

Original Research Article

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Irrigation Water, Deep Tillage and Gypsum Application Influences Soil Moisture regime, WUE and Sunflower Yield in Coastal Saline Soil of West Bengal

Avijit Manna^{1*}, Arindam Sarkar² and P. K. Tarafdar³

¹Purba Medinipur Krishi Vigyan Kendra, Bidhan Chandra Krishi Viswavidyalaya, Purba Medinipur, West Bengal -721632, India

²Regional Research Station, Bidhan Chandra Krishi Viswavidyalaya, Jhargram, West Bengal- 721507, India

³Department of Soil and Water Conservation, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal - 741252, India

*Corresponding author

ABSTRACT

Keywords

Evapotranspiration (ET), Water use efficiency (WUE), irrigation water (IW), sunflower, saline soil

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An experiment was conducted on coastal saline soils of West Bengal to evaluate the influence of different levels of irrigation, tillage depth and gypsum application on soil moisture regime, evapotranspiration (ET), water use efficiency (WUE) and crop yield of sunflower. We found significant variation in soil moisture content, ET and WUE among various treatments. Changes in soil moisture during the crop growing periods were found due to variations in applied irrigation. Deep tillage favoured higher soil moisture content at any stages of crop growth over conventional tillage; however, at maturity conventional tillage was found to be more effective for any stages of soil moisture over deep tillage. The result shows that ET increased generally with increasing irrigation level and the effect was found more prominent under deep tillage than conventional tillage. WUE was lowest under higher ET plots, i.e. when water was applied more frequently. Higher crop yield was recorded related to high ET, possibly due to increased nutrient uptake from those frequently irrigated plots. However, higher yield came with the expanse of low WUE of crops in the presence of higher amount of irrigation water.

Introduction

Availability of fresh water is one of the most important criteria for sustainable agriculture. A large proportion of available freshwater (as

much as 80%) is used by humans for crop production and allied services (Morison *et al.*, 2008). However fresh water supply is becoming scarce and decreasing day by day. Non availability of fresh water is severe under

coastal saline zone where saline water limits agricultural productions (Petersen and Shireen, 2001). Thus, coastal agriculture is mostly rainfed and largely dependent on monsoon for fresh water supply. Cropping pattern of this region is predominantly mono-cropped; mostly long duration traditional rice varieties are cultivated during kharif season. Due to intense rainfall, concentrated in very short timeframe of few months (during June to September), most of the cultivable lands remain deeply submerged in kharif season due to flat topography, low infiltration rate and high water table. During rest of the time, most of the cultivable land remains fallow due to salinity and non availability of good quality irrigation water (Manna *et al.*, 2019). Rainwater captured in ponds and tanks during monsoon season is the only viable source of freshwater for cultivation. Under such situation better water management is the only option to meet growing demands for increased crop production.

Several management strategies are in use to overcome constraints of water stress for crop production (Chiaranda and D'Andria, 1994; Debaek and Aboudrare, 2004; Panigrahi *et al.*, 1992). Scheduling irrigation on the basis of IW/CPE to increase crop water use efficiency (WUE) is one among them (Manna *et al.*, 2019; Sarkar and Sarkar, 2018). Numerous studies indicated IW/CPE method improves hydro-thermal regime of soils by moderating soil temperature and reducing soil water evaporation component of ET (Bangroo *et al.*, 2011; Patil, 2017; Verma and Acharya, 2004). Similarly, appropriate soil tillage system influence the agricultural sustainability through its affect on improving soil moisture regimes, soil water entry, physical properties and nutrient processes in soil profile. Tillage helps to influence the soil edaphic environments as it disrupts dense soil layers, decrease bulk density, increase porosity and percentage of water conducting

pores, changes soil surface configuration facilitating root development and their penetration as well as maintains organic carbon status in soil (Jabro *et al.*, 2011; Panigrahi *et al.*, 1990). Loosening of soil by tillage and leaching out by soluble salts by irrigation water can be the better option for alleviating the soil and water related constraints to productivity in the salt affected soils under coastal saline agroecological regions (Bhattacharya *et al.*, 2006). Although the effects of various tillage practices and applied irrigation levels in combination have been tested for different crops but the quantitative information of such aspects in salt affected soils, in particular, are inadequate and inconclusive and more so with sunflower crop. Increasing levels of irrigation and deep tillage along with gypsum application led to better soil physical environment under sunflower cultivation during the cropping season (Arora *et al.*, 2011; Manna *et al.*, 2019). Deep tillage benefits have been reported to vary with seasonal rainfall (Unger, 1979); irrigation regimes and soil texture (Arora *et al.*, 2011).

