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EFFECT OF MINIMUM TILLAGE AND CONVENTIONAL TILLAGE PRACTICE ON SOIL PHYSICAL PROPERTIES UNDER GROUNDNUT-BASED CROPPING SYSTEMS IN *VERTISOL*

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ABSTRACT

A field experiment was carried out to study the effect of tillage practices on soil physical properties under groundnut based cropping systems in *vertisol* during the year 2022-23 *Kharif* and *Rabi* seasons and conducted at the MARS, UAS, Dharwad. The experiment was laid out in strip plot design with two tillage practices in main-plot *i.e.*, minimum tillage with crop residue incorporation (MT) and conventional tillage without residue (CT) and four cropping systems in sub-plots (groundnut + pigeon pea, groundnut + cotton, groundnut + chilli, groundnut-wheat cropping systems). At 0–15 cm soil depth, minimum tillage with crop residue incorporation significantly improved soil physical properties by reducing bulk density (1.20 Mg m^{-3}), increasing porosity (52.14%), and enhancing aggregate stability (62.42%) compared to conventional tillage. The groundnut + pigeon pea system also improved porosity (50.88%), field capacity (27.53%), and water holding capacity (55.05%). Available water content was higher under minimum tillage (4.45 cm), while cropping systems showed no significant effect. Soil moisture content at 60 and 90 DAS was significantly greater under minimum tillage and groundnut + pigeon pea system at both 0–15 and 15–30 cm depths. Overall, minimum tillage with residue and groundnut + pigeon pea system enhanced soil health in *Vertisol*.
***Keywords* :** Minimum tillage, Conventional tillage, Cropping systems, Soil physical properties

Introduction

Tillage is a fundamental component of crop production systems that significantly influences the physical, chemical, and biological properties of soil. The type and intensity of tillage practices directly affect soil structure, bulk density, porosity, water holding capacity, aggregate stability, and moisture dynamics, all of which are critical for root growth, water infiltration, and nutrient availability (Lal, 2004; Blanco and Lal, 2008). Conventional tillage, which often involves repeated soil disturbance and residue removal, can lead to soil compaction, reduced porosity, and increased erosion, especially in clay-rich soils like *Vertisols*. In contrast, conservation tillage practices, such as minimum tillage with crop residue retention, are known to enhance soil structure, improve soil moisture conservation, and maintain long-term soil health (Kemper and Derpsch, 2011).

Cropping systems also play a crucial role in influencing soil physical properties through differences in root architecture, biomass addition, and residue quality. Intercropping systems, particularly legume-based ones, contribute to improved soil aggregation, higher porosity, and greater soil moisture retention due to enhanced root activity and organic inputs (Lithourgidis *et al.*, 2011). Groundnut-based cropping systems are widely practiced in *Vertisols* of semi-arid regions due to their adaptability and soil-enriching potential. Integrating groundnut with legumes such as pigeon pea or cereals like wheat affects the temporal and spatial utilization of soil water and nutrients, thereby influencing soil physical characteristics (Bhattacharyya *et al*., 2008). In *Vertisols*, characterized by high clay content and poor drainage, conservation tillage combined with suitable cropping systems can be a sustainable approach to mitigate soil degradation and enhance physical soil quality. However, information on the interactive effects of tillage practices and diverse groundnut-based cropping systems on soil physical properties under *Vertisol* conditions is limited. Hence, this study was undertaken to evaluate the effects of different tillage practices and groundnut-based cropping systems on bulk density, porosity, aggregate stability, moisture content, and water holding parameters at surface and subsurface soil depths.

