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Effect of deficit irrigation and foliar application on nutrient uptake of wheat

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Abstract
Coincidence of drought stress at various growth stages of wheat is a chief constraint to accomplish yield potential in wheat crop. The moisture stress at critical growth stages not only reduces the yield but also reduces the quality of produce by affecting the uptake of nutrient by the grains and straw. The present study therefore aimed at comparing the various irrigation levels, wheat varieties and stress regulators to increase the quality of wheat. The experiment was conducted in *Rabi* season of 2021-2022 at the Research farm of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur. The experiment was laid out in split-split plot design with three replications. There were thirty treatment combinations comprising of main plot treatments of three irrigation levels, sub-plot treatments of two wheat varieties and sub-sub plot treatments of five stress regulators. Observations on nutrient concentration, nutrient uptake by grains and straw were obtained. The results indicated the provision of three irrigations at CRI, flowering and milking stages enhanced the nutrient concentration and nutrient uptake in wheat crop. The wheat variety JW 3288 outperformed JW 3382 in nutrient concentration and nutrient uptake. The foliar application of 2% KCl resulted in highest nutrient concentration and uptake of the crop among all other treatments. Thus, the combination of three irrigations, variety JW 3288 and foliar application of 2% KCl could be a promising technology for enhancing the nutrient uptake in wheat under water scarce areas.

Keywords: CRI, drought stress, irrigation levels, stress regulators, wheat productivity, yield potential

Introduction

Fulfilling the need for food throughout the world is severely hampered by the lack of fresh water for agriculture and the ever-growing population. Since the climate is changing and rainfall patterns have worsened the aridity issue in many parts of the world, it is anticipated that the situation for researchers will get worse soon (Mancosu *et al*., 2015) [23]. By the middle of the twenty-first century, agriculturalists will have to find a way to supply the needs of nine billion people in terms of food (FAO, 2009) [10]. A new issue for agriculturalists today is the production of more food with less water availability, especially in semi-arid and arid zones (Shideed, 2011) [38].

India is majorly a subtropical country with around 52% area designated as rainfed. The crops grown in these areas are primarily affected by the distribution of seasonal rainfall from sowing to harvesting (Abrol *et al*., 2008) [2], soil fertility and applied fertilizer nutrients (Abrol *et al*., 2015) [1]. The occurrence of recurring dry spells further aggravates the situation during the critical stages of the crop growth period which leads to a substantial loss of crop productivity. Its performance and yield depend on environmental interaction. Among these, temperature plays a vital role in growth, development and yield (Bali *et al*., 2016) [5].

Wheat (*Triticum aestivum* L.) is the most important cereal crop for the majority of the world's population. Globally the total area, production and productivity of wheat are 215.9 m ha, 765.8 mt and 3546 kg ha^{-1} respectively (FAOSTAT, 2019) [10], which makes it the second most-produced cereal after maize. It is one of the most important staple food grains that meet nearly half of the calories needs (Ramdas *et al*., 2019) [30]. The total area, production and productivity of wheat in India are 31.76 m ha, 109.52 mt and 3464 kg ha^{-1} respectively. In Madhya Pradesh, it covers an area of 6.69 m ha with a production of 17.57 mt (ICAR-IIWBR, 2021; Sahu *et al*., 2023) [14, 35].

The productivity of wheat is susceptible to various environmental stresses, including drought, waterlogging, temperature extremes, salinity/alkalinity, and mineral deficiencies or toxicities (Tiwari *et al*., 2017) [40]. Among these stressors, moisture stress stands out as a prominent and significant factor (Narayanan, 2018) [26].

Moisture stress has been found to have profound impact on crop yield, especially when it occurs during critical stages such as heading, flowering, and soft dough formation. Employing effective irrigation strategies, such as precision irrigation and water conservation techniques, can mitigate the adverse effects of moisture stress during critical growth stages, ensuring optimal grain yield (Chen *et al*., 2023) [7].

