International Journal of Environment and Climate Change

Volume 13, Issue 9, Page 1897-1911, 2023; Article no.IJECC.103290
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Effect of Tillage and Residue Management on Wheat Yield and Water Productivity

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2023/v13i92421

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/103290

Original Research Article

Received: 14/05/2023
Accepted: 17/07/2023
Published: 24/07/2023

ABSTRACT

The present investigation was conducted in wheat at the Punjab Agricultural University, Ludhiana, to study effect of four tillage viz mould board ploughing to a depth of 25 cm followed by rotavator (PT25+R), mould board ploughing to a depth of 14 cm followed by rotavator (PT14+R), zero tillage with happy seeder (ZT) and conventional practices (CT) and three irrigation scheduling based on IW/PAN-E ratio I1 (0.6), I2 (0.8) and I3 (1.0) on soil water balance and crop growth for two consecutive years (2016-17 and 2017-18). Straw and grain yield was significantly higher in I3 over I1 and I2 by 46.05 & 38.5% and 8.72% & 11.30 % respectively during both years. Water productivity increased significantly in I2 over I1 and I3 by 27.38 & 2.26% in 2016-17 and 27.70 & 1.91% in 2017-18. During both years higher water was stored by ZT & I3 over PT25+R, PT14+R, CT, I1 and I2. During both years highest water was depleted under PT14+R & I1 over PT25+R, ZT, CT, I2 and I3. The overall mean number of tillers, leaf area index, root length and mass density were significantly higher under PT25+R than PT14+R, ZT and CT.

Keywords: Soil organic carbon; water productivity; wheat; irrigation and mould board plough tillage.

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1. INTRODUCTION

Rice-wheat cropping system is the most prevalent production system in the world, with 24 million hectares (Mha) in Asia [1]. Rice is cultivated on 43.8 Mha in India, producing 118.43 Mt grain and an estimated 165.8 Mt straw. Punjab, Haryana, and Uttar Pradesh account for 6.67%, 3.31%, and 13.11% of the total area and 9.95%, 4.07%, and13.11% of the total production in 2019-2020, respectively [2]. Wheat is the most widely grown cereal crop in terms of area as well as productivity [3]. Punjab serves as the food bowl of India, it contributes about 40%–45% of wheat and 25%–30% to the central pool of India. The state has about 28.94 lakh hectares (ha) under rice cultivation [4]. Residue generation from rice is a major issue in the north-western Indo-Gangetic plains (Punjab, Haryana and U.P).

Because of wheat planting and paddy harvesting, the window period is quite brief. Therefore, handling the paddy straw calls for a huge number of inexpensive machines. Traditional rice stubble inclusion requires a minimum of 4-5 discing procedures, which are time- and energy-intensive and expensive for small farmers. Although deep ploughing uses more energy to incorporate rice leftovers into the soil, it improves seed germination and root development for greater absorption of water and nutrients [5]. Other methods include Happy Seeder and zero-tillage direct drilling of wheat in standing rice stubbles. Among them, Happy Seeder is a more affordable technique, but it has several drawbacks, including unsatisfactory performance in fields with a lot of straw [6]. The main issue with the rice-wheat cropping technique is the yellowing of the wheat caused by water stagnation after the initial irrigation [7] due to the puddling's subsurface compaction.

In addition to burning crop debris, Punjab also faces a groundwater shortage issue. According to the recommendations of the Ground Water Resources Estimation Committee (GEC), the current groundwater development in the state is 145% based on the most recent information provided by the Central Ground Water Board (Government of India 2011). The fact that the water in a significant portion of the region is saline and unusable for irrigation despite having a good groundwater balance is another cause for concern. It's crucial to be aware that just 21% of the area in central Punjab is irrigated by canals out of the 72% that is planted with paddy [8]. Therefore, the current study was undertaken to investigate the impact of irrigation timing and residue management tillage on wheat growth and water production.

2. MATERIALS AND METHODS

Site & weather: The field experiment was carried out with wheat after paddy during the 2016–17 and 2017–18 at the University Seed Farm in Ladhowal, Ludhiana (30°58'29"N latitude and 75°47'15"E longitude at a height of 247 metres above mean sea level). The region experiences hot, dry summers from April to June, hot, humid weather from July to September, and chilly winters from November to January. The climate is subtropical and semi-arid. Mean maximum and lowest temperatures vary significantly throughout the year in different seasons. However, with dry summer spells, July temperatures hover around 38°C and reach 45°C [9]. Frequent icy spells occur during the winter, especially in December and January when the minimum temperature can drop as low as 0.5°C. The region experiences 600–700 mm of rainfall on average per year, with July to September accounting for around 80% of the total [10]. Figs. 1 and 2 show the meteorological data during the November to April wheat growing season.

