Effect of irrigation scheduling and residue management tillage on soil water balance and growth of wheat

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Abstract

The present study was conducted in wheat at the Punjab Agricultural University Seed Farm, Ladhowal, Ludhiana, to study effect of three irrigation regimes (based on IW/PAN-E ratio of 0.6 (I_1), 0.8 (I_2) and 1.0 (I_3) in main plots and four tillage practices (mould board ploughing to a depth of 25 cm followed by rotavator (PT_{25} + R), mould board ploughing to a depth of 14 cm followed by rotavator (PT_{14} + R), zero tillage with happy seeder (ZT) and conventional tillage with 2 discing + 2 cultivator followed by planking (CT) in sub plots) on soil water balance and crop growth for two consecutive years (2016-17 and 2017-18). Irrigation scheduling and tillage practices has no significant effect on plant germination and thousand grain weight. However overall mean plant height, leaf area index, root length density and root mass density were significantly higher in I_3 over I_1 and I_2 by 2.1 & 2.8%, 16.82 & 7.75%, 2.04 & 5.22% and 5.82 & 8.73% respectively. During both the years straw and grain yield were significantly higher in I_3 over I_1 and I_2. Significantly higher water productivity was observed in I_2 over I_1 and I_3 by 27.38 & 2.26% in 2016-17 and 27.70 & 1.91% in 2017-18. During 2016-17 maximum water depletion was in I_1 over I_2 and I_3 by 2.15 &4.86% and 4.5 & 7.52 in 2017-18. Over PT14 + R, ZT and CT, the tillage practice of PT25 + R significantly increased number of tillers by 5.13,19.42 & 11.82%, plant height by 3.44, 8.38 & 10.37%, leaf area index by 13.45, 26.17 & 27.36%, root length density by 19.30, 61.81 & 46.17% and root mass density by 35.90, 317.67 & 48.16% respectively. During both years significantly higher straw and grain yield were observed in PT_{25} + R over PT_{14} + R, ZT and CT. During both years significantly higher soil moisture storage was observed in I_3 and ZT compared to other irrigation and tillage practices. Water balance component E&T were higher in PT_{25} + R than ZT.

Introduction

The rice-wheat rotation is the principal cropping system of South Asian countries that occupies about 13.5 million hectares in the Indo-Gangetic Plains (IGP), of which 10 million hectares are in India, 2.2 million hectares in Pakistan, 0.8 million hectares in Bangladesh and 0.5 million hectares in Nepal. This cropping system covers about 33% of the total rice area and 42% of the total wheat area in the four countries as stated above, and account for one quarter to one third of the total rice and wheat production (Ladha et al. 2000). In India, this cropping system contributes about 40% of the country's total food grain (Bhatt and Kukal, 2016). In punjab every year about 22.9 Mt of paddy and 23.1 Mt of wheat residue is produce (Bimbraw 2019) is a major problem ot the farmers. For the sowing of wheat cereals crops generates large volume of residues (352 Mt) both on and off farm (Anonymous 2014).

Because the paddy harvesting and wheat sowing, the window period is very short. Therefore, a large number of machines at low price are required for managing the paddy straw. Conventional incorporation of rice stubbles needs minimum 4–5 tillage operations of discing, which are time and energy consuming and costly for marginal farmers. Deep ploughing consumes more energy for incorporation of the rice residues in the field but helps in better seed germination and root growth for more uptake water and nutrients (Amin et al. 2013). Other options are direct drilling of wheat in standing stubbles of rice with zero tillage and Happy Seeder. Among these, Happy Seeder is a more economical technology, but it has some limitations that in heavy straw loaded fields, its performance is not satisfactory (Sidhu et al. 2007). The major constraint observed under rice-wheat cropping system is yellowing of wheat due to stagnation of water after first irrigation (Singh and Singh 2021) Because of subsurface compaction by puddling

Beside crop residue burning Punjab has another problem of ground water depletion. As per the guidelines of Ground Water Resources Estimation Committee (GEC), the present ground water development (ratio of gross ground water draft for all uses to net ground water availability) in the state is 145% as per latest data provided by Central Ground Water Board, (Government of India 2011). Another issue of concern is that water in a large part of the area, having positive ground water balance, is saline and hence unfit for irrigation. It is important to take cognizance of the fact that central Punjab has 72% area under paddy cultivation, out of which only 21% area is irrigated by canal (Kumar et al. 2015). The present 4 study was therefore conducted to study the effect of irrigation scheduling and residue management tillage on water balance components, growth and water productivity of wheat.

Material And Method

Site & weather

The field experiment was conducted with wheat after paddy during 2016-17 and 2017-18 at the University Seed Farm, Ladhowal, Ludhiana representing the Indo-Gangetic alluvial plains situated at 30°58'29"N latitude and 75°47'15"E longitude at of 247 meters above mean sea level. The area is characterized by sub-tropical and semi-arid type of climate with hot and dry summer from April to June followed by hot and humid period during July to September and cold winters from November to January. The mean maximum and minimum temperatures show considerable fluctuations during different parts of the year. Summer temperature however around 38°C and touches 45°C with dry summer spells (Kingra and Kaur 2012). Winter experiences frequent frosty spells especially in December and January and minimum temperature dips up to 0.5°C. The average rainfall of the area is 600–700 mm, of which about 80 percent is received during July to September (Krishan, et al. 2015).

The meteorological data collected from the meteorological observatory of the Punjab Agricultural University Ludhiana during both wheat growing season (November to April) is presented in Fig. 1 and Fig. 2.

Soil Characteristics

The composite soil samples were randomly collected from 0–15 cm depth. The samples were first air dried in the shade and then sieved through 2.0 mm sieve for analyses of soil texture, pH, EC, soil organic carbon, available N, P, and K (Table 1).

Experimental Details

The experiment was initiated during rabi season of 2016 with four tillage and three irrigation treatments namely (PT_{25} + R Primary tillage to 25 ± 2 cm depth with mould board plough followed by rotavator, PT_{14} + R Primary tillage to 14 ± 2 cm depth with mould board plough followed by rotavator, ZT zero tillage, wheat sowing with Happy Seeder in paddy straw, CT conventional tillage, two discing + two cultivator followed by planking, and (IW/PAN-E) ratio 0.6, 0.8 and 1.0 on sandy loam soil sowing wheat crop. Before, start of experiment the field was under continuous rice-wheat cropping system for > 10 years.

