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Potential of irrigation regimes and organic amendments on wheat productivity in semi-arid areas of Punjab

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Abstract : The excessive application of fertilisers and faulty irrigation practices affect crop productivity as well as soil health and ecology. This loss of soil health prompts a revisit to the ways of nature, where soil health and sustainability are at the forefront while maintaining current production goals. Soil health deterioration and salinity remain a challenge in semi-arid and subtropical regions. In this study, afield experiment was conducted to determine the effects of organic amendments on wheat nutrient uptake, soil moisture, and grain yield under different irrigation regimes in the semi-arid area of Punjab. The experiment was conducted in split plot design with four irrigation regimes I_1- Soil moisture indicator, I_2- tensiometer (35 kPa), I_3 - IW/PAN-E0.9 (Recommended), and I_4 - IW/PAN-E 0.6 in main plots, along with four organic amendments *i.e.*, T_1- control, T_2-farm yard manure (@15 t ha^{-1}), T_3- rice straw mulch (@ 6 t ha^{-1}) and T_4- hydrogel (@25 kg ha^{-1}) in sub plots with three replications each. The use of I_2 resulted in higher plant height and tiller counts throughout the growth phase, which were higher than those under the recommended irrigation regime I3. Additionally, the tiller mortality was reduced by 19% in I_2 compared to I_3. However, the use of depleted irrigation (I_4) resulted in at-par grain yield and 27% higher water productivity as compared to I_3. The application of rice straw mulch and FYM showed a 10.3% and 11.6% increase in grain yield, respectively, as compared to the control treatment. Therefore, it is concluded that the application of mulch with I_4 in water-scarcity areas could be recommended for enhancing the productivity of wheat, especially in the semi-arid regions of Punjab.

Keywords: *Organic amendments,Soil moisture regime, Tensiometer, Water productivity, Wheat*

1. Introduction

Wheat (*Triticum aestivum*L.) is the second most important cereal crop in India, after rice. Wheat in India occupies 31.8 mha (Reserve Bank of India, 2024 3rd advanced estimate, 2022-23) area and a net production of 112 million tonnes (MOAFW, 2024 2nd advanced estimate).The average crop water requirement of wheat varies between 330.7 and 520.5 mm . The freshwater resources in the Indo-Gangetic plains have seen a depleting trend . Thus, the use of water-saving technology is becoming the prime focus of research. Soil moisture conservation with the use of mulching has been one of the main amendments . The use of mulch improves the crop water use efficiency up to 8 to 24% in different crops. The use of farm yard manure (FYM) to improve soil health has been long practised. FYM provides macro and micronutrients to plants which improves plant growth, ultimately translating to grain yield . Hydrogel on the other hand is a new and emerging soil amendment. In coarse-textured soils of arid and semi-arid, the use of hydrogel and other superabsorbent polymers improves soil physical properties . Hydrogel can potentially absorb nearly 300 times water of its weight (Dehkordi, 2016).

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Thus, in moisture stress conditions this can lead to improved water productivity.

Irrigation in Indian farms is an act that mostly based on visual, availability of good quality water (generally canals) and instinctive knowledge of farmers, although scientific methods and reasoning are available as to suggest how irrigation should be done. Transmission and adoption of these methods such as calculation using irrigation water to the ratio of pan evaporation readings is practically lacking (Chauhan, 2019; Vatta *et al*., 2018; Singh *et al*., 2017; Vatta *et al*., 2014; and Dhillon *et al*., 2013). Thus, an easier yet more attractive option comes out to be irrigation sensors which are hassle free (Brahmanand and Singh, 2022). Irrigation using soil moisture sensors has been gaining traction throughout the world. However, the cost of such sensors is still a major drawback to their popularity. Soil Moisture Indicator (SMI®) is a sensor developed by ICAR-Sugarcane Breeding Institute Coimbatore, under the project Farmer's Participatory Action Research Program it was developed as a cheap alternative to expensive irrometers, and commercial Time domain reflectometer (TDR)sensors (Hari *et al*.,2012) in 2021. The cost of SMI®was 1400 INR, which was cheaper than Tensiometer (7000 INR). Soil moisture indicator is having multiple lights depicting state of moisture in soil from three blue lights depicting ample moisture, followed by three green stating no need to irrigate, one orange blinker stating, consider irrigation in next few days, and two red blinkers depicting immediate need of irrigation (Hari *et al*., 2012).The use of Irrometers® (tensiometers) also sounds promising in planning irrigation. Tensiometer can provide efficient irrigation management to different types of soils. The use of IW/PAN-E for irrigation is a recommended practice in many regions of the world, in the case of wheat the IW/PAN-E should be maintained at 0.9 .

This study aimed to explore potential solutions to address the primary issues of groundwater resource overexploitation and the associated problems with rice straw burning in Punjab state. The possible outcomes of the research were to find a balance between the input and output of resources, an improved yield status, and reduced dependency on irrigation. However, the application of this article suffers from the constraints of non-replicated seasonal data. It might provide a potential direction for further research.

