soil through introduction of new tillage and residue management practice is necessary to exploit the benefits of the practice and to avoid the detriments, if any. Pigeonpea [*Cajanus cajan* (L.) Millsp.]-wheat (*Triticum aestivum* L.) rotation is one of the major cropping systems in Central India and a potential legume-cereals crop

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combination, an alternate to cereal-cereal rotation like rice-wheat in India. The country is leading in Asia with 3.58 Mha areas under pigeonpea but the yields have been substantially low. Realization of potential of any cropping system can only be possible through generation of data under diverse management practices. In a very recent study, alternate tillage and land configuration in the pigeonpea-wheat system in India was reported with promising results (Singh *et al*. 2010). Hence, the present study was planned to study the effect of continuous (6 years) tillage and crop residue management on hydro-physical environment of a sandy loam soil under pigeonpea-wheat rotation in a semi-arid climate in India.

MATERIALS AND METHODS

A field experiment on performance of wheat-based cropping systems under varying tillage and residue management is continuing since 2004 with different tillage and residue management practices in pigeonpea-wheat rotation in the experimental farm of Indian Agricultural Research Institute, New Delhi (28°37‘N, 77°09‘E, 228.7 m above mean sea level). The climate is semi-arid with mean annual rainfall of 750–800 mm, the distribution of which is unimodal with 75–80% rain occurring during the monsoon months (July–August). Temperature is usually warm in most of the period in a year; summer is hot and long and winter is severe and short with average temperatures of 32–35°C and 13–15°C, respectively. The soil (0–0.15 m) is sandy loam in texture, mild alkaline in reaction, low in soluble salt and organic matter content, and 12–15% (v/v) in available soil water content.

The treatment consisted of conventional tillage where residues was removed (CT); conventional tillage where residues of previous crops (pigeonpea or wheat) was incorporated into soil during land preparation for the next crop (CTRI); no-tillage where residues (above ground plant parts) were removed (NT); and no-tillage with crop residues (stubble) as mulch have been continuously maintained (NTRM); in a randomized block design (RBD) with three replications (plot size 6 m × 3 m). Under conventional tillage, the plots were ploughed 4 – 5 times (2 disc harrowing + 2 cultivators + 1 planking), while in no-tillage, the crop was sown without any tillage operations.

Pigeonpea (cv Pusa 991) crop has been growing as *kharif* (rainy season) followed by wheat cultivar PBW 343 during *rabi* (winter season). Pigeonpea residues @ 2 Mg/ha were applied to the wheat crop while wheat residues @ 3.0 Mg/ha were applied for pigeonpea. Pigeonpea was sown with spacing of 60 cm (row to row) and 10 cm (plant to plant), while wheat was sown in continuous lines at a row to row distance of 20 cm. A fertilizer dose of 20:60:40 kg N, P_2O_5 and K_2O/ha was applied as basal to pigeonpea, while a dose of 120:60:40 kg N, P_2O_5 and K_2O/ha applied to wheat (50% of N and full P and K as basal and rest 50% N at crown root initiation stage). For the present study, soil samples from 0–0.10, 0.10–0.20, 0.20–0.30 and 0.30–0.45 m soil depths were collected and *in-situ* observations were taken immediately after harvest of pigeonpea crop in the year 2009. Bulk density (core method), penetration resistance (Rimik cone penetrometer) and soil aggregate size distribution (Yoder 1936) were measured.

The aggregate stability was expressed by mean weight diameter (MWD) of water stable aggregates as described by Kemper and Roseneau (1986). Water retention characteristics (WRC) and pore size distribution (PSD) were measured by using pressure plate apparatus (Klute 1986). Total organic carbon in soil (processed by passing through 2 mm sieve) was determined by wet digestion with potassium dichromate along with 3:2 H_2SO_4 and 85% H_3PO_4 digestion mixture at digestion block set for 120°C for 2 hr (Synder and Trofymow 1984).