Wheat was sown on 15th November 2016 and 18th November 2017 with the seed rate of 100 kg ha^{-1} with help of seed cum fertilizer drill at row spacing of 20 cm. The different agronomic operations were performed according to experimental requirement. The crop was sown at proper soil moisture condition. All the recommended package of practices by Punjab Agricultural University, Ludhiana were followed for crop growth. The wheat was harvested on 20th of April during both season (2017&2018).

The recommended dose of fertilizers was applied at the rate of 125 kg N ha^{-1} in the form of urea and 62.5 kg P_2O_5 ha^{-1} in the form of single superphosphate. At sowing, half of N, and all P_2O_5 were applied as basal dose. The remaining half N applied before 2 days of first irrigation. Weeds were kept under control with use of recommended herbicides and hand weeding at proper stage.

Table 1
Soil properties of the experimental field

Soil parameter	Value	Method
Sand (%)	70	International pipette method
Silt (%)	18	International pipette method
Clay (%)	12	International pipette method
Soil type	Sandy loam	
pH	8.15	Jackson, 1967
EC (dS m^{-1})	0.4	Jackson, 1967
Available N (kg ha^{-1})	255	Subbiah and Asija, 1956
Olsen’s extractable P (kg ha^{-1})	17.45	Olsen et al.., 1954
Available K (kg ha^{-1})	261.1	Merwin and Peech, 1950

For Germination Count

The number of wheat seedlings emerging from one metre row length from 3 location in each plot were counted daily from sowing till constant number. The number of effective tillers were counted in randomly selected one metre row length from three location in each plot.

Plant Height

The plant height of ten randomly selected plants in each plot was measured with the help of meter scale from ground surface to apex of the plant at 45, 60, 75 DAS, and at harvesting.

Leaf Area Index

The leaf area index was measured at 50, 75, 105, and 120 DAS using leaf area meter canopy analyser

$$\mathrm{Leafareaindex} = \frac{\mathrm{Leafarea}}{\mathrm{Groundarea}}$$

Root Distribution

The root distribution was measured after harvesting. The root samples were collected from 0–15, 15–30, 30–45, and 45–60 cm soil layers. For root sampling, the soil cores were taken with the help of core sampler of 5 cm diameter. Samples were taken in between the plant rows. The root-soil cores were then collected and washed in plastic nets. Roots were carefully separated from the soil by washing the nets under water. The washed roots were further cleaned to remove any leftover weed roots, seed and other organic debris. The root length density (cm cm^{-3}) was calculated from the total length of roots measured by scanner to the volume of the core. These roots were then dried in an oven at 60° C and weighed on precision balance to calculate the root mass density (μg cm^{-3}).

Crop Straw And Grain Yield

The crop straw was harvested and threshed manually from an area of $25m^2$. Grain and straw yield were recorded in kg from 25 m^2 area in each plot and finally expressed in t ha^{-1}

Test Grain Weight

A representative sample of one thousand grains from each plot was counted manually and weighed on a precision balance and expressed in grams.

Soil Water Balance Components

Irrigation amount

The irrigation amount (liter/minute) was measured using digital flow meter installed on delivery pipe of the tube well and was divided by area to calculate irrigation water in cm.

Rainfall

The rainfall amount (mm) was recorded on the rainy day by using rain gauge installed at the experimental site, itself.

Drainage

Drainage was calculated from measuring the amount of irrigation applied and field capacity of each profile layer. The amount of water exceeding the maximum storage was calculated as drainage (cm).

Evapo-transpiration

Potential evapotranspiration (ETm) was measured from pan evaporation (EPAN) and a relationship of time (t) following seeding through a quadratic polynomial proposed by Arora et al. (1987). Substituting daily EPAN, in this relation gave an estimate of ET m:

$ETm/EPAN = 0.56 + 0.021t - 0.000125t^2$ (1)

Partitioning to crop transpiration factor and soil evaporation

ETm was partitioned to plant transpiration (Tm) and evaporation from soil surface (Em) through the crop transpiration factor Kt (equations (2) and (3) that was obtained from information on progressive leaf area index (LAI). Earlier, Hanks (1974), Rasmussen and hanks (1978) and Retta and Hanks (1980) used Kt from LAI for potential water supplies conditions, and the effect of reduced water on transpiration was incorporated through reduced soil water status. But apart from affecting temporal variation in soil water status, timing and amount of water additions also effect the pattern of leaf area development and hence the transpiration load T of the plant. Thus, Kt should be assessed from leaf area development for specific wetting histories for partitioning ETm into T• (that equals T m under plentiful water supplies):

$T\ (\text{or } Tm) = ETmKt,$ (2)

$Em = (1 - Kt)ETm$ (3)

This factor Kt was assumed to have a maximum value of 0.90 for LAI equal to or greater than 4.00. However, for LAI less than 4.0, Kt was made to decrease gradually through a square root relation (Eq. (4))

rather than linearly with decreasing LAI. This modification was considered necessary, since at low LAI, transpiration per unit LAI is more than that at high LAI.

$Kt = 0.90(LAI/4.00)^{0.5}$ (4)

Daily actual soil evaporation (Ea) was calculated by relation

$Ea = Em\ t^{-0.30}$ (5)

and actual transpiration (Ta) by

$Ta = T \times AWF/0.5$ (6)

where AWF is plant available water in each soil layer

Profile moisture storage

The profile moisture was measured up to a depth 120 cm from (0-15, 15-30, 30-60, 60-90 and 90-120 cm) thermo-gravimetrically before sowing and at the time of harvesting each crop. For profile moisture storage, the gravimetric moisture content of each layer was multiplied with bulk density and depth of layer and was expressed as mm of water and then to obtain total profile moisture storage each layer storage was added.

Water Productivity

The WP (kg $ha^{-1}cm^{-1}$) was measured by dividing the grain yield over total evapotranspiration (Ea + Ta) of each treatment.

$$\mathrm{Waterproductivity} = \frac{\mathrm{Grainyield}}{\mathrm{ET}}$$

Results And Discussion

Germination

The data pertaining to germination, as affected by residue management tillage practices and irrigation levels is presented in the Table 2. The number of plants m^{-1} row length as affected by tillage for residue management practices and irrigation levels were statically at par with each other. Among the tillage for residue management practices number of plants m^{-1}row length were highest in PT_{25} + R (36) followed by PT_{14} + R (35) and the minimum under CT (34) and ZT (34), respectively. Leghari et al. (2015) also reported that the seedling emergence was not affected by the tillage treatments during the wheat growing seasons where CT had higher emergence than reduced tillage.