Material And Methods

Site and experimental details

The study was carried out during the 2020-21 *rabi* season (October-April) at the research field of the Department of Soil Science (30°54'13" N, 75°46'52" E), Punjab Agricultural University (PAU), Punjab. The study area falls within the semi-arid to sub-tropical zone, with an annual rainfall of 759 mm. Most of this is received in 4-5 major rain spells over July-September. The maximum temperature throughout the year varies from 23.8 °C in January to 43.8 °C in May, and the minimum temperature goes as low as 1.2 °C in January to 22 °C in May. The soil of the experimental site was sandy loam (66% sand, 14% silt, 20% clay). The data regarding the basic soil properties throughout the profile are given in Table1. The area has been under a maize-wheat cropping system for the last 5 years, grown under the recommended dosage of fertiliser. The experiment was done in a split-plot layout with four irrigation treatments laid out in the main plot containing I_1- SMI® (Red$_1$ Indicator), I_2-tensiometer (Irrometers®, 35 kPa), I_3-IW/PAN-E 0.9 (PAU recommendation (Punjab, 2021)), $I_4$is used as a deficit irrigation- IW/PAN-E 0.6and four organic amendments in subplot, *i.e.*, T_1- Control (where no organic matter is added and 100% of the nutrient requirement is met using fertilisers), T_2- FYM (@ 15 t ha^{-1}), T_3- Rice Straw Mulch (@ 6 t ha^{-1}) and T_4- Hydrogel (@ 25 kg ha^{-1}) in three replications each. The hydrogel used is produced by ICAR-IARI, New Delhi, and sold commercially as PUSA HYDROGEL®. The rate of irrigation applied for each plot was 70 mm. The frequency of irrigation was calculated for I_1 and I_4using daily evapotranspiration data from PAU meteorological database (https://www.pau.edu/index.php?act= manage Weather&DO=weather), which receives its data from a meteorological observatory situated about 500m in the southeast direction of the field. The plot size was kept as 4 x 6 m, i.e., 24 m^2 was designated, and a buffer zone between subplots was 45cm, and a buffer zone between main plots was 1m.

Table 1: Pre-sowing physico-chemical properties of soil

Depth (cm)	Soil separates (%)			Textural class	Bulk Density ($Mg\ m^{-3}$)	Water Holding Capacity (% v/v)	pH (1:2 soil: Water Suspension)	EC ($dS\ m^{-1}$)	Organic carbon (%)	Av. P ($kg\ ha^{-1}$)	Av. K ($kg\ ha^{-1}$)
	Sand	Silt	Clay								
0-15	66	14	20	Sandy Loam	1.59	44.1	6.85	0.084	0.514	22.4	175.6
15-30	65	20	15	Sandy Loam	1.65	46.6	6.94	0.134	0.479	19.17	193.4
30-60	68	17	16	Sandy Loam	1.76	47.8	7.35	0.187	0.461	21.27	104.9
60-90	63	16	21	Sandy Loam	1.78	42.5	7.75	0.140	0.401	20.17	107.4
90-120	61	18	21	Sandy Loam	1.80	41.0	7.90	0.151	0.341	21.09	101.2

Total evapotranspiration recorded during the crop season by the meteorological observatory of PAU, Ludhiana, was230 mm from 10th Nov, 2020 to 14th April, 2021. To estimate the irrigation schedule using the soil moisture indicator, as no standard for irrigation was available for the wheat crop. The crop was sown in of 6x4m^2 size non-replicated plots. Irrigation in those 5 plots was given 1st when the indicator was showing Green (1), followed by Green (2) in 2nd plot, Orange in 3rd plot, Red (1) in 4th plot, and Red (2) in 5th plot. The number of irrigations needed and the yield obtained are presented in Table 2.This was taken as a baseline for scheduling irrigation in the following season, and Red1was taken as a treatment (Kumar and Kahlon, 2022).There was an issue, however, with the utilisation of the soil moisture indicator, as depicted by Kumar and Kahlon (2022) that the sensor needs to be inserted in a manner to maximise contact with the soil, and needs to be kept on for 3 minutes to achieve a stable reading. This could be a problem if the sensor is to be taken out of the field and installed in another location for a better understanding of the overall field moisture. An irrigation schedule has been added to Table 2 for a clearer understanding of the irrigation dates and total irrigation required during the growing period.

Soil sampling and analysis

Soil samples were taken before cropping to determine the initial condition, then again after harvesting the crop from plots with depths of 0-15, 15-30, 30-60, 60-90, and 90-120 cm. The samples for each depth were mixed to form a composite. Any extraneous materials (twigs, stones, leaves, roots, etc.) were eliminated from the samples after they were air-dried, crushed, and sieved using a 2 mm sieve. From each depth, samples were homogenised and laboratory-tested for their chemical and physical qualities. Different physicochemical characteristics (texture, bulk density, infiltration rate, saturated hydraulic conductivity, pH, EC, Av. N, Av. P, Av. K) were measured. Core sampling was used to determine bulk density. Using the constant head approach, the saturated hydraulic conductivity was determined. The keen box technique was used to determine the water holding capacity of the soil. The pH and EC of the soil were tested using soil water of 1:2 (soil: water). Av. K method of) was estimated using neutral Normal Ammonium acetate, through flame photometric analysis, Olsen extraction (0.5 M $NaHCO_3$) was used to assess the amount of available P for alkaline and neutral soils using ascorbic acid blue color method and measuring spectroscopic absorption at 760nm.

