Original Research Article

Optimization of Irrigation Scheduling and Foliar Spray of Silicon on Growth, Yield and Water Use Efficiency of Wheat

ABSTRACT

Silicon is generally considered a beneficial element for crop especially under water stress/deficit condition but the mechanisms remain unclear. Here, we focus on optimization of irrigation scheduling and the effect of silicon through foliar spray for improving plant tolerance under drought stresses situation at deficit irrigation levels under semi-arid tropical condition of India.A field experiment was conducted with objective of foliar spray of silicon on growth, yield and water use efficiency of wheat (*Triticum aestivum* L.) under deficit irrigation at C.P.College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Gujarat, India during the *rabi* season of 2023-24.The experiment was laid out in a split plot design with four replications, consisting of twelve treatment combinations comprising three irrigation levels in main plot *viz.,* I_1: 0.6 IW/CPE, I_2: 0.8 IW/CPE, I_3: 1.0 IW/CPE and four silicon levels in sub plot *viz*, S_0: Control, S_1: Silicon @ 0.5%, S_2: Silicon @ 1.0%, S_3: Silicon @ 1.5%.The results of the present study revealed that Irrigation scheduling at 0.8 IW/CPE combined with foliar spray of silicon @ 1.0% significantly enhanced wheat growth, yield attributes and grain yield (3970 kg/ha) and water use efficiency (10.87 kg/ha-mm) of wheat. Higher silicon levels mitigated drought stress, optimizing productivity under deficit irrigation. The maximum predicted yield (4123 kg/ha) occurred at 411.5 mm irrigation depth, beyond which yields declined.

Keywords:Field water use efficiency, Irrigation, Silicon, Triticum aestivum L.,Yield

1. INTRODUCTION

"Agricultural production being an integrated effect of soil-water-nutrient-climate continuum, a wise scientific management of the complex system is crucial for enhancing crop productivity on sustained basis without detriment to the environmental ecology. Among the various production inputs, balanced nutrients and water are considered as the two key inputs, making maximum contribution to crop productivity. Irrigation water is scarce and costly input, its economic and scientific utilization and optimal allocation among the different crops grown becomes quite imperative. Wheat is highly sensitive to water stress during the CRI and flowering stages but over irrigation may lead to excessive vegetative growth and shortening of reproductive period and ultimately decrease the yield. Thus, determining proper irrigation interval with the stages of crop growth will not only help in bringing down the number of irrigations required and but also results in getting higher crop yield. Moreover, modern agriculture based on chemicals is not sustainable due their hazardous effect on soil and climate"[3].

"Silicon (Si) is a naturally occurring beneficial nutrient which modulates plant growth and development events and has been known to improve the crop tolerance to abiotic stresses"[22]. "Silicon improved plant height, inter-node length, fresh weight, bending moment, breaking resistance, lodging index and increase tolerance of lodging. It has been widely reported that silicon increases drought tolerance in plants such as rice, cucumber, maize, wheat, pepper, and sunflower and its application may help reduce the need for irrigation, which in turn would reduce salinization of crop land. Moreover, silicon also increases tolerance to heat stress by maintaining membrane stability.This phenomenon has been reported in crops such as sorghum, wheat, maize, rice, and tomato"[2,8,17,18]. [16] suggested that "silicon application could enhance sorghum root water uptake under drought stress by activating the accumulation of soluble sugars and amino acids"."Several researchers have also reviewed recent advances on the beneficial roles of silicon on plant growth in adverse environmental conditions and conducted various experiments on soil application method"[9]. However, there was very few experiments conducted on foliar spray of silicon under deficit irrigation situation coexist remains unclear. In this study, we focus on optimization of irrigation scheduling and the effect of silicon through foliar spray for improving plant tolerance under drought stresses situation at deficit irrigation levels in detailunder semi arid tropical condition of India in North part of Gujarat state.

