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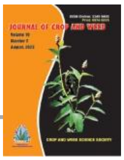

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Conservation agriculture practices influenced soil water retention parameters of *Inceptisol* of lower *Gangetic* plains

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ABSTRACT

Purpose of this experiment was to evaluate the impact of conservation agricultural (CA) practices on soil water retention parameters (moisture content at saturation, á, n, residual water content) of soils of the lower Indo-Gangetic Plains of West Bengal. The split plot experimental design was followed as 3 tillage systems [conventional tillage (CT), reduced tillage (RT) and zero tillage (ZT)] were assigned in main plots, and 3 combinations of residue and nutrient treatments [0% rice residue+100% RDF fertilization, 100% residue+75% RDF fertilization and 50% residue+75% RDF fertilization] were assigned in sub-plots. ZT resulted in the lowest moisture content at saturation and lowest á causing a higher degree of water retention at a particular tension. Moreover, a higher n value at ZT and residue retained plots can be implied as soils with better pore-size distribution and pore connectivity. Thus, it can be concluded that CA practices improved water retention properties of soil by influencing van Genuchten parameters and contributed to higher soil water retention.

***Keywords*:** Clayey soil, conservation agriculture, rice-based cropping system, soil water retention, van Genuchten parameters

The post-green revolution era is known for remarkable enhancement in food productivity, despite climbing land scarcity and its values. Intensive cultivation practices lead to exposure of farmers to several production constraints for achieving a sustainable, cost-effective and assured return from their field. Thus, from the context of economical obscurities, declining agricultural production, farmers must be fortified with a new set of cultural practices for achieving a sustainable and assured cost-effective production from their lands for ever mounting population. The principal signs for unsustainability of agricultural systems across the world are: 1) tillage-induced reduction of organic matter, destruction of soil structure, escalated rate of erosion (water and wind), reduced infiltration rate, crusting and compaction of soil, (2) inadequate return of organic materials into soil, and (3) monocropping. From this background, the theory of conservation agriculture (CA) has been developed as a substitute to this tillage-based insufficient production system which embraces three major principles: (1) minimum soil tilling, (2) keeping permanent soil cover and (3) crop diversification (FAO, 2016). CA helps in supervision Agro-ecosystems for persistent productivity, profitability and food security while preserving the resources as well as the environment (Somasundaram *et al*., 2020).

CA ameliorates soil aggregation, boosts biological activity, carbon sequestration (Bunemann *et al*., 2018), conserves water by reducing evaporation loss (Teame et al., 2017), restricts erosion (Patil et al., 2013), controls weeds and ultimately increases the yield (Das *et al*., 2018). Further, consideration the physical condition of soil is vital due to their direct as well as indirect effects on water, nutrient absorption and contribute to the optimum plant development (Dexter, 2004). Better aggregation status under CA reported to improve the gaseous exchange from soil to atmosphere and vice-versa, promote optimum soil water movement in turn influence bio-availability of nutrients which in all together improve the root growth and subsequent growth of plant and its yield. Further, soil water retention is a vital physical attribute of soil which demonstrate the status of water in soil at a particular matric suction. It is commonly observed that amount of retained water is correlated with bulk density, texture and organic matter content (Nasta *et al*., 2009; Grosbellet *et al*., 2011).

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Generally, smaller pores retain more water at higher pressures and soil water as a function of suction permits an estimation of the pore size distribution of a sample soil (Nimmo, 2005).

Modelling of soil water flow is a useful tools for the behavioural analysis of the soil-water system. Till date, plenty of model equations were formulated to express soil hydraulic functions properly, and among them van Genuchten model (van Genuchten, 1980) is widely used for estimation of soil water retention characteristics curve (SWRC). SWRC is uniquely defined as the relationship between the amount of soil moisture present and the corresponding energy state/suction within the pore. Precise estimation of hydraulic parameters (including SWRC parameters) is prerequisite for quantification of soil hydraulic functions. The van Genuchten function describes water retention data (van Genuchten, 1984)

$$\theta = \theta_r + \left[\frac{\theta_s - \theta_r}{(1 + (\alpha\psi)^n)^m}\right]$$

Where, θ is the soil moisture ($cm^3\ cm^{-3}$), Ψ is the matric suction (cm), θ *s* is moisture content at saturation, θ *r* is residual soil moisture content, m and n are model parameters. The curve-fitting parameters α, *n*, and θ *r* are obtained from non-linear regression of Eq. 1 on SWRC data. The α parameter is associated inversely to the air entry suction for drying, the n parameter describes the slope of the SWRC, and θ *r* refers to the lowest realistically obtainable moisture content (θ *r* is near or equals to zero for properly measured SWCC). Further, soils with bigger pores generally have higher α, and lower n demonstrate soils with a broader range of pore size distribution. Moreover, soils contained minerals with low surface charge density as well as lesser affinity for hydration also retain lower soil moisture at a particular matric tension and resulting in larger α (Tinjum *et al.*, 1997), The SWRC is steep when the n is large, with a rapid decrement in water content as Ψ tend to be more negative. However, lower n value demonstrate more gradual change in moisture content upon change in matric suction.