Sunflower is emerging as a promising edible oilseed crop in the country, next to rapeseed, mustard and groundnut, because of its desirable attributes of wide adaptability to different edapho-climatic condition (Shekhawat and Shivay, 2008). It is photo-insensitiveness, short duration, rich in oil having high percentage of poly unsaturated fatty acid and low cholesterol and protein content (Shekhawat *et al.*, 2008). Being drought and salt tolerant, it gains importance as favourable succeeding crop to kharif rice with better agro-technical measures where salinity and water stress become the major constraints to crop production (Rashid *et al.*, 2014). Its deep root system favours to withstand the soil moisture deficit as well as to deplete more soil moisture from greater depth. For water scarce region the amount and

timing of irrigation are more important for efficient use of applied water and for maximizing the sunflower production. Thus, sunflower holds good promise for growing as rabi crops in rainfed situations of salt affected soils under coastal saline agro-ecological regions.

The water management of sunflower is extremely important at all crop stages development due to its variation of water requirement at different growth period (Aboudrare *et al.*, 2006). Bud initiation, button stage, flowering period and seed development stages are critical stages in terms of irrigation requirement (Demir *et al.*, 2006). Sunflower crop is also highly sensitive to water stress between flowering and grain filling stages (Demir *et al.*, 2006). IW/CPE method of irrigation has been demonstrated as very beneficial for sunflower and other oilseed cultivation (Patil and Gangavane, 1990; Sumathi and Rao, 2007). Keeping the above backgrounds in consideration an experiment was conducted on improving soil moisture regime and sunflower production ensuring food and livelihood security in coastal saline agro-ecological regions. This study examined the combined effects of irrigation, deep tillage and gypsum application on soil moisture characteristics, ET and WUE of sunflower crop in coastal saline zone of West Bengal in eastern India.

Materials and Methods

Field experiment with sunflower was carried out at farmer's field, near Kakdwip, West Bengal, India (21°47'N, 88°13'E; 3 m above MSL) during winter (*rabi*) season of 2013 and 2014. Detailed topographic and climatic description has been reported elsewhere (Manna *et al.*, 2019). The average rainfall in this region is about 1800 mm per annum, of which about 80 percent occurs during the monsoon months of June to September,

usually attaining the peak in the month of July. The maximum and minimum temperatures range from 25.2° to 34.9° Celsius and 13.6° to 26.6° Celsius respectively. Monthly temperature, relative humidity, rainfall and number of rainy days during the course of investigation (2013 and 2014) are presented in SM Fig. 1 and 2 respectively. The coastal saline soils are silt to clay loam in texture, being slightly acidic to alkaline in reaction, with pH ranging from 5.4 to 8.4. 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 reported elsewhere (Manna *et al.*, 2019).

A detail of the experiment has been reported in an earlier study (Manna *et al.*, 2019). The experiment was laid out in split-split design with three replications. Irrigation levels was treated as main plot (I₁: 0.5 irrigation water (IW) / cumulative pan evaporation (CPE), I₂ : 0.75 IW/ CPE and I₃ : 1.0 IW/CPE), tillage as sub-plot treatments (T₁ : conventional, 10 cm and T₂ : deep tillage, 20 cm) and gypsum application as sub-sub treatments (A₁ : no gypsum and A₂ : with gypsum). A detail of irrigation schedule is mentioned in Table 1. Total number of irrigation excludes irrigation that were given to all treatments before imposing irrigation treatments (i.e.; at the time of establishment of plant stand). 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 reading of USDA Class A open pan evaporimeter placed at the experiment site. Recommended fertilizer dose of N, P₂O₅ and K₂O @ 80:60:40 kg were applied through urea, SSP and MOP, respectively during both the years of experiment. Gypsum (CaSO₄, 7H₂O) was applied to the field @ 50 kg ha⁻¹.

Crop was sown and harvested during January and last week of April month respectively.