Table 2
The effect of irrigation and tillage on number of plants germination (m^{-1} row)

	$I_{1(0.6)}$	$I_{2(0.8)}$	$I_{3(1.0)}$	**MEAN**
PT_{25} + R	37	35	35	**36**
PT_{14} + R	35	31	39	**35**
ZT	37	27	37	**34**
CT	36	31	34	**34**
MEAN	**36**	**31**	**36**	
CD (p = 0.05)	Tillage = NS* Irrigation = NS Tillage × Irrigation = NS			
* NS non-significant				

Irrigation levels were also statistically at par with each other. Maximum germination counted in I_1 (36) and I_3 (36) and least found in I_2 (31) respectively. Similarly, no significant difference among tillage treatment on germinations was reported by Amin and khan (2013).

Number Of Tillers

The data pertaining to number of tillers as affected by tillage for residue management practices and irrigation levels is presented in the Table 3. The number of tillers were significantly affected by tillage treatments. Among the residue management tillage practices overall mean number of tillers were significantly higher under PT_{25} + R over ZT and CT by 19.42 and 11.18% respectively. However, PT_{25} + R was at par with PT_{14} + R, while CT was at par with ZT. Leghari et al. (2015) also reported that mould board plough had a greater number of tillers per plant as compared to no tillage. The effect of irrigation levels on number of tillers was non-significant

Table 3
The effect of irrigation and tillage on number of tillers (m^{-1} row)

	$I_{1(0.6)}$	$I_{2(0.8)}$	$I_{3(1.0)}$	**MEAN**
PT_{25} + R	122	114	132	**123**
PT_{14} + R	113	114	124	**117**
ZT	100	105	104	**103**
CT	103	112	114	**110**
MEAN	**110**	**111**	**119**	
CD (p = 0.05)	Tillage = 8.05 Irrigation = NS Tillage × Irrigation = NS			

Plant Height

The plant height was recorded at 45, 60, 75 and 105 days after sowing during 2017-18 and is presented in Table 4. At 45 days after sowing, tillage had significant effect. The plant height under the tillage residue management treatment was significantly higher by 9.7% in PT_{25} + R as compared to ZT, however, PT_{14} + R and CT were statistically at par with each other at 45 day after sowing. The maximum plant height was recorded under PT_{25} + R (40.7 cm) which was statistically at par with PT_{14} + R but significantly higher than the ZT and CT. Similar trend was also observed at 60 and 75 days after sowing. At 105 days after sowing, both the tillage and irrigation had significant effect on plant height. The maximum plant height was recorded under PT_{25} + R (110.1 cm) which was statistically at par with PT_{14} + R (108.5 cm) but significantly higher than ZT (102 cm) and CT (102.4 cm). The higher plant height in PT_{25} + R may be because of enhanced nutrients and moisture availability compared to CT (Memon et al. 2013). Similarly, taller plants in deeply tilled (disc ploughed) plots than CT were recorded by Aikins and Afuakwa (2010). Higher plant height with tillage may be because of more moisture conservation with tillage (Licht and Al-Kaisi 2005).

Overall higher mean plant height was observed in I_3 than I_2 and I_1 by 2.8% and 2.13% respectively. Among the different irrigation levels, the maximum plant height was recorded under I_3 (107.4 cm) which was significantly higher than I_1 (104.2 cm) and I_2 (105.7 cm). Higher plant height in I_3 may be due to more availability of water for plant growth as reported by Yousaf et al. 2014. Five irrigations increase plant height by 28.58% over one irrigation, due to no moisture stress (Sarwar et al.2010). At harvest the tallest plant was obtained with two irrigations at CRI + flowering stage and the shortest plants from one irrigation (Rummana et al. 2018).

Table 4

The effect of irrigation and tillage on plant height (cm)

45 days after sowing				
	$I_{1(0.6)}$	$I_{2(0.8)}$	$I_{3(1.0)}$	**MEAN**
PT_{25} + R	41.0	39.0	42.0	**40.7**
PT_{14} + R	39.3	36.7	40.0	**38.7**
ZT	35.3	36.0	40.0	**37.1**
CT	35.0	37.0	40.0	**37.3**
MEAN	**37.7**	**37.2**	**40.5**	
CD (p = 0.05)	Tillage = 2.31 Irrigation = NS Tillage × Irrigation = NS			
60 days after sowing				
PT_{25} + R	56.7	57.0	57.3	**57.0**
PT_{14} + R	53.7	54.0	54.3	**54.0**
ZT	51.3	51.7	52.0	**51.7**
CT	48.7	49.0	49.3	**49.0**
MEAN	**52.6**	**52.9**	**53.3**	
CD (p = 0.05)	Tillage = 3.67 Irrigation = NS Tillage × Irrigation = NS			
75 days after sowing				
PT_{25} + R	80.2	80.7	81.0	**80.6**
PT_{14} + R	77.2	77.7	78.0	**77.6**
ZT	74.9	75.4	75.7	**75.3**
CT	72.2	72.7	73.0	**72.6**
MEAN	**76.1**	**76.6**	**77.0**	
CD (p = 0.05)	Tillage = 3.66 Irrigation = NS Tillage × Irrigation = NS			
105 days after sowing				
PT_{25} + R	109.0	110.5	110.8	**110.1**
PT_{14+}R	106.5	108.0	110.9	**108.5**
ZT	101.4	102.9	101.6	**102.0**

45 days after sowing				
CT	99.7	101.2	106.3	**102.4**
MEAN	**104.2**	**105.7**	**107.4**	
CD (p = 0.05)	Tillage = 3.80 Irrigation = .88 Tillage × Irrigation = NS			
Mean of irrigation mean	**67.65**	**68.1**	**69.55**	

Leaf Area Index

The leaf area index (LAI) was recorded at 50, 75, 105 and 120 days after sowing (DAS) during 2017-18 and shown in the Table 5. Among the residue management tillage practices overall mean LAI was significantly higher in PT$_{25+}$R over PT$_{14+}$R, ZT and CT by 13.45, 26.17 and 27.36% respectively. Higher LAI was observed in PT$_{25}$ + R over PT$_{14}$ + R, ZT and CT in 50, 75, 105 and 120 DAS. Sun et al. (2019) showed that subsoil tillage could lead to maintenance of a relatively high LAI and more prolonged LAI at different crop growth stages, which provided the possibility for plants to capture more light for photosynthesis. Shahzad et al. (2016) represent that Bed sowing had better LAI while zero tilled wheat had the minimum LAI under all cropping systems at 60, 75, 90 and 105 DAS during both years. Leaf area per plant was highest in the plots where ridge sowing was practiced under deep tillage while lowest was recorded in the flat sowing under minimum tillage (Anjum et al. 2014). Conventional tillage consistently gave a significantly higher leaf area index than reduced tillage and zero tillage probably related to finer seed bed preparation (Gangwar et al. 2004). Gajri et al. (1992) alsao reported that leaf-area development in tilled treatments was more rapid than in NT. Khan et al. (2017) found that leaf area index was enhanced up to 9.89% by deep tillage practices as compared to minimum tillage.

