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# Land and water conservation with residue management & optimizing irrigation schedule in wheat

## Effect of tillage and residue management on wheat yield and water productivity

**Abstract:** The present study investigation was conducted in wheat at the Punjab Agricultural University, Ludhiana, to study effect of four tillage ~~and three irrigation practices~~ 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). During both the year s 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 the years. Significantly higher w Water productivity was observed 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 year higher water stored by ZT & I3 over PT25+R, PT14+R, CT, I1 and I2. During both year highest water depleted under PT14+R & I1 over PT25+R, ZT, CT, I2 and I3. Overall mean of number of tillers, leaf area index, root length and mass density were significantly higher under PT25+R over than PT14+R, ZT and CT.

**Keywords:** soil organic carbon, water productivity, wheat, irrigation and ~~mould board~~ mould board plough tillage

### 1. Introduction

recast introduction discuss the formation of hard sub-soil layer , .....effect on root development and its solution Receding water table problem cause , compare increase in area, number of tubewells and water used by common flooding method with alternative measures

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 accounts for 6.67%, 3.31%, and 13.11% of the total area and 9.95%, 4.07%, and 13.11% 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 the 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 ground water 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 that 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

Field experiment was carried out with wheat after paddy during the 2016–17 and 2017–18 at the University Seed Farm in Ladhawal, 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]. Figures 1 and 2 show the meteorological data during the November to April wheat growing season.

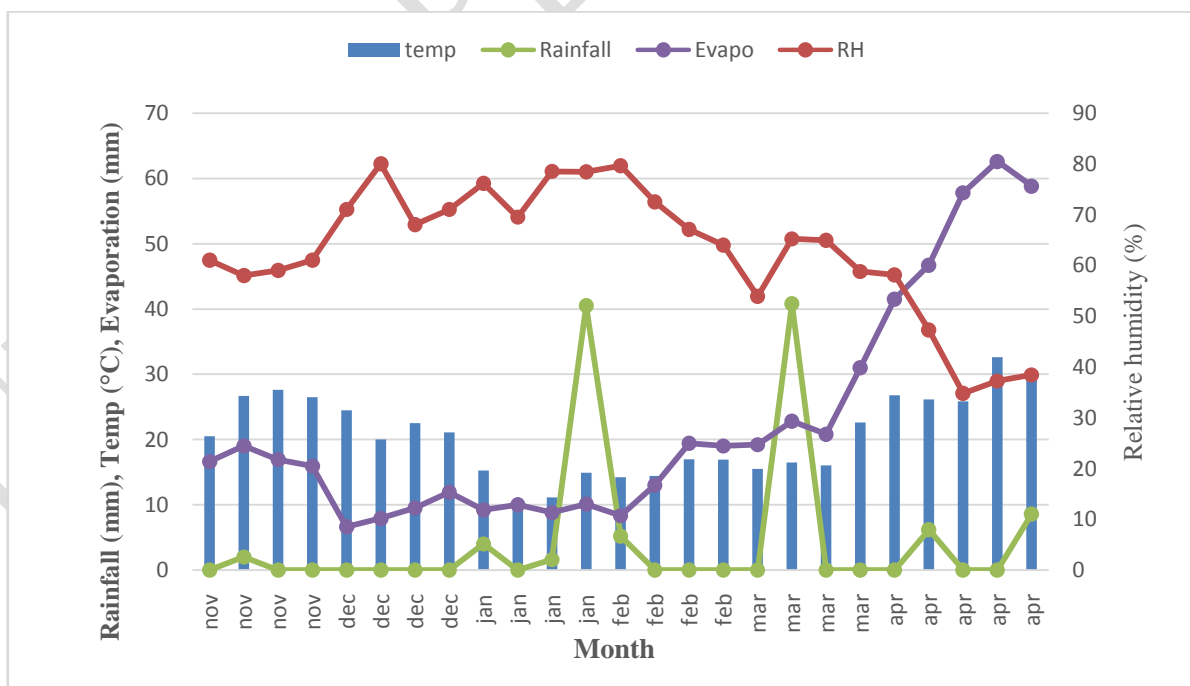


Fig. 1: Weekly average mean air temperature, relative humidity, pan evaporation and weekly rainfall and during the crop growing season 2016-17