For moisture analysis collected samples were accurately weighed (approximately 20 g) using an analytical balance in a pre-weighed empty aluminium moisture box and dried in an electric oven for overnight to a constant temperature (105°C). The per cent of moisture was calculated from the loss in weight and the results are expressed in oven dry weight basis. Water use efficiency (WUE) is the ratio of crop yield to the amount of water depleted by the crop in process of evapotranspiration (ET). It measures yield per unit area of land per unit depth of water used by crop and express as $\text{Kg.ha}^{-1}.\text{mm}^{-1}$. WUE is determined by using the following formula:

$$\text{WUE}=\text{Y}/\text{ET}$$

Where, WUE = water use efficiency ($\text{Kg.ha}^{-1}.\text{mm}^{-1}$); Y=Crop yield, Kg.ha^{-1} and ET=Evapotranspiration (mm)

The water used by the crop or total evapotranspiration (ET) was calculated by following water balance equation (Sammis *et al.*, 1986)

$$\text{ET}=\text{I}+\text{R}+\text{D}+\Delta\text{Sm}$$

Where, ET (mm) = evapotranspiration or water used by the crop; I (mm) = amount of irrigation water applied; R (mm) = amount of rainfall; D (mm) = amount of drainage; ΔSm (mm) = change in soil moisture during crop growth

The pooled data were statistically analyzed using split-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).

Results and Discussion

Changes in soil moisture content

Changes in soil moisture contents with different treatments during different crop growth stages are presented in Figure 1, 2, 3. Soil moisture content was found to vary from 7.38 to 28.42 mm (avg. 20.20 mm) and 10.37 to 31.07 mm (avg. 22.04 mm) in conventional and deep tillage respectively during 2013 in least irrigated plots (IW/CPE 0.50). Similar results were found during 2014 for same treatment; 7.88 to 29.20 mm (avg. 21.48 mm) and 10.37 to 29.69 mm (avg. 23.34 mm) for conventional tillage and deep tillage respectively. It was found to vary from 11.27 to 33.26 (avg. 25.38 mm) in conventional tillage and 14.25 to 36.35 (avg. 27.85 mm) in deep tillage when IW/CPE was maintained at 0.75 during 2013 and from 12.07 mm to 34.06 mm (avg. 25.04 mm) in conventional tillage and 14.25 to 36.35 mm (avg. 27.04 mm) in deep tillage during 2014. Highest level of soil moisture content was found when IW/CPE was maintained at 1.00 and it varied from 18.62 to 36.24 mm (avg. 28.14 mm) and 20.70 to 38.79 mm (avg. 30.43 mm) during 2013 and 19.12 to 36.74 (avg. 28.71 mm) and 20.70 to 38.79 mm (avg. 30.81 mm) in conventional tillage and deep tillage respectively during 2014. Variation in soil moisture contents during cropping season was possibly due to variation in amount of applied irrigation and evapo-transpiration (ET) needed to support crop growth. Moisture content during both year 2013 and 2014 was statistically at par. However, the characteristics variation in soil moisture contents during both experimental years for each of the irrigation treatments might be due to variations in time and amount of rainfall received in each year (SM Fig. 2).

Our experiment shows gradual depletion of soil moisture content with advancement of

crop growth stages. Occasional high peak of the soil moisture content represented increase in soil moisture immediately after receiving irrigation or rainfall. The most frequently irrigated plots (IW/CPE 1.0) registered shortest period of dryness as compared to less frequently irrigated plots having IW/CPE of 0.75 and 0.50 as expected. Similarly, moisture content during later crop growth stage was found to be more depleted in lesser irrigated plot (IW/CPE 0.50 and 0.75) than frequently irrigated plots (IW/CPE 1.0). Gurumurthy *et al.*, (2008) also noticed higher moisture regime in soil at irrigation IW/CPE of 1.2 compared with IW/CPE of 0.8 and 0.6. Depletion of the soil moisture, at maturity, in less frequently irrigated plots is quite expected because of higher evapo-transpiration demand than moisture available in soil. It was also found that moisture content during later stage was lesser than initial period in least irrigated plot (IW/CPE 0.50) whereas it was similar or higher in IW/CPE 0.75 and IW/CPE 1.0 plots during that period.

Deep tillage operation was found to increase soil moisture content at any stages of crop growth over conventional tillage; however, at maturity, conventional tillage was found to be more effective. The effects of deep tillage on soil moisture change are in accordance with the results of Gurumurthy and Rao (2006) that tilled plots recorded higher moisture content till the end of irrigation cycle where deep tillage found more superior than shallow tillage.

Increased intensity of tillage contributed to favourable soil physical environment for higher soil moisture regimes as reported by them are also in support of the present findings. Vittal *et al.*, (1983) also reported similar results of relatively higher moisture content under deep tillage which enable deeper root penetration to cause higher moisture retention in soil.

Water use efficiency and ET as influenced by different treatments

The results on evapo-transpiration (ET) and water use efficiency (WUE) as affected by the different treatments of irrigation, tillage and gypsum are presented in Table 2.