The SWRC governs the distribution of soil pores with different diameter in a particular soil and soils with larger pores diameter get desaturated and retain a lesser amount of water (at a particular matric suction) compared to soils with smaller pore diameter (Lu and Likos, 2004). The amount of retained moisture for soils with a wider pore size distribution changes more gradually upon concominant variation in matric suction (Hillel, 1998). Further, texture is considered as one of the most important factor determining SWRC and the coarse-textured structured soils exhibit lower soil water retention (Nasta *et al.*, 2009). Moreover, soil organic matter content could also modify SWRC. Rawls *et al*. (2003) reported that the impact of organic matter on soil water retention is more conspicuous at higher water potentials than at low water potential. Thus, the present experiment was conducted to find out the impact of conservation management practices on van Genuchten parameters and to identify the suitable practices for set of CA practices in terms of water retention parameters for the lower Gangetic plains of West Bengal.

MATERIALS AND METHODS

Current experiment was conducted throughout the eight cropping seasons during 2018-2021 at Bidhan Chandra Krishi Viswavidyalaya, Nadia and the cropping was rice-mustard-black gram. The experimental site lies between 22°58′N latitude, 88°32′E longitude. The climate is of the experimental station is hot and humid subtropics with 1470 mm average annual rainfall, while the mean annual minimum and maximum temperature are 18ºC and 35ºC. The soil of the study site comes under clayey textural class (7.1% sand, 30.1% silt and 63.8% clay) with hyperthermic temperature regime. On the basis of soil analysis, it was low in organic carbon (9.1 kg^{-1}), available nitrogen (222.1 kg ha^{-1}), available P_2O_5 (25.0 kg ha^{-1}) and K_2O (297.6 kg ha^{-1}), whereas pH was near neutral with reading 7.39 and EC was 0.97 ds m^{-1} (AOAC, 2006). Split plot design was followed with 3 tillage systems [conventional tillage (CT), reduced tillage (RT) and zero tillage (ZT)] in main plots, and 3 combinations of residue and nutrient treatments [0% rice residue+100% RDF fertilization, 100% residue+75% RDF fertilization and 50% residue+75% RDF fertilization] in sub-plots.

Experimental field was prepared by tillage implements in CT and RT, whereas field was left un-tilled under ZT. Sub-plot treatments were assigned depending upon doses of residue and fertilizers for cultivation of *rabi* and pre-*kharif* crops. After harvesting rice, rice straw were used as mulch before sowing of mustard. The total rice straw production was considered as 100% and a quantity of 50% and 100% of total rice straw were retained in the field for corresponding treatments.

Soil samples were collected in 2021 (after 8 cropping seasons) after harvesting of mustard from two soil depths viz. 0-10 cm and 10-20 cm with an auger from each replication. After hand crushing, the remaining soil samples were air-dried, processed and passed through the 2.0 mm sieve. Processed bulk soil samples were preserved for the laboratory analyses. Undisturbed soil samples were collected form two soil depths (0-10 cm and 10–20 cm) by using core sampler each replications every plots which were further analysed to estimate soil water retention characteristics curve (Klute and Dirksen, 1986). After saturating soil samples, six levels of matric suction (Ψ, viz. -10, -33, -66, -200, -500, and -1500 kPa) was successively applied. Water retention at -10 kPa suction was estimated by using wall hanging column and successive water retention higher matric suctions (-33, -66, -200, -500, and -1500 kPa) were estimated by using pressure plate apparatus. van Genuchten (1980) parameters were fitted to the SWRC experimental data by following van Genuchten equation:

$$\theta = \theta_r + \left[\frac{\theta_s - \theta_r}{(1 + (\alpha\psi)^n)^m}\right]$$

here θ is the soil moisture ($cm^3\ cm^{-3}$) at particular matric potential, Ψ represents the matric potential (kPa), θ_s is the soil moisture content at saturation, θ_r is the residual soil moisture content, and α, m and n are SWRC fitting parameters. By fitting SWRC data in van Genuchten equation we derived model parameters i.e. α, m, n and θ_r . *Soil* par software (Acutis and Donatelli, 2003) was used for curve fitting.