Plant height and test weight (1000 grain weight)

Five plants per plot were randomly selected, and their height was measured from the ground surface to the tip of the plant at 45, 60, 90, 120 days after sowing (DAS) and at the harvest stage of wheat. Then, the average

Table 2: Standardization of SMI® based on grain yield of Wheat (2019-2020) non-replicated and irrigation applied using different irrigation regimes during main growing season 2020-21

SMI Reading	Amount of irrigation applied (mm)*	Grain Yield (t ha^{-1})
$Green_1$	340	6.616
$Green_2$	340	6.58
Orange	210	6.411
Red_1	210	6.221
Red_2	140	5.339

Irrigation regimes	Common	Differential	Irrigation water input (mm)*
I_1	06/12/20	03/03/21, 26/03/21	210
I_2	06/12/20	19/02/21, 16/03/21	210
I_3	06/12/20	28/02/21, 24/03/21	210
I_4	06/12/20	13/03/21	140

***excluding total rainfall received during 2020-21 season 64.2mm**

values per plot were used as the mean for statistical analysis. One thousand grains were manually counted for each treatment, weighed up to three decimal points after drying, and presented in grams.

Tiller count (m^{-2})

1 m^2 quartet was chosen in the plots and the four edges were marked using wooden sticks, the tillers within the quartet were counted and recorded from each plot periodically with 45, 60, 90, and 120 DAS.

Relative leaf water content

Relative leaf water content was estimated at 120 DAS by chopping holes in the leaves using a punching device; these holes were collected in pre-weighed brown paper bags. The collected leaves were weighed immediately after returning to the lab in a high precision (0.0001 g least count) to minimize error. The samples were then dried at 60°C ± 1°C till a constant weight was obtained. Calculation is performed as per the formula given below:

$$Relative\ leaf\ water\ content = \left(\frac{W_{initial} - W_{final}}{W_{Final}}\right) \times 100 \qquad \ldots (1)$$

Where, $W_{initial}$- initial weight of leaves, W_{final}- final weight of leaves

Root length and mass density

The root sampling was done at 120 DAS for wheat from 0-15, 15-30, 30-45, 45-60, and 60-75 cm. The Root length density (RLD) (cm cm^{-3}) was measured from the total root length calculated using the modified Tennant method of root length estimation using the graph intersection count method for eachdepth to the volume of the core. The root mass density (RMD) (mg cm^{-3}) was calculated by weighing the oven-dried roots on a precision balance (0.00001 g least count).

Grain yield

The grain yield was recorded from an area of 18 m^2 per plot after drying, and then the recorded weight was converted to tonnes per hectare.

Water productivity

The WP (kg $ha^{-1}mm^{-1}$) was calculated by dividing the grain yield (t ha^{-1}) by total water use (TWU) for each treatment. Profile water use (PWU) was estimated as the moisture stored in the profile from

$$PWU = \int_{i=1}^{n} \frac{Mi \times Di}{100} - \theta_i$$

Where, Mi= gravimetric moisture content (%) just before each irrigation, Di= depth of i^{th} layer (cm), Soil moisture content (mm) at filed capacity of i^{th} layer (cm)

$$TMU = IW + RF + PWU \quad (3)$$

• Where, TMU= total water use (mm), IW= total irrigation water applied (mm), RF= total rainfall received (mm), PWU= profile water use (mm)

$$Water\ productivity = \frac{Grain\ yield}{TWU} \quad \ldots(4)$$

Statistical analysis

The data of crops recorded in the field and laboratory on different aspects at various crop growth stages were statistically analyzed according to Cochran and Cox (1957) for split plot design. using Software IBM SPSS® (26 courtesy- PAU, department of Statistics) and Duncan's multiple range test (DMRT) post hock test to check the significance of data at P = 0.05.

Results And Discussion

Plant height

Table 3 shows that the irrigation regimes didn't affect plant height at 45, 60, and 90 DAS, but there was a significant difference in the plant height at the harvest stage during the crop growth. Irrigation was applied equally at CRI (21 DAS), resulting in nearly identical moisture content across all treatments. In the following weeks,50^{th}-52^{nd}, and 5^{th} standard meteorological week, a total of 50 mm rainfall was received, which reduced the temperature and evaporation losses while conserving soil moisture. Thus, the effect of no irrigation in I_4 became less pronounced. At harvest however, I_2 (92.26 cm) shows the highest plant height which is at par with I_4 (90.50 cm) and I_3 (90.41 cm) with minimum plant height was recorded in I_1 (90.03 cm). The organic amendments didn't show any significant effect on plant height at 45 DAS, but plant height at60 DAS was significantly affected by organic amendments as, the highest plant height was observed in FYM (47.4 cm) which shows a rise of 10.7 % as compared to mulch which showed the plant height at 60 DAS (42.3 cm). The data at 90 DAS showed that FYM (79.5 cm), hydrogel (77.4 cm) and control (76.3 cm) had statistically similar plant heights and mulch resulted in a much lower plant height of 71.9 cm. However, at harvesting stage FYM resulted in highest plant height 94.8 cm an increase of 9.6% over control, followed by significantly lower plant heightin mulch 92.4 cm (6.8% increase), the second lowest height was observed in hydrogel (89.6 cm) (3.6% increase), and least was observed in control (86.5 cm).