Highest ET was recorded under maximum no of irrigation application (IW/CPE 1.0) during both year and the difference was negligible between years. It was averaged at 239.00 mm under conventional tillage and 241.17 mm under deep tillage without gypsum application and 239.81 mm and 241.65 mm respectively with gypsum application in the year 2013. Average ET was found to be 267.13 and 266.12 mm under conventional and deep tillage without gypsum and 269.89 and 267.84 mm under conventional and deep tillage with gypsum application in the year 2014. ET was found to be significantly influenced by irrigation practices; however impact of tillage depth and gypsum application was found negligible. It revealed that the ET significantly increased with increasing level of irrigation at both tillage gypsum treatments in both years but the values were higher in 2014 than in 2013. Tillage showed no significant influence over ET although it tended to increase in 2013 but decreased during 2014 under deep tillage over conventional tillage. Higher magnitudes of ET loss under frequently irrigated plots have also been reported by Sarkar (2005).

WUE of crop was found to be influenced significantly by different treatments. Higher WUE was noticed under deep tillage and when lesser amount of irrigation was applied and increased with gypsum application. WUE was found to vary from 6.19 to 5.49 kg.ha⁻¹. mm⁻¹ (avg. 5.82 kg.ha⁻¹.mm⁻¹) in conventional tillage and 6.43 to 5.86 kg.ha⁻¹. mm⁻¹ in deep tillage with different irrigation frequency without gypsum application; and 6.29 to 5.69

kg.ha⁻¹.mm⁻¹ (avg. 55.99 kg.ha⁻¹.mm⁻¹) under conventional tillage and 6.41 to 5.96 kg.ha⁻¹.mm⁻¹ (avg. 6.18 kg.ha⁻¹.mm⁻¹) under deep tillage with gypsum and irrigation application during 2013. However, lower WUE was found during second year of experiment compared to previous year. It ranged from 5.59 to 5.17 kg.ha⁻¹.mm⁻¹ (avg. 5.37 kg.ha⁻¹.mm⁻¹) under conventional tillage without gypsum and 5.78 to 5.30 (avg. 5.55) under deep tillage with gypsum; and 5.63 to 5.27 kg.ha⁻¹.mm⁻¹ (avg. 5.46 kg.ha⁻¹.mm⁻¹) under conventional without gypsum and 5.85 to 5.44 kg.ha⁻¹.mm⁻¹ (avg. 5.65 kg.ha⁻¹.mm⁻¹) under deep tillage with gypsum. The WUE by sunflower decreased significantly with increasing level of irrigation at each level of tillage and gypsum treatments in both years. Irrespective of irrigation frequency and gypsum application, deep tillage improved WUE significantly over shallow tillage in both years. Besides, addition of gypsum increased WUE at every respect of irrigation and tillage treatments. The WUE was found to be less in 2014 compared to 2013. Too much irrigation led to a decrease of crop WUE (Jin *et al.*, 1999).

0.705, n= 24) was found between WUE and ET (Table 3) indicating reduced WUE with increasing ET. Increase in ET and subsequent decrease in WUE with increasing level of irrigation was reported elsewhere (Hittinahalli *et al.*, 2003; Tolk and Howell, 2012). Researchers found significantly higher WUE at deficit irrigation than that at fully irrigated plot (Flenet *et al.*, 1996; Karam *et al.*, 2007). Lower WUE associated with higher no of irrigation might be due to greater expense of water with comparatively less seed yield (Arora *et al.*, 2011; Bharati *et al.*, 2007; Gurumurthy *et al.*, 2008; Reddy *et al.*, 2008; Charanjit *et al.*, 1998). Higher WUE in less frequently irrigated plots implied that the seed yield was disproportionate towards water used by the crop. Similar findings were reported elsewhere (Ramamoorthy *et al.*, 2009). Higher WUE with deep tillage at less frequently irrigated plots was attributed due to improved soil water retention making moisture available to sunflower throughout its growth stages (Gurumurthy *et al.*, 2008; Salih *et al.*, 1998). Improvements of WUE due to addition of sulfur through gypsum are also in consonance with the findings of Patel *et al.*, (2008).

