Original Research Article

Long Term Effect of Organic Cropping Systems on Hydraulic Properties of soils

ABSTRACT

A field study on long term effect of five organic cropping systems viz. poplar + turmeric (CS_1), sugarcane+bottle gourd – broccoli (CS_2), basmati – wheat (CS_3), sugarcane fodder(CS_4) and maize + summer moong - wheat (CS_5) on soil hydraulic properties was conducted at Natural Agriculture Farm and Research Centre, Dherekot, Jandiala Guru, Amritsar, Punjab. The depth wise soil samples from these cropping systems were collected after *rabi* (2018-19) and *kharif* (2019) seasons. Maximum soil water retentivity (MWR) in CS_2 and CS_5 was significantly higher than CS_1, CS_3 and CS_4. In 15-22.5 cm soil layer MWR was significantly lower than 0-7.5, 7.5-15 and 22.5-30 cm soil layers. At 0.1, 0.3 and 0.5 bar matric potentials CS_1 and CS_2 has significantly higher soil moisture retention compared to CS_3, CS_4 and CS_5 cropping systems. However CS_4 has significantly lower soil moisture at 0.1, 0.3, 0.5, 1 and 2 bar matric potential compared to CS_5. Soil moisture retention was significantly lower in 15-22.5 cm depth compared to 0-7.5 and 7.5-15 cm depths at all matric potentials. Plant available water in $CS_{1,}$ CS_2 and CS_5 was significantly higher by 5.7, 4.9 and 2.9 percent, respectively compared to CS_3 and by 5.5, 4.7 and 2.7 percent, respectively compared to $CS_{4.}$ Soil infiltration rate and cumulative infiltration were significantly higher in CS_4 compared to all other cropping systems. Saturated hydraulic conductivity (SHC) was significantly lower in CS_3 than all other cropping systems. In CS_1 and CS_2 SHC was at par but these cropping systems have significantly lower SHC than CS_4 and CS_5. Irrespective of cropping systems SHC of 22.5-30 cm layer was significantly lower than other soil depths. In different cropping systems unsaturated hydraulic conductivity (K_Ψ) was significantly higher in CS_4 and CS_5 compared to CS_1, CS_2 and CS_3. Soil drainage rate was significantly higher in CS_4 by 8.6, 19.3, 30.2 and 67.3 percent compared to CS_5, CS_2, CS_1 and CS_3, respectively.

Keywords: cropping systems, soil moisture retention, plant available water, infiltration rate, saturated and unsaturated hydraulic conductivity

1. Introduction

In the Indo-Gangetic plains (IGP) of India, adoption of intensive agriculture, imbalanced use of chemical fertilizers and decreased use of organic manures have lead to depletion of soil organic carbon and deterioration of soil physical properties (Jat *et al* 2017). Organic farming has been suggested as a more sustainable alternative to conventional high-input agriculture (Ram et al 2014). Organic farming combines traditional farming methods such as natural pest management, rotating crops, and organic fertiliser application with modern technologies including biological control and reduced tillage (Reganold and Wachter, 2016; Peigne et al., 2016). Organic management involves the use of cover crops and organic amendments (legumes or manure), which results in more stable soil structure, better soil fertility and greater soil organic matter content than conventional systems relying on inorganic fertilizers (Ghabbour et al., 2017; Papadopoulos et al., 2014). The use of crop rotations favours a more efficient use of soil nutrients by plants. Crops with different root lengths and densities are able to mobilize and extract nutrients and water from deeper layers. However, these roots also create biopores in the soil profile. Organic systems, due to the higher content of organic matter and the presence of cover crops would offer more favourable soil structure which can be quantified from soil hydraulic properties (Abdollahi et al., 2014; Naveed et al., 2013). There is ample scientific evidence that organic farming improves soil quality and soil fertility compared to conventional agriculture (Wheeler et al., 2015; Reganold and Wachter, 2016; Di Prima et al., 2018). The impact of organic farming on soil properties could also improve ecosystem water relations. The characteristic of soil water retention is affected by soil organic carbon (SOC) content and porosity, which are significantly influenced by organics and cropping systems (Zhou et al. 2008). Soil water retention at field capacity (FC) and permanent wilting point (PWP) are important to estimate the irrigation water depth. Understanding the relation between water storage capacity and cropping systems is important in determining the flow properties of water in soil. Soil hydraulic properties are important to understand the water transmission properties and water balance in soils. In particular, soil water retention (SWR) is a function of the distribution of pore sizes and the saturated hydraulic conductivity reflects movement of water through connected macropores (Koestel et al., 2018).

Furthermore, having information on SWR permits estimation of various soil physical quality indicators that are of agronomic importance, such as plant-available water and air-filled porosity (Reynolds et al., 2009). Organically managed soils have a greater soil organic matter content (Gattinger et al., 2012), which directly improve soil structure and water holding capacity of soils (Abdi et al., 2018), increases water infiltration (Kundel et al. 2020) and ecosystem water relations under drought conditions (Sun et al., 2022). Cropping systems have an important effect on the soil hydraulic characteristics (Bormann and Klaassen 2008). However, less is known about the effects of organic cropping systems on the physical characteristics of soil structure (Papadopoulos et al., 2014), and its impact on water retention and infiltration (Williams et al., 2017). Spatial variability of soil hydraulic properties of different soil layers add complexity to the prediction of soil water redistribution and availability in time and space (Vereecken et al., 2014; Bonfante and Bouma, 2015; De Jong van Lier and Wendroth, 2016). The current need for improvements in the water use efficiency by organic cropping systems requires a holistic assessment of the hydraulic functioning of cropped soils for efficient soil and water management. Therefore, the objective of present study was to characterize the hydraulic properties of soils under different long term organic cropping systems.

2. MATERIAL AND METHODS

2.1 Description of the study area

The research work was conducted at *Bhagat* Puran Singh Natural Agriculture Farm and Research Centre, Dherekot, Jandiala Guru, Amritsar (31^0 34' 24″ N, 75^0 03' 58″E) situated at an altitude of 236 m above mean sea level. The total area of the organic farm is 12 ha. The impact of long term five organic cropping systems viz. agroforestry (poplar + turmeric as intercrop (CS$_1$)), vegetables (sugarcane+bottle gourd – broccoli (CS$_2$)), basmati – wheat (CS$_3$), sugarcane fodder (CS$_4$) and maize + summer moong (cover crop) – wheat (CS$_5$) was studied on soil hydraulic properties. The farm has a herd of *Sahiwal* cows. In all these cropping systems, none of chemical fertilizer, herbicide and pesticide was used. Instead different crops were grown with the application of locally prepared compost, *jeeva amrita, bijamrita (*Badwal *et al.,* 2019) *and* mulching to supply nutrients. Other important principles for crop growth were intercropping of legumes and use of local species of earthworms. The pest management was done through the use of *agniastra*, the *brahmastra* and the *neemastra* (Badwal *et al.,* 2019).