Soil Characteristics: The composite soil samples were taken at random between 0 and 15 cm below the surface. The samples were sieved through a 2.0 mm sieve for soil texture, pH, EC and soil organic carbon and accessible N, P, and K analyses after initially being air-dried in the shade (Supplementary Table 1).

Experimental details: The experiment was started during the 2016 rabi season with four tillage treatments and three irrigation treatments, including (PT25+R Primary tillage to 252 cm depth with mould board plough followed by rotavator, PT14+R Primary tillage to 142 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 cultivators followed by Before the experiment began, the land had been continuously planted with rice and wheat for more than ten years.

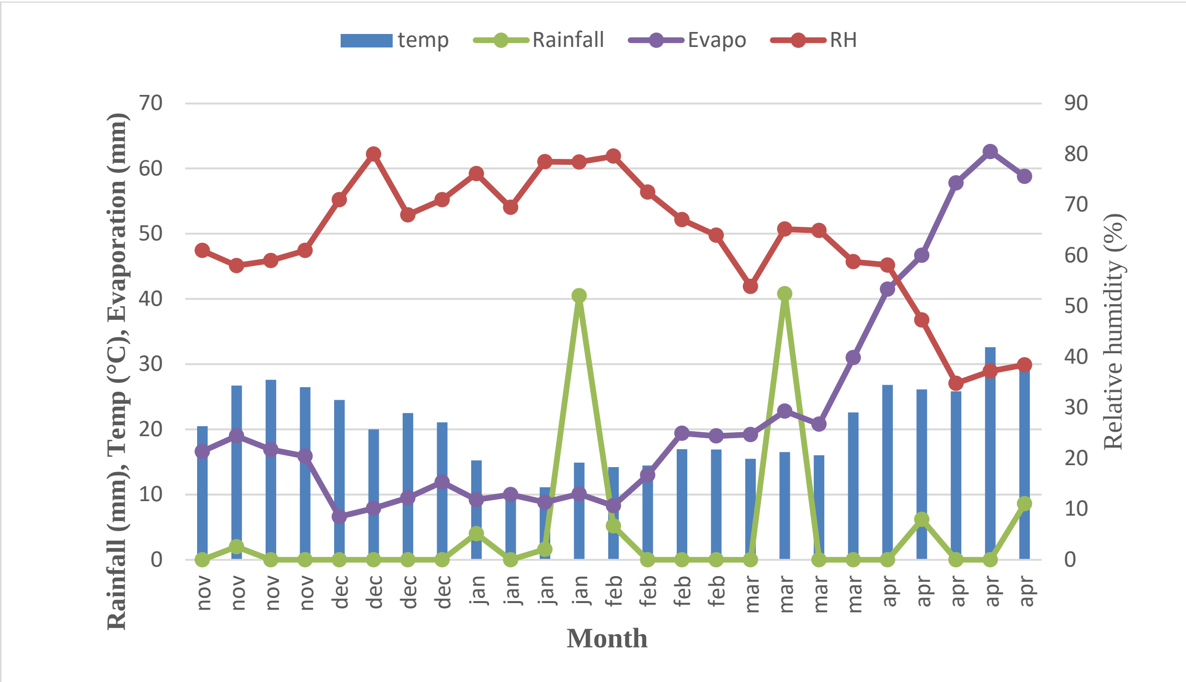

Fig. 1. Weekly average mean air temperature, relative humidity, pan evaporation and weekly rainfall and during the crop growing season 2016-17