Material and Methods

A field experiment was laid out at Main Agricultural Research Station (MARS), Dharwad during *kharif* and *rabi* seasons of 2022-2023, respectively, involved a static field experiment initiated in 2020. The study area comes under Northern Transition Zone of Karnataka (Zone 8). Dharwad is situated at 15°26' latitude and 75°07' E longitude at an altitude of 678 m above the mean sea level. The data on climatic parameters such as rainfall, maximum and minimum temperatures and relative humidity recorded at Meteorological Observatory, Main Agricultural Research Station, Dharwad during the cropping period of the experimental year 2022 and 2023 are presented in Fig. 1. The experiment was carried out by adopting strip plot design (SPD) with four replications. The gross plot size was 4.8 x 4.0 m and the net plot size was 4.2 x 3.6 m. Initial properties of soil was depicted in the Table 1 below. The recommended dose of fertilizers (RDF) was applied to all the crops at the rate as mentioned in the package of practice, University of Agricultural Sciences, Dharwad for zone-8 in the form of Urea, Diammonium phosphate (DAP), Muriate of potash (MOP) and zinc sulphate, respectively.

Table 1 : Initial soil properties of experimental site and methods employed for the analysis of soil samples

Sl. No.	Soil characteristics	Minimum tillage plot	Conventional tillage plot
1.	Particle size analysis		
	Coarse sand (%)	6.0	6.0
	Fine sand (%)	14	14
	Silt (%)	27.8	27.8
	Clay (%)	52	52
	Textural class	Clay	Clay
2.	Bulk density of soil (Mg m^{-3})	1.28	1.36
3.	Porosity of soil (%)	51.9	47.9
4.	Maximum water holding capacity (%)	55.3	52.5
5.	Field capacity of soil (%)	27.7	26.4
6.	Available water (cm)	13.45	12.12
7.	Soil aggregate stability (%)	62.3	60.6

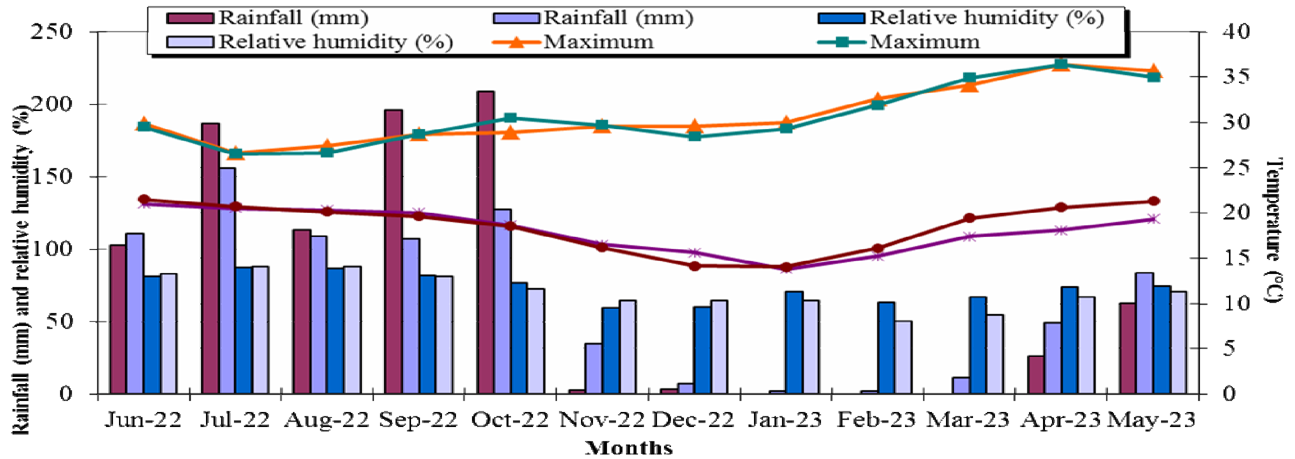

Fig. 1. Mean monthly meteorological data for the experimental year 2022 and 2023 along with mean of past 71

Treatments details

Main plot – Tillage systems (2)

1. M_1 - Minimum tillage with incorporation of previous year crop residue (Cultivator, Harrowing)
2. M_2 - Conventional tillage without incorporation of crop residue (Deep ploughing, Cultivator, Harrowing)

Sub plot – Cropping systems (4)

1. S_1 – Groundnut + Cotton (4:2)
2. S_2 - Groundnut + Pigeon pea (4:2)
3. S_3 - Groundnut + Chilli (4:2)
4. S_4 - Groundnut – Wheat

Statistical analysis of data

The data obtained from the experiment on various characters was subjected to statistical analysis as per the analysis of variance (ANOVA) technique for strip plot design as described by Gomez and Gomez (1984). The level of significance used in 'F' test was P = 0.05 and critical difference (CD) values were calculated where 'F' test was found significant.