In CS$_1$, the poplar + turmeric as intercrop is practiced in cycle since fifteen years. Every year turmeric is being sown as inter crop in the poplar during the month of April and harvested by the end of December. Before sowing of turmeric two preparatory tillage operations with rotavator were done. Two rows of turmeric were sown on 37.5 cm wide beds with plant to plant spacing of 18 cm. Paddy straw mulch was applied @ 9 t ha^{-1} after the first irrigation. No other chemical fertilizer was added to this cropping system. Irrigation was applied through flooding in the rows as and when required. In CS$_2$, sugarcane (Co J 85 var.) was sown as two rows (in 4') and 12' inter row spacing in the North-South direction. The inter row spacing (12') was used for sowing of vegetables since 15 years. Preparatory tillage with cultivator followed by rotavator was done before sowing of bottle guard and broccoli in the inter row spacing. Bottle gourd was sown during the month of March and harvested in September. Broccoli was transplanted in the month of October after bottle gourd and harvested in December to February. Only organic manures (added through compost @ 5 t ha^{-1} + *Jeeva Amrita*) were used to raise vegetables and sugarcane. In CS$_3$, basmati (Pusa Basmati 1121 var.) was transplanted in the month of July and harvested in October. After incorporation of basmati straw with discing+ rotavator, wheat (Sona Moti var) was sown as 8 rows on 120 cm beds and furrows of 30 cm. In CS$_4$**,** sugarcane fodder (KRFo93-1 var.) was sown on 75 cm beds at 75 cm plant to plant spacing during 2016 (after preparatory tillage with cultivator) and it was a 3 year ratoon crop during 2019. During three years no any tillage operation was carried out in sugarcane fodder. In CS$_5$, maize (var. local) was sown (after one preparatory tillage with rotavator) in the month of April after harvesting of wheat at a 60 cm row to row spacing and two rows of summer moong (SML 668 var.) were sown as inter/cover crop in maize during April every year. After maize, wheat was sown (after preparatory tillage of one discing+rotavator) in October as 8 rows on the beds (120 cm width and 30 cm furrow).

2.2 Soil sampling and analysis

The soil samples were taken from four sites and four depths (0-7.5, 7.5-15, 15-22.5 and 22.5-30 cm) under each cropping system after the harvest of *rabi* (2018-19) and *kharif* crops during 2019. The collected soil samples were dried, grounded and passed through 2-mm sieve for analysis. The maximum water holding capacity (MWHC, per cent) was determined using Keen's box (Richards,1954) with its internal diameter 5.6 cm and height 1.6 cm. The soil moisture characteristics curve was prepared for each sample collected from different depths and cropping systems using pressure plate apparatus (Richards, 1949) with application of 10, 30, 50 100, 200, 300 and 1500 kPa pressure. The plant available water (PAW) was calculated from the soil moisture characteristic curve as:

$$PAW = FC - PWP$$

Where, PAW is the plant available water (cm), FC is the soil moisture storage (cm) at field capacity (30kPa), PWP is the soil moisture storage (cm) at permanent wilting point (1500 kPa). The infiltration of water into the soil was measured in-situ, after the harvest of crops in the month of May 2019 and December 2019 in all cropping systems using double ring infiltrometer (Reynolds *et al.,* 2002). Saturated hydraulic conductivity of undisturbed soil cores from different soil depths were taken from different cropping systems with the help of core sampler to measure saturated hydraulic conductivity. Then the saturated hydraulic conductivity of soil was calculated using Darcy's equation as given below and detailed by Reynolds *et al.*(2002).

$$Ks = (Q \times L) / At\,(H+L)$$

where Q is the volume of water percolated (cm^3), A is the cross-sectional area of the core (cm^2) 't' is time of percolation in minutes, L is the length of core (cm), H is the height of water above soil surface in the core (cm). The unsaturated hydraulic conductivity of 0-7.5, 7.5-15, 15-22.5 and 22.5-30 cm soil depths in different cropping systems was estimated from the soil moisture retention data using a computer programme developed by Jalota and Khera (2001) using Millington and Quirk (1961) method. The drainage rate was measured from a plot of size 2 × 2 m^2 bunded on all sides saturated completely for 2 days and covered with polythene sheet in the different cropping systems. Soil samples were taken continuously from 3rd day upto 16th day in the depth increments of 0-7.5, 7.5-15, 15-22.5 and 22.5-30 cm two times a day (i.e morning at 10 am and evening at 5 pm) with the help of screw auger to calculate soil moisture storage. Deep drainage was estimated by employing the equation as suggested by Ogata and Richards (1957) between equivalent depth of water in a soil profile (W, cm) as function of drainage time (T, days) by following the mathematical expression as listed below:

$$W= AT^B \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

where A- water amount (W) at T = 1 and B- slope of W versus T plotted on a log-log scales. Differentiating equation 1 with respect to T (time) yields

$$dW/dT= AB(T)^{B-1}$$

The drainage rate (dW/dT) is expressed as a function of time (T).

3. RESULTS AND DISCUSSION

3.1 Maximum water retentivity: The pooled data pertaining to maximum water retentivity in different cropping systems at different depths is presented in Table 1. Irrespective of seasons and depths, CS_3 (basmati-wheat) has significantly lower maximum water retentivity (MWR) than all other cropping systems. MWR was at par in CS_2 and CS_5 but these cropping systems have significantly higher MWR than CS_1 and CS_4. Irrespective of cropping systems MWR of 15-22.5 cm depth was significantly lower than other soil depths. However, no significant difference in MWR was observed among 0-7.5, 7.5-15 and 22.5-30 cm depths.

