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Research Article

Evaluation of irrigation scheduling and nutrient management practices on root growth, grain quality, crop and water productivity of rice-wheat cropping system

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ABSTRACT

A field trial was carried out for two consecutive years from 2018 to 2020 at the Water Management Research Farm in CSKHPKV, Palampur, India to determine the effect of different irrigation schedule and nutrient management practices on root growth, grain quality, crop and water productivity of rice-wheat cropping system. The experiment was planned in a split plot design consisting of three irrigation levels in the main plots viz., recommended critical stage regimes, irrigation at 0.8 CPE (rice) and 0.6 CPE (wheat), irrigation at 1.0 CPE both for rice and wheat and four nutrient management practices viz., inorganic management, organic management, natural farming management, integrated management in subplots. All treatments were replicated thrice. The results showed that irrigating both rice and wheat crop at 1.0 CPE in sequence resulted in significant higher root growth and productivity of crops. Water use efficiency on an average was higher with deficit irrigation regime where rice was given 0.8 CPE and wheat 0.6 CPE irrigation in sequence. Significantly higher root growth, yield and water productivity was observed under integrated nutrient management (F4) in both the crops. Organic nutrient management (F_2) and integrated nutrient management (F_4) proved to be better in terms of quality parameters of crops. For higher average crop and water productivity of rice – wheat sequence, the crops should be irrigated at 1.0 CPE and integrated nutrient management practice (I3F4) should be followed.

Keywords**:** Irrigation regimes, nutrient management, organic, quality, root and water use efficiency

Rice-wheat crop sequence is the world's most extensively grown production system. The sustainability of this system has been challenged by the stagnating or decreasing yield levels after green revolution. Different threats to the productivity of system include groundwater pollution, declining of groundwater table, reduction in crop quality, degrading soil structure and health, weed flora, disease outbreaks and pests (Bhatt *et al.*, 2016). Depleting water table in India because of low water use efficiency in traditional irrigated rice-wheat system, inspires to work on alternative crop management practices to overcome this alarming situation (Singh *et al.*, 2014). In terms of saving water, labour, and energy, directly seeded rice (DSR) is a substitute to conventional method of transplanting rice. The main water drain is avoided without significantly reducing yield (Yadav *et al.*, 2011). Direct seeding can save labour by up to 50 per cent, water up to the extent of 35-57 per cent and reduce plant density risk (Singh *et al.*, 2002). Additionally, switching from continuous flooding to intermittent wetting and drying results in significant reduction in water use and methane emissions from the rice field. The early crop maturation under DSR also reduces the irrigation water requirements (Gill and Dhingra, 2002). In South Asia and India, irrigation efficiency has been reported to be less than 40% and 35%, respectively (Ali, 2012; Rosegrant, 1997). Proper irrigation scheduling with just enough water is required to maximize water use efficiency, as flood method reduces water and crop productivity (Qiu *et al.*, 2008). Both shortage and excess water adversely effects crop quality and productivity (Pareek *et al.*, 2021). Another poor crop management practice resulting in

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lower crop and water productivity is use of excessive amount of chemical fertilizers, which results in soil degradation and nutrient leaching into the groundwater, thus posing a health risk (Sharma *et al.*, 2022). Multi-nutrient deficiencies and an overall reduction in the soil's productive ability have been frequently observed because of improper fertiliser application (Murugan and Chithirarajan, 2015). The backdrops mentioned above lead to the popularisation of organic, natural, and integrated farming, which may restore soil health. The organic amendments influence soil fertility through their effects on the water holding capability of the soil (Bulluck *et al.*, 2002), as spongy organic matter binds the water and inorganic molecules, thus reducing the water evaporation. Thus, a robust complementary relationship exists between the nutrient supply and water availability. Further organic amendments feed the soil microbes which in turn release the nutrients (Dubey *et al.*, 2012). Moreover, organic materials release plant micronutrients in small quantities over a long period of time, ensuring a better crop quality since they contain more minerals and generally have good sensory and prolonged storage qualities (Rembialkowska, 2007).The information on inorganic nutrition of crops and its interaction with irrigation on both rice and wheat is available but limited information is available on the interaction of nutrient management practices and irrigation scheduling under different management systems, especially for direct-seeded rice-wheat system under a rainfed situation. Thus, present study was undertaken to examine the results of different irrigation scheduling and nutrient management practices on quality parameters, root studies, water studies and productivity of rice-wheat system in mid hills of Himachal Pradesh (India).