The LAI was significantly higher both under I$_3$ and I$_2$ over I$_1$, at 75, 105 and 120 DAS. Overall higher mean LAI was observed in I$_3$ over I$_1$ than I$_2$ by 16.8 and 7.7%. Higher leaf area index with tillage and irrigation may be due to more proliferation of roots because of less bulk density (Singh and Singh 2021). Similar results have also been reported by (Qamar et al. 2013 and Xu et al. 2018). Kalaydjieva et al. (2015) reducing the irrigation rates display a negative impact on the values of LAI. Benbi (1994) subsequent irrigations decreased the rate of leaf senescence and hence increased leaf area duration. Generally, LAI declined at a higher rate with late application of irrigation.

Root Length Density

The root length density was recorded at harvesting from 0–15, 15–30, 30–45 and 45–60 cm soil depths and given in Table 6. Overall higher mean RLD was observed in PT$_{25}$ + R than PT$_{14}$ + R, ZT and CT by 19.30, 61.81 and 46.17% respectively. At surface layer (0–15 cm), RLD was maximum under PT$_{25}$ + R (1.108 cm cm^{-3}), which is significantly higher than PT$_{14}$ + R (1.002 cm cm^{-3}) followed by CT (0.850 cm

cm^{-3}) and ZT (0.749 cm cm^{-3}). Among the irrigation levels, there was no significant difference in I_3 (0.944 cm cm^{-3}), I_1 (0.933 cm cm^{-3}) and I_2 (0.905 cm cm^{-3}). Similar trend was followed under15-30 and 45–60 cm depths in tillage and irrigation treatments. Ji et al. (2013) also reported significantly higher (41.4%) RLD with mouldboard over CT. However, at 30–45 cm depth, significantly higher RLD was observed under I_1 (0.363 cm cm^{-3}) compared to I_2 (0.311 cm cm^{-3}) but at par with I_3 (0.332 cm cm^{-3}). Overall higher mean RLD was observed in I_3 over I_1 and I_2 by 5.83 and 8.74% respectively

Table 5
The effect of irrigation and tillage on leaf area index

50 days after sowing				
	$I_{1(0.6)}$	$I_{2(0.8)}$	$I_{3(1.0)}$	**MEAN**
PT_{25} + R	1.3	1.6	1.7	**1.6**
PT_{14} + R	1.0	1.2	1.4	**1.2**
ZT	0.8	0.9	1.3	**1.0**
CT	0.7	0.8	0.9	**0.8**
MEAN	**1.0**	**1.1**	**1.3**	
CD (p = 0.05)	Tillage = 0.086 Irrigation = 0.07 Tillage × Irrigation = NS			
75 days after sowing				
PT_{25} + R	3.0	3.2	3.4	**3.2**
PT_{14} + R	2.5	2.6	2.9	**2.7**
ZT	2.1	2.4	2.7	**2.4**
CT	2.0	2.3	2.5	**2.3**
MEAN	**2.4**	**2.6**	**2.9**	
CD (p = 0.05)	Tillage = 0.060 Irrigation = 0.8 Tillage × Irrigation = NS			
105 days after sowing				
PT_{25} + R	4.7	4.9	4.9	**4.8**
PT_{14} + R	4.2	4.3	4.8	**4.4**
ZT	3.4	4.1	4.4	**4.0**
CT	4.0	4.1	4.5	**4.2**
MEAN	**4.1**	**4.4**	**4.6**	
CD (p = 0.05)	Tillage = 0.20 Irrigation = 0.1 Tillage × Irrigation = NS			
120 days after sowing				
PT_{25} + R	3.7	3.8	4.0	**3.9**
PT_{14} + R	3.3	3.6	3.8	**3.6**
ZT	2.9	3.4	3.7	**3.3**

50 days after sowing				
CT	3.1	3.3	3.5	**3.3**
MEAN	**3.2**	**3.5**	**3.7**	
CD (p = 0.05)	Tillage = 0.11 Irrigation = 0.15 Tillage × Irrigation = NS			
Mean of irrigation mean	**2.7**	**2.9**	**3.1**	

Table 6

The effect of irrigation and tillage on root length density (cm cm⁻³)

0–15 cm				
	$I_{1(0.6)}$	$I_{2(0.8)}$	$I_{3(1.0)}$	**MEAN**
PT_{25} + R	1.104	1.100	1.119	**1.108**
PT_{14} + R	1.010	0.990	1.007	**1.002**
ZT	0.727	0.750	0.770	**0.749**
CT	0.890	0.780	0.880	**0.850**
MEAN	**0.933**	**0.905**	**0.944**	
CD (p = 0.05)	Tillage = 0.065 Irrigation = NS Tillage × Irrigation = NS			
15–30 cm				
PT_{25} + R	0.547	0.543	0.553	**0.548**
PT_{14} + R	0.403	0.373	0.420	**0.399**
ZT	0.237	0.290	0.300	**0.276**
CT	0.350	0.360	0.390	**0.367**
MEAN	**0.384**	**0.392**	**0.416**	
CD (p = 0.05)	Tillage = 0.036 Irrigation = NS Tillage × Irrigation = NS			
30–45 cm				
PT_{25} + R	0.507	0.383	0.410	**0.433**
PT_{14} + R	0.417	0.310	0.350	**0.359**
ZT	0.283	0.303	0.313	**0.300**
CT	0.243	0.247	0.253	**0.248**
MEAN	**0.363**	**0.311**	**0.332**	
CD (p = 0.05)	Tillage = 0.028 Irrigation = 0.036 Tillage × Irrigation = 0.04			
45–60 cm				
PT_{25} + R	0.377	0.377	0.417	**0.390**
PT_{14} + R	0.293	0.340	0.320	**0.318**
ZT	0.197	0.197	0.227	**0.207**