In the study it was seen that the application of FYM increases the plant height throughout the growth period of wheat, this might be because FYM is a sink for nutrient elements and supply essential nutrients (1% N, 0.13% P, up-to 4% K, 0.5% S) (Mahongnao *et* al., 2023) to the plant. The application of mulch had no effect on the final height of the crop, although initially lower height could have been the result of resistance offered by the mulch in emergence, this however is recovered by the plant during the log phase of the crop. Plant height reflect the balanced uptake of nutrients application of FYM leads to increase in the nutrient concentration in the soil especially the macro nutrients which are N, P, K (0.5%, 0.2%, 0.5%

Table 3. Effect of irrigation regime and organic amendment on plant height (cm) throughout weight growth season

Treatment	Plant height (cm)			
	45 DAS	60 DAS	90 DAS	Harvest
*Irrigation**				
I_1	23.21	45.71	76.28	90.03b
I_2	23.01	43.90	75.65	92.26a
I_3	23.69	43.58	75.78	90.42ab
I_4	24.21	45.70	77.35	90.50ab
CD (p = 0.05)	NS	NS	NS	1.86
*Organic amendments***				
T_1	23.77	45.67ab	76.25a	86.50d
T_2	24.54	47.4a	79.52a	94.80a
T_3	21.18	42.32b	71.88b	92.35b
T_4	24.65	43.52ab	77.42a	89.57c
CD (p= 0.05)	0.45	0.83	4.31	2.23
Interaction(p= 0.05)	0.90	1.65	NS	NS

*I_1- SMI (Red_1), I_2- Tensiometer (35 kPa), I_3- IW/Pan-E (0.9), I_4- IW/Pan-E (0.6)

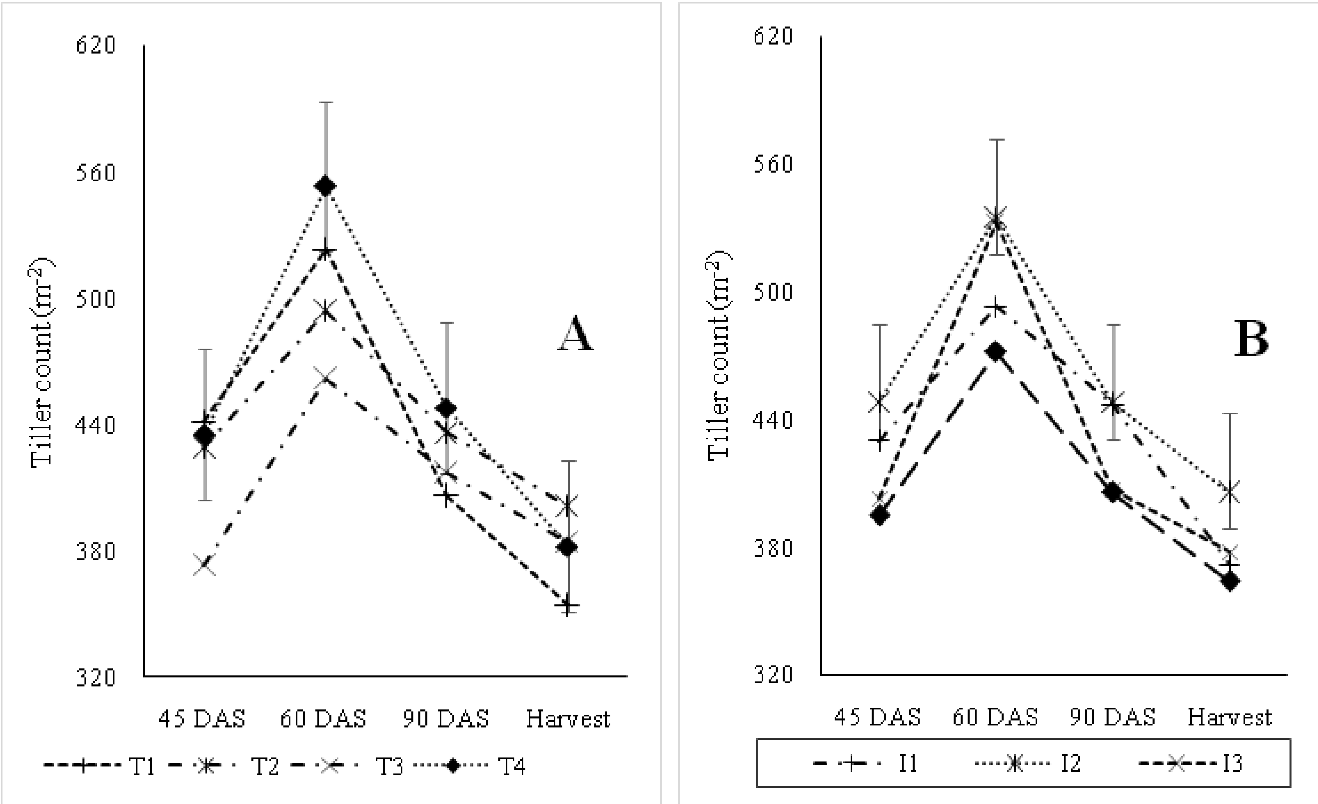
**T_1- Control, T_2- FYM, T_3- Mulch, T_4- Hydrogel