All the data sets were processed and analyzed using standard procedures in the Statistical Package for Social Sciences (SPSS 2004). Means were compared using least significant difference (LSD) where the analysis of variance (F-test) was significant at $P<0.05$ (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Bulk density (ρ_b) *and soil penetration resistance*

Significantly different bulk density was recorded among the treatments only in upper 0-0.1 m soil layer; for rest of the

Table 1 Tillage and residue management effects on soil bulk density (ρ_b) and resistance to penetration (PR) (Values followed by similar letters within a particular parameter at particular depth are not significantly different at $P<0.05$ level of significance)

Soil depth (m)	Treatment	ρ_b (Mg/m^3)	PR (MPa)
0-0.10	CT	1.59^{b}	1.39^{b}
	CTRI	1.52^{c}	1.27^{bc}
	NT	1.64^{a}	1.77^{a}
	NTRM	1.58^{b}	1.65^{a}
0.10-0.20	CT	1.70^{b}	1.80^{a}
	CTRI	1.68^{b}	1.75^{a}
	NT	1.78^{a}	1.80^{a}
	NTRM	1.66^{bc}	1.72^{a}
0.20-0.30	CT	1.59^{a}	1.55^{a}
	CTRI	1.65^{a}	1.56^{a}
	NT	1.65^{a}	1.48^{a}
	NTRM	1.65^{a}	1.42^{a}
0.30-0.45	CT	1.61^{a}	1.27^{a}
	CTRI	1.63^{a}	1.26^{a}
	NT	1.62^{a}	1.23^{a}
	NTRM	1.62^{a}	1.18^{a}

CT: Conventional tillage where residue was removed (CT); CTRI: Conventional tillage where residue of previous crops (pigeonpea or wheat) was incorporated into soil; NT: No-tillage where residues (above-ground plant parts) were removed; and NTRM: No-tillage with crop residues (stubble) as mulch have been continuously maintained layers down the profile, differences were not significant. In 0-0.10 m layer, conventional tillage with residue incorporation (CTRI) over the years resulted in lowering the ρ_b (1.52 Mg/m^3), which was the minimum among of treatments (Table 1). No-tillage plots where above-ground crop stubbles were removed (NT), showed significantly higher ρ_b value (1.64 Mg/m^3), while residue retention as mulch (NTRM) reduced ρ_b (1.58 Mg/m^3) in this layer. Conventional tillage where residues were completely removed (CT), recorded significantly less ρ_b (1.59 Mg/m^3) than CTRI and NT, but was at par with NTRM.

Residue incorporation (or retention) in respective tillage treatments significantly affected ρ_b of 0–0.10 m soil layer. In CTRI, residues were incorporated with each ploughing (both summer and winter) and this continuous practice possibly led to significantly lowering the surface ρ_b. In NTRM, crop residue mulch at surface reduced the direct contact of field machinery with soil surface and thus, possibly alleviated compaction to a significant extent; the other major factor might be non-exposure of soil surface to the direct impact of rain drops. Higher ρ_b at 0–0.10 m depth in NT (1.64 Mg/m^3) could primarily be attributed to lack of seasonal loosening by tillage machineries, contrary to a lower value in CT, as reported also by others (Alletto and Coquet 2009, Alvarez and Steinbach 2009). Residue incorporation (or retention) in respective tillage treatments significantly affected ρ_b of surface layer. Lower values of ρ_b at surface of (0-0.10 m) to a significantly higher value at sub-surface in conventional practices (CT and CTRI) demonstrated the compaction at sub-surface subjected to constant tillage operations over years.

Measured values of soil penetration resistance (PR) were averaged for the depths for which ρ_b observations were made (Table 1). The soil water content of all the treatments were similar (0.23–0.24 m^3 m^{-3}. Thus, the variation in soil strength was a result of changes in ρ_b only. The magnitude of PR for 0–0.10 m layer was significantly higher in NT and NTRM treatments than in CT and CTRI (Table 1). Below this layer, PR among the treatments was mostly at par and no definite trend was noticed.

Aggregate size distribution

The proportion of soil in various aggregate fractions sharply decreased with the increase in their size ranges and nearly 64–77% of soil was associated with <0.25 mm size of aggregates in all the depths (Table 2). The difference among treatments were significant in 0–0.10 and 0.10–0.20 m soil layers and down the profile, these were at par. Larger fractions within macro-aggregates showed a tendency of accumulation under no-tillage practices (NT and NTRM), though the effect of residue in conventional tillage (CTRI) was perceptible, especially in 0–0.10 and 0.10–0.20 m layers.