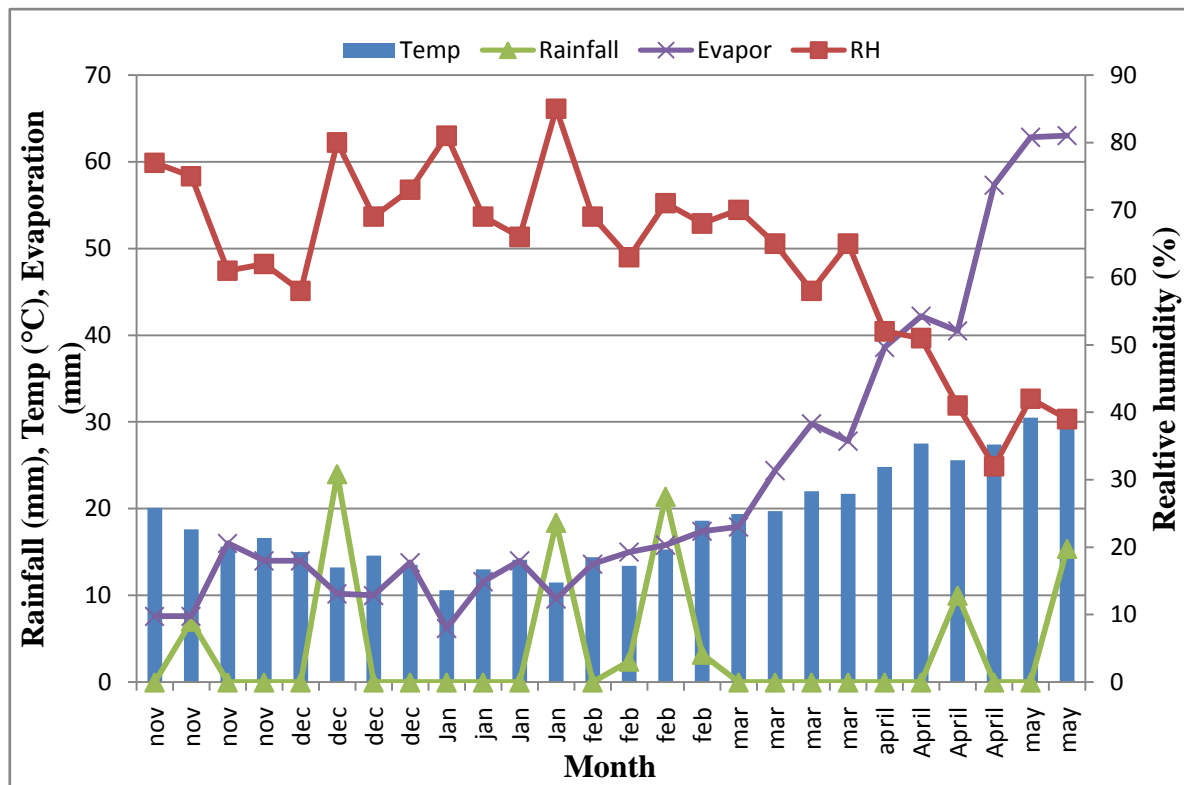


Fig. 2: Weekly average mean air temperature, relative humidity, pan evaporation and weekly rainfall and during the crop growing season 2017-18

#### 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, soil organic carbon, [give intial valees i.e.at the start of the experiment](#) and accessible N, P, and K analyses after initially being air dried in the shade ([SupplementaryTable 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 cultivator followed by Before the experiment began, the land had been continuously planted with rice and wheat for more than ten years.

With the aid of a seed cum fertiliser drill and a row spacing of 20 cm, wheat was planted on the 15<sup>th</sup> of November 2016 and the 18<sup>th</sup> of November 2017 at a seed rate of 100 kg ha<sup>-1</sup>. The various agronomic procedures were carried out in accordance with 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<sup>-1</sup> in the form of urea and 62.5 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> in the form of single superphosphate to achieve the necessary dose. Half of the N and all of the P<sub>2</sub>O<sub>5</sub> were applied as the basal dose at sowing. the remaining N applied two days before to the first irrigation. By using the recommended herbicides and hand weeding at the right time, weeds were maintained under control.

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## 23 Observations recorded

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

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

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

38 Each plot provided a representative sample of thousand grains, which was physically counted, weighed on a  
39 precision balance, and stated in grams. The irrigation amount (liter/minute) was measured using digital flow meter  
40 installed on delivery pipe of the tube well and was divided by area to calculate irrigation water in cm. The rainfall  
41 amount (mm) was recorded on the rainy day by using rain gauge installed at the experimental site. Drainage was  
42 calculated from measuring the amount of irrigation applied and field capacity of each profile layer. The amount of  
43 water exceeding the maximum storage was calculated as drainage (cm). Potential evapotranspiration (ET<sub>m</sub>) was  
44 measured from pan evaporation (EPAN) and a relationship of time (t) following seeding through a quadratic  
45 polynomial proposed by Arora et al. [11]. Substituting daily EPAN, in this relation gave an estimate of ET m:

$$46 \quad \text{ET}_m/\text{EPAN} = 0.56 + 0.021t - 0.000125t^2 \quad (1)$$

47 ET<sub>m</sub> was partitioned to plant transpiration (T<sub>m</sub>) and evaporation from soil surface (E<sub>m</sub>) through the crop  
48 transpiration factor K<sub>t</sub> (equations (2) and (3) that was obtained from information on progressive leaf area index (LAI).  
49 Earlier, Rasmussen and hanks [12] and Retta and Hanks [13] used K<sub>t</sub> from LAI for potential water supplies conditions,  
50 and the effect of reduced water on transpiration was incorporated through reduced soil water status. But apart from  
51 affecting temporal variation in soil water status, timing and amount of water additions also effect the pattern of leaf  
52 area development and hence the transpiration load T of the plant. Thus, K<sub>t</sub> should be assessed from leaf area  
53 development for specific wetting histories for partitioning ET<sub>m</sub> into T (that equals T m under plentiful water  
54 supplies):

$$55 \quad T \text{ (or } T_m) = \text{ET}_m K_t, \quad (2)$$

$$56 \quad E_m = (1 - K_t)\text{ET}_m \quad (3)$$

57 This factor K<sub>t</sub> was assumed to have a maximum value of 0.90 for LAI equal to or greater than 4.00. However,  
58 for LAI less than 4.0, K<sub>t</sub> was made to decrease gradually through a square root relation (equation (4)) rather than