MATERIALS AND METHODS

Experimental site

The field research was accomplished for two years from 2018-2020 at the Water Management Research Farm of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India. The experimental site lies in 32º06´05´´N latitude and 76º33´02´´E longitude at an elevation of 1282 meters above mean sea level. Out of the 1600mm average annual rainfall 80 per cent is received during the months of June to September. The mean weekly weather data of both years of study is presented in fig. 1 and 2. The soil of experiment location was clay loam acidic in reaction (pH 5.3), medium in available nitrogen (278 kg ha^{-1}), high in available phosphorus (28.7 kg ha^{-1}) and low in available potassium (182.4 kg ha^{-1}).

Treatment details

The trial was conducted using a split-plot design with irrigation schedules in main plots and nutrient management practices in sub-plot. Treatments were replicated thrice. Table 1 shows the details of the treatment imposed.

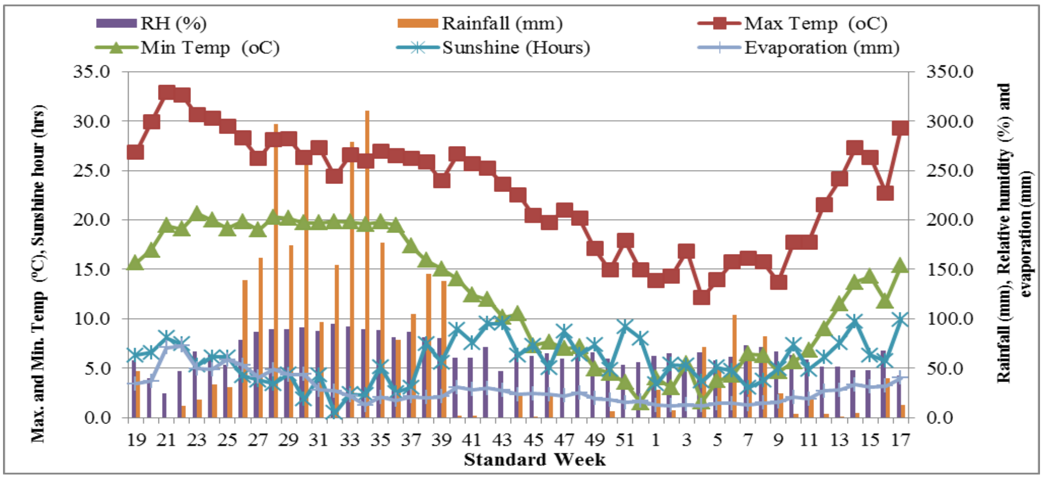

Fig. 1: Mean weekly weather data at Palampur during May, 2018 to May, 2019

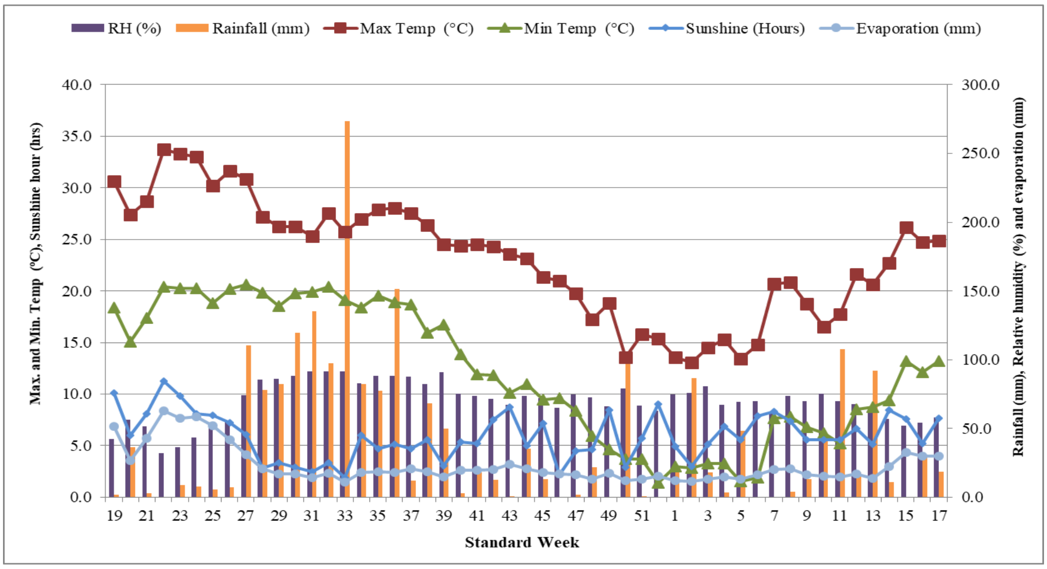

Fig. 2: Mean weekly weather data at Palampur during May 2019 to May 2020

Table 1: Treatment details

Rice	Wheat
Main plot: Irrigation schedules	**Main plot: Irrigation schedules**
I_1: Irrigation at Recommended critical stages	**I_1:** Recommended critical stages
I_2: Irrigation at 0.8 CPE	**I_2:** Irrigation at 0.6 CPE
I_3: Irrigation at 1.0 CPE	**I_3:** Irrigation at 1.0 CPE
Sub plot: Nutrient Management Practices	**Sub plot: Nutrient Management Practices**
F_1: Inorganic management (60:30:30 N:P_2O_5:K_2O kg ha^{-1}) (source- Urea, SSP and MOP)	**F_1:** Inorganic management (120:60:30 N:P_2O_5:K_2O kg ha^{-1}) (source- Urea, SSP and MOP)
F_2: Organic management (15 t FYM + *Azotobacter* + PSB (seed treatment) + Vermiwash (monthly interval)	**F_2:** Organic management (15 t FYM + *Azotobacter* + PSB (seed treatment) + Vermiwash (monthly interval)
F_3: Natural farming management (Bijamrit + Jivamrit + Ghanjivamrit as per recommendations)	**F_3:** Natural farming management (Mulch + Bijamrit + Jivamrit + Ghanjivamrit as per recommendations)
F_4: Integrated management (75% NPK+ 25% N through FYM + *Azospirillium*/*Azotobacter* + PSB (seed treatment)	**F_4:** Integrated management (75% NPK+ 25% N through FYM + *Azospirillium*/*Azotobacter* + PSB (seed treatment)