We found strong negative correlation (r=-

Table.1 Total number and interval of irrigation water used during the experimentation

Treatments	Total number of irrigation during crop growth period		Interval of irrigation(days)	
	2013	2014	2013	2014
I ₁	3	3	25 and 17	21 and 15
I ₂	4	4	19, 16 and 11	36, 13 and 10
I ₃	6	6	19, 14, 11, 9 and 9	33, 12, 9, 7 and 7

Table.2 Effect of irrigation, tillage and gypsum application on evapotranspiration (ET; mm) and water use efficiency (WUE; kg.ha⁻¹.mm⁻¹) of sunflower (Pooled data of two years, 2013 and 2014)

Treatments	ET				WUE			
	2013		2014		2013		2014	
Irrigation/ Tillage	T1	T2	T1	T2	T1	T2	T1	T2
	Without gypsum (A1)							
I1	184.55	185.77	210.75	209.38	6.19	6.43	5.59	5.78
I2	217.87	220.04	247.92	249.22	5.78	6.07	5.35	5.56
I3	314.57	317.70	342.72	339.76	5.49	5.86	5.17	5.30
Mean	239.00	241.17	267.13	266.12	5.82	6.12	5.37	5.55
	With gypsum (A2)							
I1	185.64	186.94	214.44	212.36	6.29	6.41	5.63	5.85
I2	217.33	219.72	249.09	248.70	5.97	6.16	5.49	5.68
I3	316.46	318.30	346.13	342.46	5.69	5.96	5.27	5.44
Mean	239.81	241.65	269.89	267.84	5.99	6.18	5.46	5.65
	a							
CD (P=0.05)		I	T	A	IXT	IXA	TXA	IXTXA
ET	2013	11.72	NS	NS	NS	NS	NS	NS
	2014	12.83	NS	NS	NS	NS	NS	NS
WUE	2013	0.25	0.13	0.06	NS	NS	NS	NS
	2014	0.23	0.12	0.05	NS	NS	NS	NS

Table.3 Pearson correlation matrix between WUE, ET, sunflower seed and stover yield

Parameters	WUE (kg.ha ⁻¹ .mm ⁻¹)	ET (mm)	Seed yield (kg.ha ⁻¹)	Stover yield (kg.ha ⁻¹)
<i>WUE (kg.ha⁻¹.mm⁻¹)</i>	1			
<i>ET (mm)</i>	-0.71 ^a	1		
<i>Seed yield (kg.ha⁻¹)</i>	-0.53 ^b	0.97 ^a	1	
<i>Stover yield (kg.ha⁻¹)</i>	-0.58 ^b	0.98 ^a	0.99 ^a	1

a and b indicates significance level at p <0.01 and 0.001 respectively (n= 24)

Table.4 Effect of irrigation, tillage and gypsum application on seed yield (kg.ha⁻¹) and stover yield (kg.ha⁻¹) of sunflower (Pooled data of two years, 2013 and 2014)

Treatments Irrigation/Tillage	Seed yield (kg.ha ⁻¹)						Stover yield (kg.ha ⁻¹)					
	2013		Mean	2014		Mean	2013		Mean	2014		Mean
	T1	T2		T1	T2		T1	T2		T1	T2	
Without gypsum (A1)												
I1	1142.0	1194.0	1168.0	1179.0	1211.0	1195.0	3182.0	3268.0	3225.0	3352.0	3437.0	3394.5
I2	1260.0	1335.0	1297.5	1326.0	1385.0	1355.5	3406.0	3488.0	3447.0	3598.0	3686.0	3642.0
I3	1727.0	1862.0	1794.5	1772.0	1801.0	1786.5	4740.0	4854.0	4797.0	4838.0	4976.0	4907.0
Mean	1376.3	1463.7	1420.0	1425.7	1465.7	1445.7	3776.0	3870.0	3823.0	3929.3	4033.0	3981.2
With gypsum (A2)												
I1	1168.0	1198.0	1183.0	1207.0	1242.0	1224.5	3249.0	3333.0	3291.0	3417.0	3498.0	3457.5
I2	1298.0	1353.0	1325.5	1367.0	1412.0	1389.5	3479.0	3500.0	3489.5	3635.0	3733.0	3684.0
I3	1802.0	1897.0	1849.5	1824.0	1862.0	1843.0	4929.0	4921.0	4925.0	5098.0	5209.0	5153.5
Mean	1422.7	1482.7	1452.7	1466.0	1505.3.0	1485.7	3885.7	3918.0	3901.8	4050.0	4146.7	4098.3

CD (P=0.05)		I	T	A	I X T	I X A	T X A	I X T X A
Seed yield	2013	74.0	28.9	19.7	84.7	80.9	NS	NS
	2014	68.4	34.0	15.5	79.9	70.8	NS	NS
Stover yield	2013	197.3	79.8	52.4	NS	NS	NS	NS
	2014	204.5	83.3	53.8	NS	214.2	NS	NS

