Effects of different irrigation frequencies and incorporation of rice straw on yield and water productivity of wheat crop

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Abstract: The current rapid increase in irrigation water consumption is considered unsustainable and threatens the world food production. Therefore, it is mandatory to promote modern techniques and to manage existing conventional irrigation methods. The present study was attempted to determine the effects of different irrigation frequencies and rice straw incorporation rates on yield and water productivity of the wheat crop. The experiment was arranged with randomize complete block design involving nine treatments (RS_0I_7, RS_0I_{15}, RS_0I_{22}, RS_1I_7, RS_1I_{15}, RS_1I_{22}, RS_2I_7, RS_2I_{15} and RS_2I_{22}) under three replications. Results exposed that the incorporation of rice straw with different irrigation frequencies significantly improved physico-chemical properties of soil. Moreover, soil bulk density, infiltration rate, pH, electrical conductivity significantly decreased and soil porosity significantly increased under all treatments. Furthermore, maximum crop yield and crop water productivity of 7706.4 kg/hm^2 and 1.92 kg/m^3 respectively were found under RS_1I_{15} treatment. Based on experimental results it can be concluded that irrigation frequency and incorporation of rice straw had significant effects on the physico-chemical properties of soil, total grain yield and water productivity of the wheat crop. However, this study suggested that the wheat crop yield and water productivity could be increased by incorporating 1 t/hm^2 rice straw with 15 d of irrigation frequency.

Keywords: physico-chemical, irrigation frequency, rice straw, wheat, crop water productivity
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1 Introduction

Pakistan is the sixth most heavily populated country in the world, with a current population of 202.086 million and an annual growth rate of 1.93%. The population has increased from 32.4 million in mid of 1948 to 144.5 million in 2003, and exceeded 168 million in 2010. The estimated population for the year 2025 would be 226.76 million[1]. In addition, agriculture in Pakistan is considered as a central pillar of the country. The importance of agriculture to Pakistan's economy is explained by the fact that agricultural outputs contribute to 24.7% of the gross domestic production (GDP) and employs 47.3% of the employment strength of Pakistan. Wheat, cotton, rice and maize are the major crops[2].

Wheat (*Triticum aestivum* L.) is an essential staple food crop in Pakistan that constituted 9% of household consumption, and it is also cultivated at a large scale throughout the country. In rural households, wheat is consumed at a high level compared to the urban household, whereas it was considered as the second most consumed commodity. However, its yield had been significantly affected by many issues like shortage of water, increases in prices of agricultural input and droughts over years and challenges of low wheat production in Pakistan are still considerable. It is also discussed by other scientists that the low grain yield could be mainly due to the increased moisture scarcity from sowing throughout the growing season, which adversely affects plant growth and development[3].

In Pakistan, the wheat crops growing season starting from October to April (Rabi) period and in this time abundant amount of water is required for agriculture use. However, the sever scarcities of water intimidate the opportunity to satisfy those necessities[4]. The current rapid increase in irrigation water use is considered unsustainable and threatens future food production[5-7]. Therefore, effectual applying of the available water is required if higher agriculture production is desired, and the wise use of water can contribute to more crop output[8-10]. Irrigation plays an essential role in improving the productivity of wheat crop. Khokhar et al.[11] investigated the consequences of irrigation frequency on water use and yield of wheat, and found that 8.01 kg/hm^2·mm of wheat yield was obtained when field was watered after every 35 d interval. Karrou et al.[12] evaluated the performance of deficit irrigation of wheat by comparing with farmer's practice and full irrigation revealed that deficit irrigation showed 1500 m^3/hm^2 water saving in wheat compared to the farmer's practice and full irrigation. Another research found that 2 d and 6 d irrigation frequencies plots gave better performance

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compared to 4 d irrigation[13]. In Pakistan, sustainable agriculture depends entirely on water availability[14], and there is a high potential for improving crop water productivity. The crop water productivity may be achieved by reducing runoff, soil evaporation, plant transpiration and drainage loss using anti transpiration materials.

Rice straw is mostly applied to improve the soil physico-chemical properties[15-17] while minimize the impact of agrochemicals, which is an important concern in current agricultural activities[18]. Similarly, straw incorporation increased crop production by refining soil physical circumstances and stability down to 30 cm soil profile[19] and improving the quality of wheat grain significantly[20]. It increases the infiltration and storing of water in the rhizosphere and improved structure and macro-porosity of soil[21]. Tolk et al.[22] revealed that the wheat grain yield can be generally increased by the reduction of surface evaporation, which increases soil moisture content. Rice straw resulted in 17% increases in grain yield and 19% in above ground biomass. Yan-min et al.[23] reported that plant height was found higher at field with 8 t/hm^2 rice straw mulching rate compared with zero rice straw mulched soil, the weight of grains and grain yield/hm^2 peaked at 6 t/hm^2 rice straw mulching rate. There was also research[24] studied the effect of rice straw mulching on production of wheat and concluded that rice straw mulching enhanced plant height and number of grains, improved wheat production both qualitatively and quantitatively. Chaudhary et al.[25] conducted field trials to study the rice straw mulching at different doses at the rates of 7.5, 10.0, 12.5, 15.0, 17.5 and 20.0 t/hm^2, respectively, with no rice straw field as a control plot. They concluded that rice straw was an alternate source as a soil fertility supplement. Mousavi et al.[26] found that the treatments with rice straw mulch (RSM) led to a significant increase in water holding capacity, field capacity, water productivity and available water. Similarly, the rice straw decreased consumption of water from 7.18 L/plot (control) to 7.05 L/plot.