RESULTS AND DISCUSSION

A perusal of data revealed significant effects of tillage, residue management and depth of soil on moisture content at saturation (θs) of soil (Figure 1a, Table 1 and 2). The CT (0.431 $cm^3\ cm^{-3}$) resulted in the significantly highest θs of soil which was 1% higher than the ZT (0.426 $cm^3\ cm^{-3}$). Similar trends were found in surface and sub-surface soil, however, the effect of tillage was non-significant in the case of surface soil. For residue and nutrient management treatments, R3 (50% residue+75% RDF fertilization) resulted in 7%, 1% higher θs over the corresponding values from R1 (0% residue+ 100% RDF fertilization). Surface soil (0.438 $cm^{-3}\ cm^{-3}$) was found to have 1.05 times higher θs over subsurface soil (0.418 $cm^{-3}\ cm^{-3}$). Further, a significant interaction among tillage and residue management was observed and CT-R2 resulted in the highest θs for the 0-20 cm soil layer. In this experiment, we have encountered a reverse trend as CT resulted in the highest θs and ZT lowest. Experimental soil came under heavy clayey soil which was principally dominated by micropores than macropores. Thus, practising ZT resulted in an increment in soil bulk density which further diminished the amount of macropore and total porosity of soil and ultimately resulted in decreasing θs (Verheijen *et al*., 2019). However, retention of crop residues enhanced the θs due presence of higher quantity of organic matter (Nath *et al*., 2014).

Both conservation tillage and residue retention significantly influenced α of the surface soil layer (Fig. 1b, Table 1 and 2). RT resulted in the highest value of α which was 2.38 times higher than ZT plots and statistically at par with CT. R3 (50% residue retention + 75% of RDF fertilization) resulted in the highest corresponding value of α at surface soil which was 1.5 and 1.64 times higher than R2 and R1. The interaction among tillage and residue addition found to be non-significant, but RT-R3 showed the highest corresponding value and ZT-R3 the lowest. However, at subsurface soil layer (10-20 cm) only the impact of residue management found to be significant as R2 (100% residue+75% RDF fertilization) demonstrated the highest corresponding value and both the impacts of tillage and interaction between tillage and residue management imparted non-significant. For, overall soil depth only the impact of tillage was found to be significant and ZT had the lowest value. Impact of soil depth was also non-significant.

The air-entry value or $1/\alpha$ is describes the particular matric suction when air starts entering into the largest soil pores and also associated with pores forming an uninterrupted flow paths of water (Assouline *et al*., 1998). Higher air entry values ($1/\alpha$) or lower α value under zero tillage implied that soil under ZT management required lower potentials of water, and that's why more time needed to unsaturated specially after irrigation or rainfall. Martinez *et al*. (2008) observed the similar results after evaluating the performance of 4 year and 7 year old conventional and no-tillage systems at Mediterranean environment of Chile, respectively. They found 2.35 times increase in α of surface soil under CT over no-tillage. Sancho *et al*. (2017) also reported increase in α under CT due to loosening of surface soil. Addition rice crop residues also showed significant decrement in á due to loosening of soil and reduction in bulk density.

Impact of tillage was found to be significant on n value for surface soil and overall soil layer (Fig. 1c, Table 1 and 2). For overall soil layer, ZT had the highest value which was 1.08 and 1.06 times higher than CT and RT, respectively. However, impact of residue management was found to be non-significant at surface soil and, significant effects were observed at subsurface and overall soil layer. For, overall soil layer R3 (50% residue+75% RDF fertilization) showed the highest value of n which was 1.05 and 1.03 times higher than R1 and R2, respectively. Interaction of tillage and residue management was non-significant at each of the soil depths. Across all of the treatments, sub-surface soil showed 1.03 times higher n value than surface soil.

Our results were in association with previous scientific findings (Hartmann *et al*., 2012) who reported lower n values under CT in comparison with conservation tillage. The *n* is a dimensionless unit which express size distribution of soil pores and, generally

Table 1 : Conservation agriculture treatments and their interaction effects on van Genuchten parameters