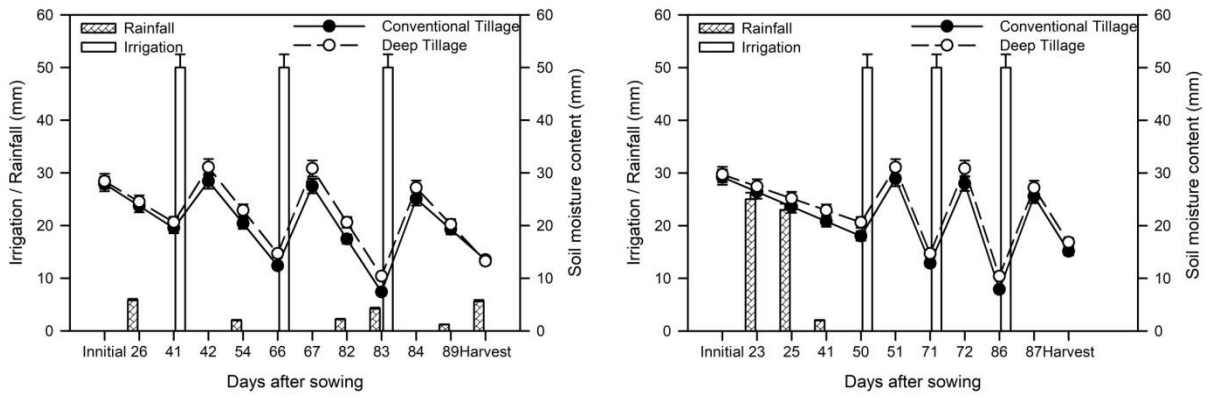


Figure.1 Effects of irrigation (IW/CPE 0.5) and tillage on soil moisture content of sunflower crop in 2013 and 2014 respectively

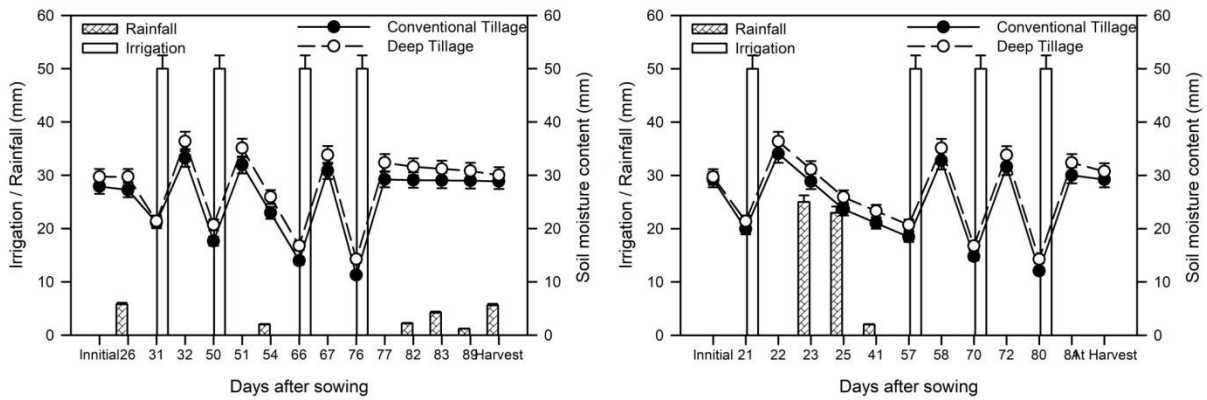


Figure.2 Effects of irrigation (IW/CPE 0.75) and tillage on soil moisture content of sunflower crop in 2013 and 2014 respectively