In 0–0.10 m layer, coarse macro-aggregates (2–8 mm) concentration in NT (0.059 g aggregate/g of soil) and NTRM (0.060 g aggregate/g of soil) was significantly higher than CTRI (0.042 g aggregate/g of soil) and more than twice of that in CT (0.029 g aggregate/g of soil). Similarly, large and small macro-aggregates were also in significantly higher amounts in both the no-tillage practices (NT and NTRM) as well as in CTRI than in CT. CT recorded significantly larger amount of micro-aggregates (<0.25 mm).

In next layer (0.10–0.20 m) also, coarse macro-aggregate proportion was significantly higher in NT and NTRM (0.055

Table 2 Aggregate size distribution and stability indices under tillage and residue management practices (Values followed by different letters in the same column are significantly different at P<0.05 level)

Soil depth (m)	Treatment	Size distribution of aggregates (g aggregate/g of soil)				Aggregate stability	
		<0.25mm	0.25-1 mm	1-2 mm	2-8 mm	Mean weight diameter (mm)	Aggregation ratio
0-0.10	CT	0.728^{a}	0.205^{b}	0.038^{b}	0.029^{c}	0.396^{c}	0.374^{b}
	CTRI	0.687^{bc}	0.226^{a}	0.046^{a}	0.042^{a}	0.477^{a}	0.457^{a}
	NT	0.644^{b}	0.231^{a}	0.067^{a}	0.059^{a}	0.591^{a}	0.553^{a}
	NTRM	0.640^{b}	0.230^{a}	0.069^{b}	0.060^{b}	0.591^{b}	0.602^{b}
0.10-0.20	CT	0.671^{a}	0.251^{a}	0.047^{a}	0.031^{b}	0.435^{b}	0.490^{ab}
	CTRI	0.672^{a}	0.237^{a}	0.038^{a}	0.053^{a}	0.525^{a}	0.488^{ab}
	NT	0.683^{a}	0.216^{b}	0.046^{a}	0.055^{a}	0.537^{a}	0.464^{b}
	NTRM	0.646^{a}	0.252^{a}	0.043^{a}	0.060^{a}	0.569^{a}	0.549^{a}
0.20-0.30	CT	0.729^{a}	0.212^{a}	0.038^{a}	0.022^{a}	0.361^{a}	0.372^{a}
	CTRI	0.705^{a}	0.241^{a}	0.030^{a}	0.024^{a}	0.374^{a}	0.418^{a}
	NT	0.704^{a}	0.232^{a}	0.034^{a}	0.029^{a}	0.404^{a}	0.420^{a}
	NTRM	0.707^{a}	0.228^{a}	0.039^{a}	0.026^{a}	0.391^{a}	0.414^{a}
0.30-0.45	CT	0.736^{a}	0.209^{b}	0.033^{bc}	0.022^{a}	0.356^{a}	0.359^{a}
	CTRI	0.767^{a}	0.174^{a}	0.036^{ac}	0.023^{a}	0.354^{a}	0.304^{a}
	NT	0.765^{a}	0.179^{a}	0.037^{ac}	0.019^{a}	0.337^{a}	0.307^{a}
	NTRM	0.766^{a}	0.167^{a}	0.043^{a}	0.023^{a}	0.361^{a}	0.305^{a}

