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Role of Composted Rice Straw and Potassium Silicate in Improving Productivity of Sakha 106 Rice Cultivar with Raised water Use Efficiency

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Abstract: The primary objective of this study appears to be an evaluation of irrigation water distribution equity among rice farmers and its effects on yield and water use efficiency. through studying the impact of spraying potassium silicate and compost under a water deficit on improving rice growth, productivity, and water use efficiency. A field experiment was conducted at the Experimental Farm Sakha Agriculture Research Station, Kafr El-Sheikh, Egypt, during 2022 and 2023 rice growing seasons. A strip plot design, with 3 replications. Three irrigation intervals were used the vertical plots were irrigation every 4, 8, and 12 days. The horizontal plots were made up of combined potassium silicate rates of 0, 0.5%, 1.5%, and 3% + recommended rate of compost rice straw (5t/ha). Growth characteristics, grain yield, and components, and rice grain quality traits were assessed. The present study revealed that extending the irrigation interval beyond I4 resulted in a significant decline in plant growth parameters, grain yield, and associated yield components. In addition to, the combined application of potassium silicate and compost demonstrated a promising effect, with increases observed in rice grain quality, yield, and its constituent components. The highest amount of total applied irrigation water was recorded by irrigation every four days, whereas I12 exerted the least. Amount I8 had the best water productivity. It could be concluded that prolonging irrigation from 8 to 12 days could be applied to enhance water and insignificant yield reduction under the case of 3% K_2SiO_3+5 t/ha compost for Sakha 106 rice cultivar.

Keywords: *Oryza sativa*, Water productivity, Grain yield and Organic fertilizer**.**

1. Introduction

Rice (*Oryza sativa* L.) constitutes the principal dietary staple for over half of the global population. The regions exhibiting the highest consumption rates are Asia, Sub-Saharan Africa, and South America **(Caraher 2023)**. Rice is grown in a variety of systems this group includes rice varieties that are susceptible to flooding, lowland rice that is rainfed, upland rice, and rice that is irrigated. Irrigated lowland rice accounts for more than 75% of global rice output **(Nasr et al 2021)**. In the coming decades, global rice production must expand to keep up with demand; however, this is only achievable if land and water resources, as well as inputs, are exploited more effectively. According to **Pirmoradian et al. (2004)**, Paddy soils are distinguished by high inputs of organic matter and a comparatively sluggish decomposition rate due to anaerobic conditions. The sustainability of rice production faces several challenges, including growing water scarcity, rapid population increase, expanding urbanization and the expected effects of climate change **(Abd El-Mageed et al. 2021)**. Estimates suggest that by 2025, irrigated rice production on 15–20 million hectares of land is anticipated to experience varying degrees of water scarcity **(Dietrich et al. 2023)**. Constituting approximately 96% of Egypt's total renewable water resources, the Nile River plays a critical role in the country's agricultural sector. Consequently, water scarcity poses a substantial threat to Egypt's food production capacity and overall food security **(Abdelaaletal, 2019)**. By focusing on these principles, water losses can be reduced and crop productivity can be enhanced in water-limited environments. A promising strategy for mitigating water scarcity challenges involves the cultivation of rice aerobically in non-puddled and non-saturated soils. This approach can be further complemented by the adoption of water-saving irrigation techniques, such as deficit irrigation. Additionally, the strategic application of fertilizers has the potential to lessen the

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detrimental effects of drought on soil moisture content and, consequently, plant productivity **(Bindraban et al. 2020)**. The utilization of organic fertilizers occupies a central role in the foundation of sustainable agricultural practices **(Rezaei et al. 2018)**. Organic fertilizers garner recognition within the domain of sustainable agriculture owing to their capacity to augment essential plant nutrients and bolster a variety of soil properties, including water retention capability, nutrient adsorption capacity, and resilience to drought conditions **(Ghosh and Devi, 2019)**. Elucidating the interactive influence of irrigation regimes and fertilizer application on crop growth is of critical importance for the advancement of water management strategies that promote sustainable agricultural practices **(Geremew et al. 2021)**. Potassium silicate, a widely recognized source of readily available potassium (K) and silicon (Si), has been demonstrated to enhance crop growth **(De Souza Junior et al. 2021)** and water use efficiency (WUE) **(Abdeen and Mancy, 2018)**. Furthermore, it would mitigate the detrimental impacts of both biotic and abiotic stressors **(Ahmed and Khurshid 2011)**. Potassium (K) plays an indispensable role within the agricultural sector. It demonstrably enhances crop production and quality, while also mitigating the detrimental effects of environmental stressors on cultivated plants **(Hasanuzzaman et al. 2018)**.

