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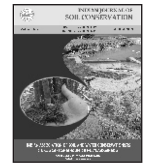

Influence of irrigation, tillage and gypsum on soil physical properties under sunflower cultivation in coastal saline zone of West Bengal

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ABSTRACT

An experiment was conducted on clay loam soils (*typic Haplaquept*) from coastal saline agro-ecological region of West Bengal to evaluate the influence of different levels of irrigation, tillage depth and gypsum application on soil physical properties during two consecutive *rabi* seasons of 2013 and 2014. Soils were analyzed for pH, EC, organic carbon (OC) content, bulk density (BD), porosity, water holding capacity (WHC), mean weight diameter (MWD), aggregate stability (AS) and structural coefficient (SC). Significant changes in soil pH (avg. 7.40), EC (avg. 4.01 dS m^{-1}) and OC (avg. 0.60%) were observed with different treatments. Deep tillage practice significantly improved BD of clayey loam soil (7.8%) over shallow tillage. MWD of soil varied from 0.56 to 0.67 mm (avg. 0.61 mm) with different treatments of irrigation, tillage and gypsum. Significant improvement in AS (ranged from 35.25% to 39.95%, avg. 37.54%) was found with increasing level of irrigation under both shallow and deep tillage; however, the effect was more prominent under deep tillage than the other. The SC of soil was ranged from 0.38 to 0.47 (avg. 0.43). Higher SC value was found under deep tillage treated plots compared to shallow tillage. The combined effect of increasing levels of irrigation and deep tillage along with gypsum application led to better soil physical environment under sunflower cultivation during the cropping season. Strong correlation among soil pH, EC, OC and soil structural indices indicated the influence of electrolyte concentration and organic matter on soil aggregation and their stability.

1. INTRODUCTION

Soil salinity is the primary constraints for crop growth in coastal saline soil (Petersen and Shireen, 2001). Sub-surface water from this region contains a high amount of soluble salts. These salts negatively affect soil chemical, physical and microbial properties. High osmotic potential of soil water decreases moisture availability for the crop resulting reduced crop growth. Specific ions concentration in irrigation water (IW) becomes toxic in range, making them unsuitable for irrigation. Scarcity of freshwater resources during crop seasons limits crop growth and production, particularly during pre and post *kharif* seasons. Rainwater captured in ponds and tanks during monsoon season is the only viable source of freshwater for cultivation. To fulfil increased crop demand and for proper utilisation of freshwater resources, crop yield in a unit area per unit of water use has to be increased. Several management strategies are in use to overcome constraints of water stress for crop production and crop water use efficiency (WUE) (Panigrahi *et al.*, 1992; Chiaranda and D'Andria, 1994; Debaek and Aboudrare, 2004). Effective water management practices for crop production in coastal saline soil require specific approaches most suitable for the region (Sen and Bandyopadhyay, 2001; Rao *et al.*, 2016).

Tillage operation disrupts the soil, and changes its volume mass relationship. Different tillages affect soil physical properties by changing conditions in the soil, and thus have a direct impact on crop growth and cost of production (Panigrahi *et al.*, 1990; Jabro *et al.*, 2011). Choice of tillage system can affect soil properties depending on site, crop species, climate, and the time the tillage system has been used. Nevertheless, tillage can have both favourable and unfavourable effects on different physical properties of treated topsoil (Bogunovic *et al.*, 2018). Direct drilling or shallow cultivation has been reported to increase micro-pores and soil aggregation stability in surface layer over conventional tillage operation (Cascio and Venezia, 1986). Sharma (1985) and Gupta and Gupta (1986) reported that the degree of changes of BD depends upon antecedent soil porosities, soil moisture status, and type and intensity of tillage operation. Loosening by tillage also decreases cohesiveness and particle to particle contact adherence, which reduces soil strength in the tilled layer. Soil strength increases with increase in BD and decreases with increase in soil water content. The effect of tillage on BD remains unchanged in deeper soil layers while soil bulk density in this layer is generally similar in no tillage and conventional tillage (Gál *et al*., 2007). It was also observed that BD in the 0-30 cm layer was higher under zero tillage than conventional tillage in silt clay loam soils. But a plough pan may be formed by tillage immediately underneath the tilled soil, causing higher BD in this horizon (Dolan *et al*., 2006). Bhattacharya *et al*. (2006) observed a significant decrease in BD upto 30 cm depth of soil by conventional tillage under both rice and wheat crops.