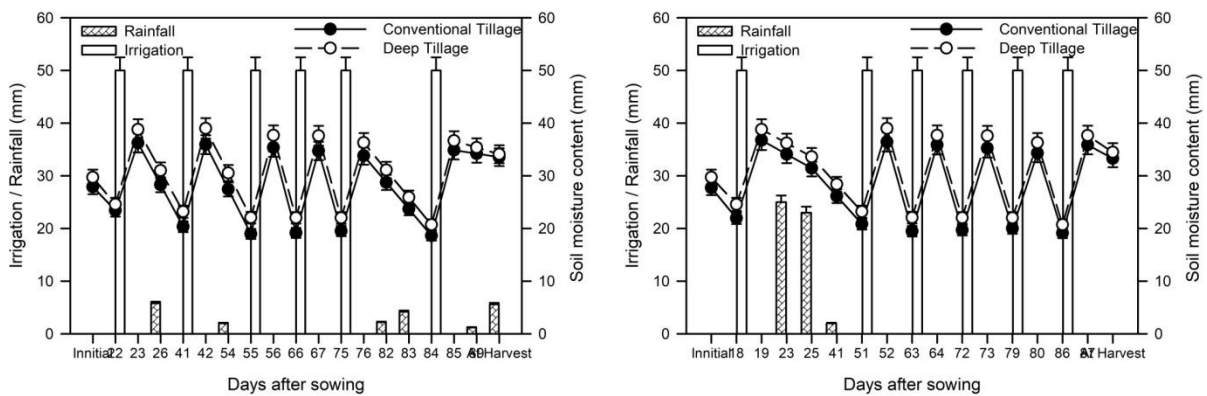
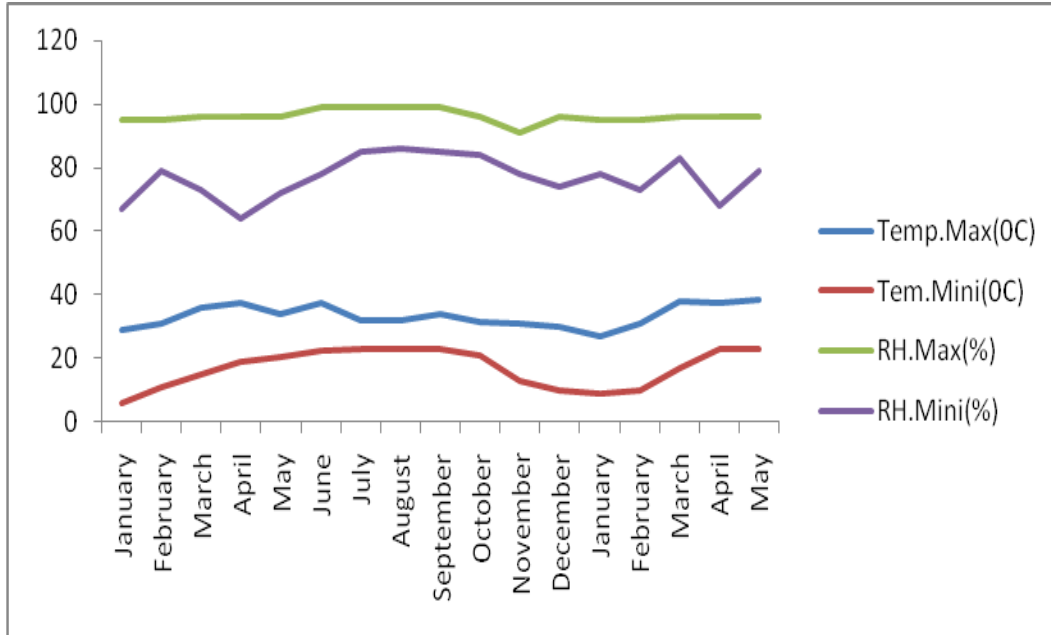
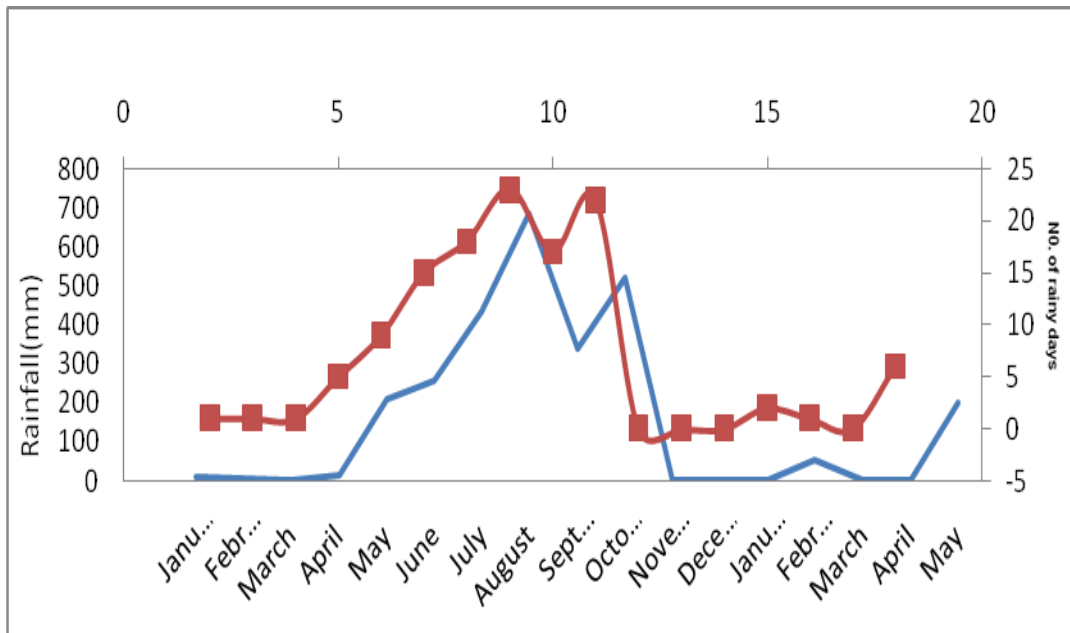