Soil sample analysis

Composite soil samples were collected randomly from 0-15 cm and 15-30 cm depth from each plot after harvest. For soil moisture analysis, soil samples were collected at 60 and 90 DAS at depth of 0-15 and 15-30 cm soil depth in both season. Bulk density of the soil sample was determined by clod method (Black, 1965). Total porosity of the soil was calculated using the below formula.

$$\text{Porosity}(\%) = \left(1 - \frac{\text{Bulk density}}{\text{Particle density}}\right) \times 100$$

Water stability of the soil aggregates was measured by wet sieving method as outlined by Yoder (1936). Maximum water holding capacity of soil was determined by using Keen- Raczkowaski brass cup as described by Piper (1966). Results are expressed in per cent. Field capacity was determined by dividing the maximum water holding capacity by two. Values are expressed in per cent. The available water content was determined by multiplying of soil moisture, bulk density and depth of soil (Black, 1965). Soil moisture content determined by weighing the moist soil samples as it was at the time of sampling and dry weight is obtained after drying the sample to constant weight in an oven at 105 °C for 24 to 48 hours. The water lost by the soil represents the soil moisture in the moist soil.

$$\text{Soil moisture content}(\%) = \frac{\text{Weight of moist soil} - \text{Weight of oven dry soil}}{\text{Weight of oven dry soil}} \times 100$$

Results and Discussions

Effect of tillage practices and cropping systems on soil physical properties

Bulk density and Porosity

Soil bulk density and porosity at the end of the *kharif* and *rabi* seasons were significantly influenced by tillage practices and cropping systems at 0-15 cm depth, while no significant effects were observed at 15-30 cm depth (Table 2). Minimum tillage with crop residue incorporation recorded lower bulk density (1.20 Mg m^{-3}) and higher porosity (52.14%) compared to conventional tillage without residues (1.38 Mg m^{-3} and 47.89%), likely due to enhanced soil organic carbon (SOC) promoting aggregate formation and porosity. These findings align with Thomas *et al.* (2007) and Hernanz *et al.* (2014), who noted that the effects of tillage on soil physical properties are confined mostly to the topsoil. Tian *et al.* (2022) similarly reported lower bulk density under zero tillage compared to conventional tillage across multiple depths. Cropping systems also had a significant effect, with the groundnut-wheat system recording the highest bulk density (1.34 Mg m^{-3}) and lowest porosity (48.87%), while groundnut + pigeon pea and groundnut + cotton systems showed lower bulk density and higher porosity due to greater biomass addition and SOC inputs. These results are consistent with Mamta *et al.* (2020), who reported improved soil structure and porosity under intercropping due to enhanced organic matter and microbial activity.

Aggregate stability

Soil aggregate stability was significantly influenced by tillage practices, with minimum tillage combined with crop residue incorporation recording higher stability (62.42%) compared to conventional tillage (60.52%) (Table 3). This improvement is attributed to enhanced soil organic carbon (SOC) and microbial activity under minimum tillage, which promote the formation and stabilization of macro-aggregates, as supported by He *et al.* (2009) and Bronick and Lal (2005). Conventional tillage, in contrast, disrupts soil structure and breaks down binding agents such as root fragments and fungal hyphae, leading to poor aggregation. Although cropping systems did not show significant differences overall, groundnut + pigeon pea and groundnut + cotton systems tended to enhance aggregate stability due to greater biomass return and organic inputs compared to the groundnut-wheat system. This is consistent with findings by Degryze *et al*., (2005), who observed that fresh biomass inputs increase aggregate formation and water-holding capacity. Overall, conservation tillage and residue-rich cropping systems improve soil structure by enhancing SOC and microbial-mediated aggregation.