Irrigation management

Scheduling of irrigation was done with the Cumulative Pan Evaporation (CPE) method. The irrigation water was given through a hose pipe system at an interval of 3-5 days (rice) and 15 days interval (wheat) based on CPE. Irrigation water requirement was calculated based on the daily evaporation data recorded from June to October for rice crop and November to April for wheat crop for respective years. The irrigation requirement was obtained by using the formula: **(Evaporation – Effective rainfall) × CPE**

As the crop was direct seeded hence the critical stages were taken as active tillering, panicle initiation, booting/heading and grain filling. Since during panicle initiation and booting or heading stages a well distributed rain was received hence irrigation was applied during active tillering and grain filling stages only. In wheat irrigation was given at crown root initiation stage, tillering, late jointing, flowering and last at dough stage.

Nutrient management

For inorganic nutrient management, the recommended dose of 60:30:30 and 120:60:30 kg ha^{-1} N:P_2O_5:K_2O was used in rice and wheat, respectively which were supplied from urea (46% N), SSP (16% P_2O_5) and MOP (60% K_2O) fertilizers, respectively. In case of integrated management, 75 % of the nutrients were applied through chemical fertilizers and remaining 25 % N were applied through FYM (0.47 % N, 0.37 % P and 0.62 % K). In addition, biofertilisers such as *Azotobacter* and PSB were also used as seed treatment. Under organic cultivation, FYM @ 15 t ha^{-1} was added into the soil during the sowing of crop. Moreover, vermiwash (diluted to 1:10 ratio with water) was also sprayed at 30 days intervals @500 litre ha^{-1}. For natural management, *ghanjeevamrit* @ 395 kg ha^{-1} was crushed and the powdered form was applied in the rows just before sowing of seeds. The *jeevamrit* prepared freshly was used as per treatment diluted to 1:10 ratio using water and sprayed at interval of 30 days @500 litre ha^{-1}. The *ghanjeevamrit* and *jeevamrit* are combination of cow dung, cow urine, jaggery, pulse flour and pinch of native soil where *ghanjeevamrit* is its dried form and the *jeevamrit* is its liquid form. In natural farming 2 cm thick crop residue from previous crop is spread on field after sowing and during the weeding operation the residue is returned.