Based on the above researches, this study was planned to evaluate the effect of different rice straw mulching rates and different irrigation frequencies on yield and water productivity, aimed to further improve the wheat production and soil physical properties.

2 Materials and methods

2.1 Location of experimental site

The field research was conducted during the year 2015-16, at the tentative place of the Department of Irrigation and Drainage, Faculty of Agricultural Engineering, Sindh Agriculture University at Tandojam, Sindh, Pakistan. The study area was located at Latitude 25°25′28″N and Longitude 68°32′26″E, and at an elevation of about 26 m above mean sea level (MSL). The detail location was shown in Figure 1.

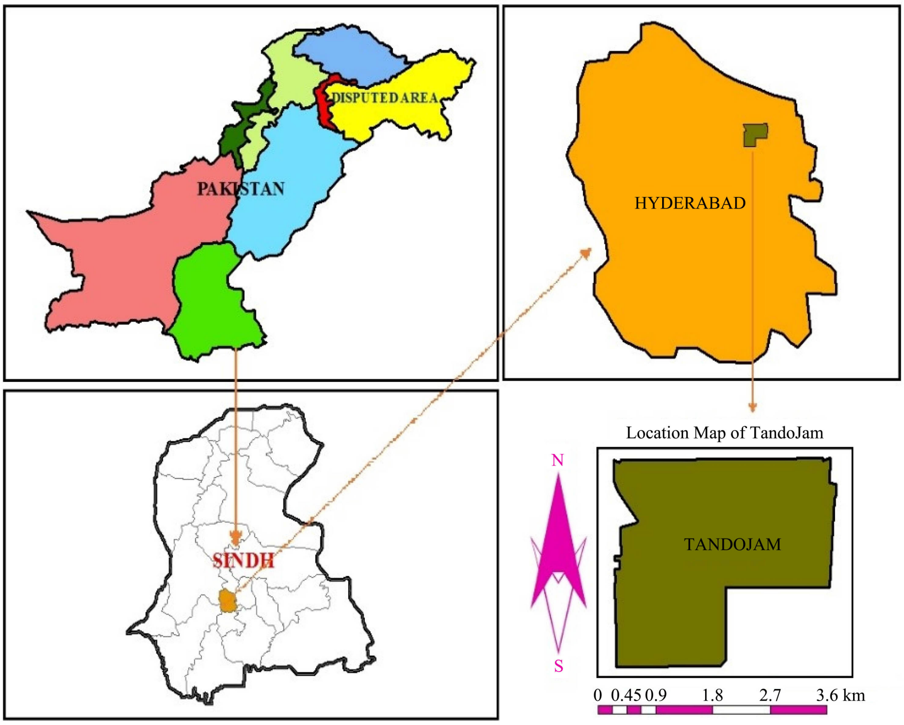


Figure 1 Geographical location of the experiment field site

2.2 Climate condition

The experimental area has a mostly semi-arid climate. Annual rainfall is 145-155 mm, which is lower than potential evapotranspiration. More than 90% of the rainfall was received during summer monsoon period July-Sep, and meager rain occurred due to rare westerly waves that extend to the southern parts of the country. It is impossible to conduct crop production in this area without irrigation. The experimental area was situated in southern parts of Sindh, which was slightly cooler and more humid than the northern parts due to the Arabian Sea. Temperature ranges from cool to cold in winter and from hot to very hot during summer. The monthly distributions of the maximum and minimum temperatures and rainfall during 2015-2016 at the experimental site were illustrated in Figure 2.

2.3 Experimental design

The research was piloted to evaluate the effect of different rice straw mulching rates and different irrigation frequencies on yield and water productivity of the wheat crop. The experiment was laid out in a split plot with randomize complete block design as shown in Figure 3a. For this purpose, the total experiment site of 833 m^2 (17 × 49) was divided into 27 sub plots of 25 m^2 (5×5) each. The research comprised with nine treatments, including three different irrigation frequencies of 7 d (I_7), 15 d (I_{15}), and 22 d (I_{22}) and three different rice straw mulching rates of no rice straw, rice straw at 1 t/hm^2, and 2 t/hm^2. Each treatment was conducted with three replications. A complete explanation of the treatments was displayed in Table 1.