Maximum water holding capacity

At 0–15 cm soil depth, maximum water holding capacity was significantly influenced by both tillage practices and cropping systems (Table 3). Minimum tillage with incorporation of crop residues recorded the highest water holding capacity (55.97%), showing a 7.3% increase over conventional tillage (52.15%), primarily due to enhanced organic matter content, which improves soil aggregation and creates more macropores for better water retention (Eynard *et al*., 2004; McGarry *et al*., 2000; Hudson, 1994). Cropping systems also affected water retention, with the groundnut + pigeon pea system showing significantly higher water holding capacity (55.05%) than the groundnut-wheat system (53.1%), likely due to greater litter fall and increased SOC that enhance aggregation. The interaction effects were not significant, though the combination of minimum tillage with groundnut + pigeon pea resulted in the highest observed value (56.9%). At 15–30 cm depth, however, no significant differences were observed across treatments.

Field capacity

At 0–15 cm soil depth, field capacity was significantly influenced by both tillage practices and cropping systems (Table 4). Minimum tillage with incorporation of crop residues recorded the highest field capacity (27.99%) compared to conventional tillage without residues (26.08%), primarily due to reduced bulk density and improved soil structure that enhanced moisture retention. Among cropping systems, the groundnut + pigeon pea system recorded significantly higher field capacity (27.53%) followed by groundnut + cotton (27.20%), likely due to greater biomass input and residue return that increased organic matter and porosity. The highest field capacity (28.45%) was observed under minimum tillage with crop residue in the groundnut + pigeon pea system, while the lowest (25.5%) was under conventional tillage without residue in the groundnut-wheat system. Similar trends were reported by Alam and Salahani (2013), attributing increased field capacity to improved soil structure and organic matter under conservation practices.

Available water

At 0–15 cm depth, available water content was significantly higher under minimum tillage with crop residue incorporation (4.45 cm) compared to conventional tillage without residue (4.32 cm), showing a 3.0% increase (Table 4). This improvement can be attributed to greater surface residue retention under minimum tillage, which enhances soil structure and promotes the formation of larger pores that improve infiltration and reduce runoff. Although cropping systems did not significantly affect available water, the groundnut + pigeon pea system recorded relatively higher values, likely due to better biomass input and residue cover. These findings align with McGarry *et al.* (2000), who reported that no-till systems can increase available water in the soil by up to 15% compared to conventional tillage.

Soil moisture content at 60 DAS and 90 DAS

Soil moisture content at both 60 and 90 DAS was significantly influenced by tillage practices and cropping systems, particularly at 0–15 cm and 15–30 cm depths (Table 5). Minimum tillage with incorporation of crop residues consistently recorded higher soil moisture compared to conventional tillage without residue incorporation 26.92% vs. 24.55% at 60 DAS (0–15 cm), and 28.35% vs. 25.93% at 15–30 cm. Similarly, at 90 DAS, soil moisture was 11.28% higher under minimum tillage (23.28%) than under conventional tillage (20.92%) at surface depth, primarily due to enhanced pore continuity, reduced disturbance, and improved infiltration associated with residue retention. Groundnut + pigeon pea cropping system showed superior moisture retention (26.55% at 60 DAS, 22.79% at 90 DAS) over groundnut–wheat and other systems, likely owing to higher biomass production and litter return, which improved soil organic matter and water retention. These results align with findings by Zuniga *et al.* (2019), Yin *et al.* (2015), Budu *et al.* (2022), and Slawinski *et al.* (2012), who noted better moisture conservation under no-till or conservation systems due to improved soil structure and reduced evaporation losses. The interaction effects were generally non-significant, yet the combination of minimum tillage with groundnut + pigeon pea system consistently recorded the highest soil moisture content across both depths and stages. Overall, conservation tillage coupled with legume-based intercropping enhances soil moisture conservation, especially critical under moisture-stressed conditions.