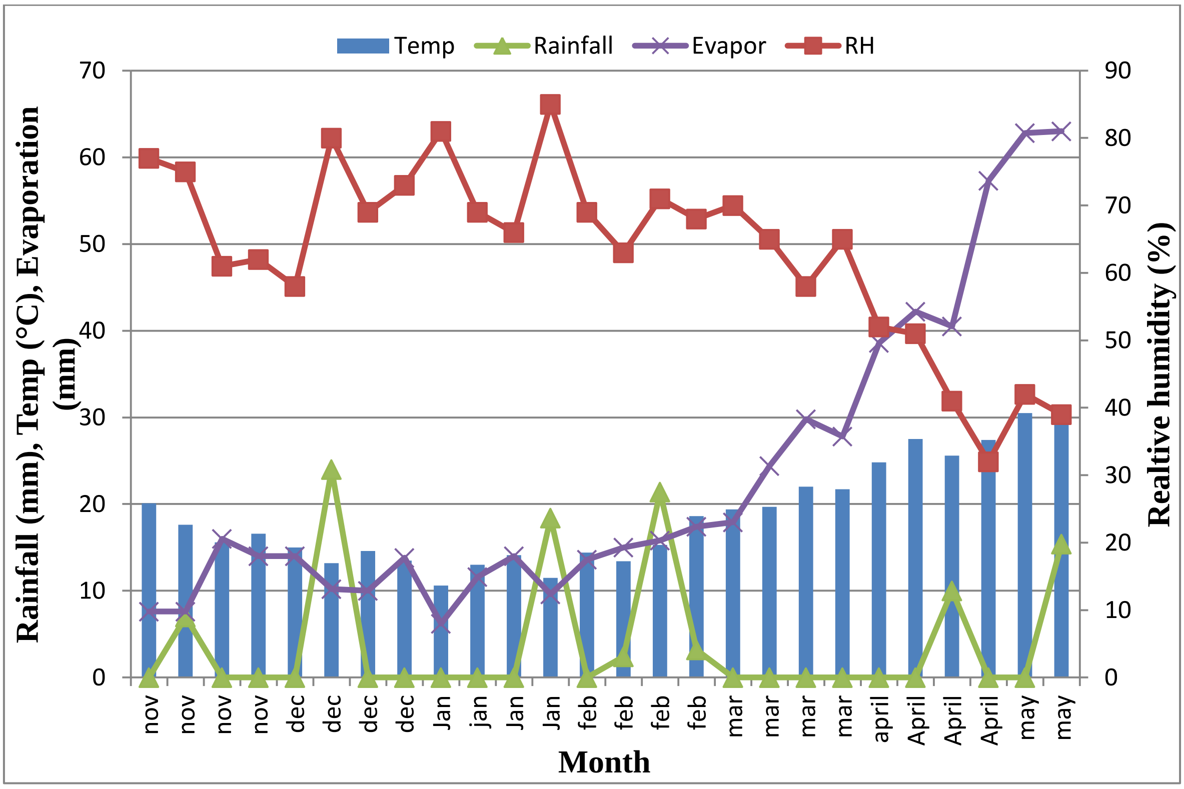

Fig. 2. Weekly average mean air temperature, relative humidity, pan evaporation and weekly rainfall during the crop growing season 2017-18

With the aid of a seed cum fertiliser drill and a row spacing of 20 cm, wheat was planted on the 15th of November 2016 and the 18th of November 2017 at a seed rate of 100 kg ha^{-1}. The various agronomic procedures were carried out following the needs of the experiment. The crop was planted at the ideal soil moisture level. For crop growth, we adhered to the entire package of recommendations made by PAU, Ludhiana. In both seasons, the wheat was harvested on April 20 (2017 & 2018).

Fertilizers were sprayed at the rates 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 to achieve the necessary dose. Half of the N and all of the P_2O_5 were applied as the basal dose at sowing. the remaining N was applied two days before the first irrigation. By using the recommended herbicides and hand weeding at the right time, weeds were maintained under control.

Observations recorded: Every day from seeding until a constant number, the number of wheat seedlings emerging from three locations along a one-meter row length in each plot was counted. In each plot, three randomly chosen locations with a one-meter row length were used to count the effective tillers. With the aid of a metre scale, the height of ten randomly chosen plants per plot was measured at 45, 60, 75, and harvesting DAS from the ground to the plant's top. Using a leaf area metre canopy analyser, the leaf area index was measured at 50, 75, 105, and 120 DAS.

$$\text{Leaf area index} = \frac{\text{Leaf area}}{\text{Ground area}}$$

After harvesting, the root distribution was measured. The soil layers from which the root samples were taken ranged from 0 to 15, 15, 30, 30, 45, and 60 cm. With the aid of a core sampler with a 5 cm diameter, soil samples were taken to sample the roots. The spaces between the plant rows were sampled. In plastic nets, the root-soil cores were then gathered and cleaned. The nets were thoroughly washed under water to gently remove the roots from the soil. To get rid of any remaining weed seeds, roots, or other organic matter, the washed roots underwent additional cleaning. From the total length of roots measured by scanning to the volume of the core, the root length density (cm cm^{-3}) was determined. After being dried at 60 °C in an oven, these roots were weighed on a precision scale to determine the root mass density (g cm^{-3}). From a $25m^2$ area, the crop straw was hand gathered and threshed. Each plot's 25 m^2 of grain and straw yield was recorded in kg, and the results were then reported in t ha^{-1}.