In West Bengal, sunflower is second important oilseed crop after rapeseed-mustard during *rabi* season, and it is cultivated on about 21,000 ha (2014-15). Sunflower (*Helianthus annuus* L.) holds a promising position among edible oilseed crops in this agro-ecological region due to its oil quality, nutritive values, economic return and its well fitness in local cropping system under rainfed condition. Sulphur has now gained importance for balanced fertilization, particularly in oilseed crop as it helps to increase oil content of the crop (Hassan *et al*., 2007). It is also a very essential element for protein production, formation of chlorophyll and vitamins, and activation of various enzymes (Patel *et al*., 2008). Sulphur application as gypsum has been found to be superior to others for oilseed crop (Ghosh *et al*., 2000). Gypsum, apart from its source of sulphur, also provides calcium to soil which is needed for flocculation of clays *viz-a-viz* improved soil structure.

Keeping all this view in mind, an investigation was undertaken to identify a suitable combination of irrigation, tillage practices and gypsum for the region. Attempts were also made to understand their impact on soil physical properties under sunflower cultivation during *rabi* season.

2. MATERIALS AND METHODS

The present experiment was conducted at farmer's field, near Kakdwip, West Bengal, India situated at $21^0$47'N, $88^0$13'E and 3 m above mean sea level (AMSL) during winter (*rabi*) season of 2013 and 2014. The topography of the area is characterized by sub-normal relief, and is having a low medium slope with slight to medium runoff (Bandyopadhyay *et al*., 2003). The climate of the region is classified as sub tropical hot and humid with moderate to high mean annual rainfall (1800 mm, Bandyopadhyay *et al*., 2003). Most of the rainfall (above 80%) is received during SW monsoon (June to October). The average temperature varies from 13.6°C in winter to 38.3°C in summer. The soil of the selected area belongs to the *typic Haplaquept* group with the characteristics of very deep, but, poorly drained soil. Soil is clay loamy in texture with good WHC. The soil properties of the area are presented in Table 1. The area is mainly mono-cropped (cropping intensity is 134%) with paddy grown in monsoon (*kharif*) season (Bandyopadhyay *et al.,* 2001).

The experiment was laid out in split-split design with three irrigation levels as main plot (I_1: 0.5 irrigation water (IW) / cumulative pan evaporation (CPE), I_2: 0.75 IW/ CPE and I_3**:** 1.0 IW/CPE), two sub-plot treatments (T_1: conventional, 10 cm and T_2: deep tillage, 20 cm) and two sub-sub treatments (A_1: no gypsum and A_2: with gypsum). The land was prepared thoroughly by ploughing twice, crosswise and lengthwise, followed by harrowing by power tiller. Sunflower (*var.* KBSH-44) was sown with plant-to-plant and row-to-row spacing of 60 cm and 30 cm, respectively. The recommended fertilizer dose for sunflower is 80:60:40 kg N: P_2O_5: K_2O ha^{-1}. The $1/3^{rd}$ of N and a full dose of P_2O_5 and K_2O were applied as basal. Another $1/3^{rd}$ of N was applied at 30 days and remaining $1/3^{rd}$ at 60 days after sowing. Gypsum ($CaSO_4$ $7H_2O$) was added to the field as basal (250 kg ha^{-1}) for sulphur nutrition of crops, as well as for soil physical improvement.