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

$$61 \quad K_t = 0.90(\text{LAI}/4.00)^{0.5} \quad (4)$$

62 Daily actual soil evaporation ( $E_a$ ) was calculated by relation

$$63 \quad E_a = E_m t^{0.30} \quad (5)$$

64 and actual transpiration ( $T_a$ ) by

$$65 \quad T_a = T \times \text{AWF}/0.5 \quad (6)$$

66 where AWF is plant available water in each soil layer

67 The profile moisture was measured up to a depth 120 cm from (0-15, 15-30, 30-60, 60-90 and 90-120 cm)  
68 thermo-gravimetrically before sowing and at the time of harvesting each crop. For profile moisture storage, the  
69 gravimetric moisture content of each layer was multiplied with bulk density and depth of layer and was expressed as  
70 mm of water and then to obtain total profile moisture storage each layer storage was added. The WP ( $\text{kg ha}^{-1}\text{cm}^{-1}$ ) was  
71 measured by dividing the grain yield over total evapotranspiration ( $E_a+T_a$ ) of each treatment.

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

### 72 3. Results

#### 73 Germination

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

80 **Table 1:** The effect of irrigation and tillage on number of plants germination and number of tillers

Treatments	Plant germination ( $\text{m}^{-1}$ row)				Number of tillers ( $\text{m}^{-1}$ 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
$\text{PT}_{25+\text{R}}$	37	35	35	36	122	114	132	123
$\text{PT}_{14+\text{R}}$	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 $\times$ Irrigation = NS				Tillage = 8.05      Irrigation = NS Tillage $\times$ Irrigation = NS			

81 \* NS non-significant

82 Irrigation levels were also statistically at par with each other. Maximum germination counted in  $I_1$  (36) and  $I_3$   
83 (36) and least found in  $I_2$  (31) respectively. Similarly, no significant difference among tillage treatment on germinations  
84 was reported by Amin and Khan [15].

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## 85 Number of tillers

86 The data pertaining to number of tillers as affected by tillage for residue management practices and irrigation  
87 levels is presented in the [Table 1](#). The number of tillers were significantly affected by tillage treatments. Among the  
88 residue management tillage practices overall mean number of tillers were significantly higher under PT<sub>25</sub>+R over ZT  
89 and CT by 19.42 and 11.18% respectively. However, PT<sub>25</sub>+R was at par with PT<sub>14</sub>+R, while CT was at par with ZT.  
90 Leghari et al. [14] also reported that mould board plough had a greater number of tillers per plant as compared to no  
91 tillage. The effect of irrigation levels on number of tillers was non-significant

## 92 Plant height

93 The plant height was recorded at 45, 60, 75 and 105 days after sowing during 2017-18 and is presented in  
94 [Table 2](#). At 45 days after sowing, tillage had significant effect. The plant height under the tillage residue management  
95 treatment was significantly higher by 9.7% in PT<sub>25</sub>+R as compared to ZT, however, PT<sub>14</sub>+R and CT were statistically at  
96 par with each other at 45 day after sowing. The maximum plant height was recorded under PT<sub>25</sub>+R (40.7 cm) which  
97 was statistically at par with PT<sub>14</sub>+R but significantly higher than the ZT and CT. Similar trend was also observed at 60  
98 and 75 days after sowing. At 105 days after sowing, both the tillage and irrigation had significant effect on plant  
99 height. The maximum plant height was recorded under PT<sub>25</sub>+R (110.1 cm) which was statistically at par with PT<sub>14</sub>+R  
100 (108.5 cm) but significantly higher than ZT (102 cm) and CT (102.4 cm). The higher plant height in PT<sub>25</sub>+R may be  
101 because of enhanced nutrients and moisture availability compared to CT [16]. Similarly, taller plants in deeply tilled  
102 (disc ploughed) plots than CT were recorded by Aikins and Afuakwa [17]. more moisture is likely conserved by  
103 tillage, which results in more plant height [18].

104 Overall higher mean plant height was observed in I<sub>3</sub> than I<sub>2</sub> and I<sub>1</sub> by 2.8% and 2.13% respectively. Among the  
105 different irrigation levels, the maximum plant height was recorded under I<sub>3</sub> (107.4 cm) which was significantly higher  
106 than I<sub>1</sub> (104.2 cm) and I<sub>2</sub> (105.7 cm). Higher plant height in I<sub>3</sub> may be due to more availability of water for plant growth  
107 as reported by Yousaf et al. [19]. Five irrigations increase plant height by 28.58% over one irrigation, due to no  
108 moisture stress [20]. At harvest, two irrigations at the CRI + flowering stage produced the tallest plant, whereas one  
109 irrigation produced the shortest plants [21].