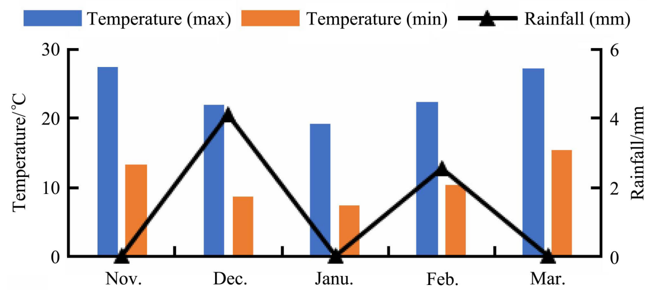
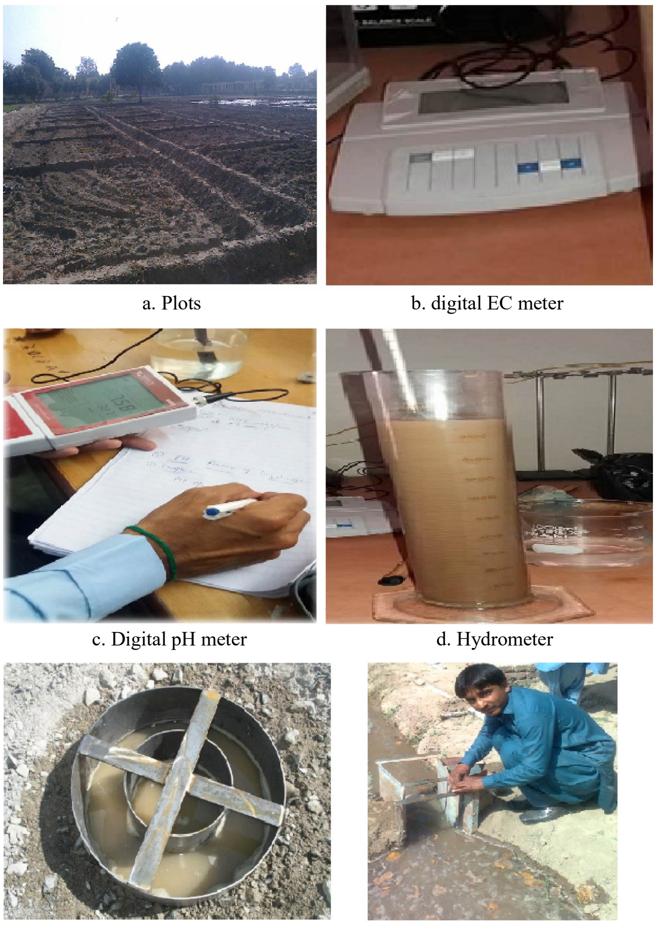


Figure 2 Monthly mean temperature (°C) and rainfall (mm) during the experiment



a. Plots b. digital EC meter

c. Digital pH meter d. Hydrometer

e. Double ring infiltrometer f. Cut-throat flume

Figure 3 Experimental setup and equipment used during the study

Table 1 Detailed description of different irrigation frequencies and rice straw mulching rates

Treatments	Descriptions	Symbols
T1	No rice straw and 7 d of irrigation frequency	RS_0I_7
T2	No rice straw and 15 d of irrigation frequency	RS_0I_{15}
T3	No rice straw and 22 d of irrigation frequency	RS_0I_{22}
T4	Rice straw at 1 t/hm^2 and 7 d of irrigation frequency	RS_1I_7
T5	Rice straw at 1 t/hm^2 and 15 d of irrigation frequency	RS_1I_{15}
T6	Rice straw at 1 t/hm^2 and 20 d of irrigation frequency	RS_1I_{22}
T7	Rice straw at 2 t/hm^2 and 7 d of irrigation frequency	RS_2I_7
T8	Rice straw at 2 t/hm^2 and 15 d of irrigation frequency	RS_2I_{15}
T9	Rice straw at 2 t/hm^2 and 22 d of irrigation frequency	RS_2I_{22}

2.4 Soil sampling and analyzing

In order to determine the physico-chemical properties of soil, 81 core soil samples were collected from the experimental field at the depths of 0-20 cm, 21-40 cm and 41-60 cm respectively with the help of tube auger. The soil samples were collected, packed and brought to the laboratory of Irrigation and Drainage department for analyzing. The same procedure was repeated before and after the harvesting of wheat crop. These soil samples were examined for texture, bulk density, porosity, PH and EC determination.

2.4.1 Soil texture

The infiltration rate and water holding capacity of the soil are mostly biased on soil texture. In this study, Bouyoucos Hydrometer technique[27] was used to calculate the particle size distribution as shown in Figure 3d.

2.4.2 Soil bulk density

For determination of dry bulk density of the soil, the composite soil samples were carried out from the plots of experimental field at the depths of 0-60 cm with the help of tube auger of known diameter. These samples were labeled, packed and brought to the laboratory and calculated the wet weight with electric balance. Samples were placed in a 105°C oven for 24 h, and then dry weight of each sample was measured. The soil dry bulk density of the soil was calculated by Equation (1)[28].

$$\text{Dry bulk density } (\rho_d) = \frac{\text{Dry weight of soil sample}}{\text{Total volume of soil sample}} \quad (1)$$

2.4.3 Soil porosity

The soil porosity was determined by Equation (2) given by Kanwar and Chopra[29].

$$\mathcal{D} = \frac{V_V}{V_T} \times 100 \quad (2)$$

where, $\mathcal{D}$ is porosity, %; V_v is the total volume of voids in the aggregates; V_t is the total bulk volume of aggregates.