Treatments		Saturated moisture content (θs, cm^3 cm^{-3})			α (cm^{-1})			n			Residual water content (θr, cm^3 cm^{-3})		
		0-0.10 m	**0.10-0.20 m**	**Mean**	**0-0.10 m**	**0.10-0.20 m**	**Mean**	**0-0.10 m**	**0.10-0.20 m**	**Mean**	**0-0.10 m**	**0.10-0.20 m**	**Mean**
CT	R1	0.425aA	0.414bcB	0.420de	0.041bA	0.047aA	0.044ab	1.160aB	1.183aA	1.172a	0.097aB	0.137aA	0.117a
	R2	0.440aA	0.436aB	0.438a	0.037bcA	0.044aA	0.041abc	1.083aB	1.110aA	1.097a	0.010aB	0.033aA	0.017a
	R3	0.454aA	0.417bcB	0.435ab	0.032bcA	0.019aA	0.026cd	1.117aB	1.240aA	1.179a	0.037aB	0.133aA	0.085a
ZT	R1	0.425aA	0.413bcB	0.419de	0.016bcA	0.020aA	0.018d	1.167aB	1.293aA	1.230a	0.093aB	0.183aA	0.138a
	R2	0.437aA	0.414bcB	0.425cd	0.012bcA	0.040aA	0.026cd	1.280aA	1.143aB	1.212a	0.163aA	0.093ab	0.128a
	R3	0.449aA	0.421bB	0.435ab	0.012cA	0.021aA	0.017d	1.300aA	1.293aA	1.297a	0.197aA	0.177aA	0.187a
RT	R1	0.422aA	0.411cB	0.416e	0.020bcA	0.033acA	0.026cd	1.140aB	1.190aA	1.165a	0.073aB	0.100aA	0.087a
	R2	0.443aA	0.419bcB	0.431bc	0.032bcA	0.029aA	0.030bcd	1.160aB	1.187aA	1.174a	0.067aB	0.103aA	0.085a
	R3	0.452aA	0.420bcB	0.436ab	0.080aA	0.026aA	0.053a	1.107aB	1.287aA	1.197a	0.047aB	0.193aA	0.120a

Different letters are significantly different at $p < 0.05$ according to Duncan multiple range test. Different lowercase letters in vertical line denotes the interaction effects between tillage and residue management and different upper class letters in horizontal line denotes effect of soil depth

Table2: Impact of residue management on van Genuchten parameters of experimental soil. Error bars indicating standard error of mean.

Treatments	Saturated moisture content (θs, cm^3 cm^{-3})			α (cm^{-1})			n			Residual water content (θr, cm^3 cm^{-3})		
	0-0.10 m	**0.10-0.20 m**	**Mean**	**0-0.10 m**	**0.10-0.20 m**	**Mean**	**0-0.10 m**	**0.10-0.20 m**	**Mean**	**0-0.10 m**	**0.10-0.20 m**	**Mean**
R1	0.424cA	0.413bB	0.419c	0.0287aA	0.0334aA	0.0311a	1.156aB	1.222abA	1.189ab	0.088aB	0.140aA	0.114a
R2	0.440bA	0.423aB	0.431b	0.0268aA	0.0376aA	0.0322a	1.174aA	1.147aA	1.161b	0.110aA	0.077bA	0.094a
R3	0.452aA	0.419aB	0.435a	0.0413aA	0.0219bA	0.0316a	1.174aB	1.273aA	1.224a	0.093aB	0.168aA	0.1305a

Different letters are significantly different at $p < 0.05$ according to Duncan multiple range test. Different lowercase letters in vertical line denotes the effects of residue management and different upper class letters in horizontal line denotes effect of soil depth