## 110 Leaf area index

111 The leaf area index (LAI) was recorded at 50, 75, 105 and 120 days after sowing (DAS) during 2017-18 and  
112 shown in the [Table 3](#). Among the residue management tillage practices overall mean LAI was significantly higher in  
113 PT<sub>25</sub>+R over PT<sub>14</sub>+R, ZT and CT by 13.45, 26.17 and 27.36 % respectively. Higher LAI was observed in PT<sub>25</sub>+R over  
114 PT<sub>14</sub>+R, ZT and CT in 50, 75, 105 and 120 DAS. Sun et al. [22] showed that subsoil tillage could lead to maintenance of a  
115 relatively high LAI and more prolonged LAI at different crop growth stages, which provided the possibility for plants  
116 to capture more light for photosynthesis. Shahzad et al. [23] represent that Bed sowing had better LAI while zero tilled  
117 wheat had the minimum LAI under all cropping systems at 60, 75, 90 and 105 DAS during both years. The plots where  
118 ridge sowing was used under deep tillage had the highest leaf area per plant, while the plots where flat sowing under  
119 minimum tillage was used had the least [24]. Zero tillage and reduced tillage both consistently produced much lower  
120 leaf area index than conventional tillage, which was likely due to the latter's finer seed bed preparation [25]. According

121 to Gajri et al. [26], tilled treatments had higher leaf-area development than NT, Khan et al. [27] observed that deep  
 122 tillage procedures improved leaf area index by up to 9.89%.

123 **Table 2:** The effect of irrigation and tillage on plant height (cm)

45 days after sowing				
	I <sub>1(0.6)</sub>	I <sub>2(0.8)</sub>	I <sub>3(1.0)</sub>	MEAN
PT <sub>25+R</sub>	41.0	39.0	42.0	40.7
PT <sub>14+R</sub>	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
<b>MEAN</b>	<b>37.7</b>	<b>37.2</b>	<b>40.5</b>	
<b>CD (p=0.05)</b>	Tillage = 2.31		Irrigation = NS	Tillage × Irrigation = NS
60 days after sowing				
PT <sub>25+R</sub>	56.7	57.0	57.3	57.0
PT <sub>14+R</sub>	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
<b>MEAN</b>	<b>52.6</b>	<b>52.9</b>	<b>53.3</b>	
<b>CD (p=0.05)</b>	Tillage = 3.67		Irrigation = NS	Tillage × Irrigation = NS
75 days after sowing				
PT <sub>25+R</sub>	80.2	80.7	81.0	80.6
PT <sub>14+R</sub>	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
<b>MEAN</b>	<b>76.1</b>	<b>76.6</b>	<b>77.0</b>	
<b>CD (p=0.05)</b>	Tillage = 3.66		Irrigation = NS	Tillage × Irrigation = NS
105 days after sowing				
PT <sub>25+R</sub>	109.0	110.5	110.8	110.1
PT <sub>14+R</sub>	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
<b>MEAN</b>	<b>104.2</b>	<b>105.7</b>	<b>107.4</b>	
<b>CD (p=0.05)</b>	Tillage = 3.80		Irrigation = .88	Tillage × Irrigation = NS
<b>Mean of irrigation mean</b>	<b>67.65</b>	<b>68.1</b>	<b>69.55</b>	

124  
 125 The LAI was significantly higher both under I<sub>3</sub> and I<sub>2</sub> over I<sub>1</sub>, at 75, 105 and 120 DAS. Overall higher mean  
 126 LAI was observed in I<sub>3</sub> over I<sub>1</sub> than I<sub>2</sub> by 16.8 and 7.7%. Higher leaf area index with tillage and irrigation may be due to  
 127 more proliferation of roots because of less bulk density [7]. Similar results have also been reported by  
 128 [28-29]. Kalaydjieva et al. [30]. Reducing irrigation rates has a detrimental effect on LAI values. Subsequent irrigations,  
 129 according to Benbi (1994), prolonged leaf area by slowing the process of leaf senescence. LAI generally decreased  
 130 more quickly when irrigation was applied later.