Wheat is successfully grown with reduced irrigation in different parts of the world where scarcity of water resources for irrigation is common (Shao *et al*., 2011; Sisodiya *et al*., 2022) [37, 39]. Scientific research revealed that moisture stress affects wheat yield and improves water use efficiency (Baozhen *et al*., 2014; Hamid *et al*., 2012) [6,11]. Moreover, when properly practiced, it enhances the quality of crop products like protein content of maize and wheat, quality of fibre in cotton, sucrose concentration of sugar beet and wine colour density (FAO, 2002) [8].

The foliar nutrition method is an important method of fertilization since foliar nutrients usually penetrate the leaf cuticle or stomata and enter the cells, facilitating easy and rapid utilization of nutrients by the crop (Rajasekar *et al*., 2017) [29]. Foliar applications of nutrients and additional soil application resulted in improved productivity and quality of crops (Rehman *et al*., 2014; Kumar *et al*., 2015) [33, 19]. Foliar feeding of nutrients, especially potassium is essential to alleviate the effect of salt and moisture stress on the plant by influencing physiological mechanisms (Hasanuzzaman *et al*., 2018; Ahmad *et al*., 2019; Meena *et al*., 2020) [13, 3, 24].

Ascorbic acid (AA), an essential organic compound, plays a crucial role in supporting the growth and development of higher plants, albeit in trace amounts (Padh, 1990) [27]. It helps maintain cellular integrity and overall plant health, allowing the crop to better withstand the oxidative stress associated with deficit irrigation (Malik *et al*., 2015) [22]. Secondly, ascorbic acid enhances the crop's stress tolerance mechanisms (Zulfiqar and Ashraf, 2021) [44].

Therefore, the present investigation was carried out to intensify the efforts towards enhancing the nutrient uptake and wheat productivity under moisture stress conditions by implementing effective mitigation measures such as partial irrigation, stress effective and tolerant genotypes, and stress regulators.

Materials and Methods

Study site and climate

A field experiment was conducted during *rabi* season of 2021-2022 at the Research farm of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (23°90' N latitude, 79°58' E longitude, and 411.78 m above mean sea level). The weather conditions had been favorable for the growth and development of the wheat crop. The mean weekly maximum temperature ranged from 20.80 to 40.60 ºC while the mean weekly minimum temperature ranged between 3.90 to 20.40 ºC. The total rainfall received during the cropping season was 53.5 mm with 7 rainy days (Fig.1.).