The seeds were soaked overnight and treated with Mancozeb fungicide. Sowing was done during the last week of January of each year. Irrigation was applied based on the IW/CPE approach where a known amount (5 cm) of IW was applied when CPE reached a predetermined level (Sarkar and Sarkar, 2018). The CPE data was collected from the

Table: 1
Physico-chemical characteristics of surface soil samples of experimental site

Physical Properties		Chemical Properties	
Sand (%)	36.7	pH (soil : water :: 1:2.5)	7.03
Silt (%)	24.1	EC (dS m^{-1})	2.97
Clay (%)	39.2	Organic Carbon (%)	0.61
Textural Class	Clay Loam	Available Nitrogen (kg ha^{-1})	200.6
Bulk Density (g cm^{-3})	1.27	Available Phosphorus (kg ha^{-1})	17.7
Mean Weight Diameter (mm)	0.62	Available Potassium (kg ha^{-1})	345.7
Aggregate Stability (%)	48.7		
Dispersion Ratio	75.21		

reading of USDA Class A open pan evaporimeter placed at the experiment site. Crop was harvested at maturity during last week of April month. Soil sample was collected from each plot after harvest of the crop in each year and was air-dried before laboratory analysis. Soil pH and EC were determined in soil and water ratio 1: 2.5 (w/v) following Jackson (1973). Soil organic carbon was determined following the method of Walkley and Black (1934). The BD (g cm^{-3}) of undisturbed core soil sample was determined using the ratio of the weight of dried soil and the volume of core sampler following method by Blake and Hartge (1986). Soil porosity was calculated by the formula:

$$\text{Soil Porosity (\%)} = \left(1 - \frac{\text{Bulk Density}}{\text{Particle Density}} \times 100\right) \quad ...(1)$$

Particle density (g cm^{-3}) was considered as 2.65 (Brogowski *et al.*, 2014). Water-stable aggregates and their distribution in each soil layer under different treatments were determined by wet sieving method using Yoder apparatus (Yoder, 1936). The amount of aggregates remaining in each size fraction was used to calculate the MWD of the water stable aggregates following the relationship proposed by Van Bavel (1949) as:

$$\text{Mean weight diameter (mm)} = \frac{\sum_{i=1}^{n} X_{iWi}}{\sum_{i=1}^{n} W_i} \quad ...(2)$$

Where, n = number of fractions (0.1−0.25, 0.25−0.50, 0.50−1.0, 1.0−2.0, >2.0 mm), X_i = mean diameter (mm) of the sieve size class (0.175, 0.375, 0.75, 1.5 and 2.0 mm) and W_i = weight of soil (g) retained on each sieve.

The aggregate stability percent or degree of aggregation (AS) of soil was calculated by the difference between percent clay and silt as obtained by mechanical analysis and that obtained by the suspension of untreated sample. SC, another index of soil aggregation was calculated from the following equation (Shein *et al.*, 2001).

$$\text{Structural coefficient} = \left(\frac{D - S}{S}\right) \quad ...(3)$$

Where, D = percentage of primary particles <0.25 mm in diameter; S = percentage of soil aggregate <0.25 mm in diameter.

The pooled data were statistically analyzed using split plot design by applying the technique of analysis of variance (ANOVA) prescribed for the design to test the significance at 5% probability level (Gomez and Gomez, 1984).

3. RESULTS AND DISCUSSION

Table 2 shows changes in soil pH, EC and OC content as influenced by different treatments. Soil reaction was found to vary from neutral to saline in range (~7.09 to 7.75, avg. 7.40). Application of good quality IW had reduced soil salinity to neutral range, and soil pH was significantly correlated with the amount of IW applied. Leaching of exchangeable sodium salts from soil might have decreased soil pH. Similar reports were available elsewhere (Singh *et al.*, 2016). However, we did not find any significant influence of tillage depth and gypsum application on soil reaction. Soil EC in our experiment ranged widely from 3.30 to 4.80 dSm^{-1} (avg. 4.01 dSm^{-1}) indicating varied salt concentration in soil. All our treatments showed a significant effect on soil EC. However, the effect of irrigation was most prominent. Irrigation water (IW) dissolves the salts present on soil surface and leaches them to deeper part along with percolating water. Tillage operation opens pore space, thereby facilitating water movement and leaching of salt enriched water. It also helps in better contact of soil with water. Thus, soil EC was greatly reduced with tillage operation and tillage depth. Organic carbon (OC) content in our soil was low and found to vary from 0.58% to 0.62% (avg. 0.60%). Soil OC content was slightly higher in plots receiving higher amount of IW. However, the influence of irrigation and gypsum