131 **Table 3:** The effect of irrigation and tillage on leaf area index

50 days after sowing				
	I <sub>1(0.6)</sub>	I <sub>2(0.8)</sub>	I <sub>3(1.0)</sub>	MEAN
PT <sub>25+R</sub>	1.3	1.6	1.7	<b>1.6</b>
PT <sub>14+R</sub>	1.0	1.2	1.4	<b>1.2</b>
ZT	0.8	0.9	1.3	<b>1.0</b>
CT	0.7	0.8	0.9	<b>0.8</b>
<b>MEAN</b>	<b>1.0</b>	<b>1.1</b>	<b>1.3</b>	
<b>CD (p=0.05)</b>	Tillage = 0.086		Irrigation = 0.07	Tillage × Irrigation = NS
75 days after sowing				
PT <sub>25+R</sub>	3.0	3.2	3.4	<b>3.2</b>
PT <sub>14+R</sub>	2.5	2.6	2.9	<b>2.7</b>
ZT	2.1	2.4	2.7	<b>2.4</b>
CT	2.0	2.3	2.5	<b>2.3</b>
<b>MEAN</b>	<b>2.4</b>	<b>2.6</b>	<b>2.9</b>	
<b>CD (p=0.05)</b>	Tillage = 0.060		Irrigation = 0.8	Tillage × Irrigation = NS
105 days after sowing				
PT <sub>25+R</sub>	4.7	4.9	4.9	<b>4.8</b>
PT <sub>14+R</sub>	4.2	4.3	4.8	<b>4.4</b>
ZT	3.4	4.1	4.4	<b>4.0</b>
CT	4.0	4.1	4.5	<b>4.2</b>
<b>MEAN</b>	<b>4.1</b>	<b>4.4</b>	<b>4.6</b>	
<b>CD (p=0.05)</b>	Tillage = 0.20		Irrigation = 0.1	Tillage × Irrigation = NS
120 days after sowing				
PT <sub>25+R</sub>	3.7	3.8	4.0	<b>3.9</b>
PT <sub>14+R</sub>	3.3	3.6	3.8	<b>3.6</b>
ZT	2.9	3.4	3.7	<b>3.3</b>
CT	3.1	3.3	3.5	<b>3.3</b>
<b>MEAN</b>	<b>3.2</b>	<b>3.5</b>	<b>3.7</b>	
<b>CD (p=0.05)</b>	Tillage = 0.11		Irrigation = 0.15	Tillage × Irrigation = NS
<b>Mean of irrigation mean</b>	<b>2.7</b>		<b>2.9</b>	<b>3.1</b>

132 **Root length density**

133 The root length density was recorded at harvesting from 0-15, 15-30, 30-45 and 45-60 cm soil depths and given  
 134 in [Table 4](#). Overall higher mean RLD was observed in PT<sub>25+R</sub> than PT<sub>14+R</sub>, ZT and CT by 19.30, 61.81 and 46.17%  
 135 respectively. At surface layer (0-15 cm), RLD was maximum under PT<sub>25+R</sub> (1.108 cm cm<sup>-3</sup>), which is significantly  
 136 higher than PT<sub>14+R</sub> (1.002 cm cm<sup>-3</sup>) followed by CT (0.850 cm cm<sup>-3</sup>) and ZT (0.749 cm cm<sup>-3</sup>). Among the irrigation levels,  
 137 there was no significant difference in I<sub>3</sub> (0.944 cm cm<sup>-3</sup>), I<sub>1</sub> (0.933 cm cm<sup>-3</sup>) and I<sub>2</sub> (0.905 cm cm<sup>-3</sup>). Similar trend was  
 138 followed under 15-30 and 45-60 cm depths in tillage and irrigation treatments. Ji et al.[31] also reported significantly  
 139 higher (41.4%) RLD with mouldboard over CT. However, at 30-45 cm depth, significantly higher RLD was observed

140 under I<sub>1</sub> (0.363 cm cm<sup>-3</sup>) compared to I<sub>2</sub> (0.311 cm cm<sup>-3</sup>) but at par with I<sub>3</sub> (0.332 cm cm<sup>-3</sup>). Overall higher mean RLD was  
 141 observed in I<sub>3</sub> over I<sub>1</sub> and I<sub>2</sub> by 5.83 and 8.74% respectively.

142 **Table 4:** The effect of irrigation and tillage on root length density (cm cm<sup>-3</sup>)

0-15 cm				
	I <sub>1</sub> (0.6)	I <sub>2</sub> (0.8)	I <sub>3</sub> (1.0)	MEAN
PT <sub>25</sub> +R	1.104	1.100	1.119	<b>1.108</b>
PT <sub>14</sub> +R	1.010	0.990	1.007	<b>1.002</b>
ZT	0.727	0.750	0.770	<b>0.749</b>
CT	0.890	0.780	0.880	<b>0.850</b>
<b>MEAN</b>	<b>0.933</b>	<b>0.905</b>	<b>0.944</b>	
<b>CD (p=0.05)</b>	Tillage = 0.065		Irrigation = NS	Tillage × Irrigation = NS
15-30 cm				
PT <sub>25</sub> +R	0.547	0.543	0.553	<b>0.548</b>
PT <sub>14</sub> +R	0.403	0.373	0.420	<b>0.399</b>
ZT	0.237	0.290	0.300	<b>0.276</b>
CT	0.350	0.360	0.390	<b>0.367</b>
<b>MEAN</b>	<b>0.384</b>	<b>0.392</b>	<b>0.416</b>	
<b>CD (p=0.05)</b>	Tillage = 0.036		Irrigation = NS	Tillage × Irrigation = NS
30-45 cm				
PT <sub>25</sub> +R	0.507	0.383	0.410	<b>0.433</b>
PT <sub>14</sub> +R	0.417	0.310	0.350	<b>0.359</b>
ZT	0.283	0.303	0.313	<b>0.300</b>
CT	0.243	0.247	0.253	<b>0.248</b>
<b>MEAN</b>	<b>0.363</b>	<b>0.311</b>	<b>0.332</b>	
<b>CD (p=0.05)</b>	Tillage = 0.028		Irrigation = 0.036	Tillage × Irrigation = 0.04
45-60 cm				
PT <sub>25</sub> +R	0.377	0.377	0.417	<b>0.390</b>
PT <sub>14</sub> +R	0.293	0.340	0.320	<b>0.318</b>
ZT	0.197	0.197	0.227	<b>0.207</b>
CT	0.223	0.230	0.240	<b>0.231</b>
<b>MEAN</b>	<b>0.273</b>	<b>0.286</b>	<b>0.301</b>	
<b>CD (p=0.05)</b>	Tillage = 0.015		Irrigation = NS	Tillage × Irrigation = NS
<b>Mean of irrigation mean</b>	<b>0.48825</b>	<b>0.4735</b>	<b>0.49825</b>	