Table 1. Effect of different cropping systems on maximum water retentivity (%, v/v)

Soil depth (cm)	Cropping systems					Mean
	CS_1	CS_2	CS_3	CS_4	CS_5	
0-7.5	45.0	46.1	43.0	45.2	46.9	45.3^a
7.5-15	45.3	47.2	42.4	44.8	47.3	45.4^a
15-22.5	42.7	43.0	40.9	44.7	46.8	43.6^b
22.5-30	45.9	48.0	44.9	44.2	46.8	45.9^a
Mean	44.7^a	46.1^b	42.8^c	44.7^a	46.9^b	

Means followed by different letters are significantly different at $p < 0.05$ by Tukey's honest significant difference

The reduction of MWR in CS_3 cropping system may be due to reduction in total porosity of the soil due to puddling in basmati. CS_5 has significantly higher MWR than CS_1, CS_3 and CS_4. This may also be due to more total porosity in CS_5 compared to other cropping systems. Similar results have been observed by Suwara *et al.* (2016). However no significant difference in MWR was observed among CS_1, CS_2 and CS_4. Irrespective of cropping systems MWR of 15-22.5 cm depth was significantly lower than other soil depths. However, no significant difference in MWR was observed among 0-7.5, 7.5-15 and 22.5-30 cm depths. Similarly higher MWR has also been reported with addition of organics in surface soils by Siddika and Jeyamangalam, (2017).

3.2 Soil water retention characteristics

The pooled data pertaining to soil water retention characteristics of different cropping systems at different depths after *rabi* and *kharif* seasons is presented in Table 2.

Table 2 Effect of different cropping systems on soil water retention (percent v/v)

Soil matric potential (bars)	Cropping systems					LSD (0.05)	Soil depth (cm)				LSD (0.05)
	CS_1	CS_2	CS_3	CS_4	CS_5		0-7.5	7.5-15	15-22.5	22.5-30	
0.1	26.9	26.1	20.8	19.9	22.9	1.98	25.0	24.6	21.1	22.6	2.83
0.3	20.3	20.1	16.0	15.5	18.3	1.47	19.4	18.6	16.3	17.8	2.03
0.5	17.6	17.7	14.4	13.7	16.1	1.44	17.1	16.7	14.4	15.3	1.75
1.0	14.5	14.9	13.1	11.7	14.1	1.32	14.5	14.6	12.2	13.2	1.30
2.0	12.5	12.6	11.7	10.2	11.6	1.33	13.0	12.2	10.5	11.2	1.08
3.0	10.7	10.7	10.3	9.2	9.5	NS	11.5	10.9	8.7	9.4	1.06

Pooled data of cropping systems showed that soil moisture retention in CS_1 and CS_2 was at par at all matric potential values but these both cropping systems have significantly higher moisture retention at 0.1, 0.3 and 0.5 bar matric potential than all other cropping systems. This may be due to more aggregation in CS_1 and CS_2 (Kaur and Singh 2023) which favours moisture retention at lower suctions. Similar results were reported by Guber *et al.* (2004) where soil water retention can be predicted from soil aggregation. CS_4 has significantly lower soil moisture at 0.1, 0.3, 0.5, 1 and 2 bar matric potential compared to CS_1, CS_2 and CS_5. The lower soil moisture at different matric potentials in CS_4 may be due to lighter soil texture and less organic carbon (Kaur and Singh 2023). Similar results have been reported by Nath (2014). Soil moisture retention was significantly lower in 15-22.5 cm depth compared to 0-7.5 and 7.5-15 cm depths at all matric potentials. The lower moisture retention in 15-22.5 cm depth may be due to more compaction as indicated by significantly higher bulk density of this layer. Similar results have been reported by Singh *et al.* (2009) where moisture retention was significantly low in 15-22.5 cm depth compared to all other depths. However, at all matric potentials, no significant difference in soil moisture retention was observed among 0-7.5, 7.5-15 and 22.5-30 cm soil depths. There was also no significant difference in soil moisture retention between 15-22.5 and 22.5-30 cm depths.

3.3 Plant available water

The data pertaining to water available to plants in different cropping systems at different depths in two seasons is presented in Fig 1. Pooled plant available water (PAW) in CS_1 and CS_2 was at par but significantly higher than CS_3, CS_4 and CS_5. In CS_1, CS_2 and CS_5 PAW was significantly higher by 5.7, 4.9 and 2.9 percent, respectively compared to CS_3 and by 5.5, 4.7 and 2.7 percent, respectively compared to CS_4. Similarly Eden *et al.* (2017) also reported that plant available water generally improves after addition of organic wastes due to more aggregation and organic carbon. Overall, PAW in 15-22.5 cm depth was significantly lower than 0-7.5, 7.5-15 and 22.5-30 cm by 1.1, 1.3 and 0.8 percent. Plant available water was at par in 0-7.5, 7.5-15 and 22.5-30 cm depths. This decrease may be due to reduction in porosity of this layer.

3.4 Infiltration

3.4.1 Infiltration rate

The data pertaining to infiltration rate in different cropping systems in two seasons is presented in Fig 2. Generally infiltration rate was more after *rabi* than *kharif* season. This may be due to lower initial moisture after *rabi* than *kharif* season. After *rabi* season the initial infiltration rate was 1.2, 0.4, 0.3, 0.25 and 0.1 cm min^{-1} in CS_4, CS_5, CS_3, CS_1 and CS_2, respectively. After 1, 3, 5, 10 and 15 minutes infiltration rate was significantly higher in CS_4 compared to all other cropping systems. Significantly higher infiltration rate in CS_4 may be due to bypass flow of water in decaying root channels of ratoon sugarcane fodder crop and lighter soil texture having more macropores. Increase in infiltration rate with inclusion of perennial crops in rotation has also been reported by Basche and DeLonge (2019). Infiltration rate was also significantly higher in CS_5 compared to CS_2. The higher infiltration in CS_5 may be due to more proliferation of roots of intercropped