2. MATERIAL AND METHODS

A field experiment was conducted during the *rabi* season of 2023-24 at Agronomy Instructional Farm, C. P.College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat. Geographically, experimental site is located at 24° 19' North latitude and 72° 19' East longitude with an elevation of 154.52 m above the mean sea level in the North Gujarat Agro-climatic Zone IV (AES-I) of Gujarat. This zone is characterized by arid and semi-arid climate and soil of the experimental plot was loamy sand in texture having neutral pH (7.42). The soil was low in organic carbon (0.26%), available nitrogen (154.28 kg/ha) and medium in available phosphorus (37.64 kg/ha) and available potassium (240.67 kg/ha) as well as Available Silicon (124.56 mg/kg).Wheat variety"GW 513" was sown via driller at a depth of 5 cm on 23rd November 2023.The experiment was laid out in a split plot design with four replications, consisting of twelve treatment combinations comprising three irrigation levels in main plot *viz.,* I_1: 0.6 IW/CPE, I_2: 0.8 IW/CPE, I_3: 1.0 IW/CPE and foursilicon levels in sub plot *viz*, S_0: Control, S_1: Silicon @ 0.5%, S_2: Silicon @ 1.0%, S_3: Silicon @ 1.5%.Two common irrigations *i.e*., pre sowing and 18 DAS was applied for crop establishment to all the treatments there after 50 mm depth of irrigation water was given through flood method as per the treatments after CRI stage. Recommended dose of fertilizer 90:60:00 kg $N:P_2O_5:K_2O$/ha from that 50% recommended dose of nitrogen through urea and full dose of phosphorus through SSP was applied as basal dose and remaining half dose of nitrogen was applied in two equal splits *i.e*., 18 DAS and 35 DAS as per the treatments.Foliar spray of silicon was carried out at 45 and 60 DAS as per treatments.Various growth parameters like plant height and yield attribute *viz*., number of effective tillers per metre row length, length of spike, number of grains per spike, test weight, grain yield, straw yield and harvest index were recorded at harvest. Field water use efficiency was estimated after harvest.

Crop yield (dependent variable) was assumed as a function of various growth traits, yield components and nutrient uptake (independent variables) and the following straightline model was established by least square technique (Gomez and Gomez 1984):

$$Y = a + b\,(x)$$

where, Y = Grain yield of chickpea (kg/ha), a = Y–axis intercept, b = Regression coefficient, x = Growth and yield components

The functional relationship between crop yield with irrigation water applied (W) defined as water production function and crop yield with applied silicon (S) is fertilizer production function. The production function equations evaluated in this study are as follows.

Linear production functions:

$$Y = a + b\,(W)$$

$$Y = a + b\,(S)$$

Quadratic production functions:

$$Y = a + b\,(W) + c\,(W^2)$$

$$Y = a + b\,(S) + c\,(S^2)$$

where in: Y = Crop yield (kg/ha), W = Applied irrigation water, S = Applied Silicon, a = Y – axis intercept, b and c = Regression coefficients reflecting the yield variation per unit change in irrigation/silicon.

The data obtained on the different growth and yield components and yield were analyzed statistically by the method of analysis of variance as per the procedure outlined for split plot designgiven by [6] in SPSS software. Statistical significance was tested by P–value at 0.05 level of probability and critical difference was worked out wherever the effects were significant.

3. RESULTS AND DISCUSSION

3.1 Effect on Growth and Yield Attributes

Irrigation scheduled at 1.0 IW/CPE ratio recorded significantly paraments like higher plant height of wheat at harvest and yield attributes *viz*., number of effective tillers per meter row length, length of spike, number of grains per spike and test weight of wheat. However, it was statistically at par with 0.8 IW/CPE and significantly superior over rest of the treatment(Table 1). “This might be due to sufficient soil moisture in surrounding the root zone area throughout the crop growth duration. Hence, optimum moisture supply promoted the elongation, division, expansion of cell components, increased nutrient uptake and photosynthesis. Which ultimately, increased plant growth and yield attributes. The results obtained in the present investigation are in accordance with results”[5,7,13]. “In case of silicon levels, foliar spray of silicon @ 1.5% recorded significantly higher growth parameters and yield attributes and it was at par with 1.0% foliar spray of silicon superior over the rest of the lower treatments. This might be due to positive response of silicon on effective tillers in wheat especially, increased the chlorophyll content in leaf, photosynthetic efficiency, metabolic activity of plant and thus leads to the more productionof photosynthates reflected in better growth, higher dry accumulation and stimulate more growth and yield of plant. Similar results were reported”[4,9].