0–15 cm				
CT	0.223	0.230	0.240	**0.231**
MEAN	**0.273**	**0.286**	**0.301**	
CD (p = 0.05)	Tillage = 0.015 Irrigation = NS Tillage × Irrigation = NS			
Mean of irrigation mean	**0.48825**	**0.4735**	**0.49825**	

Root Mass Density

The root mass density was determined from 0–15, 15–30, 30–45 and 45–60 cm soil depths at harvesting and is presented in Table 7. At 0–15 cm depth, overall higher mean RMD was observed in PT$_{25}$ + R than PT$_{14}$ + R, ZT and CT by 35.9, 317.7 and 48.2% respectively. PT25 + R (0.528 μg cm^{-3}) was significantly higher RMD over PT$_{14}$ + R (0.403 μg cm^{-3}), CT (0.367 μg cm^{-3}) and ZT (0.367 μg cm^{-3}). Similarly, I$_3$ (0.375 μg cm^{-3}) had significantly higher RMD than I$_2$ (0.355 μg cm^{-3}) and I$_1$ (0.354 μg cm^{-3}). Similar results were found in 30–45 cm depth for tillage treatments, and irrigation levels. At 15–30 cm depth, tillage showed significant difference in RMD, but irrigation levels were at par with each other. PT25 + R (0.157 μg cm^{-3}) had significantly higher than PT$_{14}$ + R (0.098 μg/cm^3), CT (0.092 μg cm^{-3}) and ZT (0.032 μg cm^{-3}). Ren et al. (2018) found that Mouldboard plough tillage has higher root mass density than NT. Mu et al. (2016) also found that deep mouldboard plough tillage has higher RMD than shallow mouldboard plough tillage. Zhao et al. (2014) reported thatwhere deep tillage not only increased root proliferation and the depth to which roots penetrated (Shirani et al. 2002), but also increased the biomass of deeper root (Varsa et al. 1997).

Table 7

The effect of irrigation and tillage on root mass density (μg cm^{-3})

0–15 cm				
	$I_{1(0.6)}$	$I_{2(0.8)}$	$I_{3(1.0)}$	**MEAN**
PT_{25} + R	0.503	0.530	0.550	**0.528**
PT_{14} + R	0.413	0.390	0.407	**0.403**
ZT	0.140	0.140	0.163	**0.148**
CT	0.360	0.360	0.380	**0.367**
MEAN	**0.354**	**0.355**	**0.375**	
CD (p = 0.05)	Tillage = 0.012 Irrigation = 0.013 Tillage × Irrigation = 0.021			
15–30 cm				
PT_{25} + R	0.190	0.157	0.220	**0.189**
PT_{14} + R	0.150	0.147	0.120	**0.139**
ZT	0.027	0.030	0.045	**0.034**
CT	0.101	0.109	0.112	**0.107**
MEAN	**0.117**	**0.111**	**0.124**	
CD (p = 0.05)	Tillage = 0.037 Irrigation = NS Tillage × Irrigation = NS			
30–45 cm				
PT_{25} + R	0.150	0.150	0.170	**0.157**
PT_{14} + R	0.093	0.093	0.107	**0.098**
ZT	0.031	0.032	0.034	**0.032**
CT	0.091	0.091	0.095	**0.092**
MEAN	**0.091**	**0.092**	**0.101**	
CD (p = 0.05)	Tillage = 0.009 Irrigation = 0.008 Tillage × Irrigation = NS			
45–60 cm				
PT_{25} + R	0.094	0.090	0.102	**0.095**
PT_{14} + R	0.094	0.045	0.080	**0.073**
ZT	0.018	0.017	0.019	**0.018**

0–15 cm				
CT	0.084	0.087	0.092	**0.088**
MEAN	**0.073**	**0.060**	**0.073**	
CD (p = 0.05)	Tillage = 0.037 Irrigation = NS Tillage × Irrigation = NS			
Mean of irrigation mean	**0.15875**	**0.1545**	**0.16825**	

Straw Yield

The data pertaining to straw yield recorded at harvesting during 2016-17 and 2017-18 is presented in Table 8. Among the tillage treatments, maximum straw yield was recorded under PT$_{25}$ + Rduring both the years and had a significant effect. Overall, significantly higher straw yield was observed in PT$_{25}$ + R than PT$_{14}$ + R, CT and ZT by 12.31, 32.71 & 21.67 in 2016-17 and 10.45, 32.14 & 19.35 in 2017-18 respectively. The straw yield during 2016-17 was 7.3, 6.5, 6.0 and 5.5 t ha^{-1} under PT$_{25}$ + R, PT$_{14}$ + R, CT and ZT respectively.

Irrigation levels also showed statistically significant effect during both the years. Overall higher mean straw yield was observed in I$_3$ than I$_1$ and I$_2$ by 46 and 8.95% in 2016-17 and 47 and 8.70 in 2017-18 respectively. I$_3$ had maximum straw yield in I$_3$ (7.3 t ha^{-1}) which was significantly higher than I$_1$ (5.0 t ha^{-1}) but at par with I$_2$ (6.7 t ha^{-1}) in 2016-17. Similar results were recorded in year 2017-18. these results are in accordance with earlier study by Ali et al. (2007).

Table 8
The effect of irrigation and tillage on straw yield (t ha^{-1})

2016–2017					**2017-18**			
	I$_{1(0.6)}$	I$_{2(0.8)}$	I$_{3(1.0)}$	**MEAN**	I$_{1(0.6)}$	I$_{2(0.8)}$	I$_{3(1.0)}$	**MEAN**
PT$_{25}$ + R	6.1	7.8	8.0	**7.3**	6.3	7.9	8.1	**7.4**
PT$_{14}$ + R	5.0	6.9	7.5	**6.5**	5.2	7.1	7.7	**6.7**
ZT	4.2	5.8	6.5	**5.5**	4.3	5.9	6.7	**5.6**
CT	4.4	6.4	7.3	**6.0**	4.6	6.5	7.4	**6.2**
MEAN	**5.0**	**6.7**	**7.3**		**5.1**	**6.9**	**7.5**	
CD (p = 0.05)	Tillage = 0.56 Irrigation = 0.60 Tillage × Irrigation = NS				Tillage = 0.56 Irrigation = 0.93 Tillage × Irrigation = NS			

The pooled analysis of two years data of straw yield is given in Table 3.8. The analysis showed that significantly higher straw yield was recorded under PT_{25} + R(7.4 t ha^{-1}) than ZT (5.6 t ha^{-1}) and CT (6.1 t ha^{-1}) and PT_{14} + R (6.6 t ha^{-1}). Significantly higher pooled straw yield was recorded in I_3 (7.40 t ha^{-1}) than I_1 (5.05 t ha^{-1}) and I_2 (6.80 t ha^{-1}).