Crop management

Seeds of *Him Palam Lal Dhan*-1 ‘HPR-2795’ (red rice variety) and ‘HPW-236’ (wheat variety) were used for sowing of respective crops. The rice crop in both years was sown in first week of June whereas the wheat was sown in last week of October. The seeds for both crops were sown at 20 cm of row-to-row distance after preparing fine seed bed. The amount of seed rate used was 60 kg ha^{-1} in rice and, it was 100 kg ha^{-1} for wheat. The irrigation and the nutrient management were applied as per the treatment schedule. In inorganic and integrated nutrient treatment chemical weed control was followed whereas in organic and natural management practice hand weeding was followed.

Observations

A metal core was used for taking root samples from 0-0.30 m soil depth. The soil samples along with roots were water soaked overnight and then washed on a 70-mesh sieve to remove soil from them (Bohm, 1979). Sampled roots were used for the determination of the volume of the root by the displacement method (Misra and Ahmed, 1987). The collected root samples were dried in a hot air oven for duration of 24 hours at 60^0C and weighed on an electronic balance to record root weight. Iron and zinc contents were estimated by using the method given by Jackson (1973) through atomic absorption spectroscopy. Amylose content in rice grain was estimated using the automated iodine-colorimetric method. The gluten content in wheat was determined using IS: 1155: 1968. The crude protein percent in grain was obtained by multiplying per cent of nitrogen content in wheat grain with a factor of 5.75 (A.O.A.C.,1990) and 5.95 for rice (FAO food and nutrition paper 14/7, 1987) which gives the crude protein content. Following sun drying, the crops from each net plot were removed, threshed, and the grains from plots were washed, weighed, and then converted into quintals per hectare. The water use efficiency of crop was calculated by dividing yield of crop-by-crop evapotranspiration (mm). Reference evapotranspiration was calculated using the Pan Evaporation technique (ET_O). USWB class A open pan data on evaporation and an empirically developed pan coefficient were utilised to relate pan evaporation to ET_O. Crop evapotranspiration was calculated using the formula below.

$ET_O = K_{pan} \times E_{pan}$

Where, K_{pan} = pan coefficient

E_{pan} = evaporation (mm day^{-1}) from

$ET_C = ET_o \times K_c$

Where, ET_c = crop evapotranspiration (mm day^{-1})

K_C = crop coefficient

The crop coefficient values used were obtained from paper 56 of FAO Irrigation and drainage (FAO, 1988). The biomass conversion efficiency (kg ha^{-1} mm^{-1}) for above-ground biomass was calculated as total dry matter produced (kg ha^{-1}) divided by amount of water supplied through irrigation and precipitation (mm). The ratio of crop output (kg ha^{-1}) to the amount of water applied in the farmer’s field, or, the water need (WR), is called as field water use efficiency (kg ha^{-1} mm^{-1}). WR was calculated by WR (mm) = IR + ER+S where, IR = irrigation requirement, ER = Effective rainfall, S = soil profile contribution. Irrigation water use efficiency (kg ha^{-1} mm^{-1}) was generated by dividing the grain yield of crop (kg ha^{-1}) with irrigation water applied (mm).

Statistical analysis

The data generated from field was subjected to statistical analysis using the technique of analysis of variance for split plot where main plot consisted of three irrigation regimes and subplot consisted of four nutrient management practices. The data was pooled for two years and the interpretation of results was done as described by Gomez and Gomez (1984). The treatment differences were compared at 5 per cent level of significance (P=0.05)

RESULTS AND DISCUSSION

The pooled data of two years on root weight and root volume of rice and wheat has been presented in table 2 and 3. Application of irrigation at critical stages (I_1) in rice and wheat crops in sequence showed significantly maximum root weight and root volume in rice but the root parameters of wheat were maximum when the crops were irrigated at 1.0 CPE (I_3). The difference could be attributed to the well distributed rains near rice critical growth stages helping in establishment of root system whereas in wheat the contribution of rains were minimal and higher irrigation frequency may have enhanced the solubility of phosphorus resulting in better root growth besides improving availability of other primary nutrients for better dry matter. The deficit irrigation regime (I_2) where rice was given irrigation of 0.8 CPE and 0.6 CPE in wheat showed lower root index value for rice but the same in wheat recorded statistically similar root parameters as obtained under 1.0 CPE irrigation regime.