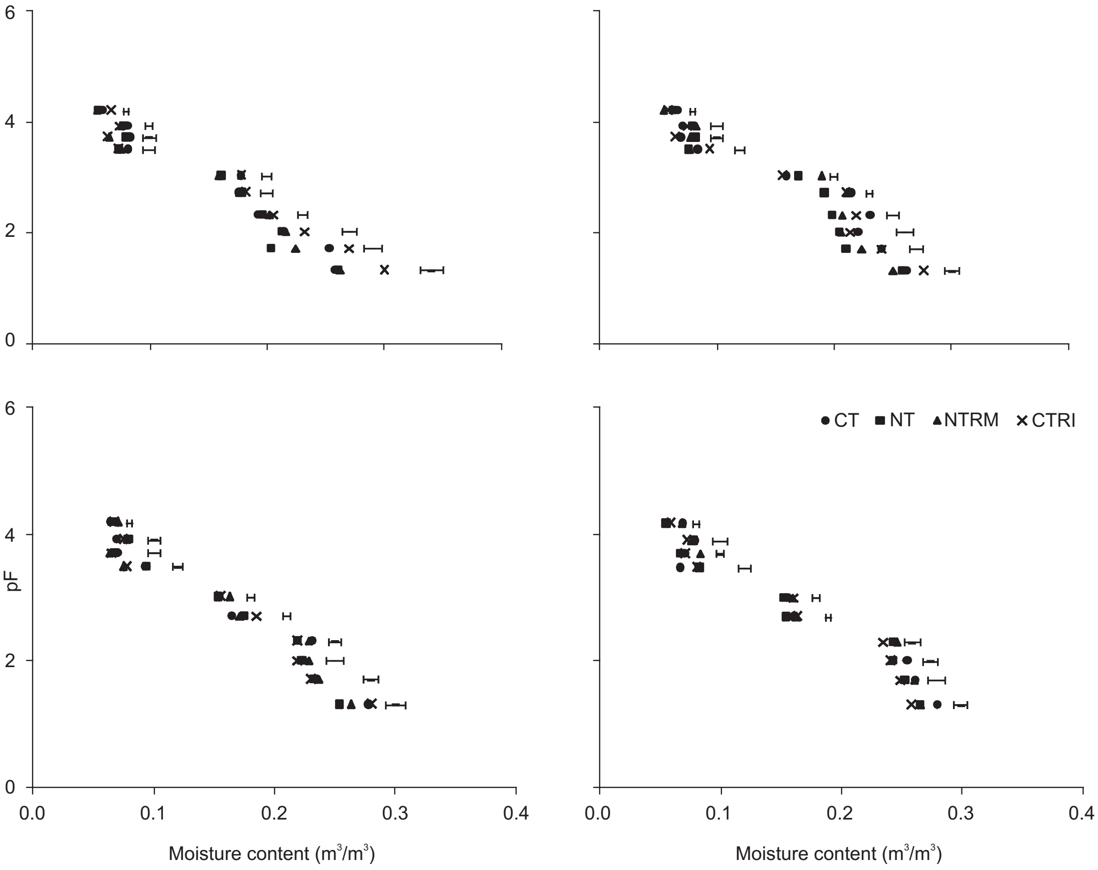

Fig 1 Soil moisture content at a) 0-0.10 m, b) 0.10-0.20 m, c) 0.20-0.30 m, and d) 0.30-0.45 m layers as affected by long-term tillage and residue management practices. (Horizontal bars indicate LSD at $P<0.05$)

and 0.060 g aggregate/g of soil, respectively) than in CT (0.031 g aggregate/g of soil), but was similar to CTRI (0.053 g aggregate/g of soil). In other size fractions, differences were non-significant. In rest of the layers (0.20–0.30 and 0.30–0.45 m), neither tillage nor the residue management could produce any significant variations in relative distribution of various size fractions of aggregates.

The aggregation index (MWD of aggregates) could clearly differentiate the conventional tillage (no residues incorporated, CT) from rest of the practices in both 0–0.10 and 0.10–0.20 m layers, while in other two layers, no significant differences were recorded. The MWD was significantly lower in conventional tillage (0.396 mm) as against 0.477, 0.591 and 0.591 mm in CTRI, NT and NTRM, respectively, in 0.0.10 m layer. Similar trend was noticed in 0.10–0.20 m layer too.

The apparently higher micro-aggregates in CT in top (0–0.10 m) layer clearly explained the possible breakdown of macro-aggregate fractions into their smaller sizes. The residue effect was more visible in conventional practices than no-tillage, where higher fractions of coarse, large and small macro-aggregates were detected in tillage with residue incorporation. Most of the prominent differences were confined to upper 0–0.10 m soil. Results showing significant improvement in soil aggregation and the improvement of average MWD due to the interactive effect of absence of soil disturbance and residue mulch cover under no-tillage. The aggregate size distribution indicated that there has been a larger effect of omission of tillage on soil structure than residue management (Chakraborty *et al.* 2010).

Soil moisture retention and pore size distribution

Considerable variation in soil moisture retention among the treatments at different potential values was observed in the entire range of the pF curve (Fig 1). In surface (0–0.10 m) layer, CTRI retained significantly higher moisture (0.300 m^3/m^3) at higher potential (pF 1.3, –2 kPa) compared to the other treatments, though at pF 1.7 (– 5 kPa) moisture retained was significantly higher (0.271 m^3/m^3) in CTRI compared to NTRM (0.225 m^3/m^3) and NT (0.204 m^3/m^3) but was at par with CT (0.254 m^3/m^3). At lower potential values (> –10 kPa), treatments did not show any appreciable differences. Though soil organic C was higher in NTRM plots, its effect in increasing water retention at higher potential was possibly nullified by presence of greater number of macro-pores. Water retention at –1500 kPa was not appreciably different among treatments, though NTRM and CTRI could retain significantly higher amount of water between –33 and –1500 kPa.