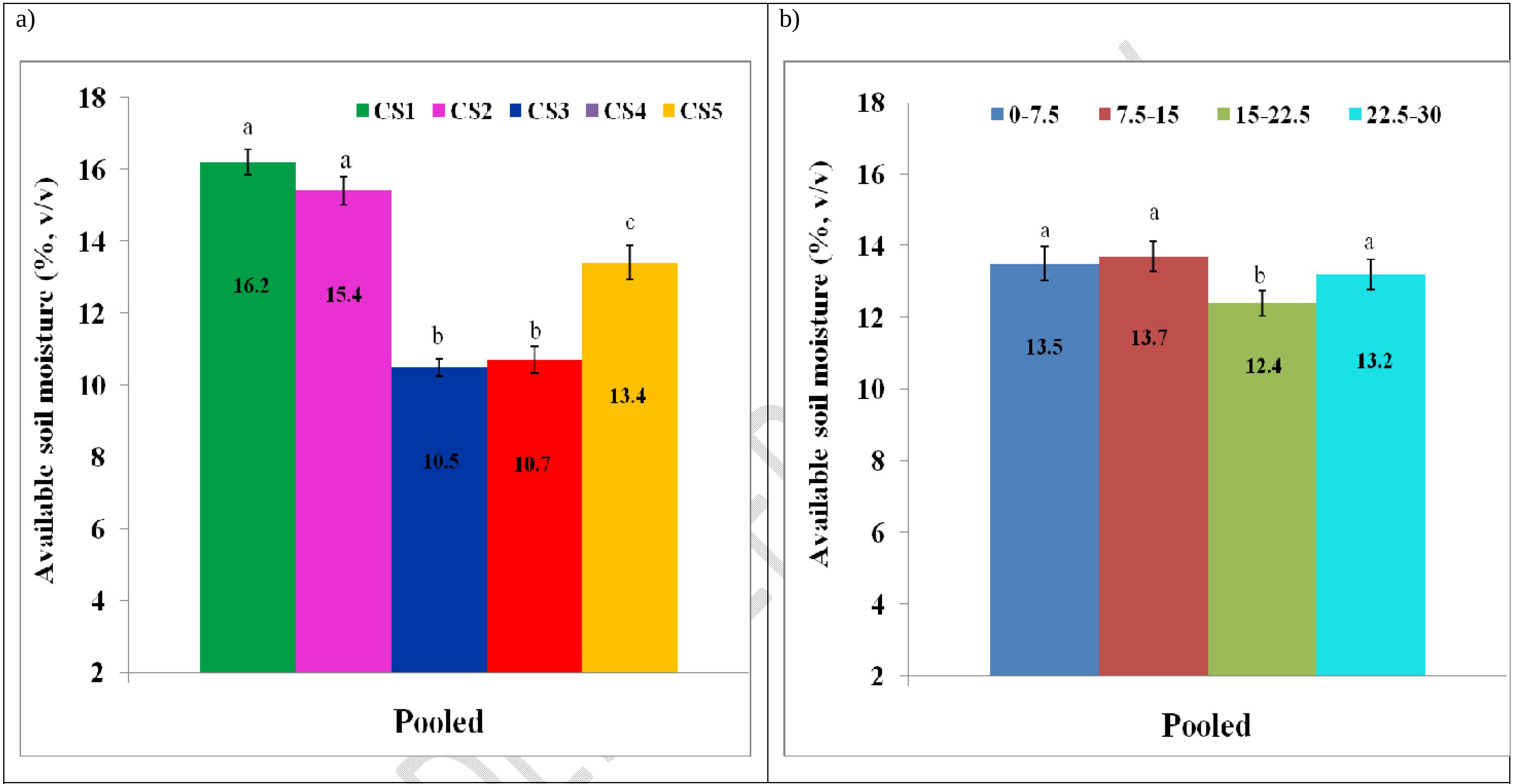


Fig.1 Effect of a) cropping systems and b) soil depths on available soil moisture (percent v/v) *Vertical bars and dissimilar letters indicate standard errors of means and significant differences at 5% level of significance respectively*

summer moong in surface soil. The lowest infiltration rate in CS_2 may be attributed to higher initial moisture content due to more organic carbon compared to CS_4 and CS_5 (Kaur and Singh 2023). Afterwards no significant difference in infiltration rate among different cropping systems was observed. After *Kharif s*eason the initial infiltration rate was 0.8, 0.3, 0.2, 0.2 and 0.15 cm min^{-1} in CS_4, CS_5, CS_3, CS_1 and CS_2, respectively. After 1, 5 and 10 minutes infiltration rate was significantly higher in CS_4 compared to all other cropping systems. Afterwards no significant difference in infiltration rate among different cropping systems was observed.

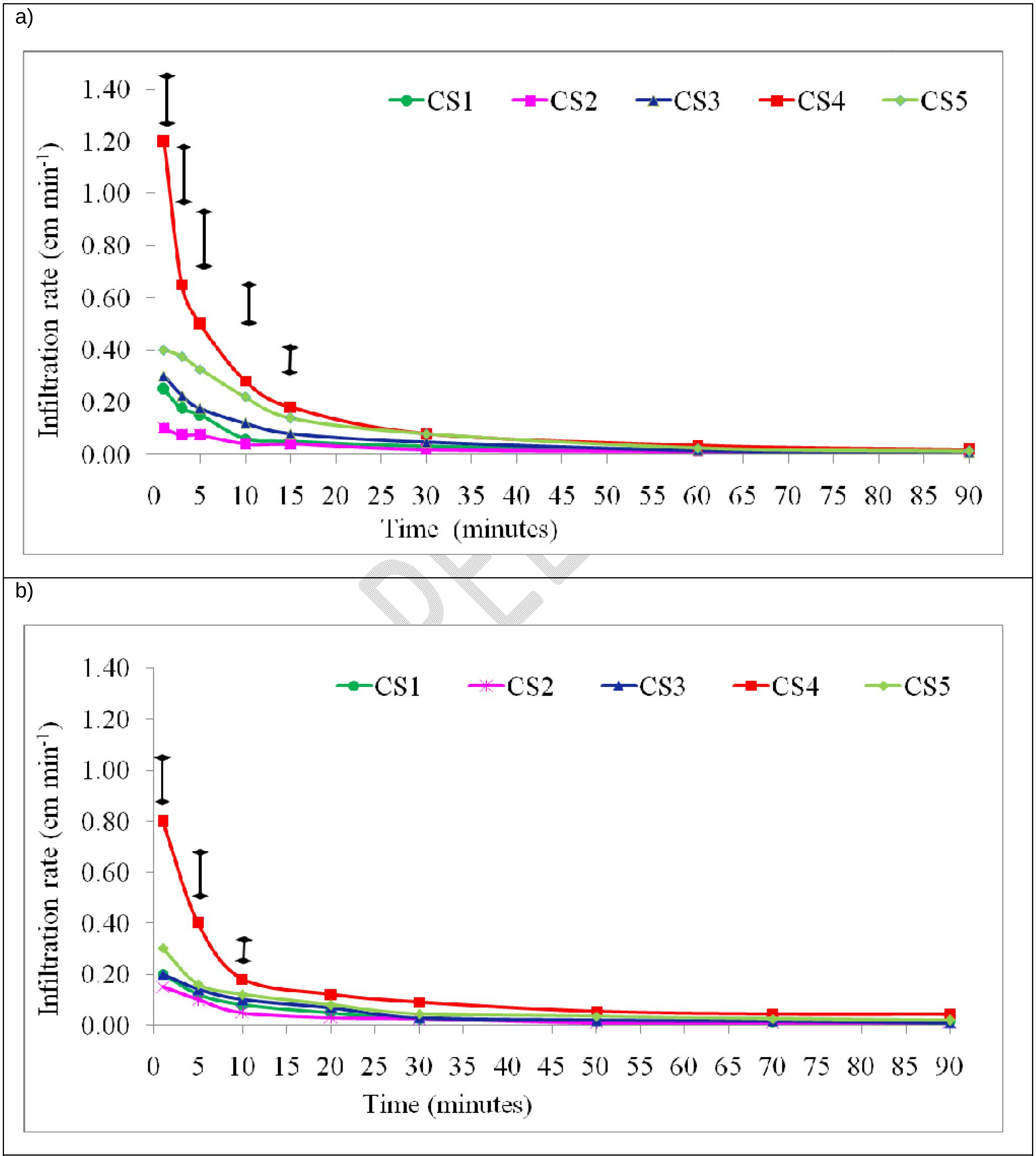


Fig. 2 Effect of long term organic farming in different cropping systems on infiltration rate of soil after a) *rabi* (2018-19) and b) *kharif* (2019) seasons.