Each plot provided a representative sample of thousand grains, which was physically counted, weighed on a precision balance, and stated in grams. The irrigation amount (litre/minute) was measured using a digital flow meter installed on the delivery pipe of the tube well and was divided by area to calculate irrigation water in cm. The rainfall amount (mm) was recorded on the rainy day by using a rain gauge installed at the experimental site. Drainage was calculated by measuring the amount of irrigation applied and the field capacity of each profile layer. The amount of water exceeding the maximum storage was calculated as drainage (cm). 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. [11]. Substituting daily EPAN, in this relation gave an estimate of ET m:

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

ETm was partitioned to plant transpiration (Tm) and evaporation from the soil surface (Em) through the crop transpiration factor Kt (equations (2) and (3) that were obtained from information on the progressive leaf area index (LAI). Earlier, Rasmussen and hanks [12] and Retta and Hanks [13] used Kt from LAI for potential water supply 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 affect 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):

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

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

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 (equation (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.

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

Daily actual soil evaporation (Ea) was calculated by relation

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

and actual transpiration (Ta) by

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

where AWF is plant available water in each soil layer

The profile moisture was measured up to a depth of 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 by the bulk density and depth of the layer and was expressed as mm of water then to obtain total profile moisture storage each layer storage was added. The WP (kg $ha^{-1}cm^{-1}$) was measured by dividing the grain yield over the total evapotranspiration (Ea+Ta) of each treatment.

$$\text{Water productivity} = \frac{\text{Grain yield}}{\text{ET}}$$

3. RESULTS AND DISCUSSION

Germination: The data on germination, as affected by residue management tillage practices and irrigation levels is presented in Table 1. 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 was 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. [14] 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.

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 [15].

Number of tillers: The data on the number of tillers affected by tillage for residue management practices and irrigation levels are presented in Table 1. The number of tillers was significantly affected by tillage treatments. Among the residue management tillage practices overall the mean number of tillers was 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. [14] 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 the number of tillers was non-significant.

Plant height: The plant height was recorded at 45, 60, 75 and 105 days after sowing during 2017-18 and is presented in Table 2. At 45 days after sowing, tillage had a 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 45 days 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. A similar trend was also observed at 60 and 75 days after sowing. At 105 days after sowing, both the tillage and irrigation had a 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 [16]. Similarly, taller plants in deeply tilled (disc-ploughed) plots than CT were recorded by Aikins and Afuakwa [17]. more moisture is likely conserved by tillage, which results in more plant height [18].

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. [19]. Five irrigations increase plant height by 28.58% over one irrigation, due to no moisture stress [20]. At harvest, two irrigations at the CRI + flowering stage produced the tallest plant, whereas one irrigation produced the shortest plants [21].

Leaf area index: The leaf area index (LAI) was recorded at 50, 75, 105 and 120 days after sowing (DAS) during 2017-18 and is shown in Table 3. 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. [22] showed that subsoil tillage could lead to the 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. [23] 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. The plots where ridge sowing was used under deep tillage had the highest leaf area per plant, while the plots where flat sowing under minimum tillage was used had the least [24]. Zero tillage and reduced tillage both consistently produced a much lower leaf area index than conventional tillage, which was likely due to the latter's finer seed bed preparation [25]. According to Gajri et al. [26], tilled treatments had higher leaf-area development than NT and Khan et al. [27] observed that deep tillage procedures improved leaf area index by up to 9.89%.

Table 1. The effect of irrigation and tillage on the number of plants germination and number of tillers

Treatments	**Plant germination (m^{-1} row)**				**Number of tillers (m^{-1} row)**			
	$I_{1(0.6)}$	$I_{2(0.8)}$	$I_{3(1.0)}$	**MEAN**	$I_{1(0.6)}$	$I_{2(0.8)}$	$I_{3(1.0)}$	**MEAN**
PT_{25}+R	37	35	35	**36**	122	114	132	**123**
PT_{14}+R	35	31	39	**35**	113	114	124	**117**
ZT	37	27	37	**34**	100	105	104	**103**
CT	36	31	34	**34**	103	112	114	**110**
MEAN	**36**	**31**	**36**		**110**	**111**	**119**	
CD (p=0.05)	Tillage = NS* Irrigation = NS Tillage × Irrigation = NS				Tillage = 8.05 Irrigation = NS Tillage × Irrigation = NS			