Table 2: Effect of irrigation scheduling and nutrient management on root weight of rice and wheat (pooled)

Treatments	Root weight (g m^{-2})			
	Rice		Wheat	
	Tillering	Harvest	Tillering	Harvest
Irrigation schedules				
I_1	24.61	49.00	11.34	98.70
I_2	20.67	44.54	12.27	105.69
I_3	18.99	44.16	12.84	108.88
SEm (±)	**0.88**	**0.89**	**0.23**	**1.23**
LSD (0.05)	**3.46**	**3.52**	**0.89**	**4.84**
Nutrient management practice				
F_1	22.79	47.38	13.37	124.25
F_2	20.25	42.28	12.10	86.13
F_3	18.75	41.71	9.48	80.50
F_4	23.92	52.22	13.66	126.81
SEm (±)	**0.42**	**0.89**	**0.40**	**0.96**
LSD (0.05)	**1.24**	**2.66**	**1.19**	**2.85**

Table 3: Effect of irrigation scheduling and nutrient management on root volume of rice and wheat (pooled)

Treatments	Root volume (cc m^{-3})			
	Rice		Wheat	
	Tillering	Harvest	Tillering	Harvest
Irrigation schedules				
I_1	221.53	440.98	113.31	986.00
I_2	186.04	400.87	122.62	1055.85
I_3	170.95	397.45	128.27	1087.69
SEm (±)	**7.94**	**8.07**	**2.25**	**12.32**
LSD (0.05)	**31.17**	**31.67**	**8.87**	**48.35**
Nutrient management practice				
F_1	205.11	426.46	133.53	1241.21
F_2	182.22	380.49	120.92	860.47
F_3	168.74	375.42	94.69	804.23
F_4	215.30	470.02	136.46	1266.80
SEm (±)	**3.77**	**8.07**	**3.99**	**9.59**
LSD (0.05)	**11.20**	**23.97**	**11.86**	**28.51**

Among the different nutrient management practices, root weight and root volume recorded being statistically similar under integrated nutrient management (F_4) and inorganic management practice (F_1) was significantly higher than the root parameters observed under organic (F_2) and natural farming practice (F_3). Lowest root weight and volume in both the crops were observed under natural farming practice (Table 2, 3). The utilization of manures along with N, P, or K fertilizers or including these fertilizers in integrated nutrient management influence the plant's root growth (Deng *et al*., 2018). Moreover, fertilizers containing phosphorus can affect root morphology including root biomass, and root volume. Enhanced root volume resulted from integrated nutrient usage due to increased root development, branching, and build-up of dry matter. The lower root growth under natural farming system could be attributed to the lower nutrient availability under system where the source is only *ghanjeevamrit* and *jeevamrit* having very low concentration of nutrients which cannot meet the demand of growing root shoot system.

The pooled data on quality studies of both the crops are presented in table 4. Among different quality parameters *viz*., iron and zinc content in grain, amylose and crude protein in rice, except iron content in rice grain no other quality parameter was significantly affected by the different irrigation regimes followed in sequence .Since the red rice variety was taken for experiment hence its iron accumulation potential is also high hence any condition which enhances the availability of iron will help in acquiring more nutrient to meet demand. In rice higher rice grain iron content was recorded when irrigation regime of 1.0 CPE was followed in rice -wheat (I_3) though it was at par with the iron content in rice under irrigation regime where rice was given 0.8CPE and wheat with 0.6 CPE (I_2) in sequence. The reduction process might have been facilitated by the more frequency of irrigation under I_3 and I_2 regimes. The reduction of Fe^{3+} in to Fe^{2+} form under reduced condition (Behera *et al*., 2018) might have supplied iron to the plants in minute quantities as reflected in the grain iron content. The increase in water soluble iron and exchangeable iron might contribute to the higher available iron (Mandal and Mitra, 1982). No quality parameter *viz*., gluten content and crude protein content was influenced by the different irrigation regimes followed in sequence.