Conclusion

The study clearly demonstrated that minimum tillage with crop residue incorporation significantly enhanced soil physical properties in *Vertisol* under groundnut-based cropping systems. At the 0–15 cm depth, minimum tillage reduced soil bulk density, and improved porosity, aggregate stability, water holding capacity, field capacity, and soil moisture content compared to conventional tillage. Among the cropping systems, the groundnut + pigeon pea intercropping system consistently performed better in improving soil physical parameters due to greater biomass addition and organic matter inputs. While interaction effects were mostly non-significant, the combination of minimum tillage with groundnut + pigeon pea showed the most beneficial outcomes across all parameters. These findings suggest that conservation tillage practices, particularly when combined with legume-based cropping systems, are effective strategies to improve soil health and moisture retention in *Vertisol*, contributing to sustainable crop production under semi-arid conditions.

Table 2 : Effect of tillage practices and cropping systems on bulk density and porosity of soil at surface and subsurface soil depths

Bulk density of soil ($Mg\ m^{-3}$)							
Cropping systems	**0-15 cm depth**			**Cropping systems**	**15-30 cm depth**		
	Tillage practices				**Tillage practices**		
	M_1	**M_2**	**Mean**		**M_1**	**M_2**	**Mean**
S_1	1.27	1.37	**1.32**	**S_1**	1.35	1.41	**1.38**
S_2	1.26	1.35	**1.31**	**S_2**	1.32	1.39	**1.36**
S_3	1.28	1.39	**1.33**	**S_3**	1.36	1.43	**1.40**
S_4	1.29	1.40	**1.34**	**S_4**	1.38	1.48	**1.43**
Mean	**1.27**	**1.38**		**Mean**	**1.35**	**1.43**	
	SE.m±	**CD at 5%**			**SE.m±**	**CD at 5%**	
M	0.011	0.050		**M**	0.017	NS	
S	0.007	0.023		**S**	0.027	NS	
M×S	0.014	NS		**M×S**	0.047	NS	

Porosity of soil (%)							
Cropping systems	**0-15 cm depth**			**Cropping systems**	**15-30 cm**		
	Tillage practices				**Tillage practices**		
	M_1	**M_2**	**Mean**		**M_1**	**M_2**	**Mean**
S_1	52.33	48.80	**50.56**	**S_1**	51.85	47.80	**49.83**
S_2	52.70	49.06	**50.88**	**S_2**	52.03	48.90	**50.47**
S_3	51.95	47.55	**49.75**	**S_3**	51.20	47.30	**49.25**
S_4	51.57	46.17	**48.87**	**S_4**	51.01	47.00	**49.01**
Mean	**52.14**	**47.89**		**Mean**	**51.52**	**47.75**	
	SE.m±	**CD at 5%**			**SE.m±**	**CD at 5%**	
M	0.63	2.85		**M**	0.85	NS	
S	0.44	1.42		**S**	1.14	NS	
M×S	0.93	NS		**M×S**	1.82	NS	

Main plots (Tillage practices)
M_1: Minimum tillage with incorporation of previous year crop residue
M_2: Conventional tillage without incorporation of crop residue

Sub plots (Cropping systems)
S_1: Groundnut + Cotton
S_2: Groundnut + Pigeon pea
S_3: Groundnut + Chilli
S_4: Groundnut - Wheat

Table 3 : Effect of tillage practices and cropping systems on soil aggregate stability and maximum water holding capacity at surface and subsurface soil depths