Figure.3 Effects of irrigation (IW/CPE 1.0) and tillage on soil moisture content of sunflower crop in 2013 and 2014 respectively

Supporting material



SM Fig.1 Temperature and Relative humidity during the course of investigation (2013 and 2014)



SM Fig.2 Monthly rainfall and number of rainy days during the course of investigation (2013 and 2014)

Effect of ET and WUE on sunflower yield

Table 4 represents effects of various treatments on sunflower seed and stover yield. Seed yield varied from 1142 to 1862 kg.ha⁻¹ (avg. 1420 kg.ha⁻¹) under different irrigation and tillage practices during 2013 when no gypsum was added. It varied from 1168 to 1897 kg.ha⁻¹ (avg. 1452.70 kg.ha⁻¹) with gypsum addition during same period. Seed yield varied from 1207 to 1862 (avg. 1485.70 kg.ha⁻¹) and 1179 to 1801 (avg. 1445.7 kg.ha⁻¹) respectively with and without gypsum application under different irrigation and tillage practices during 2014. Stover yield varied from 3249 to 4921 (avg. 3901.80 kg.ha⁻¹) and 3128 to 4854 (avg. 3823.00 kg.ha⁻¹) respectively with and without gypsum application under different irrigation and tillage practices during 2013. It varied from 3417 to 5209 (avg. 4098.30), 3128 to 4854 (avg. 3823.00 kg.ha⁻¹) and 3352 to 4976 (avg. 3981.20), 3128 to 4854 (avg. 3823.00 kg.ha⁻¹) respectively during 2014. We found significant influence of irrigation water and tillage depth on seed and stover yield. Sunflower yield was increasing when no of irrigation and tillage depth was higher. Highest yield was found with maximum no of irrigation (I₃) under deep tillage (T₂) with added gypsum (A₁).

We found strong correlation between both seed and stover yield and ET (r= 0.97 and 0.98 respectively; Table 3). However, only weak correlation was found between crop WUE and yield (r= 0.53 and 0.58 respectively for seed and stover yield). ET meets water requirement of crops. Along with water crop takes up various nutrients for their growth. Higher ET results higher nutrient uptake of crops increasing sunflower seed and stover yield. Plots receiving higher amount of irrigation water resulted higher ET value. High ET encourages higher water uptake facilitating higher nutrient uptake from soil.

This resulted in higher yield in plots receiving higher amount of irrigation water. Tillage depth and gypsum application had similar positive influence on crop yield. Tillage depth modified soil moisture regime thereby influencing nutrient uptake of crop. Positive influence of tillage on crop yield was reported elsewhere. Positive influence of gypsum application on soil properties under sunflower cultivation were reported earlier by Manna *et al.*, (2019). Better soil environment with gypsum application increased nutrient uptake thereby increasing crop yields.

In conclusions, our study indicates importance of IW/CPE approach on soil moisture studies and its influence on ET, WUE of crops. Generally, soil moisture content was gradually depleting with advancement of crop stages. Deep tillage increased soil moisture content at any stages of crop growth over conventional tillage, but at maturity found to be more effective over deep tillage. Variation of soil moisture content may be ascribed by the variations of evapotranspirational need of the crop at various crop stages in different treatments. The result showed that ET increased generally with increasing irrigation level and the effect found more superior under deep tillage than conventional tillage. Irrespective of the level of tillage and gypsum application WUE found to decrease with increasing level of irrigation. Tillage and addition of gypsum also affect to increase the WUE by sunflower crop. The lower water use efficiency associated with higher irrigation treatments might be due to greater expense of water with comparatively less seed yield. Higher WUE with deep tillage at less frequently irrigated plots was attributed by improved soil water retention making moisture available to sunflower throughout its growth stages. Thus, though higher yield was obtained from plots receiving higher amount of irrigation, it came at the expense of low crop WUE.

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