3.2 Effect on Grain and straw Yield

“Irrigation scheduled at 1.0 IW/CPEratio recorded significantly higher grain yield (4149 kg/ha) and straw yield (5525 kg/ha) of wheat and it was at par with irrigation scheduled at 0.8 IW/CPE and superior over 0.6 IW/CPE ratio(Table 1).“Higher grain and straw yield observed under irrigation scheduled at 1.0 IW/CPE ratio and 0.8 IW/CPE treatment due to the favorable soil water balance (applied water), since water plays a vital role in the carbohydrate metabolism, protein synthesis, cell division, cell enlargement and partitioning of photosynthates to sink for improved development of growth traits. Increase in irrigation frequency tented to increase consumptive use of water, which provided congenial condition throughout the growth period of the crop. Besides adequate soil moisture in the rhizosphere of crop which results in higher photosynthesis and translocation of photosynthesis towards reproductive structures”.The results are in agreement with the findings”[1,10,15].

In case of silicon levels, foliar spray of silicon @ 1.5% recorded significantly higher grain yield (4023 kg/ha) and straw yield (5462 kg/ha) of wheat and it was at par with silicon @ 1.0%. “This might be due increase in grain yield and straw yield of wheat might be attributed to the increase in growth and yield characteristics of wheat and also to the stimulating effect of silicon in reducing biotic and abiotic stress. Silicon application may enhance crop yield by several indirect action such as decreased shading due to greater leaf erectness. Erectness of leaves as a result of silicon fertilization improves the photosynthesis, thereby indirectly increasing yield. The results are in tune with findings”[3,12].

The interaction effect between irrigation scheduling and silicon levels was found to be significant with respect to grain yield of wheat (Table 2). Data indicated that a significantly higher grain yield (4112 kg/ha) of wheat was recorded when irrigation was applied at 1.0 IW/CPE ratio along with the foliar spray of silicon @ 1.5%. However, it was at par with 0.8 IW/CPE ratio along with 1.0 and 1.5% foliar spray of silicon and 1.0 IW/CPE ratio along with rest of the silicon levels.

3.3 Regression of Growth Traits and Yield Components on Grain Yield of Wheat

All the independent variables showed a significant positive and linear relationship with grain yield suggesting an increment in grain yield of wheat with increase in given growth traits and yield component (Table 3). However, the magnitude of this reinforcement varied with the independent variable, *viz.,* growth trait and yield component and their units. The explained total variation as indicated by coefficient of determination (R^2) in grain yield by growth traits (plant height) and yield components (number of effective tillers per meter row length, length of spike, number of grains per spike and test weight) chosen as independent variables individually ranged from 72.92 to 88.54%. The variance ratio for testing R^2 was highly significant in all the relationships. This suggests that the grain yield of wheat can be adequately predicted using the tested independent variables, *viz.,* growth traits and yield components.

Table 1: Effect of irrigation scheduling and silicon levels on growth, yield attributes and yield of wheat

Treatment	Plant height at harvest (cm)	No. of effective tillers per meter row length	Length of spike (cm)	No. of grains per spike	Test weight (g)	Grain yield (kg/ha)	Straw yield (kg/ha)	Field water use efficiency (kg/ha-mm)
Irrigation scheduling: (I)								
I_1 : 0.6 IW/CPE	78.85	75.48	7.55	35.60	37.75	2991	3762	9.97
I_2 : 0.8 IW/CPE	85.06	83.15	8.21	40.08	41.85	3806	5049	10.87
I_3 : 1.0 IW/CPE	90.14	88.10	8.70	42.86	44.38	4023	5462	8.94
S.Em.±	2.01	1.43	0.17	0.90	0.80	77.12	132.99	-
C.D. at 5%	6.95	4.96	0.57	3.12	2.78	266.88	460.21	-
Silicon levels: (S)								
S_0 : Control (Water spray)	80.04	78.55	7.82	37.53	39.24	3472	4302	9.46
S_1 : Silicon @ 0.5%	83.39	81.47	8.05	38.80	40.44	3567	4644	9.72
S_2 : Silicon @ 1.0%	86.69	83.58	8.31	40.48	42.39	3675	4912	10.02
S_3 : Silicon @ 1.5%	88.61	85.38	8.45	41.24	43.23	3713	5173	10.12
S.Em.±	1.76	0.73	0.13	0.45	0.39	31.38	99.99	-
C.D. at 5%	5.12	2.12	0.38	1.30	1.12	91.04	290.13	-
Interaction								
C.D. at 5%	NS	3.68	NS	2.25	1.95	157.69	NS	-

Table 2: Interaction effect between irrigation scheduling and silicon levels on grain yield of wheat

Interaction effect between (I×S)	Silicon levels			
	S_0	S_1	S_2	S_3
I_1	2847	3032	3038	3049
I_2	3612	3665	3970	3978
I_3	3957	4005	4018	4112
S.Em.±	54.34			
C.D. at 5%	157.69			