2.4.4 Infiltration rate

To determine the infiltration rate, a double ring infiltrometer was used to determine infiltration rate before and after the experiment of soil under saturated conditions. The procedure was adopted by Bouwer[30] and Daniel[31] as shown in Figure 3e.

2.4.5 Soil pH and EC

For determination of pH of soil samples, 20 g of soil sample was weighed and added into 50 mL distilled water. The suspension was stirred for 15 min and allowed to settle for 30 min and again stirred for 2 min. After that, pH was recorded by immersing electrode of digital pH meter as shown in Figure 3b. EC was measured in 1:2 soil-water suspension by conductivity meter as shown in Figure 3c.

2.5 Irrigation water quality

In order to control the quality of irrigation water, three water samples were collected after 10, 20 and 30 min intervals and taken to the laboratory of Irrigation and Drainage department for the determination of EC_W, pH and sodium absorption ratio (SAR). Equation (3) adopted by Rowell[32] was used to calculate the SAR.

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{++} + \text{Mg}^{++}}{2}}} \quad (3)$$

where, Na^+ is Sodium; Ca^{++} is Calcium; Mg^{++} is Magnesium.

2.6 Irrigation plan for all treatments

The study was carried at three irrigation frequencies 7 d, 15 d and 22 d. To apply the required depth of water to plots, a cut-throat flume (8” × 1.5’) was installed at the center of field channel at the time of irrigation as shown in Figure 3f. To determine the flow rate, Equation (4) was used[33].

Formula for free flow (if $H_d/H_u < 0.68$)

$$Q_f=3.99(h_u)^{1.939} \tag{4}$$

The amount of irrigation water required was calculated by Equation (5)[34,35]

$$D=\frac{SMD}{100}\times\rho_b\times d_r \tag{5}$$

where, D is the depth of water required, cm; SMD is soil moisture deficit level; ρ_b is bulk density, g/cm^3; d_r is root depth, cm.

The time of irrigation application to required depth of water was calculated by Equation (5)[36,37].

$$QT=28\times A\times D \tag{6}$$

where, Q is discharge required (LPS); T is time of application, h; A is area to be irrigated, hm^2; D is the depth of irrigation to be applied, cm.

2.7 Sowing and yield of wheat crop

The wheat crop was sown in basin irrigation method under all treatments after 100 mm socking doze. When the soil was reached at the field capacity condition; a wheat variety of Tando Jam-83 (TJ-83) was sown in the experimental plots. Wheat crop was collected in bags after harvest and weighed for yield calculation.

2.8 Water productivity

Water productivity (WP) under all treatments was calculated by Equation (7).

$$WP=\frac{Y}{I} \tag{7}$$

where, WP is water productivity, kg/m^3; Y is yield, kg; I is irrigated water, m^3.

2.9 Statistical analysis

To evaluate the significance and interactions of different irrigation frequencies and straw mulching rates on soil physicochemical properties, crop yield and water productivity, analysis of variance (ANOVA) was used. The means were compared using Duncan's multiple range test, with p<0.05 level being considered significant. All statistical analyses were conducted using IBM Statistical Package for Social Scientists (SPSS 18.0).

3 Results

The present research was conceded to determine the effects of different rice straw mulching rates and different irrigation frequencies on yield and water productivity of the wheat crop. To achieve the proposed objectives of the research study the results of the following parameters are described in detail.

3.1 Soil physico-chemical properties

3.1.1 Soil texture

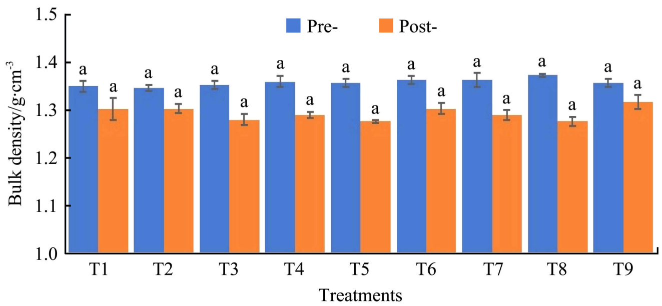
The textural class of soil profile before the experiment was clay loam at all depths. After wheat growth, the textural classes of the soil profile remained unchanged. The results of soil particles percentages were presented in Table 2.