** NS non-significant*

Table 2. The effect of irrigation and tillage on plant height (cm)

	45 days after sowing			
	$\mathbf{I_{1(0.6)}}$	$\mathbf{I_{2(0.8)}}$	$\mathbf{I_{3(1.0)}}$	**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**
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**	

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 [7]. Similar results have also been reported by [28-29]. Kalaydjieva et al. [30]. Reducing irrigation rates has a detrimental effect on LAI values. Subsequent irrigations, according to Benbi (1994), prolonged leaf area by slowing the process of leaf senescence. LAI generally decreased more quickly when irrigation was applied later.

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 4. Overall higher mean RLD was observed in PT_{25}+R than in PT_{14}+R, ZT and CT by 19.30, 61.81 and 46.17% respectively. At the 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}). A similar trend was followed under 15-30 and 45-60 cm depths in tillage and irrigation treatments. Ji et al. [31] 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.

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 5. 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 a significant difference in

Table 3. 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**
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 4. 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**
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**	

Table 5. 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**
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**	

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/cm³), CT (0.092 µg cm^{-3}) and ZT (0.032 µg cm^{-3}). Ren et al. [32] found that Mouldboard plough tillage has higher root mass density than NT. Mu et al. [33] also found that deep mouldboard plough tillage has higher RMD than shallow mouldboard plough tillage. Zhao et al. [34] reported that deep tillage increased root proliferation and root penetration depth where it was employed [35], but also increased the biomass of deeper roots [36].

Straw yield: The data on straw yield recorded at harvesting during 2016-17 and 2017-18 is presented in Table 6. Among the tillage treatments, the maximum straw yield was recorded under PT_{25}+R during both 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 effects during both 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 the year 2017-18. These results are per the earlier study by Ali et al. [37].

The pooled analysis of two years of data on straw yield 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 on grain yield was recorded at harvesting during both years and is illustrated in Table 6. 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 during 2016-17 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. [38] found that deep tillage systems increased the performance of soil amendments, which in turn improved wheat yield. Schneidera et al. [39] represent that deep tillage has the highest potential to increase yield. Higher grain yield has been observed under deep tillage compared to shallow tillage [40]. Ozpinar [41] observed that the mouldboard plough recorded higher grain production than NT because these tillage systems were more effective at controlling weeds. Lund et al [42] found that grain yield was reduced under NT by 10-15% more than mouldboard plough.

Irrigation levels also have a 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 the 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 the year 2017-18, I_3 (5.5 t ha^{-1}) had the 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 [35] also discovered that the 200 mm irrigation treatment produced the highest grain yield, whereas the control produced the lowest. Sarwar et al [20] and Maqsood [43] also reported that the wheat yield increased with an increase in irrigation scheduling. overall results are in accordance with Ali et al [37] and Martinez et al [44].

Water balance components and Water productivity: The data on water balance as affected by tillage and irrigation practices is represented in Table 7. 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 was 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.

Table 6. The effect of irrigation and tillage on straw yield and grain yield

Treatments	Straw yield (t ha^{-1})								Grain yield (t ha^{-1})							
	2016-2017				2017-18				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	$I_{1(0.6)}$	$I_{2(0.8)}$	$I_{3(1.0)}$	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**	4.2	5.2	5.6	**5.0**	4.4	5.3	5.8	**5.2**
PT_{14}+R	5.0	6.9	7.5	**6.5**	5.2	7.1	7.7	**6.7**	3.9	4.9	5.5	**4.8**	4.0	5.1	5.6	**4.9**
ZT	4.2	5.8	6.5	**5.5**	4.3	5.9	6.7	**5.6**	3.5	4.4	4.9	**4.3**	3.6	4.6	5.1	**4.4**
CT	4.4	6.4	7.3	**6.0**	4.6	6.5	7.4	**6.2**	3.7	4.6	5.2	**4.5**	3.9	4.7	5.4	**4.7**
MEAN	**5.0**	**6.7**	**7.3**		**5.1**	**6.9**	**7.5**		**3.8**	**4.8**	**5.3**		**4.0**	**4.9**	**5.5**	
CD (p=0.05)	Tillage = 0.56 Irrigation= 0.60 Tillage × Irrigation = NS				Tillage = 0.56 Irrigation = 0.93 Tillage × Irrigation = NS				Tillage =0.18 Irrigation= 0.62 Tillage × Irrigation = NS				Tillage = 0.25 Irrigation = 0.63 Tillage × Irrigation = NS			