Silicon (Si) application has emerged as a strategy to enhance plant tolerance and resistance to environmental stresses. Research has shown that Si-treated crops exhibit significantly greater root weight and volume compared to controls grown under drought conditions, with documented increases ranging from 20% to 200%. This augmented root development is hypothesized to be a critical factor underlying the observed increase in drought resistance **(Ahmed et al., 2011)**. Beyond its stress-mitigating properties, silicon (Si) application possesses the potential to function as a growth regulator, promoting enhanced plant growth even under water deficit stress conditions **(Bukhari et al. 2021)**. Research indicates that silicon (Si) application in drought-stressed wheat enhances the activity of antioxidant enzymes, such as superoxide dismutase, catalase, and glutathione reductase. This enzymatic response coincides with a decrease in foliar hydrogen peroxide (H_2O_2) concentration, suggesting a potential role for Si in mitigating oxidative stress. Notably, the activity of peroxidase and ascorbate peroxidase enzymes remained unaffected by Si application in this particular study. Corroborating these findings, independent studies have documented significant yield increases in various crops, including rice, maize, cucumber, tomato, and soybean, following potassium silicate application **(Shirani Rad et al. 2022)**. To address the challenges posed by water deficit stress and achieve superior crop yields in terms of both quantity and quality, two promising strategies have emerged: the deployment of high-yielding crop genotypes and the implementation of optimized crop nutrition programs. To achieve this objective, research is paramount to elucidate the interactive effects of diverse irrigation regimes and fertilizer formulations on crop growth. This critical knowledge will serve as the foundation for developing more efficient water management practices, ultimately fostering increased agricultural productivity.

2. Materials and methods

Study Site

A two-year field experiment was conducted from 2022 to 2023 at the Experimental Farm of the Rice Research and Training Center (RRTC) located in Sakha, Kafr El-Sheikh Governorate, Egypt. Meteorological data for the experimental sites are presented in Table 1, obtained from the Sakha Meteorological Station.

TABLE 1. Monthly, temperature means and relative humidity (RH) at the study area during the experimental period

Month	**2022**				**2023**			
	Air temperature (0C)		**Relative humidity (RH)**		**Air temperature (0C)**		**Relative humidity (RH)**	
	Max.	**Man.**	**7:30**	**13:03**	**Max.**	**Man.**	**7:30**	**13:30**
May	29	10	70.5	42.5	30	12	76.3	45
June	33	15	82.5	50	33	16.5	82.4	56
July	32	15.7	80	54.7	32.6	17.3	81	55
August	32	16.3	83.2	56	33.5	17.2	83.5	56.5
September	32.5	13	74.3	47.7	33	15	77.5	82
Mean	32	14	78.1	50.18	32.4	15.6	80.1	58.9

The average meteorological data collected from May to September across the experimental sites revealed maximum temperatures of 32.5 °C and 33.5 °C, minimum temperatures of 10 °C and 12 °C, and mean relative humidity of 78.1 % and 80.1 % for the 2022 and 2023 seasons, respectively. All experimental plots were preceded by a barley (Hordeum spp.) crop. The results of soil property analyses from both mechanical and chemical experiments are presented in Table 2.

TABLE 2. Mechanical and chemical analysis of the experiments soil

Soil chemical properties	seasons	
	2022	2023
pH (1:2.5)	8.2	8.3
EC (dS m^{-1})	3.2	3.39
Organic matter%	1.22	1.35
Total nitrogen mg/kg	435	515
Available P, mg/kg (0.5 M $NaHCO_3$)	5.8	6.3
Available Ammonium (mg/kg)	16	17.3
Available Nitrate (mg/kg)	13.5	14.6
Available Potassium (mg/kg)	215	240.8
Anions (meq L^{-1})		
CO_3^-	--	--
HCO_3	5.56	5.4
Cl^-	9	10.2
SO_4^-	18.33	18.3
Cations (meq/L)		
Ca^{++}	10.01	11.38
Mg^+	5	6.2
Na^+	1.88	2
K^+	16	14.8

Experimental Design

A factorial strip-plot design with three replicates was employed for the experiment. The vertical plots consisted of three irrigation schedules applied as main effects: irrigation every 4 days (I4), irrigation every 8 days (I8), and irrigation every 12 days (I12). The horizontal plots, however, were made up of combined the potassium silicate rates of Control (0), 0.5% K_2SiO_3, 1.5% K_2SiO_3, 3% K_2SiO_3, recommended compost rice straw (5t/ha), 0.5% K_2SiO_3 + 5t/ha compost, 1.5% K_2SiO_3 + 5t/ha compost, 3% K_2SiO_3 + 5t/ha compost.