3.3 Regression of Growth Traits and Yield Components on Grain Yield of Wheat

All the independent variables showed a significant positive and linear relationship with grain yield suggesting an increment in grain yield of wheat with increase in given growth traits and yield component (Table 3). However, the magnitude of this reinforcement varied with the independent variable, *viz.,* growth trait and yield component and their units. The explained total variation as indicated by coefficient of determination (R^2) in grain yield by growth traits (plant height) and yield components (number of effective tillers per meter row length, length of spike, number of grains per spike and test weight) chosen as independent variables individually ranged from 72.92 to 88.54%. The variance ratio for testing R^2 was highly significant in all the relationships. This suggests that the grain yield of wheat can be adequately predicted using the tested independent variables, *viz.,* growth traits and yield components.

Table 3: Empirical estimates for the regression of growth traits and yield components on grain yield of wheat

Relationship	Regression constant		Coefficient (R^2)	Test statistic F value for testing R^2
	a	b		
Yield – Plant height (cm)	-2049.2	66.787	0.729**	26.92
Yield – No. of effective tillers per mtr row length	-2291.9	71.72	0.868**	65.83
Yield – Length of spike (cm)	-2849.9	791.6	0.872**	68.61
Yield – No. of grains per spike	-1353.7	125.53	0.885**	77.22
Yield – Test weight (g)	-1795.0	130.7	0.854**	58.59

3.4 Irrigation Water and Yield Relation:

The relation between grain yield (Y) of wheat under each level of applied water (water production function) was developed which explained 99% variation (Fig 1). It showed quadratic response. The resultant water production function and test statistics are as follows.

$$Y = -11790 + 77.53\,W - 0.0942\,W^2 \quad (R^2 = 0.99) \text{ ……………………… } \textbf{Quadratic}$$

The test statistic (R^2 and F – value) of quadratic production function were highly significant. The water production functions developed for wheat under different irrigation scheduling were used to determine economic irrigation water level that a farmer can use. The predicted maximum seed yield was 4162 kg/ha with applied water of 411.5 mm beyond which the yield decreased (Fig 1) with increase in irrigation water applied. Similar things were reflected here, the maximum grain yield (Y_{max}) of 4023 kg/ha was recorded at 1.0 IW/CPE ratio with 450 mm depth of irrigation water, means over the application of 411.2 mm depth of water, there was decreasing in trend in grain yield of wheat. Similar results were in tune with the finding of Malve et al (2017) in wheat.

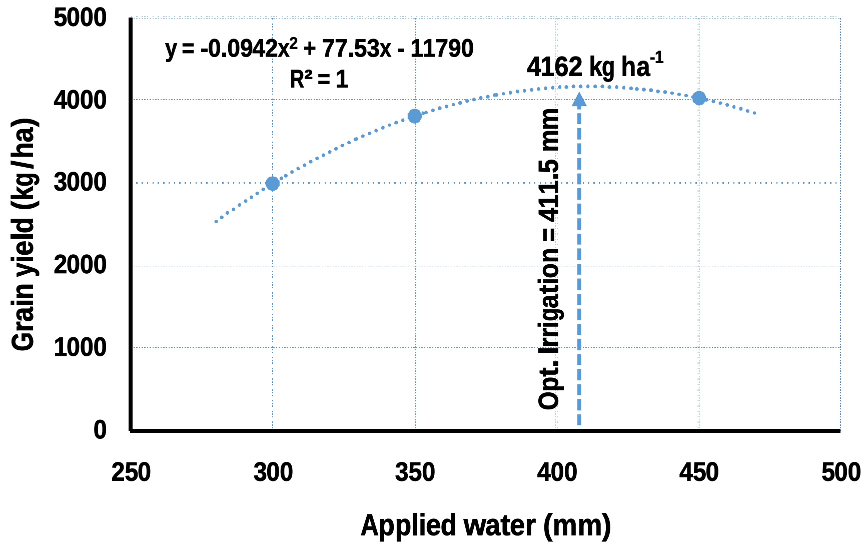

Fig. 1: Predicted yield response of wheat to applied water applied

3.5 Silicon and Yield Relation:

The relation between wheat grain yield (Y) under silicon levels (S) were studied in linear and polynomial 2nd order function (Eq. 1 & 2) and established following linear production function with regression coefficient of 96.76%(Fig 2). The resultant fertilizer production function and test statistics are as follows. Linear production function indicated that each unit increase in dose silicon through foliar spray, there was stagnant linearly increased in grain yield of wheat.