Soil aggregate stability (%)							
Cropping systems	**0-15 cm depth**			**Cropping systems**	**15-30 cm depth**		
	Tillage practices				**Tillage practices**		
	M_1	**M_2**	**Mean**		**M_1**	**M_2**	**Mean**
S_1	62.45	60.55	**61.50**	**S_1**	61.32	59.90	**60.61**
S_2	62.48	60.56	**61.52**	**S_2**	61.40	60.10	**60.75**
S_3	62.40	60.49	**61.44**	**S_3**	60.90	59.80	**60.35**
S_4	62.37	60.48	**61.42**	**S_4**	60.43	59.60	**60.02**
Mean	**62.42**	**60.52**		**Mean**	**61.01**	**59.85**	
	SE.m±	**CD at 5%**			**SE.m±**	**CD at 5%**	
M	0.40	1.79		**M**	0.76	NS	
S	0.70	NS		**S**	1.20	NS	
M×S	1.67	NS		**M×S**	2.04	NS	

Maximum water holding capacity (%)							
Cropping systems	**0-15 cm depth**			**Cropping systems**	**15-30 cm**		
	Tillage practices				**Tillage practices**		
	M_1	**M_2**	**Mean**		**M_1**	**M_2**	**Mean**
S_1	56.20	52.60	**54.40**	**S_1**	55.80	51.80	**53.80**
S_2	56.90	53.20	**55.05**	**S_2**	56.20	52.40	**54.30**
S_3	55.60	51.80	**53.70**	**S_3**	55.10	51.30	**53.20**
S_4	55.20	51.00	**53.10**	**S_4**	54.70	49.80	**52.25**
Mean	**55.97**	**52.15**		**Mean**	**55.45**	**51.33**	
	SE.m±	**CD at 5%**			**SE.m±**	**CD at 5%**	
M	0.44	1.96		**M**	0.69	NS	
S	0.34	1.09		**S**	1.07	NS	
M×S	1.15	NS		**M×S**	1.81	NS	

Main plots (Tillage practices)
M_1: Minimum tillage with incorporation of previous year crop residue
M_2: Conventional tillage without incorporation of crop residue

Sub plots (Cropping systems)
S_1: Groundnut + Cotton
S_2: Groundnut + Pigeon pea
S_3: Groundnut + Chilli
S_4: Groundnut - Wheat

Table 4 : Effect of tillage practices and cropping systems on field capacity and available water at 90 DAS in surface and subsurface depths

Field capacity of soil (%)								Aavailable water at 90 DAS in							
Cropping systems	0-15 cm depth			Cropping systems	15-30 cm depth			Cropping systems	0-15 cm depth			Cropping systems	15-30 cm		
	Tillage practices				Tillage practices				Tillage practices				Tillage practices		
	M_1	M_2	Mean		M_1	M_2	Mean		M_1	M_2	Mean		M_1	M_2	Mean
S_1	28.10	26.30	**27.20**	S_1	27.80	26.00	**26.90**	S_1	4.47	4.32	**4.40**	S_1	5.11	5.01	**5.06**
S_2	28.45	26.60	**27.53**	S_2	28.00	26.40	**27.20**	S_2	4.50	4.41	**4.45**	S_2	5.19	5.01	**5.10**
S_3	27.80	25.90	**26.85**	S_3	27.50	25.70	**26.60**	S_3	4.42	4.33	**4.38**	S_3	5.07	5.00	**5.03**
S_4	27.60	25.50	**26.55**	S_4	27.10	25.20	**26.15**	S_4	4.41	4.21	**4.31**	S_4	5.12	5.08	**5.10**
Mean	**27.99**	**26.08**		**Mean**	**27.60**	**26.08**		**Mean**	**4.45**	**4.32**		**Mean**	**5.12**	**5.03**	
	SE.m±	**CD at 5%**			**SE.m±**	**CD at 5%**			**SE.m±**	**CD at 5%**			**SE.m±**	**CD at 5%**	
M	0.18	0.81		**M**	0.35	NS		**M**	0.03	0.12		**M**	0.06	NS	
S	0.17	0.54		**S**	0.54	NS		**S**	0.09	NS		**S**	0.10	NS	
M×S	0.46	NS		**M×S**	0.91	NS		**M×S**	0.15	NS		**M×S**	0.17	NS	