Table 2 Soil texture before and after the experiment at various depths

S No	Before Experiment					After Experiment			
	Depth/cm	Sand/%	Silt/%	Clay/%	Textural Class	Sand/%	Silt/%	Clay/%	Textural Class
1	0-20	28.8	45.6	25.6	Clay Loam	30.2	42.9	26.9	Clay Loam
2	21-40	28.8	48.4	22.8	Clay Loam	30.8	45.4	23.8	Clay Loam
3	41-60	28.8	45.6	25.6	Clay Loam	25.8	42.3	31.9	Clay Loam

3.1.2 Soil bulk density

The results of the average soil dry bulk density of the soil horizons of experimental field up to 60 cm depth were presented in Figure 4. After experiment, soil bulk density significantly decreased (p<0.05) under all treatments. The maximum reduction of the bulk density of 7.3% was obtained under RS_2I_{15} treatments, whereas the smallest reduction of 2.99% occurred under RS_0I_{15} and RS_2I_{22} treatments, respectively.



Note: T1(RS0I7) = no RS with 7 d of irrigation frequency, T2(RS_0I_{15}) = no RS with 15 d of irrigation frequency, T3(RS_0I_{22}) = no RS with 22 d of irrigation frequency, T4(RS_1I_7) = RS @ 1 t/hm^2 with 7 d of irrigation frequency, T5(RS_1I_{15}) = RS @ 1 t/hm^2 with 15 d of irrigation frequency, T6(RS_1I_{22}) = RS @ 1 t/hm^2 with 22 d of irrigation frequency, T7(RS_2I_7) = RS @ 2 t/hm^2 with 7 d of irrigation frequency,T8 (RS_2I_{15}) = RS @ 2 t/hm^2 with 15 d of irrigation frequency and T9 (RS_2I_{22}) = RS @ 2 t/hm^2 and 22 d of irrigation frequency. Different letters denoted significant differences between treatments at p<0.05 and error bars indicate the standard deviation (SD) of the mean value.

Figure 4 Mean soil bulk density of before and after experiment under all treatments

3.1.3 Porosity of soil

The results of average porosity of composite soil samples were presented in Figure 5. The average porosity of soil significantly increased after the treatments at different rice straw mulching rates and irrigation frequencies. It was revealed that the highest and lowest mean soil porosities were 35.8 and 33.1 % under RS_0I_{15} and RS_1I_{22} treatments, respectively. However, maximum soil porosity increase was 16% under RS_1I_{15}, whereas minimum soil porosity

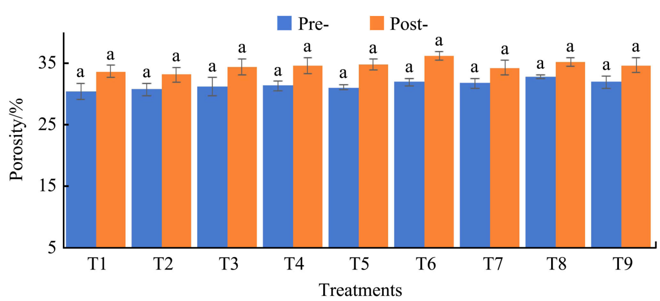


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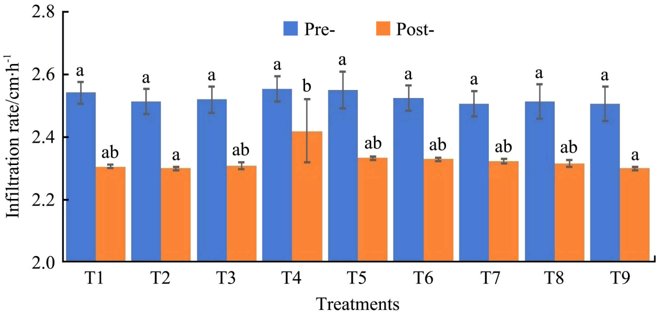
Figure 5 Porosity of soil before and after experiment under nine treatments increase was occurred under T5 (RS @ 2 t/hm^2 with 15 d of irrigation frequency).

3.1.4 Infiltration rate

Figure 6 presented the results of infiltration rate of the soil. Before the cultivation of crop, minimum infiltration was 2.50 cm/h under T2 (RS_0I_{15}). But after applying the different rice straw mulching rates and irrigation frequencies, it significantly decreased under all treatments. The maximum decrease of 9.45 % was found under RS_0I_7 and RS_1I_7 treatments respectively, whereas the minimum reduction of 7.50% was found under RS_2I_7 treatment.



Note: T1(RS0I7) = no RS with 7 d of irrigation frequency , T2(RS_0I_{15}) = no RS with 15 d of irrigation frequency, T3(RS_0I_{22}) = no RS with 22 d of irrigation frequency, T4(RS_1I_7) = RS @ 1 t/hm^2 with 7 d of irrigation frequency, T5(RS_1I_{15}) = RS @ 1 t/hm^2 with 15 d of irrigation frequency, T6(RS_1I_{22}) = RS @ 1 t/hm^2 with 22 d of irrigation frequency, T7(RS_2I_7) = RS @ 2 t/hm^2 with 7 d of irrigation frequency,T8 (RS_2I_{15}) = RS @ 2 t/hm^2 with 15 d of irrigation frequency and T9 (RS_2I_{22}) = RS @ 2 t/hm^2 and 22 d of irrigation frequency. Different letters denoted significant differences between treatments at p<0.05 and error bars indicate the standard deviation (SD) of the mean value.