143 **Root mass density**

144 The root mass density was determined from 0-15, 15-30, 30-45 and 45-60 cm soil depths at harvesting and is  
 145 presented in Table 5. At 0-15 cm depth, overall higher mean RMD was observed in PT<sub>25</sub>+R than PT<sub>14</sub>+R, ZT and CT by  
 146 35.9, 317.7 and 48.2% respectively. PT<sub>25</sub>+R (0.528µg cm<sup>-3</sup>) was significantly higher RMD over PT<sub>14</sub>+R (0.403µg cm<sup>-3</sup>),  
 147 CT (0.367µg cm<sup>-3</sup>) and ZT (0.367µg cm<sup>-3</sup>). Similarly, I<sub>3</sub> (0.375µg cm<sup>-3</sup>) had significantly higher RMD than I<sub>2</sub> (0.355µg  
 148 cm<sup>-3</sup>) and I<sub>1</sub> (0.354µg cm<sup>-3</sup>). Similar results were found in 30-45 cm depth for tillage treatments, and irrigation levels. At

149 15-30 cm depth, tillage showed significant difference in RMD, but irrigation levels were at par with each other.  
 150 PT<sub>25</sub>+R (0.157 $\mu\text{g cm}^{-3}$ ) had significantly higher than PT<sub>14</sub>+R (0.098 $\mu\text{g/cm}^3$ ), CT (0.092 $\mu\text{g cm}^{-3}$ ) and ZT (0.032 $\mu\text{g cm}^{-3}$ ).  
 151 Renet al.[32] found that Mouldboard plough tillage has higher root mass density than NT. Mu et al.[33] also found  
 152 that deep mouldboard plough tillage has higher RMD than shallow mouldboard plough tillage. Zhao et al. [34]  
 153 reported that deep tillage increased root proliferation and root penetration depth where it was employed [35], but also  
 154 increased the biomass of deeper root [36].

155 **Table 5:** The effect of irrigation and tillage on root mass density ( $\mu\text{g cm}^{-3}$ )

0-15 cm				
	I <sub>1(0.6)</sub>	I <sub>2(0.8)</sub>	I <sub>3(1.0)</sub>	MEAN
PT <sub>25</sub> +R	0.503	0.530	0.550	<b>0.528</b>
PT <sub>14</sub> +R	0.413	0.390	0.407	<b>0.403</b>
ZT	0.140	0.140	0.163	<b>0.148</b>
CT	0.360	0.360	0.380	<b>0.367</b>
<b>MEAN</b>	<b>0.354</b>	<b>0.355</b>	<b>0.375</b>	
<b>CD (p=0.05)</b>	Tillage = 0.012		Irrigation = 0.013	Tillage $\times$ Irrigation = 0.021
15-30 cm				
PT <sub>25</sub> +R	0.190	0.157	0.220	<b>0.189</b>
PT <sub>14</sub> +R	0.150	0.147	0.120	<b>0.139</b>
ZT	0.027	0.030	0.045	<b>0.034</b>
CT	0.101	0.109	0.112	<b>0.107</b>
<b>MEAN</b>	<b>0.117</b>	<b>0.111</b>	<b>0.124</b>	
<b>CD (p=0.05)</b>	Tillage = 0.037		Irrigation = NS	Tillage $\times$ Irrigation = NS
30-45 cm				
PT <sub>25</sub> +R	0.150	0.150	0.170	<b>0.157</b>
PT <sub>14</sub> +R	0.093	0.093	0.107	<b>0.098</b>
ZT	0.031	0.032	0.034	<b>0.032</b>
CT	0.091	0.091	0.095	<b>0.092</b>
<b>MEAN</b>	<b>0.091</b>	<b>0.092</b>	<b>0.101</b>	
<b>CD (p=0.05)</b>	Tillage = 0.009		Irrigation = 0.008	Tillage $\times$ Irrigation = NS
45-60 cm				
PT <sub>25</sub> +R	0.094	0.090	0.102	<b>0.095</b>
PT <sub>14</sub> +R	0.094	0.045	0.080	<b>0.073</b>
ZT	0.018	0.017	0.019	<b>0.018</b>
CT	0.084	0.087	0.092	<b>0.088</b>
<b>MEAN</b>	<b>0.073</b>	<b>0.060</b>	<b>0.073</b>	
<b>CD (p=0.05)</b>	Tillage = 0.037		Irrigation = NS	Tillage $\times$ Irrigation = NS
<b>Mean of irrigation mean</b>	<b>0.15875</b>		<b>0.1545</b>	<b>0.16825</b>