Compost rice straws as recommended by the Rice Research and Training Center, were implemented.

Photo 1: Image showing the treatments used

The chemical composition of compost used in 2022 and 2023 seasons were C 30.6(%), N 1.55(%), C/N ratio 16.06, P 0.68(%) and K 1.9(%). The experiment was conducted across two growing seasons. Potassium silicate applications were administered at two time points: 20 and 40 days after transplanting. On May 7th of each season, seeds of the Sakha 106 rice cultivar were sown at a seeding rate of 143 kg/ha. To promote germination, seeds were pre-treated with a 24-hour soaking period followed by a 48-hour incubation period. The nursery received the recommended rates of nitrogen, phosphorus, and zinc. Following a 30-day nursery period, seedlings were meticulously transplanted into their designated experimental plots. Each subplot measured 25 square meters (5 x 5 m). Seedlings were transplanted manually with a spacing of 20 cm between both hills and rows. A planting density of 4-5 seedlings per hill was employed. Standard agronomic practices for rice cultivation, as recommended by the Rice Research and Training Center, were implemented throughout the experiment. To minimize lateral water movement and ensure precise water management, a two-meter-wide ditch separated each main plot. All irrigation water applications were measured using a calibrated water meter connected to a water pump. water use efficiency (WUE) was calculated as the total grain yield per unit of water transpired by the crop (kg grains/m^3 water). To assess dry matter production and leaf area, three randomly selected hills from each sub-subplot were destructively harvested at the booting stage. Leaf area index (LAI) was then estimated using a portable area meter (model LI-3000A) on these samples. Plant height and total panicle number were determined at harvest by measuring ten randomly chosen hills within each plot. Additionally, ten panicles were collected from each plot to evaluate panicle length, the number of filled and unfilled grains per panicle, panicle weight, 1000-grain weight and grain yield. Grain moisture content was standardized, and yield was estimated from a designated 6 m² area. Adhering to the technical recommendations of the Rice Research and Training Center (RRTC), rice grain quality characteristics were assessed using a standardized method outlined by **Juliano (1971)**.

Statistical Analyses

A statistical analysis of variance (ANOVA) was conducted on the collected data, following the methodologies described by **Gomez and Gomez (1984).** Duncan's Multiple Range Test **(Duncan, 1955)** was employed for post-hoc comparisons of treatment means. The entire statistical analysis was performed using the software package "COSTAT.

Results and Discussion

3.1Growth characteristics

Data from Table 3 reveal that the I4 treatment consistently outperformed I8 and I12 treatments across all measured growth parameters: leaf area index (LAI), dry matter content, and plant height. This enhanced growth response can likely be attributed to the beneficial effects of increased water availability on plant cell division and elongation. The observed increase in vegetative growth, total dry matter production, and plant height in the I4 treatment can be attributed, in part, to enhanced nitrogen availability. This is hypothesized to be a consequence of the treatment promoting more favorable root development, thereby facilitating improved nitrogen mobility within the soil solution and greater nitrogen uptake by plant roots. These findings support previous research by **Wahab et al. (2022).**

TABLE 3. Leaf area index, dry matter and plant height of Sakha 106 rice cultivar as affected by irrigation intervals and fertilizer treatments.

Treatment	LAI		Dry matter (g/m^2)		Plant height (cm)	
	2022	2023	2022	2023	2022	2023
Irrigation intervals(I)						
I4	4.51a	4.83a	1125.4a	1140.3a	95.59a	100.01a
I8	4.10b	4.27b	1078.7b	1089.9b	90.69b	93.76b
I12	3.06c	3.13c	864.6c	875.1c	84.80c	87.34c
f. test	**	**	**	**	**	**
Fertilizer (T)						
T1	1.48f	1.66f	1020.5f	1032.7f	87.95f	91.29f
T2	2.68e	2.87e	1021.7e	1033.9e	89.15e	92.50e
T3	2.98e	3.17e	1021.9e	1034.2e	89.45e	92.79e
T4	3.44d	3.63d	1022.4d	1034.7d	89.91d	93.25d
T5	4.66c	4.85c	1023.7c	1035.9c	91.13c	94.48c
T6	5.11b	5.30b	1024.1b	1036.3b	91.58b	94.92b
T7	5.28ab	5.46ab	1024.3ab	1036.5ab	91.75ab	95.09ab
T8	5.49a	5.68a	1024.5a	1036.7a	91.96a	95.31a
f. test	**	**	**	**	**	**
Interactions						
I X T	NS	NS	NS	NS	NS	NS