Figure 6 Infiltration Rate of soil before and after experiment under all treatments

3.1.5 pH of soil sample

The pH of experimental soil before and after the crop growth was presented in Figure 7. The maximum value before the experiment was measured as 8.26 under T4. After experiment, pH of soil significantly decreased (p<0.05) under all treatments, ranged from 8.26 to 7.76. The maximum and minimum reductions were 7.78% and 6.77% under RS_1I_{15} and RS_2I_{22} treatments, respectively.

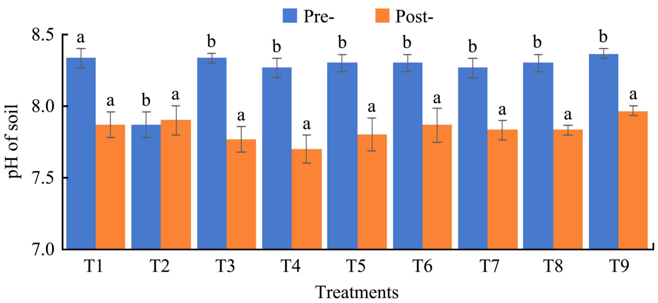


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Figure 7 pH of soil before and after experiment under nine treatments

3.1.6 Electrical conductivity of soil (EC_e)

Figure 8 indicated the average electrical conductivity of the soil saturation extract (EC_e) of different soil depths before and after the experiment. The EC_e maximum and minimum mean values before the experiment were 1.083 dS/m and 1.046 dS/m under RS_2I_7 and RS_2I_{15} treatments, respectively. After experiment, EC_e values significantly decreased (p<0.05) under all treatments, maximum reduction of 12.4% (0.133 dS/m) was found under RS @ 1 t/hm^2 with 15 d of irrigation frequency.

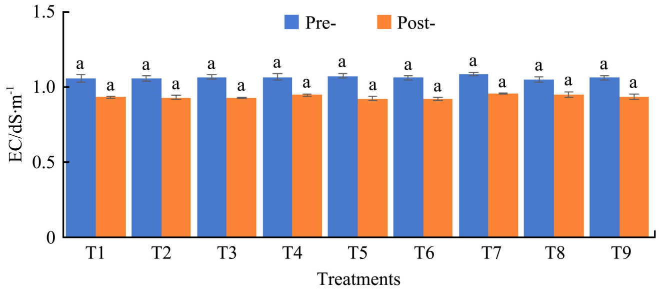

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Figure 8 Electrical Conductivity of soil before and after experiment under different treatments

3.2 Quality of irrigation water

Table 3 showed the average results of ECw, pH and SAR of irrigation water source were 1350, 7.7 and 6.70 respectively. The analysis of data revealed that the water can be termed as good quality water (ECw < 1500 μS/cm, SAR < 10).

Table 3 Irrigation water quality of the experiment

Source of water	ECw/μS·cm^{-1}	pH	SAR
Tube well	1356	7.7	6.67

3.3 Irrigation water used

Figure 9 showed the volume of water applied to the wheat crop. Average volumes of water applied to the crop were 12.31 m^3/plot under treatments RS_0I_7, RS_1I_7 and RS_2I_7, 9.95 m^3/plot under treatments RS_0I_{15}, RS_1I_{15} and RS_2I_{15}, and 8.76 m^3/plot under treatments RS_0I_{22}, RS_1I_{22} and RS_2I_{22}. These volumes were further calculated on hectare as 4924 m^3/hm^2, 3980 m^3/hm^2 and 3504 m^3/hm^2 with 7, 15 and 22 d of irrigation frequencies respectively.

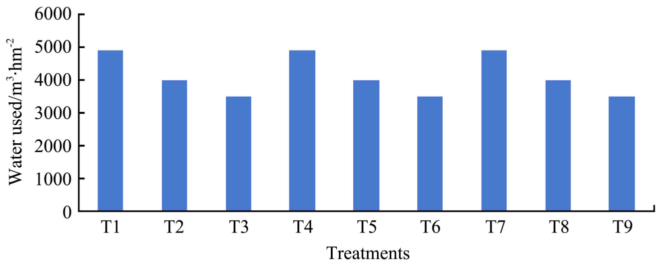

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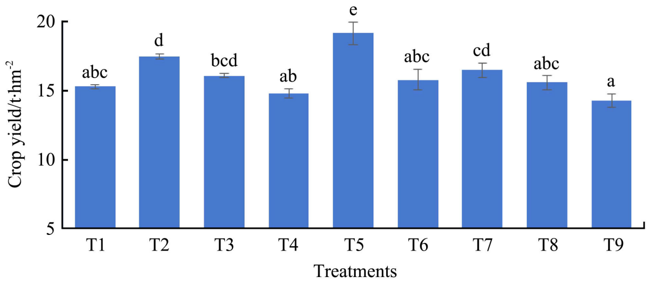
Figure 9 Irrigation water used