Main plots (Tillage practices)
M_1: Minimum tillage with incorporation of previous year crop residue
M_2: Conventional tillage without incorporation of crop residue

Sub plots (Cropping systems)
S_1: Groundnut + Cotton
S_2: Groundnut + Pigeon pea
S_3: Groundnut + Chilli
S_4: Groundnut - Wheat

Table 5 : Effect of tillage practices and cropping systems on soil moisture content at 60 and 90 DAS in surface and subsurface soil depths

Soil moisture content (%) at 60 DAS								Soil moisture content (%) at 90 DAS							
Cropping systems	0-15 cm depth			Cropping systems	15-30 cm depth			Cropping systems	0-15 cm depth			Cropping systems	15-30 cm		
	Tillage practices				Tillage practices				Tillage practices				Tillage practices		
	M_1	M_2	Mean		M_1	M_2	Mean		M_1	M_2	Mean		M_1	M_2	Mean
S_1	27.79	24.80	**26.30**	S_1	28.91	26.30	**27.61**	S_1	23.48	21.04	**22.26**	S_1	25.24	23.70	**24.47**
S_2	28.11	25.00	**26.55**	S_2	29.61	26.50	**28.06**	S_2	23.80	21.77	**22.79**	S_2	26.22	24.02	**25.12**
S_3	26.29	24.40	**25.34**	S_3	27.79	25.90	**26.84**	S_3	22.99	20.79	**21.89**	S_3	24.84	23.32	**24.08**
S_4	25.50	24.01	**24.75**	S_4	27.10	25.00	**26.05**	S_4	22.88	20.06	**21.47**	S_4	24.72	22.89	**23.80**
Mean	**26.92**	**24.55**		**Mean**	**28.35**	**25.93**		**Mean**	**23.28**	**20.92**		**Mean**	**25.25**	**23.48**	
	SE.m±	**CD at 5%**			**SE.m±**	**CD at 5%**			**SE.m±**	**CD at 5%**			**SE.m±**	**CD at 5%**	
M	0.26	1.19		**M**	0.24	0.83		**M**	0.13	0.57		**M**	0.09	0.39	
S	0.42	1.36		**S**	0.43	1.38		**S**	0.28	0.88		**S**	0.24	0.76	
M×S	1.01	NS		**M×S**	0.80	NS		**M×S**	0.33	NS		**M×S**	0.61	NS	

Main plots (Tillage practices)
M_1: Minimum tillage with incorporation of previous year crop residue
M_2: Conventional tillage without incorporation of crop residue

Sub plots (Cropping systems)
S_1: Groundnut + Cotton
S_2: Groundnut + Pigeon pea
S_3: Groundnut + Chilli
S_4: Groundnut - Wheat

References

Alam, M.K. and Salahin, N. (2013). Changes in soil physical properties and crop productivity as influenced by different tillage depths and cropping patterns. *Bangladesh Journal of Agricultural Research*, 38(2), 289-299.

Bhattacharyya, R., Pandey, S.C., Bisht, J.K., Bhatt, J.C., Gupta, H.S. (2008). Conservation tillage and crop rotation effects on soil aggregation and carbon pools in the Indian Himalayas. *Soil Science Society of America Journal*, **72**(2), 496–507.

Black, C.A. (1965). Methods of analysis part-II. *American Society Agronomy*, pp. 18-22.

Blanco, C.H. and Lal, R. (2008). No‐tillage and soil‐profile carbon sequestration, An on‐farm assessment. *Soil Science Society of America Journal*, **72**(3), 693-701.

Budu, M., Darkwa, T.A., Amaglo, H., Baffour, N., Aidoo, I.A., Ahorsu, S. and Bessah, E. (2022). The impact of tillage and weed control methods on physical properties of sandy clay loam forest in Cassava cultivation. *Applied and Environmental Soil Science*, **12**(1), 1-12.