Table: 2
Changes in soil pH, EC and organic carbon content as influenced by irrigation, tillage and gypsum application (Pooled data of two years, 2013 and 2014)

Treatments Irrigation (I)/Tillage (T)	pH			EC (dS m^{-1})			OC (%)		
	T1	T2	Mean	T1	T2	Mean	T1	T2	Mean
Without gypsum (A1)									
I1	7.70	7.56	7.63	4.70	4.50	4.60	0.58	0.59	0.59
I2	7.45	7.38	7.41	4.10	4.00	4.05	0.58	0.61	0.59
I3	7.27	7.17	7.22	3.60	3.50	3.55	0.59	0.63	0.61
Mean	7.47	7.37	7.42	4.13	4.00	4.07	0.58	0.61	0.60
With gypsum (A2)									
I1	7.66	7.50	7.58	4.65	4.45	4.55	0.58	0.59	0.59
I2	7.41	7.35	7.38	4.00	3.65	3.83	0.59	0.62	0.60
I3	7.24	7.13	7.18	3.55	3.40	3.48	0.59	0.63	0.61
Mean	7.44	7.33	7.38	4.07	3.83	3.95	0.59	0.61	0.60
CD (P=0.05)	I	T	A	I	T	A	I	T	A
	0.20	NS	NS	0.17	0.09	0.07	NS	0.02	NS

application was not significant in our experiment. Organic carbon content was also found to vary significantly with tillage operation. Tillage operations are reported to modify the soil structure and OC distribution in soils (Vian *et al.*, 2009; Wong *et al.*, 2010). Soil pulverization brings up plant roots and biomass from deeper depth to soil surface, enriching them in organic matter (Singh *et al.*, 2016).

The influence of various treatments on soil physical properties is presented in Table 3. The BD of soil varied from 1.17 to 1.28 g cm^{-3} (avg. 1.23 g cm^{-3}) among all the treatments. Effect of deep tillage system on soil bulk density over swallow tillage, irrespective of irrigation regime, reduced the value by 4.72% and 3.96%, respectively under without and with gypsum application. Though soil BD was found to decrease by 4.06% and 5.64 % with irrigation levels, it was statistically insignificant. However, the change was significant in deep tillage. We did not find any significant changes in BD with gypsum application. The decreasing trend of BD with increasing irrigation regimes may be resulted from the breaking down of clods due to increasing number of wetting and drying cycles with increasing frequency of irrigation. Similar results were reported by Bharambe *et al.* (2002). Greater reduction of soil BD following deep tillage than shallow was reported elsewhere (Pal and Phogat, 2005; Meng *et al.,* 2016). Higher depth of penetration and soil pulverisation in deep tillage led to significant changes in soil BD compared to shallow ones. Lowered BD due to tillage and irrigation improves soil physical environment for better root growth and movement of soil moisture and nutrients leading to higher crop yields. Increased biomass production by reducing BD in soil has also been reported elsewhere (Bharadwaj and Omanwar, 1992). Very strong negative correlation ($r = -0.86$, $p<0.001$, Table 4) between OC and BD indicates dominant role of OC on soil structure. Organic matter helps in better soil aggregation and increases number of soil micropores, thus lowering soil BD. The BD of soil was also strongly to moderately correlated ($r = 0.62$ and 0.58, $p<0.01$, respectively) with soil pH and EC, which possibly indicates the influence of electrolytes on soil aggregation and soil physical environment. Role of soil aggregation on soil BD was noticed where AS and SC were strongly correlated ($r = -0.81$, $p<0.001$) with BD.