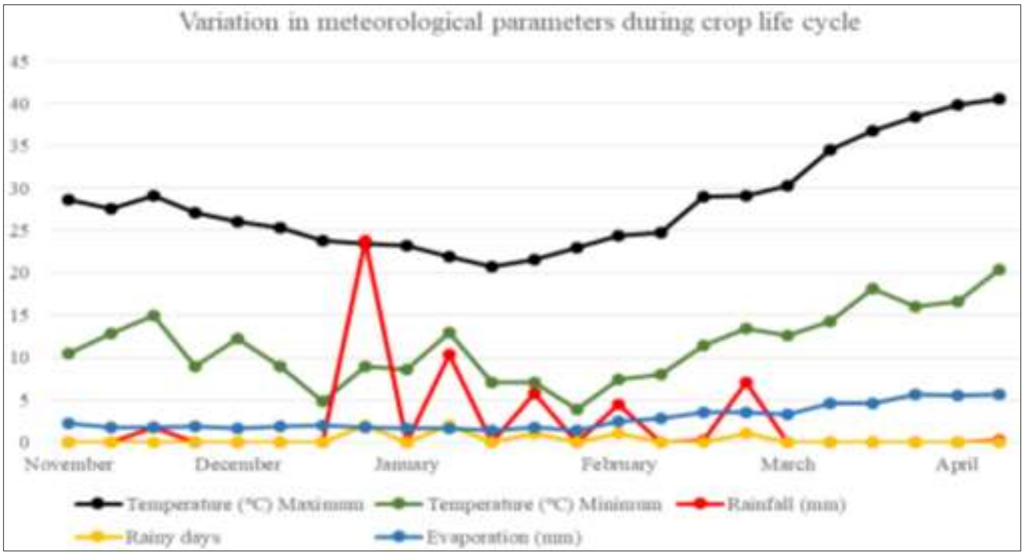

Fig 1: Meteorological data during *Rabi* season 2021-2022

Experimental details

The experiment was laid out in split-split plot design with three replications. There were 30 treatment combinations comprising of main plot treatments of three irrigation levels (I_1- one irrigation at CRI, I_2- two irrigation at CRI and flowering and I_3- Three irrigations at CRI, flowering and milking stage), subplot treatments of 2 wheat cultivars (JW3288 and JW3382) and sub-sub plot treatments of 5 stress regulators (S_1- Control (Water spray) at tillering (40-45) and flowering (75-80 DAS), S_2- 1% KCl application at tillering (40-45) and flowering (75-80 DAS) S_3- 2% KCl application at tillering (40-45) and flowering (75-80 DAS), S_4- 0.1% Ascorbic acid application at tillering (40-45) and flowering (75-80 DAS) and S_5- 0.2% Ascorbic acid application at tillering (40-45) and flowering (75-80 DAS). Sowing of the crop was done on 8 November 2021 at a row spacing of 20 cm by drilling at the seed rate of 100 kg/ha. The crop was fertilized with 90:60:40 kg of N: P_2O_5: K_2O per hectare through urea, single super phosphate and muriate of potash, respectively. Harvesting was done when the panicle matured and plant was dried up.

Observations

Observation on nutrient concentration and nutrient uptake by the wheat crop was recorded under all treatments. Nitrogen concentration in the grain and straw samples was determined by Micro-Kjeldhal method (Kermanian *et al*., 2007) [18] and thereafter uptake was calculated. The phosphorus concentration and uptake by grain and straw were determined by the procedures outlined by Jackson (1973) [16]. Total potassium in wheat grain and straw were estimated by flame photometry method on a tri-acid digest of plant material (Prasad *et al*., 2006) [28]. The data was collected through Google sheet and analysed statistically by using the techniques of the analysis of variance (ANOVA). Critical difference (CD) at 5% level of significance was determined for each character to compare the differences among treatment means.

Results and Discussion

Nutrient concentration in wheat

Nutrient concentration in wheat was directly impacted by the treatments. The irrigation levels, wheat varieties and stress regulators had a significant impact on the nitrogen, phosphorus and potassium concentration of wheat (Table 1). Highest nitrogen, phosphorus and potassium concentration in grain (1.86%, 0.45% and 0.62%) and straw (0.66%, 0.21% and 0.016%) was reported in I_3- three irrigations. This may be attributed to higher nutrient availability and uptake due to greater availability of moisture at different crop growth stages (Tyagi *et al*., 2015; Lakra and Husein, 2020) [41, 21]. Among the wheat varieties, variety JW-3288 resulted in higher grain nitrogen, phosphorus and potassium concentration (1.63%, 0.36% and 0.50%) as compared to JW-3382 (Fig.2.). This may be due to the genotypes differences in stress tolerating ability and growth pattern which might have resulted in the higher nutrient concentration in drought tolerant wheat cultivar (Kumari *et al*., 2019; Rana *et al*., 2020) [19,31]. Among the stress regulators, the foliar application of S_3-2% KCl resulted in highest nitrogen, phosphorus and potassium concentration in grain (1.80%, 0.43% and 0.58%) and straw (0.65%, 0.19% and 1.56%) followed by S_1-2% KCl. Potassium is involved in the regulation of various physiological processes within the plant, including nutrient transport. By improving potassium availability, it can facilitate the uptake of nitrogen, phosphorus, and potassium from the soil due to their positive interaction, leading to higher nutrient concentrations in plant tissues (Raza *et al*., 2013; Hamouda *et al*., 2015) [32,12].