Table 4: Effect of irrigation scheduling and nutrient management on quality parameters in rice and wheat grain (pooled)

Treatments	Rice grain				Wheat grain	
	Fe (ppm)	Zn (ppm)	Amylose g 100 $^{-1}$ g	Crude protein (%)	Gluten content (%)	Crude protein content (%)
Irrigation schedules						
I_1	16.64	27.70	18.67	8.32	8.47	9.27
I_2	18.07	27.12	19.18	8.35	8.57	9.24
I_3	18.87	26.83	19.47	8.40	8.68	9.17
SEm (±)	**0.30**	**0.50**	**0.23**	**0.03**	**0.06**	**0.04**
LSD (0.05)	**1.20**	**NS**	**NS**	**NS**	**NS**	**NS**
Nutrient management practice						
F_1	17.14	26.14	19.86	8.13	8.81	9.42
F_2	18.94	28.52	18.66	8.67	8.44	9.46
F_3	16.81	26.03	18.32	7.93	8.32	9.07
F_4	18.54	28.18	19.59	8.70	8.72	9.95
SEm (±)	**0.43**	**0.53**	**0.26**	**0.01**	**0.08**	**0.05**
LSD (0.05)	**1.28**	**1.57**	**0.78**	**0.03**	**0.25**	**0.14**

Organic nutrient management (F_2) and integrated nutrient management (F_4) though were statistically at par with one another resulted in significantly higher iron and zinc content in rice grain as compared to other nutrient management practices. Iron chelates formed by the application of FYM in organic nutrient management (F_2) and integrated nutrient management (F_4) must have aided in the movement of iron to plant roots (Lindsay and Schwab, 1982) which were taken up by the plants. Singh *et al*. (2010) reported that the utilization of biofertilizers and organic manures had a favourable effect on the amount of zinc in rice.

Natural farming management (F_3) being at par with organic nutrient management (F_2) recorded significantly lower rice grain amylase content and wheat grain gluten content as compared to other nutrient management systems. Integrated nutrient management (F_4) being at par with organic nutrient management (F_2) recorded significantly higher crude protein (%) in rice and wheat grain. Nitrogen being important nutrient for protein build up playing crucial role in crude protein content is facilitated by varying organic and inorganic sources (Dixit and Gupta, 2000) and this was possible through integrated nutrient management. The outcomes are comparable with Choudhary *et al*. (2005) and they concluded that enhanced protein percent in grain and yield of wheat and rice in the north-west Himalayas were the result of integrated nutrient management using organic and chemical fertilisers. Mangaraj *et al*. (2021) also reported higher protein content in rice with integrated nutrient management.

The pooled data on grain yield of both crops (rice and wheat) as affected by irrigation scheduling and nutrient management is given in table 5. Irrigating crops at their critical stages (I1) resulted in significantly higher yield for rice in rice-wheat sequence whereas irrigation of 1.0 CPE in crops (I_3) recorded higher yield for wheat crop. The next best yield for rice was obtained when crops in sequence were given 1.0 CPE whereas for wheat it was irrigation schedule of I2 where rice was given 0.8 CPE irrigation and wheat 0.6 CPE irrigation. In general irrigating crops to 1.0 CPE requirement gave higher average yield for both crops in sequence. The result corroborates with findings of Nayak *et al*. (2015) who found a notable increment in yield when more irrigations were applied in wheat as was the case with 1.0 CPE with more frequent irrigation were applied. In case of rice a well distributed rain did not show the impact of frequent irrigations.

Table 5: Effect of irrigation scheduling and nutrient management on grain yield and biomass conversion efficiency in rice and wheat (pooled)

Treatments	Grain yield ($q\ ha^{-1}$)		Biomass conversion efficiency ($kg\ ha^{-1}\ mm^{-1}$)	
	Rice	**Wheat**	**Rice**	**Wheat**
Irrigation schedules				
I_1	26.12	25.19	8.40	9.21
I_2	23.93	25.99	7.57	12.14
I_3	25.17	27.40	7.64	11.24
SEm (±)	**0.18**	**0.32**	**0.07**	**0.16**
LSD (0.05)	**0.72**	**1.26**	**0.27**	**0.62**
Nutrient management practice				
F_1	30.39	30.71	9.43	12.61
F_2	20.44	20.19	6.45	8.54
F_3	18.13	19.28	5.76	8.16
F_4	31.35	34.59	9.84	14.14
SEm (±)	**0.21**	**0.30**	**0.06**	**0.13**
LSD (0.05)	**0.62**	**0.90**	**0.20**	**0.38**