Grain Yield

The data pertaining to grain yield was recorded at harvesting during both the years and is illustrated in Table 3.9. Overall, significantly higher mean grain yield was observed in PT_{25} + R than PT_{25} + R, ZT and CT by 4.17, 16.28 and 11.11% in 2016-17 and 6.12, 18.18 and 10.64% in 2017-18 respectively. Among the tillage treatments maximum grain yield was recorded under PT_{25} + R during2016-17 and 2017-18. PT_{25} + R had (5.0 and 5.2 t ha^{-1}) significantly higher grain yield than PT_{14} + R (4.8 and 4.9 t ha^{-1}), CT (4.5 and 4.7 t ha^{-1}) and ZT (4.3 and 4.4 t ha^{-1}) for 2016-17 and 2017-18 respectively. Ding et al. (2021) found that deep tillage systems improved the wheat yield by increasing efficiency of soil amendments. Schneidera et al. (2017) represent that deep tillage has the highest potential to increase yield. Higher grain yield has been observed under deep tillage compared to shallow tillage (Alamouti and Navabzadeh 2007). Ozpinar (2006) seen that mouldboard plough recorded higher grain yield than NT due to better weed control achieved by these tillage systems. Lund et al. (1993) found that grain yield was reduced under NT by 10–15% than mouldboard plough.

Irrigation levels also have statistically significant effect on grain yield during both years. Overall, significantly higher mean grain yield was observed in I_3 than I_1 and I_2 by 39.47 and 10.41% in 2016-17 and 37.5 and 12.24% in 2017-18 respectively. In year 2016-17 maximum grain yield was recorded in I_3 (5.3 t ha^{-1}) which is significantly higher than I_1 (3.8 t ha^{-1}) but statistically at par with I_2 (4.8 t ha^{-1}). In year 2017-18, I_3 (5.5 t ha^{-1}) had highest mean grain yield which is significantly higher than I_1 (4.0 t ha^{-1}) but statistically at par with I_2 (4.9 t ha^{-1}). Shirazi et al. (2014) also found that maximum grain yield was obtained in 200 mm irrigation treatment and minimum in control. Sarwar et al. (2010) and Maqsood (2002) who also reported that the wheat yield increased with increase in irrigation scheduling. overall results are in accordance with Ali et al. (2007) and Martinez et al. (2008).

Table 9

The effect of irrigation and tillage on grain yield (t ha^{-1})

2016–2017					**2017-18**			
	$I_{1(0.6)}$	$I_{2(0.8)}$	$I_{3(1.0)}$	**MEAN**	$I_{1(0.6)}$	$I_{2(0.8)}$	$I_{3(1.0)}$	**MEAN**
PT_{25} + R	4.2	5.2	5.6	**5.0**	4.4	5.3	5.8	**5.2**
PT_{14} + R	3.9	4.9	5.5	**4.8**	4.0	5.1	5.6	**4.9**
ZT	3.5	4.4	4.9	**4.3**	3.6	4.6	5.1	**4.4**
CT	3.7	4.6	5.2	**4.5**	3.9	4.7	5.4	**4.7**
MEAN	**3.8**	**4.8**	**5.3**		**4.0**	**4.9**	**5.5**	
CD (p = 0.05)	Tillage = 0.18 Irrigation = 0.62 Tillage × Irrigation = NS				Tillage = 0.25 Irrigation = 0.63 Tillage × Irrigation = NS			

Water Balance Components And Water Productivity

The data pertaining to water balance as affected by tillage and irrigation practices is represented in Table 10 and Table 11. Maximum ET recorded in PT_{25} + R followed by PT_{14} + R, CT and ZT during both years. ET was maximum in I_3 followed by I_2 and I_1. Maximum soil water depletion was under I_1 where less irrigation was applied in both years. More drainage was reported in I_3 where more irrigation was applied in both years. In I_2 maximum drainage observed under ZT during both years. In irrigation level I_3 maximum drainage was observed in CT and minimum drainage under PT_{14} + R during both years.

The data pertaining to the effect of irrigation and tillage on water productivity is recorded illustrated in Table 12. Overall mean higher water productivity was observed in I_2 than I_1 and I_3 by 27.39 and 2.26% in 2016-17 and 27.70 and 1.91% in 2017-18 respectively. Maximum WP observed under I_2 was 140.0 and 143.8 kg ha^{-1} cm^{-1} for years 2016-17 and 2017-18 which was significantly higher than I_1 having WP 109.9 and 112.6 kg ha^{-1} cm^{-1} respectively. Zain et al. (2021) found that rise in WUE when the irrigation changed from I20 to I35, WUE declined dramatically when irrigation level changed from I35 to I50. Ali et al. (2007) found highest water productivity was obtained in the alternate deficit treatment, where deficits were imposed at maximum tillering (jointing to shooting) and flowering to soft dough stages of growth period, followed by single irrigation at crown root initiation stage. It was observed that WUE increased with an increase in irrigation up to a certain limit and then tended to decrease. Tillage treatment had not any significant difference in WP during both years. However, maximum WP was found under PT_{25} + R (138.3, 141.9 kg ha^{-1} cm^{-1}) followed by PT14 + R (128.9, 132.3 kg ha^{-1} cm^{-1}), ZT (128.6, 132.3 kg ha^{-1}

cm^{-1}) and least under CT (119.9, 123.5 kg ha^{-1} cm^{-1}) for 2016-17 and 2017-18 respectively. Similarly, higher WP in deep tillage has been reported by Joshi (2013) and Memon et al. (2013).