Degryze, S., Six, J., Brits, C. and Merckx, R. (2005). A quantification of short-term macroaggregate dynamics, influences of wheat residue input and texture. *Soil Biology and Biochemistry,* **37**, 55-66.

Eynard, A., Schumacher, T.E., Lindstrom, M.J. and Maio, D.D. (2004). Porosity and pore-size distribution in cultivated *Ustoll*s and *Usterts*. *Soil Science Society of America Journal,* **68**, 1927-1934.

Gomez, K.A. and Gomez, A.A. (1984). *Statistical Procedures for Agricultural Research*, 2nd Ed. John Wiley and Sons. New York, pp. 639.

He, J., Kuhn, N.J., Zhang, X.M., Zhang, X.R. and Li, H.W. (2009). Effect of 10 years of conservation tillage on soil properties and productivity in the farming-pastoral ectone of inner Mongolia, China. *Soli Use and Management*, **25**, 201-209.

Hernanz, J.L., Giron, V.S., Navarrete, L. and Sanchez, M.J. (2014). Long-term (1983–2012) assessment of three tillage systems on the energy use efficiency, crop production and seeding emergence in a rain fed cereal monoculture in semiarid conditions in central Spain. *Field Crops Research,* **166**, 26–37.

Hudson, B.D. (1994). Soil organic-matter and available water capacity. *Journal of Soil and Water Conservation,* **49**, 189-194.

Kemper, W.D. and Derpsch, R. (2011). Soil and water conservation, From tillage to conservation agriculture. *FAO*, Rome.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science*, **304**(5677), 1623-1627.

Lithourgidis, A.S., Dordas, C.A., Damalas, C.A. and Vlachostergios, D. (2011). Annual intercrops, an alternative pathway for sustainable agriculture. *Australian Journal of Crop Science*, **5**(4), 396-410.

Mamta, K.R., Shambhavi, S., Kumar, R., Bairwa, R., Meena, P. and Dahiya, G. (2020). Effect of cropping system and tillage practices on soil physical properties and maize growth. *International Journal of Chemical Studies*, **8**(2), 1372-1378.

McGarry, D., Bridge, B.J. and Radford, B.J. (2000). Contrasting soil physical properties after zero and traditional tillage of an alluvial soil in the semi-arid subtropics. *Soil and Tillage Research,* **53**, 105-115.

Piper, C.S. (2002). Soil and plant analysis. Hans publishers, Bombay, India, **12**, 368-370.

Slawinski, C., Cymerman, J., Witkowska, W.B. and Lamorski, K. (201)., Impact of diverse tillage on soil moisture dynamics, *International Agrophysics*. 26, 301-309.

Thomas, G.A., Dalal, R.C. and Standley, J. (2007). No-till effects on organic matter, pH, cation exchange capacity and nutrient distribution in a *Luvisol* in the semi-arid subtropics. *Soil and Tillage Research,* **94**, 295-304.

Tian, M., Qin, S., Whalley, W.R., Zhou, H., Ren, T. and Gao, W. (2022). Changes of soil structure under different tillage management assessed by bulk density, penetrometer resistance, water retention curve, least limiting water range and X-ray computed tomography. *Soil and Tillage Research*, **2**(1), 155-162.

Yin, B.Z., Zhen, W.C., Ma, Y.H. (2015). Effects of subsoiling-seeding on soil water, temperature and microbial characteristics of summer maize field. *Chinese Journal of Eco-Agriculture*. **23**, 285-293.

Yoder and Robert E. (1936). A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. *Agronomy Journal,* **28**(5), 337.

Zuniga, F., Horn, R., Rostek, J., Peth, S., Uteau, D. and Dorner, J. (2019). Anisotropy of intensity–capacity parameters on aquands with contrasting swelling–shrinkage cycles. *Soil Tillage Research*, **193**, 101-113.