$Y = -3482.1 + 166.2\,S$ ($R^2 = 0.967$) ……………………………..**Linear (Eq. a)**

$Y = -3467.8 + 251.7\,S - 57\,S^2$ ($R^2 = 0.99$) …………………….. ….**Quadratic (Eq. b)**

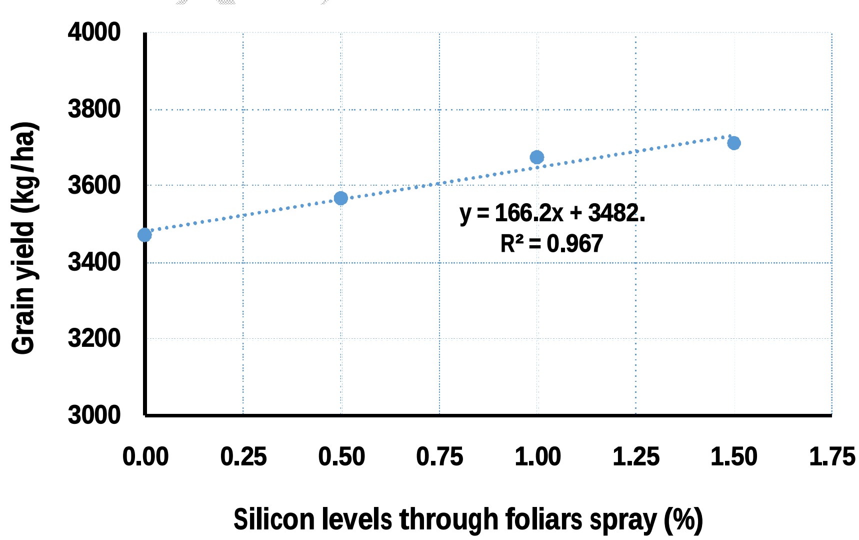

Fig. 2: Predicted yield response of wheat to silicon levels

3.6 Effect on Field Water Use Efficiency

Field water use efficiency affected by irrigation scheduling and silicon levels (Table 1). Numerically, higher field water use efficiency (10.87 kg/ha-mm) of wheat was recorded under 0.8 IW/CPE ratio with 350 mm consumptive use of water. While, lowest field water use efficiency (8.94 kg/ha-mm) was recorded under 1.0 IW/CPE ratio with 450 mm consumptive use of water. The decrease in water productivity under higher irrigation treatment (1.0 IW/CPE ratio) because of yield increased due to increase in irrigation levels could not compensate for the crop evapotranspiration at higher levels. These results are in conformity with finding of [11,14].Likewise, foliar spray of silicon significantly influenced field water use efficiency of wheat. Significantly higher field water use efficiency (10.12 kg/ha-mm) was obtainedwith foliar spray of silicon @ 1.5% which was followed by 1.0% (10.02 kg/ha-mm), 0.5% (9.72 kg/ha-mm) and control (9.46 kg/ha-mm).

4. CONCLUSION

Based on the findings, it can be concluded that irrigation water at optimum quantity is essential to improve crop yield. Apart from this, if irrigation level is in deficit levels, foliar spray of silicon is essential to alleviate water stress in crop and helps in getting grain yield. The interaction effect between irrigation scheduling and silicon levels was found to be significant in this experiment.Irrigation applied at 0.8 IW/CPE ratio along with foliar spray of silicon @ 1.0% at 45 and 60 DAS recorded higher growth parameters, yield components grain yield of wheat. Field water use efficiency shows a decreasing trend with an increase in the amount of water utilized however, increasing trend was noticed in silicon levels.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models(ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