In 0.10–0.20 m layer, moisture retention at relatively higher suctions (pF 1.3, 1.7 and 2.3) was significantly different between conventional and no-tillage, and the effect of residue management in respective tillage was not pronounced. In 0.20–0.30 and 0.30–0.45 m layers, the moisture retention values at various potentials did not show any appreciable difference and the shapes of the moisture retention curves were similar. In none of the layers, difference among treatments at wilting point potential (4.2 pF) was observed indicating negligible effect of tillage and residue management in modifying the water retention characteristic near wilting point, which is fundamentally guided by the soil texture.

A significant higher portion of macro-pores (at pF > 2.3) was recorded in NT and NTRM in 0–0.10 and 0.10–0.20 m layers. For rest of the layers, the macro–pores were nearly the same among the treatments (Table 3). In 0–0.10 m layer, volume of macro-pores was 0.181 and 0.186 m^3/m^3 in NT and NTRM, respectively, which was 40% higher than CT and 30% higher than CTRI. Similar trend was noticed in 0.10–0.20 m also, where the no-tillage practices resulted in macro-pores volume to the tune of 0.153 m^3/m^3, which was 30–35% higher than the conventional tillage practice. In 0.20–0.30 and 0.30–0.45 m layers also the macro-pores were higher under no-tillage, though the difference was non-significant (Chakraborty *et al*. 2010, Kumari *et al.* 2011).

In all the tillage or residue management practices or soil depths, the transmission and residual pores together constituted nearly 30–35% of total pores. In 0–0.10 m layer, the transmission pore volume was significantly higher in CTRI (0.067 m^3/m^3) compared to NT (0.048 m^3/m^3), NTRM (0.047 m^3/m^3) and CT (0.043 m^3/m^3). However, the NTRM, where the transmission and storage pores together occupied the highest space (0.346 m^3/m^3), was at par with NT (0.337 m^3/m^3) and CTRI (0.320 m^3/m^3) but significantly different than CT (0.296 m^3/m^3). But difference in storage pore volume was non-significant in this layer. In 0.10–0.20 m layer, CTRI recorded significantly higher transmission pores (0.062 m^3/m^3) compared to both NTRM (0.045 m^3/m^3) and CT (0.042 m^3/m^3) but was at par with NT (0.053 m^3/m^3), possibly because the transmission pores constitute a part of macro-pores (transmission pores retained water at 0.2–1.0 m of suction head while macro-pores corresponds to water held between 0-0.5 m suction head). The storage pores were at par among the treatments.

Table 3 Pore size distribution under different tillage and residue management practices. (Mp: macro-pore; Tp: transmission pore; Sp: storage pore and Rp: residual pore); values followed by different letters in the same columns are significantly different at the P<0.05 level

Depth (m)	Treatment	Different pore volume (m^3/m^3)			
		Mp	Tp	Sp	Rp
0-0.10	CT	0.142^{b}	0.043^{b}	0.154^{a}	0.296^{a}
	CTRI	0.156^{b}	0.067^{a}	0.164^{a}	0.320^{a}
	NT	0.181^{a}	0.048^{b}	0.156^{a}	0.337^{a}
	NTRM	0.186^{a}	0.047^{b}	0.160^{a}	0.346^{a}
0.10-0.20	CT	0.125^{b}	0.042^{b}	0.153^{a}	0.278^{ab}
	CTRI	0.117^{b}	0.062^{a}	0.155^{a}	0.272^{b}
	NT	0.151^{a}	0.053^{ab}	0.141^{a}	0.293^{ab}
	NTRM	0.153^{a}	0.045^{b}	0.150^{a}	0.304^{a}
0.20-0.30	CT	0.099^{a}	0.054^{ab}	0.159^{a}	0.258^{a}
	CTRI	0.096^{a}	0.062^{a}	0.152^{a}	0.248^{a}
	NT	0.115^{a}	0.031^{b}	0.157^{a}	0.272^{a}
	NTRM	0.114^{a}	0.035^{b}	0.158^{a}	0.272^{a}
0.30-0.45	CT	0.093^{a}	0.025^{a}	0.187^{a}	0.280^{a}
	CTRI	0.102^{a}	0.018^{a}	0.184^{a}	0.286^{a}
	NT	0.110^{a}	0.022^{a}	0.189^{a}	0.299^{a}
	NTRM	0.107^{a}	0.025^{a}	0.174^{a}	0.280^{a}