The pooled data of soil porosity shows almost an opposite trend of result found in BD (Table 3). It ranged from 52.07% to 56.21% (avg. 53.60%) in our experiment. The mean values do not show any consistent variation with

Table: 3
Effect of irrigation, tillage and gypsum application on the soil bulk density, porosity and water holding capacity of soil (Pooled data of two years, 2013 and 2014)

Treatments Irrigation (I)/Tillage (T)	Bulk density (g cm^{-3})			Porosity (%)			WHC (%)		
	T1	T2	Mean	T1	T2	Mean	T1	T2	Mean
Without gypsum (A1)									
I1	1.28	1.23	1.25	52.07	53.95	53.01	48.73	50.11	49.42
I2	1.26	1.22	1.24	52.63	54.33	53.48	48.71	49.56	49.14
I3	1.26	1.18	1.22	52.82	55.83	54.32	48.71	49.69	49.20
Mean	1.26	1.21	1.23	52.51	54.70	53.60	48.72	49.79	49.25
With gypsum (A2)									
I1	1.27	1.24	1.25	52.26	53.57	52.92	48.60	50.80	49.70
I2	1.26	1.23	1.24	52.82	53.95	53.39	48.39	50.30	49.34
I3	1.26	1.17	1.21	52.82	56.21	54.51	49.50	51.58	50.54
Mean	1.26	1.21	1.23	52.63	54.58	53.60	48.83	50.89	49.86
CD (P=0.05)	I	T	A	I	T	A	I	T	A
	NS	0.03	NS	NS	1.18	NS	NS	1.12	0.59

Table: 4
Pearson correlation between various soil physico-chemical parameters

	pH	EC	OC	BD	Porosity	WHC	MWD	AS	SC
pH	1.00								
EC	0.87**	1.00							
OC	-0.68**	-0.60*	1.00						
BD	0.62*	0.58*	-0.86**	1.00					
Porosity	-0.62*	-0.58*	0.86**	-1.00	1.00				
WHC	-0.45	-0.21	0.59*	-0.63**	0.63**	1.00			
MWD	-0.90**	-0.90**	0.76**	-0.68**	0.68**	0.48	1.00		
AS	-0.83**	-0.86**	0.78**	-0.81**	0.81**	0.53*	0.92**	1.00	
SC	-0.70**	-0.50	0.84**	-0.81**	0.81**	0.79**	0.73**	0.76**	1.00

** and ** indicates significant level of p<0.01 and 0.001, respectively (n = 24)* irrigation level but significantly increased under deep tillage (T_2) over shallow tillage (T_1); 4.17% and 3.68% increase under no gypsum and with gypsum, respectively in both years. Such variation of soil porosity may be the reflection of finer clod formation causing a decline in BD and improved pore size distribution in soil. Such improvement of soil porosity caused by decreased BD has been reported elsewhere (Gurumurthy and Rao, 2006; Srinivasan and Mc Dwell, 2009; Meng *et al.,* 2016).

The pooled result data depicted that irrespective of gypsum application, the WHC of soil shows no marked change with the application of IW (Table 3), but it significantly increases in deep tillage over shallow tillage treatments under each level of applied irrigation. The pooled data ranged from 48.71% to 51.58% (avg. 49.56%) in the experiment. Water holding capacity of soil was found to have increased 4.22% and 2.20% and with gypsum (A_1) and without gypsum (A_2), respectively under deep tillage condition (T_2). Application of gypsum improved the WHC of soil only in the deep tillage plots (2.21%) irrespective of irrigation levels although the effect of different irrigation regimes on WHC was not significant. Soil amendment with gypsum may lead to better soil aggregation which increases the proportion of finer pores, enhancing WHC of soil. The changes of WHC in soil under deep tillage may be attributed to the variation of microspores and their distribution due to deep tillage operation. Similar findings have also been reported by Singh and Reddy (1986) and Gurumurthy and Rao (2006). Also, better soil aggregation is associated with increased number of small pore space, thus increasing WHC of soil (Haynes and Naidu, 1998). The WHC was moderately correlated with OC and BD ($r = 0.59$, $p < 0.01$ and $r = -0.63$, $p<0.001$ respectively). However stronger correlation ($r = 0.79$, $p<0.001$) was found with SC of soil, indicating possible aggregation and pore space re-distribution of WHC of soil.