156 **Straw yield**

157 The data pertaining to straw yield recorded at harvesting during 2016-17 and 2017-18 is presented in Table 6.  
 158 Among the tillage treatments, maximum straw yield was recorded under PT<sub>25</sub>+R during both the years and had a

159 significant effect. Overall, significantly higher straw yield was observed in PT<sub>25+R</sub> than PT<sub>14+R</sub>, CT and ZT by 12.31,  
 160 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,  
 161 6.0 and 5.5 t ha<sup>-1</sup> under PT<sub>25+R</sub>, PT<sub>14+R</sub>, CT and ZT respectively.

162 Irrigation levels also showed statistically significant effect during both the years. Overall higher mean straw  
 163 yield was observed in I<sub>3</sub> than I<sub>1</sub> and I<sub>2</sub> by 46 and 8.95% in 2016-17 and 47 and 8.70 in 2017-18 respectively. I<sub>3</sub> had  
 164 maximum straw yield in I<sub>3</sub> (7.3 t ha<sup>-1</sup>) which was significantly higher than I<sub>1</sub> (5.0 t ha<sup>-1</sup>) but at par with I<sub>2</sub> (6.7 t ha<sup>-1</sup>) in  
 165 2016-17. Similar results were recorded in year 2017-18. these results are in accordance with earlier study by Ali et al.  
 166 [37].

167 The pooled analysis of two years data of straw yield showed that significantly higher straw yield was  
 168 recorded under PT<sub>25+R</sub> (7.4 t ha<sup>-1</sup>) than ZT (5.6 t ha<sup>-1</sup>) and CT (6.1 t ha<sup>-1</sup>) and PT<sub>14+R</sub> (6.6 t ha<sup>-1</sup>). Significantly higher  
 169 pooled straw yield was recorded in I<sub>3</sub> (7.40 t ha<sup>-1</sup>) than I<sub>1</sub> (5.05 t ha<sup>-1</sup>) and I<sub>2</sub> (6.80 t ha<sup>-1</sup>).

170 **Table 6:** The effect of irrigation and tillage on straw yield and grain yield

Treatments	Straw yield (t ha <sup>-1</sup> )								Grain yield (t ha <sup>-1</sup> )							
	2016-2017				2017-18				2016-2017				2017-18			
	I <sub>1(0.6)</sub>	I <sub>2(0.8)</sub>	I <sub>3(1.0)</sub>	MEAN	I <sub>1(0.6)</sub>	I <sub>2(0.8)</sub>	I <sub>3(1.0)</sub>	MEAN	I <sub>1(0.6)</sub>	I <sub>2(0.8)</sub>	I <sub>3(1.0)</sub>	MEAN	I <sub>1(0.6)</sub>	I <sub>2(0.8)</sub>	I <sub>3(1.0)</sub>	MEAN
PT <sub>25+R</sub>	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 <sub>14+R</sub>	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			

171

## 172 Grain yield

173 The data pertaining to grain yield was recorded at harvesting during both the years and is illustrated in [Table](#)  
 174 [6](#). Overall, significantly higher mean grain yield was observed in PT<sub>25+R</sub> than PT<sub>25+R</sub>, ZT and CT by 4.17, 16.28 and  
 175 11.11% in 2016-17 and 6.12, 18.18 and 10.64% in 2017-18 respectively. Among the tillage treatments maximum grain  
 176 yield was recorded under PT<sub>25+R</sub> during 2016-17 and 2017-18. PT<sub>25+R</sub> had (5.0 and 5.2 t ha<sup>-1</sup>) significantly higher grain  
 177 yield than PT<sub>14+R</sub> (4.8 and 4.9 t ha<sup>-1</sup>), CT (4.5 and 4.7 t ha<sup>-1</sup>) and ZT (4.3 and 4.4 t ha<sup>-1</sup>) for 2016-17 and 2017-18  
 178 respectively. Ding et al.[38] found that deep tillage systems increased the performance of soil amendments, which in  
 179 turn improved wheat yield. Schneidera et al.[39] represent that deep tillage has the highest potential to increase  
 180 yield. Higher grain yield has been observed under deep tillage compared to shallow tillage [40]. Ozpinar [41]  
 181 observed that the mouldboard plough recorded higher grain production than NT because these tillage systems were  
 182 more effective at controlling weeds. Lund et al[42] found that grain yield was reduced under NT by 10-15% than

mouldboard plough. [Give multiple relationship of different parameter with grain yields \(height, number of tillers, Leaf area index, root mass etc for different tillage treatments.](#)