* = Significant at 0.05 level, ** = Significant at 0.01 level and NS= Not significant. Means having the same letter (s) are not significantly different according to Duncan's multiple range tests. I4= irrigation every 4days, I8= irrigation every 8days and, I12= irrigation every 12days, T1= 0, T2= 0.5% K_2SiO_3, T3= 1.5% K_2SiO_3, T4= 3% K_2SiO_3, T5= 5t/ha compost, T6= 0.5% K_2SiO_3 + 5t/ha compost, T7= 1.5% K_2SiO_3 + 5t/ha compost and T8= 3% K_2SiO_3 + 5t/ha compost.

The I12 treatment exhibited the lowest values for leaf area index (LAI), dry matter (DM), and plant height. This decline in growth parameters can likely be attributed to a reduction in tiller number, total leaf area, and lower leaf death. In essence, limited water availability (characteristic of the I12 treatment) is well-documented to hinder plant growth in general. These findings are consistent with those reported by **Toscano and Romano (2021)**. Rice plants treated with the combination of potassium silicate (K2SiO3) and composted rice straw exhibited significant increases in leaf area index (LAI), dry matter (DM), and plant height compared to the control treatment across both growing seasons (Table 4). Notably, treatment T8 achieved the highest values for LAI, DM, and plant height, with no statistically significant difference observed between T8 and T7 in either season. The observed increase in silica levels is hypothesized to have contributed to a more erect plant posture, reducing self-shading of lower leaves within the canopy. This improved light interception likely enhanced photosynthetic efficiency and allowed the plants to better utilize the available space for capturing solar radiation. Consequently, this may have led to the observed increases in leaf area index (LAI), dry matter (DM), and plant height. Similar findings were reported by **Mukarram et al. (2022)** and **Hussain et al. (2021)**. The application of organic fertilizers, such as compost, offers a two-fold benefit. Firstly, it provides plants with essential nutrients, directly contributing to their growth. Secondly, compost improves various soil properties, including water-holding capacity, nutrient-holding capacity, and drought tolerance. These findings align with those reported by **Ghosh and Devi (2019) and RM, and Rashwan, (2021).** The control treatment (without fertilizer) consistently exhibited the lowest values for leaf area index (LAI), dry matter (DM), and plant height across both growing seasons, compared to all other fertilizer treatments. Furthermore, no significant interaction effect was observed between irrigation intervals and fertilizer treatments on these growth parameters in either season.

3.2 Grain yield and its attributes

Table 4 presents the impact of irrigation regimes on panicle number per hill, panicle length, filled and unfilled grain counts per panicle, as evaluated during the 2022 and 2023 growing seasons. Notably, extending irrigation intervals to 12 days resulted in a significant decrease across all measured yield components, with the exception of unfilled grains per panicle, which conversely exhibited an increase. Data presented in Table 4 reveal that the I4 treatment consistently achieved the highest values for panicle number per hill, panicle length, and number of filled grains per panicle across both growing seasons, followed by the I8 treatment (with the exception of the number of unfilled grains per panicle). Conversely, the I12 treatment exhibited the lowest values for all measured yield components in both seasons. Interestingly, the I12 treatment also produced the highest number of unfilled grains per panicle. The observed increase in unfilled grains under water stress aligns with findings reported by **Bwire et al. (2022)**. Conversely, sufficient water availability likely facilitated enhanced production and transport of dry matter to the panicles for developing grains. This may explain the greater number of panicles per hill and filled grains per panicle observed in well-watered treatments. Similar positive effects of adequate water on grain yield components have been documented by **Tripathi et al. (2018)**. These findings could potentially be attributed to increased soil moisture content during the vegetative stage of rice plant growth. Enhanced soil moisture is well-documented to influence cell division and elongation processes within plants **(Perumal et al., 2019)**. Furthermore, it may have stimulated various physiological processes such as photosynthesis, enzyme activity, and ultimately, the transport of dry matter to the panicles for grain development **(Hossain et al., 2020)**. This study revealed a positive effect of the combined application of potassium silicate (K_2SiO_3) and composted rice straw on rice growth parameters (Table 4). Treatments incorporating both potassium silicate and composted rice straw (T7 and T8) achieved the highest values for panicle number per hill, panicle length, and number of filled grains per panicle across both growing seasons, with no statistically significant difference observed between T7 and T8 (Table 4). Conversely, the addition of potassium silicate and composted rice straw (T8) resulted in the lowest number of unfilled grains per panicle. The observed increase in filled grains with silicon application could be attributed to a combination of enhanced photosynthetic activity and efficient translocation of photosynthates to the developing grains. These findings support those reported by **De Souza Junior et al. (2021)**. The combined application of silica spray and composted rice straw likely augmented rice yield through a two-pronged approach. First, it may have stimulated carbohydrate assimilation, leading to an increase in filled grains. This beneficial effect could be attributed to the enhanced soil nutrient status and moisture retention capacity, both of which are critical for optimal paddy growth. Second, the foliar application of potassium silicate might have favorably influenced yield by improving leaf water potential. These findings corroborate previous research conducted by **Patil et al. (2017) and El-Nahraw,. (2022).**The application of silicon to rice plants likely contributed to higher straw yield through several mechanisms. Firstly, it may have promoted a more erect growth habit, thereby increasing light interception and enhancing photosynthetic activity. This improved assimilation of nutrients would have supported overall plant growth and development, potentially reducing susceptibility to pests and diseases. Additionally, silicon accumulation within plant tissues could have strengthened the stems, further minimizing lodging and enhancing resilience against both biotic (pest and disease) and abiotic (environmental) stresses. These combined effects might ultimately have led to increased straw yield. These findings align with those reported by **El-Okkiah et al. (2022)**. The application of organic fertilizers, such as compost, offers a two-fold benefit for rice cultivation. Firstly, it directly contributes to plant growth by supplying essential nutrients. Secondly, compost amendments enhance various soil properties, including water-holding capacity, nutrient-holding capacity, and drought tolerance. These findings are consistent with those reported by **Ghosh and Devi (2019) and Abou Hussien, et al. (2020).**