The MWD, AS, and SC of soil, as affected by applied treatments are presented in Table 5. The MWD was observed to vary with the level of irrigation, tillage and gypsum application, ranging from 0.54 mm to 0.68 mm (avg. 0.61 mm) across the treatments. It consistently increased with the increasing level of irrigation in all the treatments. Data from the experiment exhibited highest MWD (0.67 mm) under deep tillage and high irrigation regime ($A_2T_2I_3$) which is 19.64% higher than $A_1I_1T_1$ treatment. Also, regardless of the irrigation and gypsum treatments, deep tillage improves MWD of soil (avg. 6.67% and 5.08% increment with and without gypsum application, respectively) over shallow tillage. A higher value of MWD may be reflection of the proportion of larger sized aggregates at the expense of smaller ones. Influence of calcium in the form of gypsum application was also found to improve soil aggregation and MWD. We found a significant increase in MWD from low (I_1) to high (I_3) irrigation regime under no gypsum (A_1; 12.28%) and with gypsum (A_2; 13.79%) application. Similar findings on improved MWD with increasing level of irrigation were reported by Bhattacharya *et al.* (2008). A strong negative correlation exists with BD ($R^2 = -0.46$) in surface soil, which is in conformity of findings of Dey *et al.* (2015). Fig. 1 shows the influence of soil pH, EC, OC and BD on soil MWD. Very strong negative correlation with pH and EC ($r= -0.90$, $p<0.001$) indicates the antagonistic effect of soil reaction and mono-electrolytes like Na on soil aggregation and its stability in this region. At higher soil pH, there could be prevalence of Na-salt in soil solution in this coastal region of West Bengal. This cation promotes soil dispersion, destroying soil aggregates. Soil MWD was also strongly correlated with OC content and AS of soil ($r= 0.76$ and 0.92, $p<0.001$, respectively) indicating role of OC on soil aggregation. Higher stability of soil aggregates prevents slaking of soil against disruptive force of water and air.

Table: 5

Impact of irrigation, tillage and gypsum application on mean weight diameter, aggregate stability and structural coefficient of soil (Pooled data of two years, 2013 and 2014)

Treatments Irrigation (I)/Tillage (T)	Mean weight diameter (mm)			Aggregate stability (%)			Structural coefficient		
	T1	T2	Mean	T1	T2	Mean	T1	T2	Mean
Without gypsum (A1)									
I1	0.56	0.58	0.57	35.25	36.35	35.80	0.39	0.43	0.41
I2	0.59	0.62	0.60	36.60	37.50	37.05	0.40	0.45	0.42
I3	0.63	0.66	0.64	37.75	39.35	38.55	0.41	0.46	0.44
Mean	0.59	0.62	0.60	36.53	37.73	37.13	0.40	0.45	0.42
With gypsum (A2)									
I1	0.57	0.60	0.58	36.40	37.50	36.95	0.41	0.44	0.42
I2	0.60	0.64	0.62	37.15	38.65	37.90	0.42	0.45	0.44
I3	0.64	0.67	0.66	38.00	39.95	38.98	0.43	0.47	0.45
Mean	0.60	0.64	0.62	37.18	38.70	37.94	0.42	0.45	0.43
CD (P=0.05)	I	T	A	I	T	A	I	T	A
	0.03	0.01	0.01	1.57	0.83	0.46	0.02	0.02	0.01