3.4.2 Cumulative Infiltration rate

The data pertaining to cumulative infiltration in different cropping systems in two seasons is presented in Table 3. After 90 minutes cumulative infiltration in *rabi* season was 8.6, 5.9, 3.6, 2.9 and 1.8 cm in CS_4, CS_5, CS_1, CS_3 and CS_2, respectively. Cumulative infiltration was significantly different among all cropping systems with significantly highest values in CS_4 and significantly lowest values in CS_2. The trend in cumulative infiltration was similar after *kharif s*eason with cumulative infiltration of 7.8, 4.6, 3.3, 2.7 and 2.0 cm in CS_4, CS_5, CS_1, CS_3 and CS_2, respectively after 90 minutes. Similarly, pooled cumulative infiltration after 90 minutes in CS_4, CS_5, CS_1, CS_3 and CS_2 was 8.2, 5.3, 3.4, 2.8 and 1.9 cm, respectively. The order of significance among different cropping systems was $CS_4 > CS_5 > CS_1 > CS_3 > CS_2$.

Table 3. Effect of different cropping systems on cumulative infiltration (cm) of soil.

Time	Cropping systems					LSD (0.05)
(minutes)	CS_1	CS_2	CS_3	CS_4	CS_5	
5	0.9	0.4	0.7	2.3	1.3	0.68
10	1.4	0.6	1.1	3.4	2.1	0.86
30	2.6	1.3	1.9	6.0	3.9	0.80
60	3.2	1.7	2.5	7.5	4.9	0.47
90	3.4	1.9	2.8	8.2	5.3	0.42

Significantly higher cumulative infiltration in CS_4 may be due to bypass flow of water in decaying root channels of ratoon sugarcane fodder crop and lighter soil texture having more macropores. Similarly Shukla *et al.* (2015) reported higher infiltration in long term organically grown sugarcane compared to inorganic fertilizer application treatments.

3.5 Saturated hydraulic conductivity

The pooled data pertaining to saturated hydraulic conductivity (SHC) in different cropping systems at different depths is presented in Table 4. The soil SHC ranged from 2.16-3.90, 0.56-3.18, 0.41-1.58, 10.05-131.01 and 1.45-14.53 mm h^{-1} in CS_1, CS_2, CS_3, CS_4 and CS_5 cropping systems, respectively. The order of decrease in saturated hydraulic conductivity with different cropping systems is $CS_4 > CS_5 > CS_1 > CS_2 > CS_3$.

Table 4 Effect of different cropping systems on saturated hydraulic conductivity of soil (mm h^{-1})

Soil depth	**Cropping systems**					
(cm)	**CS_1**	**CS_2**	**CS_3**	**CS_4**	**CS_5**	**Mean***
0-7.5	3.90	3.18	1.58	131.01	14.53	30.8^a
7.5-15	2.96	2.43	1.46	88.41	9.70	21.0^b
15-22.5	2.30	1.47	0.38	15.76	8.43	5.7^c
22.5-30	2.16	0.56	0.41	10.05	1.45	2.9^d
Mean*	2.83^a	1.91^{ab}	0.96^b	61.31^c	8.53^d	

Dissimilar letters are significantly different at 5 percent level of significance

In all soil depths, SHC differed significantly among cropping systems. CS_4 has significantly higher SHC than CS_1, CS_2, CS_3 and CS_5. Higher SHC in CS_4 may be due to more macropores in light textures soils. Similarly, Singh *et al*. (2009) also reported higher saturated hydraulic conductivity in soils having more sand content. CS_3 has significantly lower SHC than all other cropping systems except CS_2. This may be due to more micropores in cropping system (Basmati) where puddling is done compared to cropping system without puddling. Simiarly Singh (2011) reported significantly lower saturated hydraulic conductivity in puddled soils compared to unpuddled soils. Significant differences in SHC was observed in 7.5-15, 7.5-15, 15-22.5 and 22.5-30 cm depths. Depth wise differences in SHC were noticed where SHC was significantly lower in 22.5-30 cm depth compared to other soil depths. This may be due to formation of plough pan having higher bulk density in 15-22.5 layer where pore connectivity is less (Singh *et al*., 2009). CS_3 has significantly lower SHC than all other cropping systems. SHC was at par in CS_1 and CS_2 but these cropping systems have significantly lower SHC than CS_4 and CS_5. Irrespective of cropping systems SHC of 22.5-30 cm depth was significantly lower than other soil depths. Generally SHC decreased significantly with depth. In 0-7.5 cm depth saturated hydraulic conductivity was significantly higher than 22.5-30 cm depth. In 0-7.5 cm and 7.5-15 cm depth significant difference in SHC was also observed.

3.6 Unsaturated hydraulic conductivity

The data pertaining to unsaturated hydraulic conductivity (K_{Ψ}) in different cropping systems and different depths are presented in Fig 3.

In different cropping systems unsaturated hydraulic conductivity (K_{Ψ}) generally decreased with decrease in soil moisture content. K_{Ψ} was significantly higher in CS_4 compared to all other cropping systems at different moisture contents. K_{Ψ} at 26 percent volumetric soil moisture content was 1.2, 0.06, 0.018, 0.09 and 0.043 cm h^{-1} in CS_4, CS_5, CS_1, CS_2 and CS_3, respectively and the corresponding values at 11 percent volumetric moisture content were 3.6×10^{-4}, 5×10^{-5}, 4.2×10^{-6}, 2.5×10^{-6} and 1.2×10^{-6} cm h^{-1}. Significantly higher K_{ψ} values in CS_4 may be due to higher saturated hydraulic conductivity due to more macro pores in the soil related to coarser texture and low organic carbon. Similar results have been reported by Seema *et al.* (2019). Significant differences in K_{ψ} among cropping systems at higher moisture than lower moisture content may be due to more difference in macropores and soil aggregation (Kaur and Singh 2023).