There was no significant impact of irrigation levels and varieties, varieties and stress regulators and irrigation levels and stress regulators on nitrogen concentration in grains and straw. However, significant interaction between irrigation levels and varieties, varieties and stress regulators and irrigation levels and stress regulators on phosphorus and potassium concentration in grains and straw was observed in the experimental study (Table 2). The I_3V_1 (three irrigations + JW-3288) combination produced the highest phosphorus and potassium concentration in grain and straw, whereas the I_1V_2 (one irrigation + JW-3382) combination produced the lower nutrient concentration. There was a significant difference in the interaction of wheat varieties and stress regulators ($p>0.05$). When 2% KCl (V_1S_3) was foliar applied to the leaves of variety JW-3288, the highest phosphorus and potassium concentration was consistently seen. Similar to this, a substantial ($p>0.05$) interaction impact between irrigation levels and stress regulators on grain and straw phosphorus and potassium concentration was discovered. The I_1S_1 (one irrigation + water spray) combination recorded the lowest nutrient concentration, whereas the I_3S_3 (three irrigations + 2% KCl) combination recorded the highest.

Table 1: Effect of deficit irrigation, varieties and stress regulators on the nutrient concentration of wheat

Treatments	Nitrogen concentration (%)		Phosphorus concentration (%)		Potassium concentration (%)	
	Grain	Straw	Grain	Straw	Grain	Straw
Irrigation levels						
I_1	1.47	0.49	0.32	0.14	0.43	1.39
I_2	1.69	0.58	0.38	0.17	0.51	1.50
I_3	1.86	0.66	0.45	0.21	0.62	1.62
SEm±	0.014	0.013	0.008	0.008	0.011	0.016
C.D. (5%)	0.054	0.051	0.030	0.030	0.042	0.063
Varieties						
V_1	1.72	0.60	0.40	0.19	0.55	1.53
V_2	1.63	0.56	0.36	0.16	0.50	1.47
S.Em±	0.013	0.011	0.006	0.006	0.007	0.013
C.D. (5%)	0.044	0.037	0.021	0.021	0.024	0.044
Stress regulators						
S_1	1.53	0.50	0.33	0.15	0.47	1.43
S_2	1.74	0.61	0.40	0.18	0.55	1.53
S_3	1.80	0.65	0.43	0.19	0.58	1.56
S_4	1.62	0.55	0.36	0.17	0.50	1.48
S_5	1.69	0.58	0.38	0.17	0.53	1.51
S.Em±	0.019	0.015	0.009	0.005	0.008	0.018
C.D. (5%)	0.053	0.043	0.024	0.014	0.022	0.052