The AS of soil was found to vary significantly with different treatments similar to MWD (Table 5). Soil AS varied from 35.2% to 40.2% (avg. 37.54%) in our experiment. The value of AS increased 38.95% from shallow tillage and minimum irrigation (35.25%) to deep tillage and maximum irrigation system (39.95%). A significant improvement of soil AS was found with application of IW. There were 5.45% and 7.68% increment in AS for added gypsum (A_1), and without gypsum (A_2) however, the influence was more prominent under deep tillage than shallow tillage. A higher degree of AS is indicative of the greater stabilization of soil aggregates. Improvements of AS due to tillage activity are in support of the observation of Lima *et al.* (2009). We found very strong negative correlation between pH, EC and AS (r= -0.83 and -0.86, $p<0.001$, respectively), indicating possible influence of mono-electrolytes on soil aggregation and aggregate stability. Changes in soil AS with pH, EC, OC and BD are presented in Fig. 2. Very strong negative correlation (R^2= -0.62, $p<0.001$) with BD may indicate breaking-down of aggregate and subsequent lowering of AS. Chaney and Swiff (1984) and Lal *et al.* (1994) found that higher soil OC content improved by tillage might lead to greater AS. A similar strong correlation (r = 0.78, $p<0.001$) was found between OC and AS in this study.

Structural coefficient (SC) is another useful indicator for evaluating soil structural integrity. The results indicated a similar trend as observed for MWD and AS with different treatments. Structural coefficient of soil varied from 0.38 to 0.47 (avg. 0.43) in the present experiment. Higher values of SC (0.47 and 0.46) were noticed in deep tillage with maximum irrigation level (I_3T_2) which was 19.48% and 16.04% higher than minimum irrigation and shallow tillage (I_1T_1) for both conditions *i.e.* no gypsum and with gypsum. The effect of irrigation regime and tillage system were found significant and SC was found to increase 7.3% and 5.8% from low (I_1) to high (I_3) irrigation regime, respectively for without gypsum and with gypsum application. Deep tillage promotes soil aeration and crop root growth. Various organic substrates released during microbial decay of plant roots acts as a cementing agent favouring soil aggregation (Tisdall and Oades, 1980). Fig. 3 shows the variation of SC with soil pH, EC, OC and BD. The increasing percentage of SC was attributed to the higher proportion of SOC which yielded maximum correlation (R^2 = 0.70, $p<0.001$) than MWD and AS. Thus, SOC accumulation may be achieved

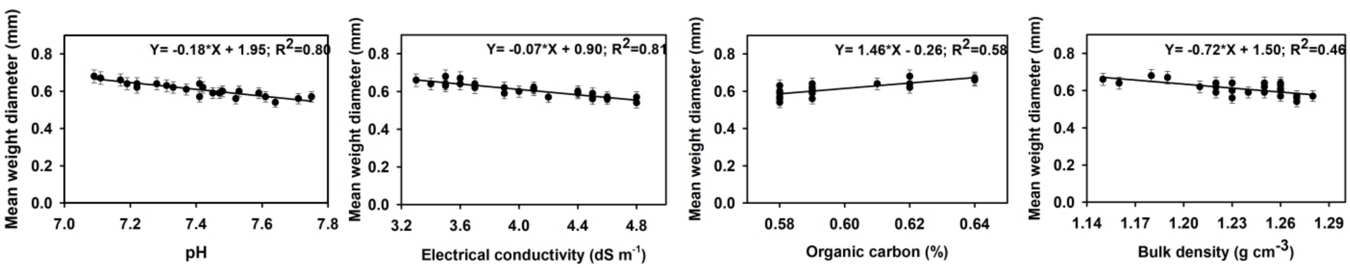

Fig. 1. Variation in soil mean weight diameter (mm) with soil pH, electrical conductivity (dS m^{-1}), organic carbon content (%) and bulk density (g cm^{-3})