Table 7. The effect of irrigation and tillage on water balance during 2016-17 and 2017-18

Treatments		2016-17								2017-18							
		E (cm)	T (cm)	R (cm)	D (cm)	I (cm)	S (cm)	H (cm)	ΔS(cm)	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	8.79	27.27	7.9	0	15	21.43	8.27	13.16	10.19
	PT_{14}+R	9.38	26.1	9.8	0	15	22.6	11.92	8.50	27.05	7.9	0	15	21.43	8.78	12.65	10.68
	ZT	8.65	25.5	9.8	0	15	22.6	13.25	8.42	25.8	7.9	0	15	21.43	10.11	11.32	9.35
	CT	9.91	25.4	9.8	0	15	22.6	12.09	8.48	26.9	7.9	0	15	21.43	8.95	12.48	10.51
I_2	PT_{25}+R	6.24	28.18	9.8	0	15	22.6	12.98	4.56	29.9	7.9	0	15	21.43	9.87	11.56	9.62
	PT_{14}+R	8.6	26.78	9.8	0	15	22.6	12.02	6.92	28.5	7.9	0	15	21.43	8.91	12.52	10.58
	ZT	6.18	26.48	9.8	1.51	15	22.6	13.23	4.5	28.2	7.9	1.40	15	21.43	10.23	11.20	9.37
	CT	6.93	26.98	9.8	1.19	15	22.6	12.3	5.25	28.7	7.9	1.11	15	21.43	9.27	12.16	10.3
I_3	PT_{25}+R	9.48	29.19	9.8	3.12	22.5	22.6	13.11	8.21	30.5	7.9	3.00	22.5	21.43	10.12	11.31	9.49
	PT_{14}+R	10.87	28.99	9.8	2.64	22.5	22.6	12.4	9.6	30.3	7.9	2.53	22.5	21.43	9.40	12.03	10.2
	ZT	9.97	28.19	9.8	3.37	22.5	22.6	13.37	8.7	29.5	7.9	3.22	22.5	21.43	10.41	11.02	9.23
	CT	10.37	27.59	9.8	4.26	22.5	22.6	12.68	9.1	28.9	7.9	4.18	22.5	21.43	9.65	11.78	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 8. 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			

Table 9. The effect of tillage on soil organic carbon of different years

Soil organic carbon (g kg^{-1})	Tillage treatments				
Year of experiment	PT_{25} + R	PT_{14} + R	ZT	CT	CD (p=0.05)
2016-17	6.66	6.48	7.36	6.41	**0.46**
2017–18	6.92	6.68	7.45	6.50	**0.47**

The data on the effect of irrigation and tillage on water productivity is recorded and illustrated in Table 8. 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 [45] found that rise in WUE when the irrigation changed from I20 to I35 and WUE declined dramatically when the irrigation level changed from I35 to I50. Ali et al [37] found that the alternating deficit treatment, whereby imposed deficits at the growth period's peak tillering (jointing to shooting) and flowering to soft dough stages, followed by a single irrigation at the crown root initiation stage, produced the highest water production. 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 Memon et al [16].

Soil organic carbon: SOC affected by tillage practices is shown in Table 9. SOC was significantly more in ZT by 12.9% and 12.8% than CT during 2016–17 and 2017–18 respectively. However, in both years SOC was at par in PT_{25} + R, PT_{14} + R and CT. High SOC in ZT may be carbon addition from rice residues on the surface and more crop residues decomposition with different tillage treatments. Bhattacharyya et al [46] found that significantly higher SOC than by 14%. Hazarika et al. [47], Singh et al. [48] and McMaster et al. [49] also reported 14% and 17% higher SOC in surface soil under ZT than in rotary tillage and CT practices respectively.

4. CONCLUSIONS

This is concluded that primary tillage up to 45 cm depth followed by rotavator pulverizes 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 were observed in ZT due to less root growth. $I_{3(1.0)}$ found higher crop yield due to the availability of moisture throughout the cropping season, the crop experiences no moisture stress Water productivity was found to be significantly higher in $I_{2(0.8)}$ which effectively uses irrigation water without stress and minimum loss of water. Overall, significantly higher ET was observed in $I_{3(1.0).}$

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Supplementary 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

Peer-review history:
The peer review history for this paper can be accessed here:
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