Though the macro-pores were higher in NT and NTRM, the transmission pores in 0.20–0.30 m layer was higher in CTRI (0.062 m^3/m^3) than no-tillage treatments. The CT treatment, where residues were always removed, showed lower value of transmission pores (0.054 m^3/m^3) compared to CTRI, but the difference was non-significant. In 0.30–0.45 m layer, the pore size difference was marginal and non-significant indicating the limit of influence by tillage and residue management over the years up to 0.30 m of soil depth.

The pore size distribution data at both 0–0.10 and 0.10–0.20 m depths suggested that the differences in their distribution between the tillage treatments were relatively greater in structural than those in textural domain of soil moisture retention curve. This significantly implies the seasonal loosening effect of the conventional tillage (Lipiec *et al*. 2006). Though the macro-pores (0.20–0.30 m layer) were higher in NT or NTRM, higher transmission pore volume in CTRI despite of the fact that the bulk density values at this layer were statistically at par, indicated the effect of long-term incorporation of residue in CTRI in improving the soil structure (as evidenced by the increase in number of medium sized pores).

Total organic carbon (TOC)

A significant difference in TOC was observed due to different tillage and residue management practices. In 0-0.10 m soil layer, TOC content in NTRM (1.57%) was significantly higher compared to CTRI (1.35%), NT (1.17%) and CT (1.11%) (Fig 2). This higher amount of TOC in NTRM plots could be attributed to continuous retention of crop residue on soil surface and the minimum disturbance of soil layers due to tillage practices. The left-over organic material led to build up of soil C, which would otherwise not possible with either traditional tillage practice or with no-tillage where residues were removed. This was more evidenced by the difference in TOC between CT and NT, which was much low

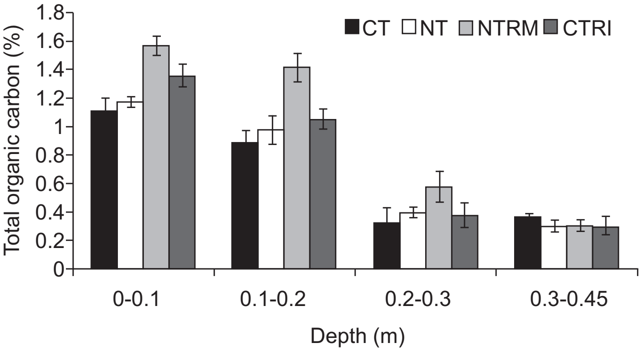

Fig 2 Total organic C as affected by tillage and residue management practices (Vertical bars indicate standard error at P<0.05)

(0.06%) compared to the same between CTRI and NTRM (0.21%). The marginal difference of TOC content between CT and NT also indicated that the effect of tillage got better manifestation with residue management practices.

Similar trend in TOC was observed in 0.10–0.20 m layer though the C-content was significantly lower than the 0–0.10 m soil. In this layer also, a significantly greater amount of TOC was recorded in NTRM (1.41%) compared to CTRI (1.05%), NT (0.97%) and CT (0.88%). Thereafter, TOC sharply reduced and in 0.20–0.30 m, only NTRM showed marginally higher amount of TOC than rest of the tillage and residue management treatments; the effect of NT and CT was similar. In 0.30–0.45 m layer, very less amount (0.2–0.3%) of TOC was recorded and no difference was visible between tillage or residue management practices.

The higher amount of TOC at 0.10–0.20 m depth in NTRM (34 and 41% over NT and CT and 16% over CTRI) plots could be attributed to retention of crop residue on soil surface and the minimum disturbance of soil layer due to tillage practices (more impounding of C in soil). The left-over organic material as mulch gradually led to build up of soil C, which would otherwise not possible with either traditional tillage practice or with no-tillage where residues were removed.