With respect to different soil depths, in the surface layer K_{ψ} was more compared to lower layers. K_{ψ} in 0-7.5 cm was significantly higher compared to 22.5-30 cm depth. It may be due to decrease in soil organic carbon with soil depth (Kaur and Singh 2023). In all depths K_{ψ} also decreased with decrease in soil moisture content. Pooled K_{Ψ} at 26 percent volumetric soil moisture content was 0.19, 0.11, 0.045 and 0.012 cm h^{-1} in 0-7.5, 7.5-15, 15-22.5 and 22.5-30 cm depths, respectively and the corresponding values at 10 percent volumetric moisture content were 5.9×10^{-5}, 3.4×10^{-5}, 4.4×10^{-5} and 2.1×10^{-5} cm h^{-1}. At lower soil moisture content differences in K_{ψ} among different soil depths were non significant because of less variability in micropores (Seema *et al.,* 2019).

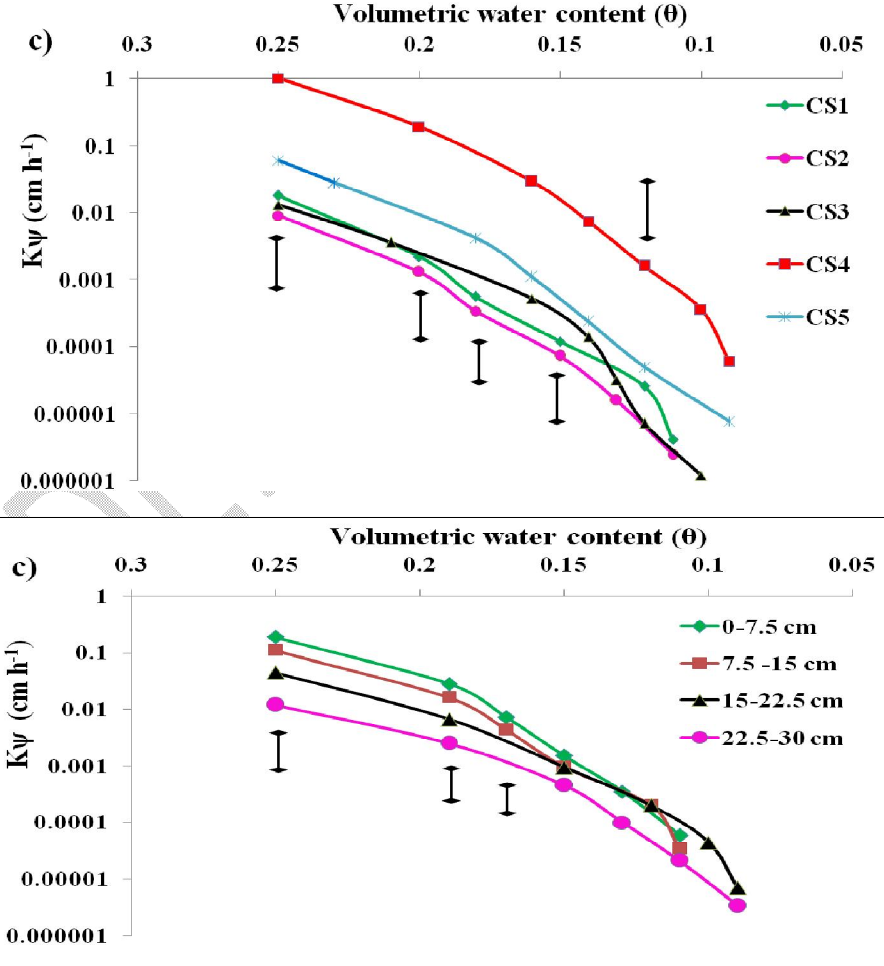


Fig.3. Effect of cropping systems (a) and soil depth (b) on unsaturated hydraulic conductivity

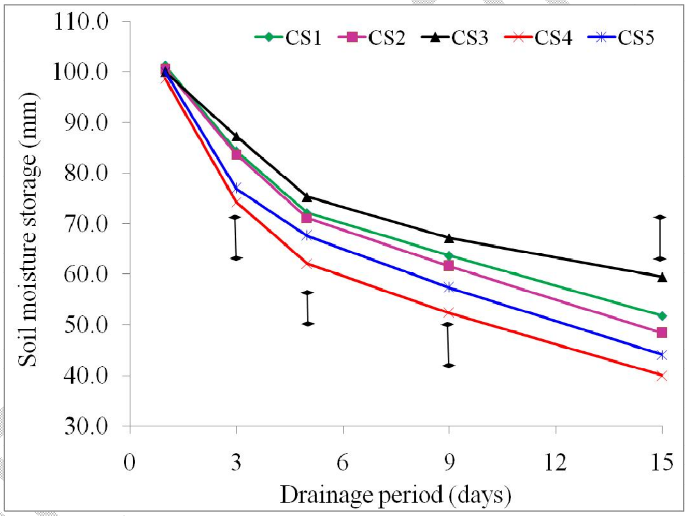
(cm h^{-1}) of soil. *Vertical bars indicate significant differences at 5% level of significance*

3.7 Deep Drainage: The curvilinear relationships were obtained between total soil water storage and drainage time under different cropping systems (Fig. 4a). These relationships indicated maximum drainage occurred under CS_4 and minimum under CS_3. However, on evaluating drainage rate as affected by function of time under cropping systems followed the trend: $CS_4 > CS_5 > CS_2 > CS_1 > CS_3$ (Fig. 4b) and Table 5.