Table 10
The effect of irrigation and tillage on water balance during 2016-17

Treatments		E (cm)	T (cm)	R (cm)	D (cm)	I (cm)	S (cm)	H (cm)	ΔS(cm)
I_1	$PT_{25}+R$	7.22	27.77	9.8	0	15	22.6	12.41	10.19
	$PT_{14}+R$	9.38	26.1	9.8	0	15	22.6	11.92	10.68
	ZT	8.65	25.5	9.8	0	15	22.6	13.25	9.35
	CT	9.91	25.4	9.8	0	15	22.6	12.09	10.51
I_2	$PT_{25}+R$	6.24	28.18	9.8	0	15	22.6	12.98	9.62
	$PT_{14}+R$	8.6	26.78	9.8	0	15	22.6	12.02	10.58
	ZT	6.18	26.48	9.8	1.51	15	22.6	13.23	9.37
	CT	6.93	26.98	9.8	1.19	15	22.6	12.3	10.3
I_3	$PT_{25}+R$	9.48	29.19	9.8	3.12	22.5	22.6	13.11	9.49
	$PT_{14}+R$	10.87	28.99	9.8	2.64	22.5	22.6	12.4	10.2
	ZT	9.97	28.19	9.8	3.37	22.5	22.6	13.37	9.23
	CT	10.37	27.59	9.8	4.26	22.5	22.6	12.68	9.92

Where E stands for Evaporation, T for transpiration, R for rainfall, D for drainage I for irrigation, S for profile water storage at sowing, H for profile water storage at harvesting and ΔS for profile water depletion

Table 11

The effect of irrigation and tillage on water balance during 2017-18

Treatments		E (cm)	T (cm)	R (cm)	D (cm)	I (cm)	S (cm)	H (cm)	ΔS(cm)
I_1	PT_{25} + R	8.79	27.27	7.9	0	15	21.43	8.27	13.16
	PT_{14} + R	8.50	27.05	7.9	0	15	21.43	8.78	12.65
	ZT	8.42	25.8	7.9	0	15	21.43	10.11	11.32
	CT	8.48	26.9	7.9	0	15	21.43	8.95	12.48
I_2	PT_{25} + R	4.56	29.9	7.9	0	15	21.43	9.87	11.56
	PT_{14} + R	6.92	28.5	7.9	0	15	21.43	8.91	12.52
	ZT	4.5	28.2	7.9	1.40	15	21.43	10.23	11.20
	CT	5.25	28.7	7.9	1.11	15	21.43	9.27	12.16
I_3	PT_{25} + R	8.21	30.5	7.9	3.00	22.5	21.43	10.12	11.31
	PT_{14} + R	9.6	30.3	7.9	2.53	22.5	21.43	9.40	12.03
	ZT	8.7	29.5	7.9	3.22	22.5	21.43	10.41	11.02
	CT	9.1	28.9	7.9	4.18	22.5	21.43	9.65	11.78

Where E stands for Evaporation, T for transpiration, R for rainfall, D for drainage I for irrigation, S for Profile water storage at sowing, H for Profile water storage at harvesting and ΔS for Profile water depletion

Table 12

The effect of irrigation and tillage on water productivity

Water productivity (kg ha^{-1} cm^{-1})								
2016-17					2017-18			
	$I_{1(0.6)}$	$I_{2(0.8)}$	$I_{3(1.0)}$	**MEAN**	$I_{1(0.6)}$	$I_{2(0.8)}$	$I_{3(1.0)}$	**MEAN**
PT_{25} + R	121.0	150.1	144.0	**138.3**	121.1	153.8	150.7	**141.9**
PT_{14} + R	110.1	139.4	137.1	**128.9**	113.6	143.0	140.4	**132.3**
ZT	109.3	139.8	136.7	**128.6**	113.0	143.7	140.1	**132.3**
CT	99.1	130.7	130.0	**119.9**	102.7	134.5	133.3	**123.5**
MEAN	**109.9**	**140.0**	**136.9**		**112.6**	**143.8**	**141.1**	
CD (p = 0.05)	Tillage = NS Irrigation = 17.7 Tillage × Irrigation = NS				Tillage = NS Irrigation = 17.3 Tillage × Irrigation = NS			

Conclusion

This is concluded that primary tillage up to 45 cm depth followed by rotavator pulverize the soil which helps in more penetration of roots into the deeper layer which enhances uptake of nutrients and moisture, ultimately increasing crop ET, growth and yield. Minimum water depletion and lower ET loss was observed in ZT due to less root growth. $I_{3(1.0)}$ found higher crop yield due to availability of moisture throughout the cropping season, crop experiences no moisture stress Water productivity found to be significantly higher in $I_{2(0.8)}$ which effectively use irrigation water without stress and minimum loss of water. Overall, significantly higher ET was observed in $I_{3(1.0)}$.

Declarations

Ethics approval Not applicable

Consent to participate Not applicable

Consent to publication All the authors approve the final manuscript and agree to its submission to the environmental science and pollution research

Author contribution All the authors contribute in the manuscript as follow

Conceptualization: K B S and M S. Review of literature: M S and K B S. Material and methods: K B S and M S. Data collection: M S. Formal analysis and investigations: M S and K B S. Writing original draft preparations: M S, B S and S S B. Reviewing and editing: M S, K B S and S S B. Supervision: K B S.

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Competing interest Authors declare no competing interests

Data availability The data used to support the finding of this study are available from the corresponding author upon request