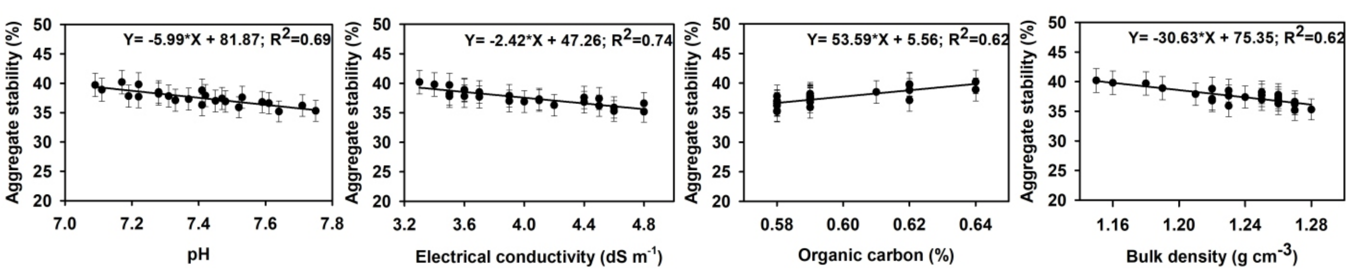

Fig. 2. Influence of soil pH, electrical conductivity (dS m^{-1}), organic carbon content (%) and bulk density (g cm^{-3}) on soil aggregate stability (%)

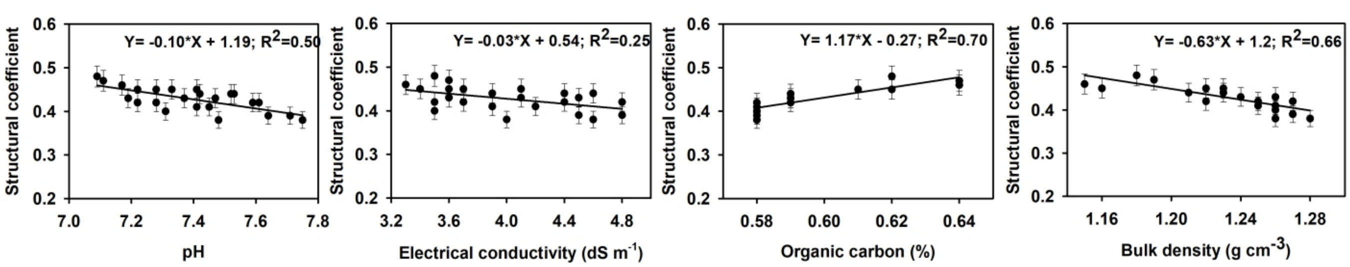

Fig. 3. Structural coefficient as affected by soil pH, electrical conductivity (dS m^{-1}), organic carbon content (%) and bulk density (g cm^{-3})

by establishing proper management practices that increase the proportion of water-stable macro aggregates and capillary pores, which result in higher water infiltration, better aeration and better microbial growth (Dey *et al.*, 2015). Similar findings were reported earlier by Sarkar and Bandyopadhyay (2018) that organic matter through its effect of binding soil particles improved soil aggregation. Structural coefficient of soil was also negatively correlated with soil reaction and BD (R^2= -0.50 and -0.66, p<0.001, respectively) similar to soil AS. Incorporation of calcium in the form of Gypsum also acted as soil particle binding agent favouring soil aggregation.

4. CONCLUSIONS

Significant changes in soil physical properties *viz.,* soil BD, porosity and WHC under the influence of tillage and IW application were found in our experiment. Tillage operation reduced soil bulk density significantly. However, the degree of change was much higher in deep tillage (4.72%). An opposite trend was found for soil porosity to BD as they were negatively correlated. Water holding capacity of soil was similarly affected with tillage and gypsum application. Deep tillage accompanied with gypsum application reported highest value (51.58%). Strong correlation of WHC with OC, BD and porosity indicated their influence on WHC of soil. Irrigation, tillage depth and gypsum application improved these soil structural indices significantly. Highest value of MWD (0.67 mm), AS (39.95%) and SC (0.47) was found under deep tillage and high irrigation regime with added gypsum ($A_2T_2I_3$).

Thus it is concluded that application of irrigation at IW/CPE of 1.0 in this coastal saline zone will be helpful for improving soil physical and chemical properties substantially. Results also suggest that agronomic practices such as deep tillage operation and amendments application such as gypsum are necessary measures to overcome negative impact of soil salinity for sustaining soil health in coastal saline zone.

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