Table 5 Empirical constants of drainage curves ($W = At^B$) for different cropping systems in 0-30 cm profile

Cropping systems	A	B	R^2
CS_1	105.1	-0.24	0.972
CS_2	105.8	-0.26	0.960
CS_3	102.4	-0.19	0.978
CS_4	102.9	-0.32	0.981
CS_5	103.6	-0.29	0.973

a)



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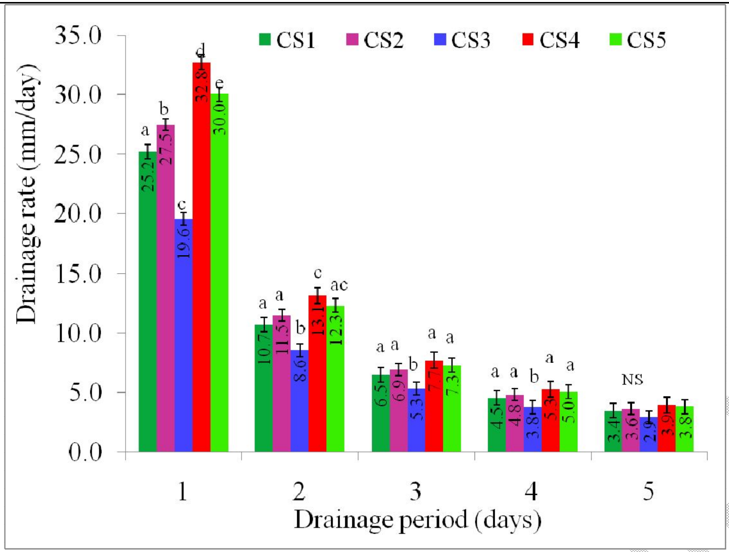

Fig.4. Periodic profile (0-30 cm) a) moisture storage (mm) and b) drainage rate (mm/day) in different cropping systems. *Vertical bars indicate significant differences at 5% level of significance*

There was steep decline as indicated by a negative and steeper slope under a cropping system. It was maximum under a CS_4 (-0.32) followed by CS_5 (-0.29) followed by CS_2 (-0.26) followed by CS_1 (-0.24) and CS_3 (-0.19). Stone *et al.* (2011) also reported similar observations for estimating drainage of different soils and field conditions. However, the value of intercept obtained was least under the CS_3 (Basmati-wheat) and maximum under CS_2 (sugarcane +vegetables). After 1 day drainage period the drainage rate was 32.8, 30.0, 27.5, 25.2 and 19.6 mm/day in CS_4, CS_5, CS_2, CS_1 and CS_3, respectively. At this drainage period, drainage rates were significantly different among all cropping systems with highest in CS_4 and lowest in CS_3 (Fig 4b). Generally the drainage rate was of the order CS_4>CS_5>CS_2>CS_1>CS_3. After 2, 3 and 4 days drainage period drainage rate was significantly lower in CS_3 compared to all other cropping systems. After 5 days drainage period no any significant difference in drainage rate among cropping systems was observed. The significantly higher drainage rate in CS_4 may be due to more infiltration rate and lighter texture of the soil. The lowest drainage rate in CS_3 may be due to formation of hardpan during puddling in basmati which lowered the saturated hydraulic conductivity and infiltration rate of water into the soil profile.

4. CONCLUSION

Conclusively, maximum water retentivity was observed in sugarcane+bottle gourd-brocoli and highest soil moisture retention at lower suctions and plant available water in poplar+ turmeric cropping systems. Infiltation rate, commulative infiltration, drainage rate, saturated and unsaturated hydraulic conductivity were highest in sugarcane fodder cropping system. However, puddling in basmati-wheat cropping system significantly reduced drainage rate, saturated and unsaturated hydraulic conductivity of the soil. The improvement in soil hydraulic properties in different cropping systems followed the trend of poplar + turmeric ≥ sugarcane + bottle gourd – broccoli > maize + summer moong – wheat > basmati – wheat > sugarcane fodder. Thus, agroforestry and vegetable based cropping system is promising for improvement in soil hydraulic properties in the state of Punjab compared to the prevalent rice (basmati) – wheat cropping system where water availability to crops. The sugarcane fodder based cropping resulted in more water movement through infiltration and drainage due to perennial root decay forming root channels resulting less available water to crops. Favourable changes in soil hydraulic properties were more in surface soil layers compared to sub surface soil layer of 15-22.5 cm.

REFERENCES

1. Jat HSA, Datta PC, Sharma V, Kumar AK, Yadav M, Choudhary V, Choudhary et al. Assessing soil properties and nutrient availability under conservation agriculture practices in a reclaimed sodic soil in cereal-based systems of North-West India. Arch Agron Soil Sci. 2017; 64 (4):531–45.

2. Ram M, Davari MR, Sharma SN. Direct, residual and cumulative effects of organic manures and biofertilizers on yields, NPK uptake, grain quality and economics of wheat (*Triticum aestivum* L.) under organic farming of rice-wheat cropping system. J Org Syst. 2014; 9 (1):16–30.

3.Reganold JP, Wachter JM. Organic agriculture in the twenty-first century. Nat. Plants. 2016; 2: 1–8.

4.Peigne J, Casagrande M, Payet V, David C, Sans FX, Blanco-Moreno JM, Cooper et al. How organic farmers practice conservation agriculture in Europe. Renew Agric Food Syst. 2016; 31: 72–85. https://doi.org/10.1017/ s1742170514000477.

5.Ghabbour E A, Davies G, Misiewicz T, Alami RA, Askounis E M, Cuozzo NP, Filice et al. National comparison of the total and sequestered organic matter contents of conventional and organic farm soils. *Adv Agron.* 2017; 146: 1–35

6. Papadopoulos A, Bird NRA, Whitmore AP, Mooney SJ. Does organic management lead to enhanced soil physical quality? Geoderma. 2014; 213: 435-43. https://doi.org/10.1016/j. geoderma.2013. 08.033

7. Abdollahi L, Munkholm LJ, Garbout A. Tillage system and cover crop effects on soil quality: II. Pore characteristics. Soil Sci Soc Am J. 2014; *78*(1): 271-79. https://doi.org/10.2136/sssaj2013.07.0302

8. Naveed M, Moldrup P, Arthur E, Wildenschild D, Eden M, Lamandé M, Vogel et al. Revealing soil structure and functional macroporosity along a clay gradient using x ray computed tomography. Soil Sci Soc Am J. 2013; *77*(2): 403-11. https://doi.org/10.2136/sssaj2012.0134

9. Wheeler SA, Zuo A, Loch A. Watering the farm: Comparing organic and conventional irrigation water use in the Murray-Darling Basin, Australia. Ecol Econ. 2015; 112: 78–85.

10. Di Prima S, Rodrigo-Comino J, Novara A, Iovino M, Pirastru M, Keesstra S, Cerda, A. Soil physical quality of citrus orchards under tillage, herbicide, and organic managements. Pedosphere. 2018; 28: 463-77.