3.4 Crop yield

Figure 10 showed the treatment-wise average yields per plot and total yields per hectare of wheat crop cultivated in the experimental field. It indicated that the different rice straw mulching rates and different irrigation frequencies had a significant effect (p<0.05) on average yield of wheat crop. The highest grain yield of 7114.0 kg/hm^2 was achieved under RS @ 1 t/hm^2 with 15 d of irrigation frequency (RS_1I_{15}), and the lowest grain yield of 5730 kg/hm^2 was obtained under RS @ 2 t/hm^2 and 22 d of irrigation frequency (RS_2I_{22}). Comparison of the rice straw mulching rates and different irrigation frequencies showed that the average crop yield was ranked as RS_1I_{15} > RS_0I_{15} > RS_2I_7 > RS_0I_{22} > RS_1I_{22} > RS_2I_{15} > RS0I7 > RS_1I_7 > RS_2I_{22} under all treatments.

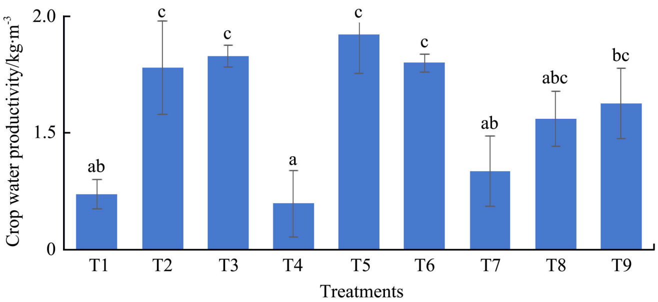


Note: T1(RS_0I_7) = no RS with 7 d of irrigation frequency , T2(RS_0I_{15}) = no RS with 15 d of irrigation frequency, T3(RS_0I_{22}) = no RS with 22 d of irrigation frequency, T4(RS_1I_7) = RS @ 1 t/hm^2 with 7 d of irrigation frequency, T5(RS_1I_{15}) = RS @ 1 t/hm^2 with 15 d of irrigation frequency, T6(RS_1I_{22}) = RS @ 1 t/hm^2 with 22 d of irrigation frequency, T7(RS_2I_7) = RS @ 2 t/hm^2 with 7 d of irrigation frequency,T8(RS_2I_{15}) = RS @ 2 t/hm^2 with 15 d of irrigation frequency and T9(RS_2I_{22}) = RS @ 2 t/hm^2 and 22 d of irrigation frequency.

Figure 10 Total grain yield

3.5 Crop water productivity

Results of crop water productivity were depicted in Figure 11. Highest crop water productivity of 1.92 kg/m^3 was achieved under RS @ 1 t/hm^2 with 15 d of irrigation frequency (RS_1I_{15}), whereas the lowest crop water productivity of 1.20 kg/m was obtained under RS_1I_7 treatment. Comparison of the rice straw mulching rates and different irrigation frequencies showed that the average crop water productivity was ranked as RS_1I_{15} > RS_0I_{22} > RS_1I_{22} > RS_0I_{15} > RS_2I_{22} > RS_2I_{15} > RS_2I_7 > RS0I7 > RS_1I_7 under all treatments.



Note: T1(RS_0I_7) = no RS with 7 d of irrigation frequency , T2(RS_0I_{15}) = no RS with 15 d of irrigation frequency, T3(RS_0I_{22}) = no RS with 22 d of irrigation frequency, T4(RS_1I_7) = RS @ 1 t/hm^2 with 7 d of irrigation frequency, T5(RS_1I_{15}) = RS @ 1 t/hm^2 with 15 d of irrigation frequency, T6(RS_1I_{22}) = RS @ 1 t/hm^2 with 22 d of irrigation frequency, T7(RS_2I_7) = RS @ 2 t/hm^2 with 7 d of irrigation frequency,T8(RS_2I_{15}) = RS @ 2 t/hm^2 with 15 d of irrigation frequency and T9(RS_2I_{22}) = RS @ 2 t/hm^2 and 22 d of irrigation frequency.

Figure 11 Crop water productivity under nine treatments

4 Discussions

4.1 Effect of different rice straw mulching rates and different irrigation frequencies on soil physicochemical properties

The results of this study indicated that rice straw incorporation with different irrigation frequencies had positive effects on soil physico-chemical characteristics, soil yields and water productivity of the wheat crop. The incorporation of rice straw showed a non-significant effect on soil texture, however, there was a slight change in the relative proportion of soil separates at different depth of the profile. Avnimelech et al.[38] also reported similar results that the addition of rice straw improves drainage and aeration but does not effect on the texture of the clay soil. However, the incorporation of rice straw increased aggregate stability in higher or medium soils[39]. In this study, soil bulk density significantly decreased under all treatment. The maximum soil bulk density decrease of 7.3% was achieved was found under RS_2I_{15} and the minimum reduction of 2.99% was found under RS_0I_{15} and RS_2I_{22}. These findings matched with Pervaiz et al.[40] that the bulk density decreased when adding rice straw to soil. Sharma et al.[41] reported that applying 6 t/hm^2 rice straw decreased bulk density from 1.44 to 1.40 g/cm^3 compared with no rice straw control. Similarly, Singh et al.[42] reported that applying rice straw improved soil bulk density and at different rates.