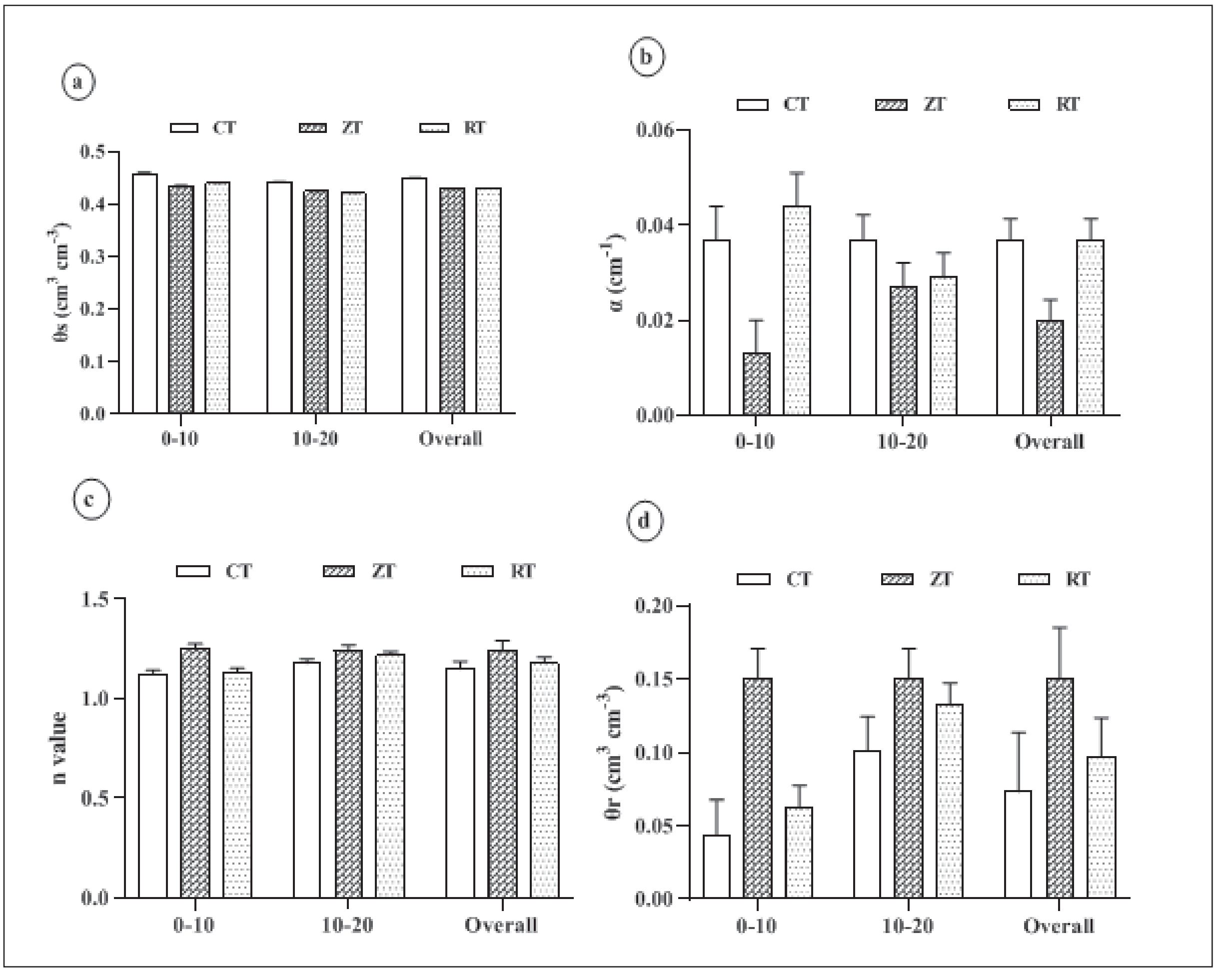

Fig. 1 (a-d): Impact of tillage on van Genuchten parameters of experimental soil. Error bars indicating standard error of mean

higher n value implies for greater moisture reduction rate (Fang *et al.*, 2023). Thus, higher moisture reduction rate under ZT attributed to the better pore space orientation over CT. Similarly, rice residue retention also demonstrated higher moisture reduction rate due optimum pore size orientation which resulted in better soil water retention properties (Li *et al.*, 2019).

Significant effect of tillage on θ*r* at surface soil layer and overall soil layer were observed (Figure 1d, Table 1 and 2). The impact of conservation tillage was found to be prominent as ZT resulted in 2.06 and 1.55 times higher θ*r* over CT and RT, respectively. Considering the impact of residue retention, R3 resulted in 48 and 70% higher θ*r* over R1 and R2, respectively. However, impact of residue retention was non-significant at surface soil layer. Moreover, tillage and residue management interaction was found to be non-significant at each of the soil layers. Depth of soil significantly influenced the θ*r* as sub-surface soil showed 1.49 times higher corresponding value than surface soil.

The greater the value of θ*r* implies stronger water adsorption capacity of soil. Soil under ZT system causes densification due to absence of physical soil manipulation and concomitant compaction along with precipitation and applied irrigation water (Kundu *et al.*, 2021). Higher bulk density in ZT resulted in subsequent increase micropores which retain water with strongly and as result greater degree of θ*r* is achieved. In case of residue management treatments, 100% retention of rice residues over soil surface cause concomitant decrease in soil bulk density and lesser value of θ*r*.

CONCLUSION

The current study demonstrated the impact of short term CA practices on van Genuchten model parameters and ultimately influenced the soil water retention characteristics of the experimental soil. Practicing zero tillage resulted in lowest moisture content at saturation and á causing higher degree of water retention at a particular tension. It can be interpreted as minimized water loss over conservation tillage system. However, higher n value at ZT and residue retained plots can be implied as soils with better pore-size distribution and pore connectivity. Thus, it can be concluded that conservation management practices influenced the water retention properties of soil by influencing van Genuchten parameters and contributed to higher retention of soil water.

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