respectively) and are main factors of amino acids, energy production in a cell and as an osmo-regulatory compound respectively. Irrigation regime had no apparent effect on the plant height of wheat. The effect of FYM application on plant height was observed .

Tiller count

The effect of organic amendments and irrigation on the number of tillers per m^2 was recorded on 45, 60, 90 DAS and at harvest (Table 4 and Fig. 1). The least number of tillers per m^2 (395) was observed at 45 DAS under I_4.The use of tensiometer-based irrigation scheduling increased the tiller count by 11.8 % as compared to any other treatment. A similar trend was observed for tiller count at 60 DAS, with 11.7% higher tiller count in T2, which was significantly at par with I_3 (IW/PAN-E 0.9) as compared to I_4. The tiller count at90 DAS indicates that a significant number of tillers were affected by the irrigation regimes, as the highest tiller count was observed in I_2 and I_1, where both showed a rise of approximately 10% in tiller count compared to I_4. The tiller count at the harvest stage showed that the tensiometer-based irrigation (I_2) increased the effective tiller count by 10.3% over I_4 and by 8.3% compared to the recommended irrigation practice (I_3). The tiller count at 45 DAS shows that the highest tiller count was observed in hydrogel-amended plots, which was 15.6% higher than T_3 (straw mulched plots).

The tiller count at 60 DAS also shows a similar trend, with T_4 increasing the tiller count by 16.6% compared to mulch and by 1.8% over the control. After 90 DAS, the highest number of tillers were reported in T_4, followed by a significantly lower tiller count in T_2, and T_3 produced even lower tiller counts, with the least tillers being in T_1. The increase in tiller count of organically amended plots as compared to the control was 9.5% in T_4,



T_1- Control, T_2- FYM, T_3- Mulch, T_4- Hydrogel
I_1- SMI (Red$_1$), I_2- Tensiometer (35 kPa), I_3- IW/Pan-E (0.9), I_4- IW/Pan-E (0.6)

Fig. 1: Effect of organic amendments and irrigation regime on plant tiller count per m^2

7.1% in T_2 and 2.8% in T_3. However, in case of tiller per m^2 at harvest it was seen that the highest number of tillers were observed in T_2 (401 tiller m^{-2}), followed by T_3 (384 tiller m^{-2}) which was at par with T_4 (382 tiller m^{-2}) and the least tiller count was observed in T_1 (354 tiller m^{-2}). The interaction between these two treatments also showed significant results.

The application of hydrogel affected several tillers in the vegetative stage of the crop, which might be attributed to the moisture retention property of hydrogel as defined by . Although it was observed that as the season progressed, the effect of the hydrogel after 90 DAS showed little impact on the tiller count, and higher tiller mortality was observed compared to the mulch and FYM treatments. The effect of FYM was consistent throughout the growing season, and this might be attributed to the fact that FYM provides a sink of nutrients and moisture, which are released slowly throughout the growing season. Higher tiller count at harvest in mulch was also reported by.

Tiller Mortality

The mortality data tells us that the maximum tiller death occurred in T_1 with 33.09% tiller loss from vegetative to reproductive stage, this is followed by T_4 (31.69 %), and least losses in tiller was observed in T_3 (18.05 %) which was a par with T_2 (19.37 %) (Table 4). The irrigation treatment also showed significant effect in tiller mortality with highest losses were in I_1 (28.36 %), and I_3 (28.13 %) which were seen at par with each other, the lower losses of tillers were seen in I_4 (21.92 %) and I_2 (23.78 %) which were statistically at par. The interaction between these two was also significant.

The effect of a limited irrigation regime on tiller mortality was studied by (1981), who stated that a limited irrigation regime results in a reduced number of tillers per unit area, while at the same time, tiller mortality is also

Table 4. Effect of irrigation regime and organic amendment on tiller count and tiller mortality

Treatment	**Tiller Count**				**Tiller Mortality (%)**
	45 DAS	**60 DAS**	**90 DAS**	**Harvest**	
*Irrigation**					
I_1	430b	493b	447a	372bc	28.33b
I_2	448a	535a	448a	406a	23.74a
I_3	403c	533a	407b	378b	28.11b
I_4	395c	472c	406b	364c	21.90a
CD (*P*= 0.05)	8.05	10.26	9.04	10.04	1.91
*Organic amendments***					
T_1	441a	523b	406d	354c	33.07b
T_2	429b	494c	436b	401a	19.33a
T_3	373c	462d	417c	384b	18.03a
T_4	435ab	553a	448a	382b	31.66b
CD (p = 0.05)	5.26	12.05	8.78	8.62	2.44
Interaction (p=0.05)	NS	NS	18.08	17.25	4.88