A significantly maximum grain yield of both the crops was recorded under integrated nutrient management followed by inorganic nutrient management practices. Higher yield in integrated nutrient management may be because of combined source of nutrients where the direct inorganic nutrient supply met the immediate requirement whereas the organic supplements besides improving the physical and chemical condition also met the long-term demand of crop. Kwami *et al*., 2022 reported adequate supply of nitrogen and increased nutrient availability throughout the growth period of crop for better dry matter production using inorganic and organic sources. The lower yield of crops under organic and natural farming practice could be ascribed to inadequate supply of nutrients through plant growth period and this was more severe under natural farming where the external source is very limited. The organic manure alone cannot fulfil the nutrients requirements of wheat (Sheoran *et al*., 2017) and rice as plant's ability to absorb nutrients depends mostly on its vegetative development, which is influenced favourably by the application of nitrogen fertilisers and the availability of photosynthates for the synthesis of yield components. Fazily *et al*., (2021) experienced comparable outcomes as well.

Irrigation at critical crop growth stages of rice-wheat crop sequence gave higher biomass conversion efficiency, irrigation and field water use efficiency for rice as compared to other irrigation schedules (Table 5 and 6).

Significantly higher biomass conversion efficiency, irrigation and field water use efficiency for rice crop in rice -wheat sequence was observed under irrigation schedule where both crops were irrigated at their critical stages whereas these indexes for wheat crop were highest when the deficit irrigation regime (I2) was followed where rice was given 0.8 CPE and wheat 0.6 CPE irrigation in sequence. In rice growing season the evapotranspiration demand is high as a result the water deficit is generated and as a defence mechanism plant try to develop uniform root system (Kim *et al*., 2020) at early phenological stage for more scavenging area as a result more yield can be obtained (Uga *et al*., 2013). In comparison to rice, the evapotranspiration losses are slow so the root may not exert sufficient effort for root development hence the frequent application can help in mobilizing nutrient required for better growth and this was observed as the yield was higher under I_2 and I_3 irrigation schedules. Further since water use efficiency increases either by enhancing the crop yield or minimizing the water applied, higher crop yield of rice in rice -wheat sequence under critical stages regimes (I_1) is major reason for increased water use efficiency. In wheat, irrigation provided at 0.6 CPE (I_2) resulted in significantly greater biomass conversion efficiency, irrigation and field water use efficiency as the numerator was decreased without significant decrease in yield and this reflected on the water use efficiency index.

Table 6: Effect of irrigation scheduling and nutrient management on irrigation and field water use efficiency in rice and wheat (pooled)

Treatments	Irrigation water use efficiency (kg ha^{-1} mm^{-1})		Field water use efficiency (kg ha^{-1} mm^{-1})	
	Rice	**Wheat**	**Rice**	**Wheat**
Irrigation schedules				
I_1	26.12	10.08	3.05	3.46
I_2	21.67	25.54	2.73	4.35
I_3	18.13	16.26	2.78	4.07
SEm (±)	**0.18**	**0.39**	**0.02**	**0.06**
LSD (0.05)	**0.72**	**1.55**	**0.08**	**0.23**
Nutrient management practice				
F_1	26.80	20.17	3.44	4.65
F_2	17.89	13.34	2.32	3.05
F_3	15.90	12.70	2.06	2.91
F_4	27.32	22.97	3.59	5.23
SEm (±)	**0.19**	**0.24**	**0.02**	**0.05**
LSD (0.05)	**0.56**	**0.72**	**0.07**	**0.14**

Among the different nutrient management practices, pooled data showed significantly greater biomass conversion efficiency, irrigation and field water use efficiency of rice and wheat were noted in integrated nutrient management (F_4) followed by inorganic nutrient management (F_1), organic nutrient management (F_2) and natural farming management (F_3) in descending order (Table 5, 6). In sequence the water use efficiency index values under organic and natural farming system were similar for wheat whereas for rice the organic practice improved this water use efficiency in comparison to natural farming practice. Since the root system is crucial for the uptake of moisture and the control of the rate of leaf photosynthesis (Kong *et al*., 2013); and there is positive correlation of water use with root length and root biomass (Abdolshahi *et al*., 2015), hence plants with larger root systems in integrated nutrient management (F_4) and inorganic nutrient management (F_1) resulted in higher grain yield than those with smaller roots (Streda *et al*., 2012), thus increasing water use efficiency.