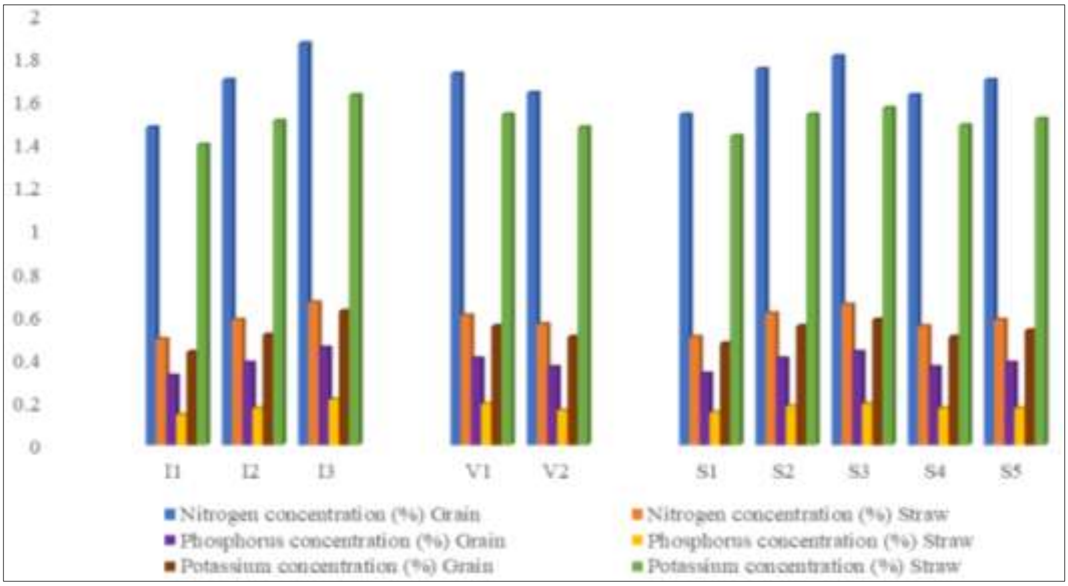

Fig 2: Effect of deficit irrigation, wheat genotypes and stress regulators on nutrient concentration

Table 2: Interaction effect of deficit irrigation, varieties and stress regulators on the nutrient concentration of wheat

Treatments	Nitrogen concentration (%)		Phosphorus concentration (%)		Potassium concentration (%)	
	Grain	Straw	Grain	Straw	Grain	Straw
Irrigation levels x varieties						
I_1V_1	1.51	0.50	0.33	0.16	0.45	1.41
I_1V_2	1.44	0.48	0.30	0.13	0.42	1.36
I_2V_1	1.72	0.59	0.38	0.19	0.52	1.52
I_2V_2	1.67	0.57	0.37	0.16	0.51	1.48
I_3V_1	1.93	0.71	0.50	0.22	0.67	1.68
I_3V_2	1.80	0.62	0.40	0.19	0.57	1.56
SEm±	0.022	0.019	0.011	0.011	0.012	0.023
C.D. (5%)	NS	NS	0.037	0.037	0.042	0.77
Varieties x Stress regulators						
V_1S_1	1.58	0.52	0.36	0.17	0.49	1.47
V_1S_2	1.78	0.64	0.42	0.19	0.57	1.56
V_1S_3	1.84	0.68	0.45	0.20	0.60	1.59
V_1S_4	1.64	0.55	0.36	0.19	0.50	1.49
V_1S_5	1.75	0.62	0.42	0.19	0.57	1.56
V_2S_1	1.48	0.47	0.31	0.14	0.44	1.39
V_2S_2	1.69	0.59	0.37	0.16	0.52	1.49
V_2S_3	1.76	0.63	0.41	0.17	0.55	1.53
V_2S_4	1.60	0.54	0.36	0.16	0.50	1.47
V_2S_5	1.63	0.54	0.34	0.16	0.49	1.46
S.Em±	0.027	0.022	0.012	0.007	0.011	0.026
C.D. (5%)	NS	NS	NS	0.020	0.032	0.074
Irrigation levels x Stress regulators						
I_1S_1	1.28	0.36	0.22	0.13	0.34	1.27
I_1S_2	1.52	0.51	0.32	0.15	0.44	1.40
I_1S_3	1.61	0.58	0.38	0.16	0.50	1.46
I_1S_4	1.47	0.51	0.35	0.14	0.46	1.42
I_1S_5	1.49	0.50	0.32	0.14	0.44	1.40
I_2S_1	1.59	0.54	0.37	0.15	0.47	1.47
I_2S_2	1.77	0.63	0.41	0.18	0.56	1.54
I_2S_3	1.79	0.63	0.40	0.19	0.55	1.53
I_2S_4	1.62	0.53	0.34	0.18	0.48	1.46
I_2S_5	1.70	0.58	0.37	0.17	0.52	1.50
I_3S_1	1.72	0.59	0.41	0.18	0.59	1.55
I_3S_2	1.93	0.70	0.47	0.21	0.64	1.65
I_3S_3	2.01	0.76	0.52	0.22	0.69	1.70
I_3S_4	1.78	0.60	0.40	0.21	0.56	1.57
I_3S_5	1.88	0.67	0.45	0.22	0.62	1.63
S.Em±	0.033	0.027	0.015	0.009	0.014	0.032
C.D. (5%)	NS	NS	NS	0.025	0.039	0.091