*I_1- SMI (Red_1), I_2- Tensiometer (35 kPa), I_3- IW/Pan-E (0.9), I_4- IW/Pan-E (0.6)
**T_1- Control, T_2- FYM, T_3- Mulch, T_4- Hydrogel

reported to be the least. The effect of mulch on tiller mortality was studied by Singh *et al.*(2011), who concluded that the mulched plot produces a lesser number of tillers at the vegetative stage, and the majority of these tillers get converted to effective tillers; thus, the losses are minimal.

Relative leaf water content (RLWC)

The data of RLWC (Table 5)indicates that there was no significant effect of organic amendments on the RLWC, though the irrigation regimes did show significant variation,and the value ranges from 66.93% to 74.34%. The least RLWC was noted in I_4 (68.49%), with I_1, I_2, I_3 performing similarly. This is due to the fact that a similar amount of irrigation was applied to I_1, I_2, I_3 and no irrigation (except for CRI) was given to I_4 (till flowering initiation). The moisture stress, because of no irrigation, is reflected by the leaf in I_4. This is supported by research like and , who also stated that as the amount and frequency of irrigation were reduced, so did the RLWC (%).The transfer of photosynthates from tillers to effective tillers after 60 days of sowing could be the reason for the non-responsiveness of organic amendments, as also explained by Bhattacharya and Bhattacharya (2021).

Root length and mass density

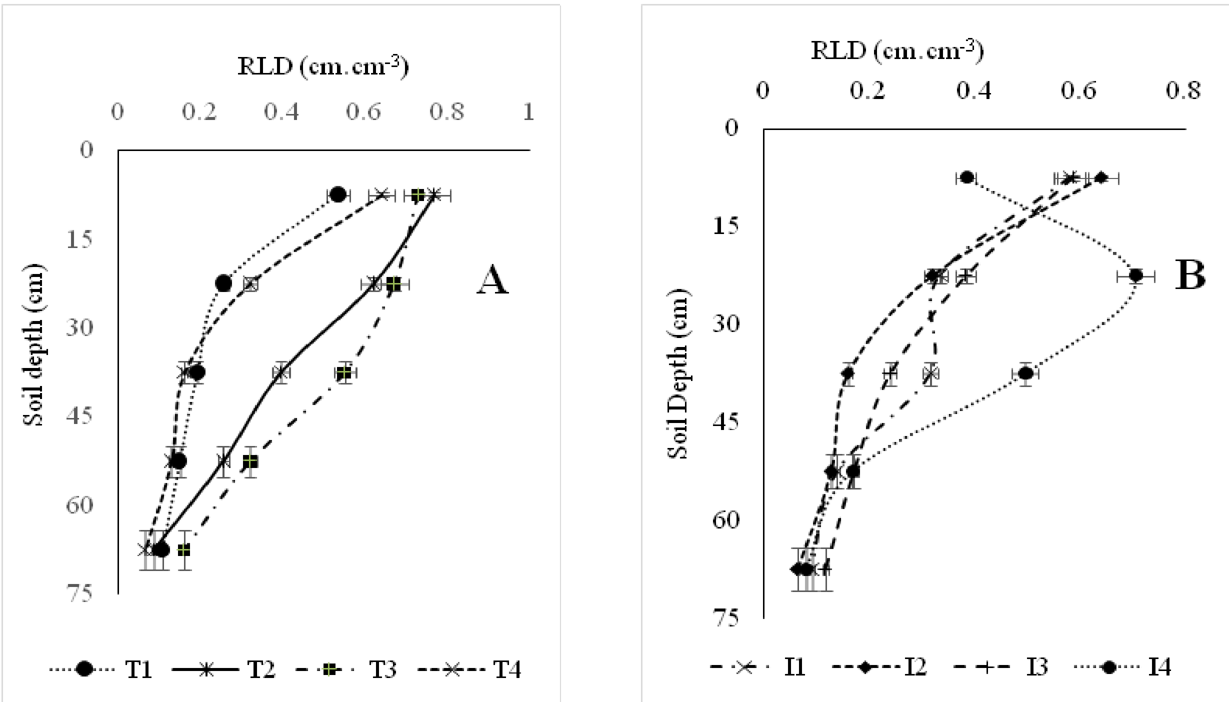
The data pertaining to the root length density as affected by irrigation regimes shows that in I_4 where less irrigation was applied to the soil, the roots explored deeper and higher rooting density was observed near 20 to 45 cm depth, which might be caused by reduced moisture content. At subsurface layers, the increases wereabout112% (in 15-30 cm), and 206% (in 30-45 cm) as compared to I_2, which was lowest. In terms of organic amendments, incorporation of FYM improved RLD in surface layer with an increase of 43.40% as compared to control, in sub soil layers however the effect of mulch became much more pronounced as it shows an increase of 168%, 190%, 146% in 15-30, 30-45, 45-60 cm depth, respectively. This could be because of the insulation effect of mulch as it acts as a barrier between the atmosphere and soil, reducing evaporation (Dhaliwal *et al*., 2019), thus resulting in higher profile moisture in mulched plots in deeper layers. Root mass density shows that in I_4 the surface root mass density was the lowest (reduction of 62.2% as compared to I_2); however, similar to RLD, I_4 shows higher root mass density in subsurface layers, 13%, 36.8% in 15-30 cm, 30-45 cm, respectively. Organic amendments show that mulching improves root mass density by 48.9%, 87.5% in 15-30 cm and 30-45 cm, respectively.