11. Zhou X, Lin HS, White EA. Surface soil hydraulic properties in four soil series under different land uses and their temporal changes. Catena. 2008; 73:180-88

12. Koestel J, Dathe A, Skaggs TH, Klakegg O, Ahmad MA, Babko M, Giménez et al. Estimating the permeability of naturally structured soil from percolation theory and pore space characteristics imaged by x-ray. Water Res Res. 2018; *54*(11): 9255-63. https://doi.org/10.1029/2018WR023609

13. Reynolds WD, Drury CF, Tan CS, Fox CA, Yang XM. Use of indicators and pore volume-function characteristics to quantify soil physical quality. Geoderma. 2009; 152(3-4): 252-63. https://doi.org/10.1016/ j.geoderma.2009.06.009

14. Gattinger A, Muller A, Haeni M, Skinner C, Fliessbach A, Buchmann N, Mader et al. Enhanced top soil carbon stocks under organic farming. Proc National Academy Sciences USA. 2012; 109 (44) : 18226-31. https://doi.org/10.1073/pnas.1209429109

15. Abdi E, Babapour S, Majnounian B, Amiri GZ, Deljouei A. How does organic matter affect the physical and mechanical properties of forest soil? J For Res. 2018; 29: 657-62

16. Kundel D, Bodenhausen N, Jørgensen HB, Truu J, Birkhofer K, Hedlund K, Mader et al. Effects of simulated drought on biological soil quality, microbial diversity and yields under long-term conventional and organic agriculture. FEMS Microbiol Ecol. 2020; 96(12) fiaa205 https://doi.org/10.1093/ femsec/fiaa205.

17. Sun Q, Klaus VH, Wittwer R, Liu Y, Heijden MGA, van der, Gilgen et al. Water uptake patterns of pea and barley responded to drought but not to cropping systems. Biogeosci Discuss. 2022;19(6): 1853-69. https://doi. org/10.5194/bg-2021-217.

18. Bormann H, Klaassen K. Seasonal and land use dependent variability of soil hydraulic and soil hydrological properties of two Northern German soils. Geoderma. 2008; 145:295-302

19.Williams DM, Blanco-Canqui H, Francis CA, Galusha TD. Organic farming and soil physical properties: An assessment after 40 years. Agronomy J. 2017;109(2): 600-09. https://doi.org/10.2134/ agronj 2016.06.0372

20. Vereecken H, Huisman JA, Pachepsky Y, Montzka C, van der Kruk J, Bogena H, Weihermüller et al. On the spatiotemporal dynamics of soil moisture at the field scale. J Hydrol. 2014;516: 76–96. https://doi.org/10.1016/j.jhydrol.2013.11.061.

21. Bonfante A, Bouma J. The role of soil series in quantitative land evaluation when expressing effects of climate change and crop breeding on future land use. Geoderma. 2015; 259–260: 187–195. https://doi.org/10.1016/j.geoderma.2015.06.010.

22. De Jong van Lier Q, Wendroth O.. Re-examination of the field capacity concept in a Brazilian Oxisol. Soil Sci Soc Am J. 2016; 79: 9-19. https://doi.org/10.2136/sssaj2015.01.0035.

23. Badwal DS, Kumar M, Singh H, Simran, Kaur S. Zero Budget natural farming in India- A review. Int J Curr Microbiol Appl Sci. 2019; 8:869-873.
24. Richards LA. Diagnosis and improvement of saline and alkali soils. USDA. Agricultural Handbook. 1954; 60:107-108.
25. Richards LA. Pressure membrane apparatus construction and use. Agri Eng.1949; 28:451-54.

26. Reynolds WD, Elrick DE, Youngs EG. Single-ring and double or concentric-ring infiltrometers. *In:* Dane, J.H. and Topp, G.C. (ed) Methods of Soil Analysis (2002) Pp 8. Soil Sci Soc Am Madison, Wisconsin.

27. Jalota SK, Khera R. *Computer programmes package for soil physics*. 2001. Agrotech Academy, Udaipur, India.

28. Millington RJ, Quirk JP. Permeability of porous solids. Trans Faraday Soc. 1961; 57:1200-06.

29. Ogata G, Richards LA. Water content changes following irrigation of bare-field soil that is protected from evaporation. Soil Sci Soc Am Proc. 1957; 21:355-56.

30. Suwara I, Pawlak-Zaręba K, Gozdowski D, Perzanowska A. Physical properties of soil after 54 years of long-term fertilization and crop rotation. Plant Soil Env. 2016; 62:389-94.

31. Siddika MMA, Jeyamangalam F. Short term effect of organic manure on the physical & chemical properties of the soil. Int J Trend Res Dev.2017; 17: 35-37. www.ijtrd.com/papers/IJTRD7706.pdf

32. Kaur J, Singh D. Effect of long-term organic cropping systems on physico-chemical properties of the soils of Indian Punjab. Int J Plant Soil Sci. 2023 ;35(7): 167-77
33. Guber A, Pachepsky Y, Shein E, Rawls WJ. Soil aggregates and water retention. Dev Soil Sci. 2004; 30: 143-51
34. Nath TN. Soil texture and total organic matter content and its influences on soil water holding capacity of some selected tea growing soils in sivasagar district of Assam, India. *Int J Chemical Sci.*2014; 12: 1419-29.
35. Singh KB, Jalota SK, Sharma BD. Effect of continuous rice-wheat rotation on soil properties from four agro-ecosystems of Indian Punjab. Comm Soil Sci Plant Anal. 2009;40:2945-2958.

36. Eden M, Gerke HH, Houot S. Organic waste recycling in agriculture and related effects on soil water retention and plant available water: a review. Agron Sustain Dev. 2017; 37: 1-21.
37.Basche AD, DeLonge MS. Comparing infiltration rates in soils managed with conventional and alternative farming methods: A meta-analysis. PLoS ONE.2019; 14(9):1-22. e0215702. https://doi.org/10.1371/journal.pone.0215702.
38. Shukla SK, Singh PN, Chauhan RS, Solomon S. Soil physical, chemical and biological changes and long term sustainability in subtropical India through integration of organic and inorganic nutrient sources in sugarcane. Sugar Tech.2015; 17:138-49.
39. Singh KB. Dynamics of hydraulic properties of puddled soils*. In Hydraulic Conductivity - Issues, Determination and Applications,* Lakshmanan Elango (Ed.), 2011; ISBN: 978-953-307-288-3, InTech Europe University Campus Slavka Krautzeka 83/A 51000 Rijeka, Croatia.
40. Seema, Dahiya R, Phogat VK, Sheoran HS. Hydraulic properties and their dependence on physico-chemical properties of soils: a review. Curr J Appl Sci Tech. 2019; 38: 1-7
41. Stone LR, Klocke NL, Schlegel AJ, Lamm FR, Tomsicek DJ. Equations for drainage component of the field water balance. Appl Eng Agric. 2011; 27:345-350.