Nutrient uptake

The nutrient uptake in grain and straw varied significantly (p>0.05) among the various irrigation levels, wheat varieties and stress regulators (Table 3). Highest nitrogen, phosphorus and potassium uptake in grain (80.42, 19.52 and 26.77 kg ha^{-1}) and straw (39.57, 12.24, 96.06 kg ha^{-1}) was reported in I_3-three irrigations. It might be explained by superior soil moisture conditions during plant growth, which aided in greater nutrient absorption and utilisation by the plant. These findings are in close confirmation with Verma *et al*., (2015); Meena *et al*., (2021) [42, 24]. Among the wheat varieties, variety JW-3288 resulted in higher grain nitrogen, phosphorus and potassium uptake (67.00, 15.95 and 21.52 kg ha^{-1}) as compared to JW-3382. Better root system, ability to use nutrients and environmental adaptation in JW 3288 might have resulted in higher nutrient uptake by the cultivar. Similar findings have also been reported by Rezaei *et al*., (2010) [34] and Ahmad *et al*., (2022) [4]. Among the stress regulators, the foliar application of S_3-2% KCl resulted in highest nitrogen, phosphorus and potassium uptake in grain (75.50, 18.20, 24.39 kg ha^{-1}) and straw (37.73, 10.78 and 89.43 kg ha^{-1}) followed by S_1-2% KCl. The alleviation of drought stress and stomatal regulation in plants due to the application of potassium might have resulted in higher nutrient availability, nutrient concentration and ultimately higher nutrient uptake. Similar findings have been reported by Ishfaq *et al*., 2023 [15]; Wang *et al*., 2023 [43].

Wheat types and irrigation levels had a substantial (p>0.05) interaction impact on nutrient uptake in grain and straw (Table 4). The I_3V_1 (three irrigations + JW-3288) combination produced the highest nitrogen, phosphorus and potassium uptake in grain and straw, whereas the I_1V_2 (one irrigation + JW-3382) combination produced the lower nutrient uptake. There was a significant difference in the interaction of wheat varieties and stress regulators (p>0.05). When 2% KCl (V_1S_3) was foliar applied to variety JW-3288, the highest nutrient uptake was consistently seen. Similar to this, a substantial (p>0.05) interaction impact between irrigation levels and stress regulators on grain and straw nutrient uptake was discovered. The I_1S_1 (one irrigation + water spray) combination recorded the lowest nutrient uptake, whereas the I_3S_3 (three irrigations + 2% KCl) combination recorded the highest. Similar findings were also reported by Shabbir *et al*., 2015; Johnson *et al*., 2022 [36, 17].

Table 3: Effect of deficit irrigation, varieties and stress regulators on the nutrient uptake of wheat

Treatments	Nitrogen uptake (Kg/ha)		Phosphorus uptake (Kg/ha)		Potassium uptake (Kg/ha)	
	Grain	Straw	Grain	Straw	Grain	Straw
Irrigation levels						
I_1	42.09	21.71	9.13	6.23	12.47	60.80
I_2	62.82	30.27	13.97	8.92	19.12	77.78
I_3	80.42	39.57	19.52	12.24	26.77	96.06
SEm±	1.56	0.84	0.45	0.41	0.61	1.73
C.D. (5%)	6.15	3.30	1.76	1.63	2.40	6.81
Varieties						
V_1	67.00	33.17	15.95	10.39	21.52	83.65
V_2	56.55	27.87	12.47	7.87	17.39	72.77
S.Em±	0.69	0.66	0.24	0.30	0.28	0.80
C.D. (5%)	2.41	2.30	0.85	1.07	0.98	2.77
Stress regulators						
S_1	48.79	23.98	10.90	7.32	15.10	67.44
S_2	65.51	32.84	15.21	9.50	20.78	81.37
S_3	75.50	37.73	18.20	10.78	24.39	89.43
S_4	55.54	27.13	12.32	8.75	17.06	73.41
S_5	63.54	30.91	14.40	9.31	19.95	79.42
S.Em±	1.14	0.94	0.37	0.27	0.43	1.52
C.D. (5%)	3.25	2.69	1.07	0.78	1.24	4.33