Irrigation levels also have statistically significant effect on grain yield during both years. Overall, significantly higher mean grain yield was observed in I<sub>3</sub> than I<sub>1</sub> and I<sub>2</sub> 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<sub>3</sub> (5.3 t ha<sup>-1</sup>) which is significantly higher than I<sub>1</sub> (3.8 t ha<sup>-1</sup>) but statistically at par with I<sub>2</sub> (4.8 t ha<sup>-1</sup>). In year 2017-18, I<sub>3</sub> (5.5 t ha<sup>-1</sup>) had highest mean grain yield which is significantly higher than I<sub>1</sub> (4.0 t ha<sup>-1</sup>) but statistically at par with I<sub>2</sub> (4.9 t ha<sup>-1</sup>). 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] who also reported that the wheat yield increased with increase in irrigation scheduling. overall results are in accordance with Ali et al [37] and Martinez et al [44].

[Discuss shoot/root ratio](#)

### Water balance components and Water productivity

The data pertaining to water balance as affected by tillage and irrigation practices is represented in Table 7. Maximum ET recorded in PT<sub>25</sub>+R followed by PT<sub>14</sub>+R, CT and ZT during both years. ET was maximum in I<sub>3</sub> followed by I<sub>2</sub> and I<sub>1</sub>. Maximum soil water depletion was under I<sub>1</sub> where less irrigation was applied in both years. More drainage was reported in I<sub>3</sub> where more irrigation was applied in both years. In I<sub>2</sub> maximum drainage observed under ZT during both years. In irrigation level I<sub>3</sub> maximum drainage was observed in CT and minimum drainage under PT<sub>14</sub>+R during both years.

**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 <sub>1</sub>	PT <sub>25</sub> +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 <sub>14</sub> +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 <sub>2</sub>	PT <sub>25</sub> +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 <sub>14</sub> +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 <sub>3</sub>	PT <sub>25</sub> +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 <sub>14</sub> +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

205 The data pertaining to the effect of irrigation and tillage on water productivity is recorded illustrated in [Table](#)  
 206 [8](#). Overall mean higher water productivity was observed in I<sub>2</sub> than I<sub>1</sub> and I<sub>3</sub> by 27.39 and 2.26 % in 2016-17 and 27.70  
 207 and 1.91 % in 2017-18 respectively. Maximum WP observed under I<sub>2</sub> was 140.0 and 143.8 kg ha<sup>-1</sup> cm<sup>-1</sup> for years 2016-17  
 208 and 2017-18 which was significantly higher than I<sub>1</sub> having WP 109.9 and 112.6 kg ha<sup>-1</sup> cm<sup>-1</sup> respectively. Zain et al [45]  
 209 found that rise in WUE when the irrigation changed from I<sub>20</sub> to I<sub>35</sub>, WUE declined dramatically when irrigation level  
 210 changed from I<sub>35</sub> to I<sub>50</sub>. Ali et al[37] found that the alternating deficit treatment, whereby imposed deficits at the  
 211 growth period's peak tillering (jointing to shooting) and flowering to soft dough stages, followed by a single irrigation  
 212 at the crown root initiation stage, produced the highest water production. It was observed that WUE increased with  
 213 an increase in irrigation up to a certain limit and then tended to decrease. Tillage treatment had not any significant  
 214 difference in WP during both years. However, maximum WP was found under PT<sub>25</sub>+R (138.3, 141.9 kg ha<sup>-1</sup> cm<sup>-1</sup>)  
 215 followed by PT<sub>14</sub>+R (128.9, 132.3 kg ha<sup>-1</sup> cm<sup>-1</sup>), ZT (128.6, 132.3 kg ha<sup>-1</sup> cm<sup>-1</sup>) and least under CT (119.9, 123.5 kg ha<sup>-1</sup>  
 216 cm<sup>-1</sup>) for 2016-17 and 2017-18 respectively. Similarly, higher WP in deep tillage has been reported by Memon et al [16].

217 **Table 8:** The effect of irrigation and tillage on water productivity

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

## 218 Soilorganiccarbon

219 SOC affected with tillage practices is shown in [Table 9](#). SOC was significantly more in ZT by 12.9% and 12.8% than CT  
 220 during 2016–17 and 2017–18 respectively. However, in both years SOC was at par in PT<sub>25</sub>+R, PT<sub>14</sub>+R and CT. High SOC in ZT  
 221 may be carbon addition from rice residues on the surface and more crop residues decomposition with different tillage  
 222 treatments. Bhattacharyya et al [46] had found that significantly higher SOC than by 14%. Hazarika et al. [47] also re-  
 223 ported 14% and 17% higher SOC in surface soil under ZT than rotary tillage and CT practices respectively.

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

Soil organic carbon (g kg <sup>-1</sup> )	Tillage treatments				
Year of experiment	PT <sub>25</sub> +R	PT <sub>14</sub> +R	ZT	CT	CD (p=0.05)
2016-17	6.66	6.48	7.36	6.41	<b>0.46</b>
2017-18	6.92	6.68	7.45	6.50	<b>0.47</b>

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## 225 5. Conclusions [Rewrite the conclusion](#)

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

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