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Figures

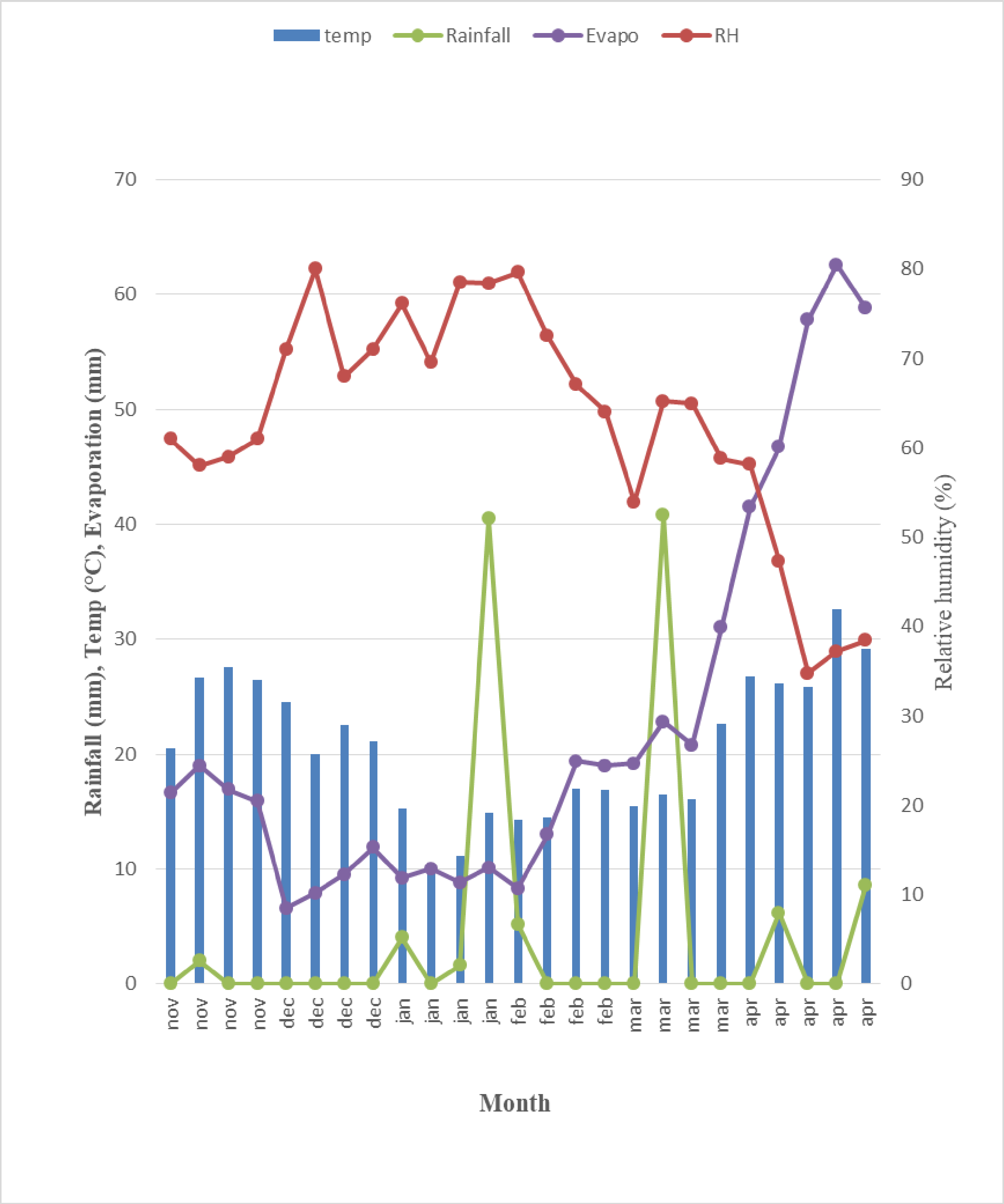

Figure 1

Weekly average mean air temperature, relative humidity, pan evaporation and weekly rainfall and during the crop growing season 2016-17

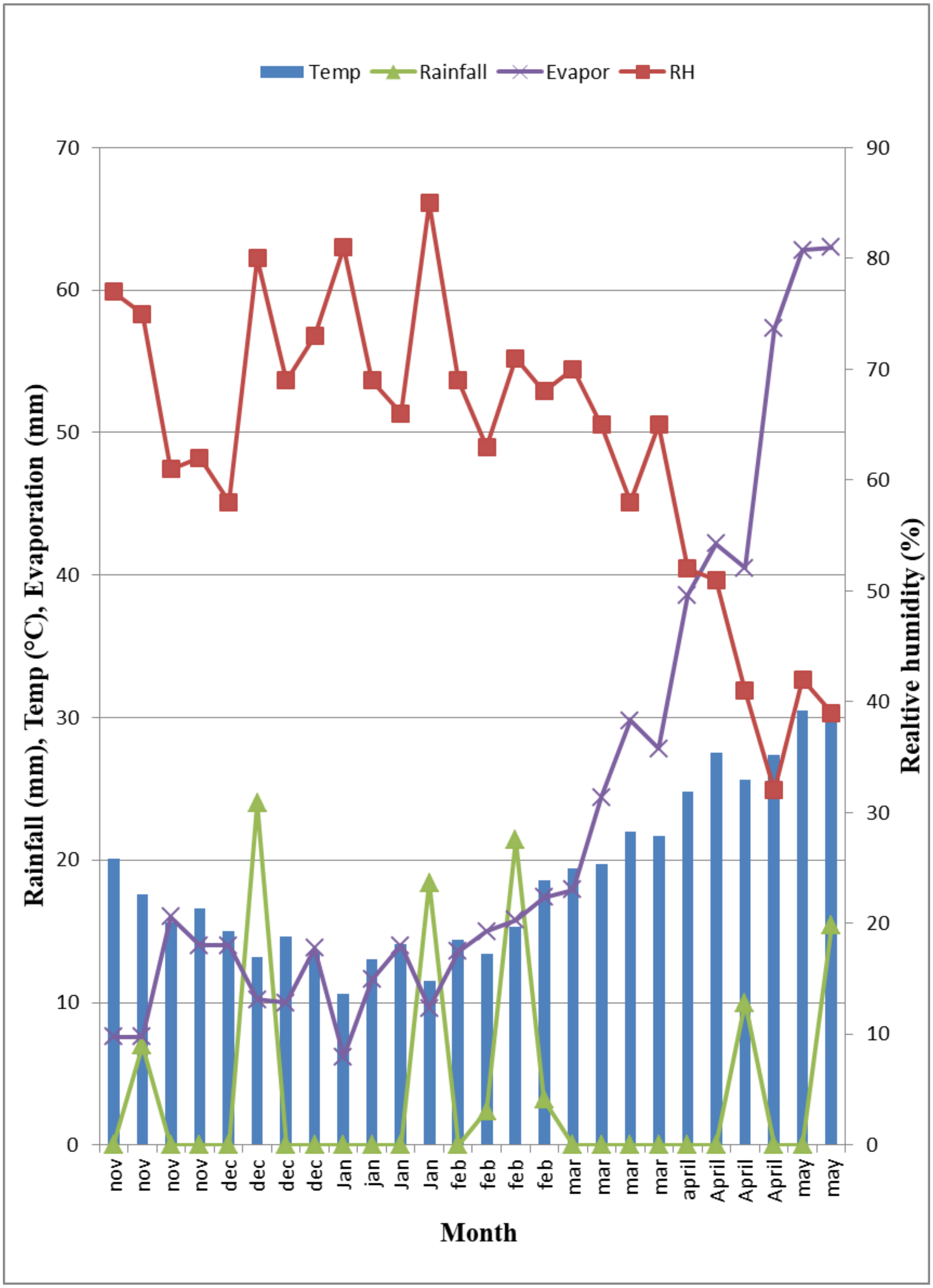

Figure 2

Weekly average mean air temperature, relative humidity, pan evaporation and weekly rainfall and during the crop growing season 2017-18