investigated the impact of various mulch treatments on plant growth parameters, including root development. They concluded that the use of mulch in wheat proves to be beneficial in root growth under both irrigated and rainfed systems. concluded with similar findings that mulched plots had better root proliferation. This may be attributed to the fact that the use of mulch preserves soil moisture. studied the effect of irrigation regimes on wheat root distribution and stated that when wheat is grown in depleted irrigation regimes (IW/Pan-E ≤0.7), it reduces surface root growth but promotes deeper root density. This might be attributed to the fact that when grown under a depleted moisture state, the roots need to penetrate deeper to find water resources for growth.

Yield Attributes

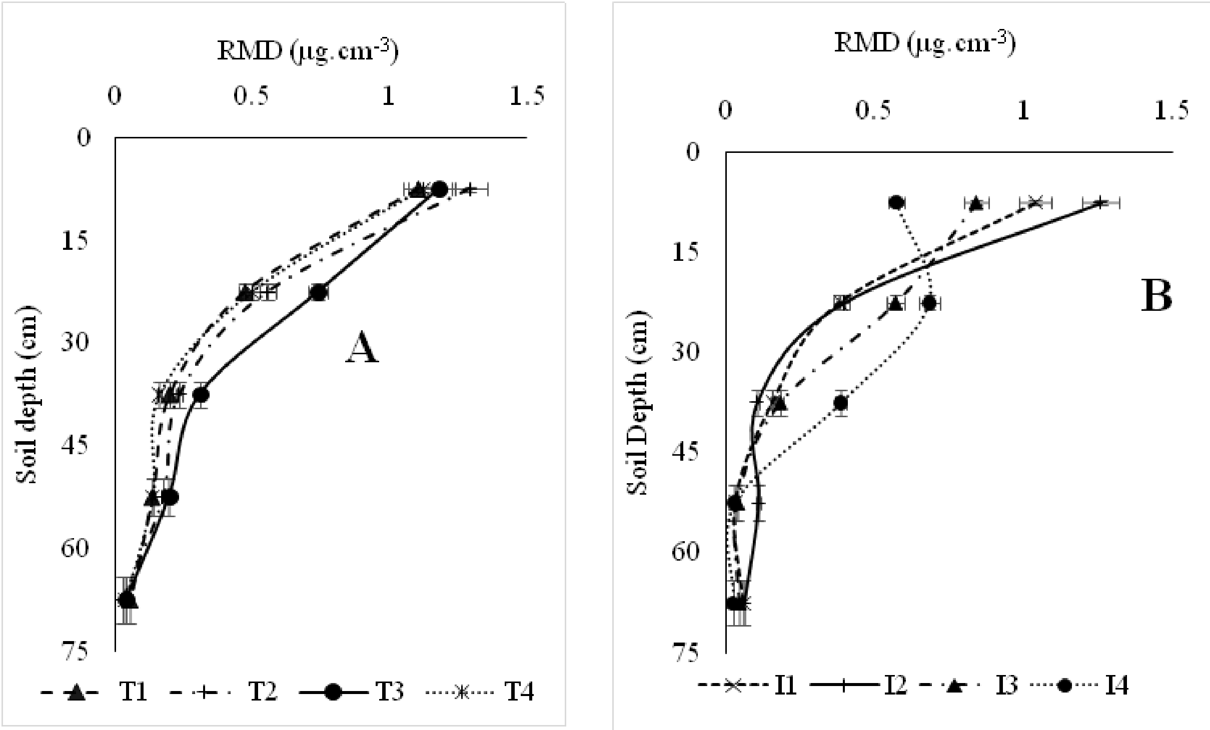
Thousand grain weight (TGW)

The test weight means the weight of thousand grains, this is an important yield parameter. Application of organic amendments and irrigation regimes didn't show any significant changes in the TGW values, and the range of TGW was from 40.06 g to 43.60 g (Table 5). The interaction between irrigation and organic amendments was also non-significant.