The pooled data on interaction impact of irrigation scheduling and nutrient management on water studies is shown in table 7. On pooled basis**,** in general higher irrigation water use efficiency in both rice and wheat was recorded with integrated nutrient application at all the levels of irrigation**.** Integrated nutrient management (F_4) being at par with inorganic nutrient management (F_1) recorded significantly higher irrigation water use efficiency of rice compared to organic nutrient management (F_2) and natural farming management (F_3) for all the irrigation levels. Significantly higher irrigation water utilization efficiency of rice was noted when the irrigation was applied at critical stages in crops and integrated nutrient management (I_1F_4) was practiced, which was also at par with inorganic nutrient management for the same irrigation level (I_1F_1).

Significantly higher irrigation water use efficiency in wheat was recorded with integrated nutrient management (F_4) at all the irrigation levels**.** Irrespective of the irrigation levels, organic nutrient management (F_2) and natural farming (F_3) were statistically at par with one another on pooled basis. A further critical evaluation of interaction showed that significantly higher irrigation water use efficiency in case of wheat was noted when it was provided 0.6 CPE irrigation in sequence and integrated nutrient management (I_2F_4) was practiced. In combination deficit irrigation schedule with 0.8CPE in rice and 0.6CPE in wheat (I_2) with integrated nutrient management recorded higher irrigation water use efficiency for rice and wheat in sequence.

Table 7: Interaction effect of irrigation levels and nutrient management practices on water studies in rice and wheat (pooled)

Nutrient management (NM) \ Irrigation(I)	Irrigation water use efficiency of rice (kg ha^{-1} mm^{-1})			Irrigation water use efficiency of wheat (kg ha^{-1} mm^{-1})			Field water use efficiency of wheat (kg ha^{-1} mm^{-1})		
	I_1	I_2	I_3	I_1	I_2	I_3	I_1	I_2	I_3
F_1	31.97	26.60	21.82	11.82	30.14	18.54	11.82	30.14	18.54
F_2	20.64	17.93	15.09	7.98	19.79	12.24	7.98	19.79	12.24
F_3	19.17	15.32	13.19	7.60	18.88	11.62	7.60	18.88	11.62
F_4	32.70	26.81	22.44	12.91	33.37	22.63	12.91	33.37	22.63
	SEm±	**LSD (0.05)**		**SEm±**	**LSD (0.05)**		**SEm±**	**LSD (0.05)**	
I x M	**0.33**	**0.97**		**0.42**	**1.25**		**0.08**	**1.25**	
M x I	**0.34**	**1.23**		**0.54**	**1.84**		**0.09**	**1.84**	

Significantly higher field water use efficiency in wheat was recorded with integrated nutrient management (F_4) at all the irrigation levels. A further evaluation of interaction between irrigation levels and nutrient management showed that irrigation at 0.6 CPE and integrated nutrient management (I_2F_4) practice resulted in significantly higher field water utilization efficiency of wheat.

CONCLUSION

Irrigation schedule of irrigation at critical stages (I_1) and irrigation of 1.0 CPE (I_3) in both crops of rice -wheat sequence gave individual higher yield for rice and wheat, respectively but in combination irrigation schedule of 1.0 CPE in crops (I3) was found effective for root growth and output of rice and wheat in rice -wheat sequence. However the water use efficiency index for crops in combination was higher when rice is irrigated with 0.8 CPE and wheat with 0.6 CPE requirement (I2). Among different nutrient management systems, it was observed that integrated nutrient management (F4) resulted in enhanced root growth, water and crop productivity of both crops. Moreover, organic nutrient management along with integrated management improved quality parameters of crops. Irrespective of irrigation schedule, higher crop and water productivity can be achieved if integrated nutrient management practice is followed. It is concluded that irrigation at critical stages and integrated nutrient management (I_1F_4) in rice and irrigation at 0.6 CPE with same nutrient management system (I_2F_4) in wheat should be adopted under low water available conditions to increase water productivity and maintain sustainable yields in rice-wheat cropping system.

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