Singh et al.[42] also found that applying water at different quantities did not affect soil bulk density. However, maximum soil porosity was found at 32.9% before the experiment started, but after harvest, it significantly increased to 35.8% under rice straw mulching rate at 1 t/hm^2 with irrigation frequency of 15 d (RS_1I_{15}). Similar results were reported by Richard et al.[43] that rice straw incorporation increased the porosity of soil, ranges from 25% to 40%. Furthermore, porosity directly affects infiltration rate, incorporation of rice straw can increase the stability of soil. In this study, the maximum significant infiltration reduction rate of 0.24 cm/h was found under rice straw mulching rate at 1 t/hm^2 with 7 d of irrigation frequency (RS_1I_7). There were also studies revealed that organic matter could reduce infiltration rate by changing soil structure, proportion of macro pores, and aggregate constancy[44]. Wu et al.[45] reported that the incorporation of rice straw is a water conserving technique and decreases the infiltration rate by reducing runoff.

It was found in this study that both irrigation and organic mulches had significant influences on the electrical conductivity and pH of the soil. Before the experiment, the highest EC_e was observed at the top layer of soil up to 30 cm while the lowest EC_e was observed at a depth of 41-60 cm. After harvest, a decrease of soil EC_e was observed in all treatments, and the highest reduction of 0.133 dS/m was found under RS_1I_{22}. These results were in agreement with Ashraf et al.[46] who reported that adding straw rice straw to the loamy soil reduces the ECe of soil of up to 48%. Chaudhry et al.[47] also assessed that by applying straw mulching, the electrical conductivity of soil decreased to 53% as compared to bare soil. Furthermore, soil pH is one of the most vital aspects affecting metal solubility, plant nutrients uptake and movement, plant growth and many other attributes and reactions[48]. Incorporating rice straw has been reported to have the ability to buffer soil pH[49,50]. Before the experiment, the highest pH was observed at a depth of 0-30 cm down, and the lowest pH was observed at a depth of 40 to 60 cm. Statistical analysis showed that the difference in pH was significant (p < 0.05) in all treatments. Results showed momentous effect of irrigation frequency and rice straw mulching on soil pH, whereas the value of pH decreased from 8.36 to 7.96. The present study agreed with research conducted by Broschat[51], which found that rice straw can affect the soil pH and decreased the values in the top layer of the soil. Bolan and Hadley[52] and Rashad et al.[53] also assessed that soil pH decreased after application of rice straw due to the release of H^+ via nitrification during composition.

4.2 Effect of different irrigation frequencies and rice straw mulching rates on yield and water productivity of the wheat crop

All the irrigation and mulch treatments significantly affected the grain yield of wheat. The highest grain yield of 7.7 t/hm^2 was observed under RS_1I_{15} treatment, while the lowest grain yield of 5.73 t/hm^2 was observed under RS_2I_{22}, makes a difference of 1.97 t/hm^2 (Figure 9). The output of this research is similar to previous studies conducted by Acharya et al.[54] and Singh et al.[42], which revealed that using different rice straw mulching rates with various irrigation intervals gave significantly better grain yield of 0.58-2.96 mg/hm^2 than no rice straw mulch as 0.36-1.78 mg/hm^2. Zamir et al.[55] conducted similar research and found that rice straw mulching gave maximum yield (6.33 t/hm^2) as compared to traditional methods (4.92 t/hm^2). Figure 10 revealed that applying rice straw mulching and irrigation significantly (p<0.05) impacted crop water productivity (CWP). Highest CWP, which was 1.93 kg/m^3, was observed under RS @ 1 t/hm^2 with 15 d of irrigation frequency (RS_1I_{15}), while the minimum crop water productivity (CWP) was 1.24 kg/m^3 that observed in T1 (RS_0I_7). Keshaverz et al.[56] and Ashraf et al.[46] achieved crop water productivity values as 1.32-2 kg/m^3 of wheat in Mashad region of Iran. However, for comparable circumstances in Syria, Oweis and Hachum[57] found crop water productivity of 1.2-1.8 kg/m^3. Moreover, Lee et al.[58] resulted that applying straw mulching with 15 d of irrigation interval get crop water productivity of 1.50 to 2.28 kg/m^3 of the wheat crop. These studies further proved that rice straw mulching has the capability to enhance crop water productivity.

5 Conclusions

This study showed the positive effects of irrigation and rice straw incorporation and physico-chemical properties of the clay loam soil. Mulching with rice straw could significantly reduce the soil bulk density, infiltration rate, soil pH and ECe, while soil porosity was significantly increased. The maximum crop yield (7706 kg/hm^2) and highest water productivity (1.93 kg/m^3) were obtained under 15 d of irrigation frequency followed by 1 t/hm^2 of rice straw mulching (RS_1I_{15}). This study recommended that using rice straw mulching at the rate of 1 t/hm^2 with 15 d of irrigation frequency provide better yield and water utilization, further increase soil fertility and crop water productivity.

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