T_1- Control, T_2- FYM, T_3- Mulch, T_4- Hydrogel
I_1- SMI (Red_1), I_2- Tensiometer (35 kPa), I_3- IW/Pan-E (0.9), I_4- IW/Pan-E (0.6)

Fig. 2 (a): Effect of irrigation regime and organic amendment on root length density (cmcm^3)



T_1- Control, T_2- FYM, T_3- Mulch, T_4- Hydrogel
I_1- SMI (Red$_1$), I_2- Tensiometer (35 kPa), I_3- IW/Pan-E (0.9), I_4- IW/Pan-E (0.6)

Fig. 2 (b): Effect of irrigation regime and organic amendment on root mass density (µgcm^{-3})

Grain yield

The grain yield also considered to be the economic yield of the crop, it was seen that highest yield was produced by T_2 (6.16 t ha^{-1}) which was significantly higher as compared to T_3 (6.07 t ha^{-1}), which was even lower in T_1 (5.44 t ha^{-1}), and lowest was produced by T_4 (5.38 t ha^{-1}). The effect of irrigation regimes was non-significant in producing higher grain yield. The interactive effect was also non-significant.Even though thousand-grain weight in the plots was non-significant, the drastic yield difference was probably associated with the fact that higher effective tillers were present in T_2 and T_3, which led to higher grain production.

This might be due to the fact that during grain production wheat was under heat stress as the temperature in the final weeks (March 15 onwards) was higher than 35°C, and mulch reduced diurnal temperature variation thus reducing the effect of heat stress in later stages of crop as also reported by . also studied the effect of heat stress on yield reduction and stated that heat stress at any stage will lead to reduction in grain yield.

Water productivity

The range of WP was reported between 20.54 (kg ha^{-1} mm^{-1}) and 30.08 (kg ha^{-1} mm^{-1}) (Table 5). The highest WP (kg ha^{-1} mm^{-1}) was recorded in T_3 (24.02 kg ha^{-1} mm^{-1}), which was significantly higher than all other amendments, with T_2 (23.38 kg ha^{-1} mm^{-1}), T_1 (22.47 kg ha^{-1} mm^{-1}), which was at par with T_4(22.36 kg ha^{-1} mm^{-1}). This means that the use of mulch reduces water loss due to evaporation from the soil, thereby retaining more moisture throughout the profile and reducing total water consumption from the soil . The effect of irrigation also showed a significant improvement in WP under depleted irrigation regime I_4 (29.27 kg ha^{-1} mm^{-1}), which was significantly higher than all the other irrigation treatments I_1 (20.70 kg ha^{-1}mm^{-1}), I_2 (21.11 kg ha^{-1} mm^{-1}), I_3 (21.14 kg ha^{-1} mm^{-1}) and these three were at par.

The use of deficit irrigation leads to higher water productivity (WP) as less irrigation is applied to the field, resulting in a 70 mm water saving in I_4. Under moisture-stress situations, proper irrigation management has the ability to boost water productivity (WP) for a variety of

Table 5: Effect of organic amendments and irrigation regimes on yield parameters of wheat

Treatment	Relative leaf water content (%)	Thousand grain weight ($g1000^{-1}$ seed)	Grain yield ($t\ ha^{-1}$)	Water productivity ($kg\ ha^{-1}mm^{-1}$)
*Irrigation**				
I_1	71.56a	42.31	5.77	20.7b
I_2	71.84a	41.26	5.78	21.10b
I_3	71.23a	41.22	5.73	21.14b
I_4	68.48b	41.92	5.76	29.27a
CD (p = 0.05)	1.99	NS	NS	0.75
*Organic amendments***				
T_1	69.31	42.34	5.44b	22.47c
T_2	71.00	41.94	6.16a	23.37b
T_3	71.56	41.23	6.07a	24.02a
T_4	71.31	41.19	5.38b	22.36c
CD (P = 0.05)	NS	NS	0.49	1.23
Interaction CD (p = 0.05)	NS	NS	NS	NS

I_1- SMI (Red_1), I_2- Tensiometer (35 kPa), I_3- IW/Pan-E (0.9), I_4- IW/Pan-E (0.6)
***T_1- Control, T_2- FYM, T_3- Mulch, T_4- Hydrogel*

crops, and the yield produced may be similar to that achieved with full irrigation schedules. . The use of mulch increased soil moisture storage, thus reducing the losses, and this accounted for increased water productivity .

Conclusions

In this experiment, the effect of irrigation showed a significant improvement in water productivity under a deficit irrigation regime, i.e.,I_4 (29.27 kg ha^{-1} mm^{-1}), which was significantly higher than all the other irrigation treatments. The application of depleted irrigation (I_4) resulted in 27% higher water productivity compared to I_3. I_4 also shows significant yield parity with the current recommended method of wheat irrigation (I_3); thus, the adoption of I_4 in the farming areas of Punjab with sandy loam soil can be explored further for recommendations. However, Irrigation deficit at the flowering stage may lead to higher tiller mortality, potentially reducing yield. The use of hydrogel has the potential to increase the vegetative growth of the plant because of moisture retention. Still, the economic yield (grain yield) under hydrogel doesn't show any improvement. The application of mulch and FYM shows a 10.3% and 11.6% increase in grain yield as compared to the control treatment. It is concluded that the application of FYM in conjunction with I_1 in water-sufficient areas and mulch with I_4 in water-stressed areas could be recommended for improving the productivity of wheat.

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Conflict Of Interest Statement

We, the authors of this paper, certify that there is no conflict of interest regarding the research conducted and results published.

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