CONCLUSIONS

Residue retention as surface mulch along with omission of tillage may significantly and positively improve soil hydro-physical properties under the present soil and climatic condition in pigeonpea-wheat rotation.

REFERENCES

Alletto L and Coquet Y. 2009. Temporal and spatial variability of soil bulk density and near-saturated hydraulic conductivity under two contrasted tillage management systems. *Geoderma* **152:** 85–94.

Alvarez R and Steinbach H S. 2009. A review of the effects of tillage systems on some soil physical properties, water content, nitrate availability and crops yield in the Argentine Pampas. *Soil and Tillage Research* **104:** 1–15.

Álvaro-Fuentes J, Cantero-Martínez C, López M V, Paustian K, Denef K, Stewart C E and Arrúe J L. 2009. Soil aggregation and soil organic carbon stabilization: effects of management in semiarid Mediterranean agroecosystems. *Soil Science Society of America Journal* **73**: 1 519–29.

Blake G R and Hartge K H. 1986. Bulk density. (*In*) *Methods of Soil Analysis*, *Part 1, 2nd edition* pp 363–75. A Klute (Ed). ASA Agronomy Series No. 9, Madison, Wisconsin, USA.

Chakraborty D, Garg R N, Tomar R K, Dwivedi B S, Aggarwal P, Singh, Ravender, Behera U K, Thangasamy A and Singh D. 2010. Soil physical quality as influenced by long-term application of fertilizers and manure under maize-wheat system. *Soil Science* **175**(3): 128–36.

Derpsch R. 2005. The extent of conservation agriculture adoption worldwide: implications and impact. (*In*) *Proceedings of Paper Presented at 3rd World Congress on Conservation Agriculture,* Nairobi, Kenya.

Derpsch R and Friedrich T. 2009. Global overview of conservation agriculture Adoption. (*In*) *Proceedings of Lead Papers, 4th World Congress on Conservation Agriculture* New Delhi, India pp 429–438.

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research*. John Willey & Sons, NY.

Kemper W D and Rosenau R C. 1986. Aggregate stability and size distribution. (*In*) *Methods of Soil Analysis*, *Part I,* pp 425–42. (Klute A (Ed.); American Society of Agronomy, Series No. 9, Madison, Wisconsin, USA.

Klute A.1986. Water retention: Laboratory Methods. (*In*) *Methods of Soil Analysis, Part I,* pp 635–62. Klute A (Ed). American Society of Agronomy, Series No. 9, Madison, Wisconsin, USA.

Lipiec J, Kuœ J, S³owiñska-Jurkiewicz A and Nosalewicz A.2006. Soil porosity and water infiltration as influenced by tillage methods. *Soil and Tillage Research* **89:** 210–20.

López-Fando C, Dorado J, Pardo M T. 2007. Effects of zone-tillage in rotation with no-tillage on soil properties and crop yields in a semi-arid soil from central Spain. *Soil and Tillage Research* **95**: 266–76.

Kumari M, Chakraborty D, Gathala M, Pathak, H, Dwivedi B S, Tomar R K, Garg R N, Singh R and Ladha J K. 2011. Soil aggregation and associated organic matter fractions as affected by tillage in a rice-wheat rotation in north India. *Soil Science Society of America Journal* **75** (2) doi:10.2136/sssaj2010.0185

Osunbitan J A, Oyedele D J and Adeklu K O. 2005. Tillage effects on bulk density, hydraulic conductivity and strength of a loamy sandy soil in southwestern Nigeria. *Soil and Tillage Research* **82**: 57–64.

Singh V K, Dwivedi B S, Shukla A K and Mishra R P. 2010. Permanent raised bed planting of the pigeonpea-wheat system on a Typic Ustochrept: Effects on soil fertility, yield, and water and nutrient use efficiencies. *Field Crops Research* **116**: 127–39.

Synder J D and Trofymow J A. 1984. A rapid accurate wet oxidation diffusion procedure for determining organic and inorganic carbon in pot and soil samples. *Communication in Soil Science and Plant Nutrition* **15**: 587–97.

SPSS .2004. Version 13.0. *Command Syntax Reference 2004*, SPSS Inc., Chicago, IL.

Yoder R E. 1936. A direct method of aggregate analysis and study of the physical nature of erosion losses. *Journal of the American Society of Agronomy* **28:** 337–51.