REFERENCES

1. Alam, M. S., Naresh, R. K., Vivek, K. S. & Singh, H. L. (2022). Effect of sowing methods and irrigation scheduling on production and productivity of wheat crop. *International Biology Forum International Journal.* 14(2): 445-452.
2. Bosnic, P., Bosnic, D., Jasnic, J. & Nikolic, M. (2018). Silicon mediates sodium transport and partitioning in maize under moderate salt stress. *Environmental and Experimental Botany*. 155: 681-687.
3. Choudhary, R. N., Kinjal, J. S., Doba, S. D. &Maheriaya, V. D. (2020). Effect of varying levels of silicon and restricted irrigation on productivity of wheat (*Triticum aestivum* L.) under Bhal condition of Gujarat. *International Journal of Chemical Studies*. 9(1): 1269-1272.
4. Choudhary, R., Sharma, S. K., Yadav, S. K., Jat, G., Signh, H. & Naik, S. (2022). Effect of silicon fertilization on wheat productivity and profitability in Southern. *Rajasthan Indian Journal of Agricultural Sciences*. 92(4): 501–504.
5. Damor, N. N., Solanki, R. M., Hadiyal, J. G. &Dharaiya, B. K. (2021). Effect of drip irrigation schedules and fertigation levels on growth parameters and yields of wheat (*Triticum aestivum* L.). *Journal of Pharmacognosy and Phytochemistry*. 10(2): 1546-1550.
6. Gomez, K. A. & Gomez, A. A. (1984). Statistical procedures for agricultural research. John Wiley and Sons.
7. Goswami, S., Ramyajit, M., Puste, A. M., Sarkar, S., Banerjee, H. & Jana, K. (2020). Influence of irrigation and tillage management on growth, yield and water-use efficiency of wheat (*Triticum aestivum* L.) in Gangetic plains in West Bengal. *Indian Journal of Agronomy*. 65(1): 47-52.
8. Javaid, T., Farooq, M. A., Akhtar, J., Saqib, Z.A. & Anwar-ul-Haq, M. (2019). Silicon nutrition improves growth of salt-stressed wheat by modulating flows and partitioning of Na^+, Cl^- and mineral ions. *Plant Physiology and Biochemistry*, 141: 291-299.
9. Jinger, D., Dhar, S., Dass, A., Sharma, V. K., Shukla, L., Parihar, M. & Jatav, H. S. (2020). Crop productivity, grain quality, water use efficiency, and soil enzyme activity as influenced by silicon and phosphorus application in aerobic rice (*Oryza sativa* L.). *Communications in Soil Science and Plant Analysis*, 51(16).

10. Kumar, K., Nand, V., Pyare, R., Maurya, N. K., Niwas, R. & Singh, S. (2021). Effect of irrigation schedules on productivity of late sown varieties of wheat (*Triticum aestivum* L.). *International Journal of Chemical Studies*. 9(1): 3273-3277.
11. Malav, J. K., Ramani, V. P. & Sajid M. (2016). Effect of nitrogen and silicon fertilization on growth, yield and yield attributes of rice (*Oryza sativa* L.) under lowland conditions. *The Ecoscan*. 10(2): 213-216.
12. Malve, S. H., Rao, P. V., & Dhake, A. (2017). Impact of drip irrigation and N-fertigation scheduling on wheat (Triticum aestivum) under semi-arid tropical environment. *Indian Journal of Agricultural Sciences* 87(5): 580-8.
13. Niwas, R., Singh, B. N., Verma, V. K., Kumar, V., Kumar K., Singh, D. P. & Singh, D. (2020). Effect of irrigation management (IW/CPE ratio and critical growth stages) on yield and quality of wheat (*Triticum aestivum* L.) *International Journal of Microbiology and Applied Sciences*. 11: 1349-1354.
14. Pachore, R. A. &Deore, S. B. (2022). Effect of moisture stress on wheat crop by IW/CPE approach on water requirement and water use efficiency. *International Journal of Agriculture, Environment and Biotechnology*. 15(1): 619-625.
15. Singh, A., Niwas, R., Yadav, A. S., Kumar, J., & Kumar, S. (2022). Effect of irrigation scheduling on growth and yield of late sown wheat (*Triticum aestivum* L.). *The Pharma Innovation Journal*. 9(5): 299-301.
16. Sonobe, K., Hattori, T., An, P., Tsuji, W., Eneji, A. E., Kobayashi, S., Kawamura, Y., Tanaka, K. & Inanaga, S. (2010). Effect of silicon application on sorghum root responses to water stress. Journal of Plant Nutrition, 34: 71-82.
17. Yan, G., Fan, X., Zheng, W., Gao, Z., Yin, C., Li, T. & Liang, Y. (2021). Silicon alleviates salt stress-induced potassium deficiency by promoting potassium uptake and translocation in rice (Oryza sativa L.) Journal of Plant Physiology, 258–259.
18. Yin, L., Wang, S., Tanaka, K., Fujihara, S., Itai, A., Den, X. & Zhang, S. (2016). Silicon-mediated changes in polyamines participate in silicon-induced salt tolerance in Sorghum bicolor L. Plant Cell Environment, 39: 245-258.