Table 4: Interaction effect of deficit irrigation, varieties and stress regulators on the nutrient uptake of wheat

Treatments	Nitrogen uptake (Kg/ha)		Phosphorus uptake (Kg/ha)		Potassium uptake (Kg/ha)	
	Grain	Straw	Grain	Straw	Grain	Straw
Irrigation levels x varieties						
I_1V_1	47.48	24.89	10.53	7.57	14.24	68.92
I_1V_2	36.71	18.53	7.73	4.88	10.71	52.68
I_2V_1	65.29	30.36	14.58	9.73	19.85	77.77
I_2V_2	60.34	30.19	13.36	8.11	18.40	77.79
I_3V_1	88.24	44.25	22.74	13.86	30.47	104.27
I_3V_2	72.60	34.88	16.31	10.61	23.07	87.85
SEm±	1.20	1.15	0.42	0.53	0.49	1.39
C.D. (5%)	4.18	4.00	1.47	1.85	1.70	4.81
Varieties x Stress regulators						
V_1S_1	52.13	26.57	12.08	8.60	16.52	73.24
V_1S_2	70.24	35.09	16.96	10.64	22.77	85.54
V_1S_3	84.09	41.81	20.83	12.48	27.59	98.03
V_1S_4	59.43	28.20	13.09	9.81	18.09	76.65
V_1S_5	69.13	34.16	16.79	10.42	22.62	84.80
V_2S_1	45.46	21.40	9.72	6.03	13.68	61.64

V_2S_2	60.78	30.59	13.46	8.35	18.78	77.20
V_2S_3	66.90	33.65	15.58	9.07	21.20	80.82
V_2S_4	51.65	26.05	11.54	7.69	16.02	70.18
V_2S_5	57.96	27.66	12.01	8.19	17.29	74.03
S.Em±	1.61	1.34	0.53	0.39	0.61	2.15
C.D. (5%)	4.60	3.81	1.51	1.10	1.75	6.13
Irrigation levels x Stress regulators						
I_1S_1	27.69	13.01	4.76	4.72	7.33	45.69
I_1S_2	46.07	22.57	9.64	6.45	13.28	62.04
I_1S_3	57.43	28.33	13.50	7.63	17.83	71.28
I_1S_4	36.80	21.74	8.62	6.11	11.38	61.00
I_1S_5	42.49	22.90	9.14	6.22	12.56	63.99
I_2S_1	54.57	26.64	12.63	7.40	16.14	72.56
I_2S_2	65.49	34.05	15.17	9.40	20.73	83.02
I_2S_3	72.36	35.84	16.17	10.52	22.24	87.06
I_2S_4	56.74	25.22	11.79	8.42	16.71	69.63
I_2S_5	64.92	29.60	14.07	8.86	19.80	76.61
I_3S_1	64.13	32.30	15.32	9.83	21.83	84.07
I_3S_2	84.97	41.88	20.83	12.64	28.32	99.06
I_3S_3	96.70	49.01	24.94	14.17	33.12	109.93
I_3S_4	73.08	34.42	16.53	11.71	23.08	89.60
I_3S_5	83.21	40.23	20.00	12.84	27.50	97.65
S.Em±	1.98	1.64	0.65	0.47	0.75	2.64
C.D. (5%)	5.63	4.67	1.85	1.35	2.15	7.51

Conclusion

Wheat productivity has declined since decades due to the inappropriate irrigation practices and drought stress at critical crop growth stages. Being the staple food crop for millions, the improvement in wheat nutrient uptake and productivity becomes inevitable which can only be done with a proper combination of management practices. Henceforth, based on the experimental findings it can be concluded that the application of three irrigations (CRI, flowering and milking stages) along with cultivation of wheat variety JW 3288 and foliar application of 2% KCl can lead to higher nutrient uptake in wheat under water scarcity areas.

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