TABLE 4. Number of panicle/hill, panicle length (cm), no. of filled grains/panicle and no. of unfilled grains/panicle of Sakha 106 rice cultivar as affected by irrigation intervals and fertilizer treatments.

Treatment	No. of panicle/hill		Panicle length(cm)		No. of filled grains		No. of unfilled grains/panicle	
	2022	2023	2022	2023	2022	2023	2022	2023
Irrigation intervals (I)								
I4	20.61a	23.13a	21.18a	21.75a	129.1a	133.7a	5.4c	6.5c
I8	19.19b	22.21a	20.88a	21.45a	124.1b	129.0a	11.9b	13.1b
I12	16.45c	18.50b	18.74b	19.00b	111.7c	116.9b	16.9a	18.8a
f. test	**	**	**	**	**	**	*	*
Fertilizer (T)								
T1	16.17e	18.74d	17.85f	18.32f	104.2e	115.6e	13.0a	14.4a
T2	17.68d	20.25c	19.06e	19.53e	112.8d	119.4de	12.8ab	14.2ab
T3	17.98d	20.44c	19.48d	19.94d	118.4cd	121.8cde	12.7b	14.0b
T4	18.44c	20.67c	19.70d	20.16d	120.5c	124.7bcd	12.2c	13.6c
T5	19.58b	22.15b	21.04c	21.51c	125.2bc	128.6abc	10.7d	12.0d
T6	19.82b	22.51ab	21.49b	21.95b	128.6ab	131.9ab	10.9d	12.2d
T7	20.03ab	22.60ab	21.65ab	22.1ab	130.1ab	133.5a	10.2e	11.6e
T8	20.31a	22.88a	21.87a	22.34a	133.3a	136.7a	9.0f	10.4f
f. test	**	**	**	**	**	**	**	**
Interactions								
I X T	*	**	*	*	NS	NS	NS	NS

* = Significant at 0.05 level, ** = Significant at 0.01 level and NS= Not significant. Means having the same letter (s) are not significantly different according to Duncan's multiple range tests. I4= irrigation every 4days, I8= irrigation every 8days and, I12= irrigation every 12days, T1= 0, T2= 0.5% K_2SiO_3, T3= 1.5% K_2SiO_3, T4= 3% K_2SiO_3, T5= 5t/ha compost, T6= 0.5% K_2SiO_3 + 5t/ha compost, T7= 1.5% K_2SiO_3 + 5t/ha compost and T8= 3% K_2SiO_3 + 5t/ha compost.

According to Figure 1, the combined application of irrigation treatment I4 and fertilizer treatment T8 resulted in the highest number of panicles per hill across both growing seasons. Treatment T7 under the same irrigation regime (I4) produced the second-highest number of panicles per hill. Conversely, the treatment combination of I12 irrigation and T1 fertilizer consistently yielded the lowest number of panicles per hill in both seasons.

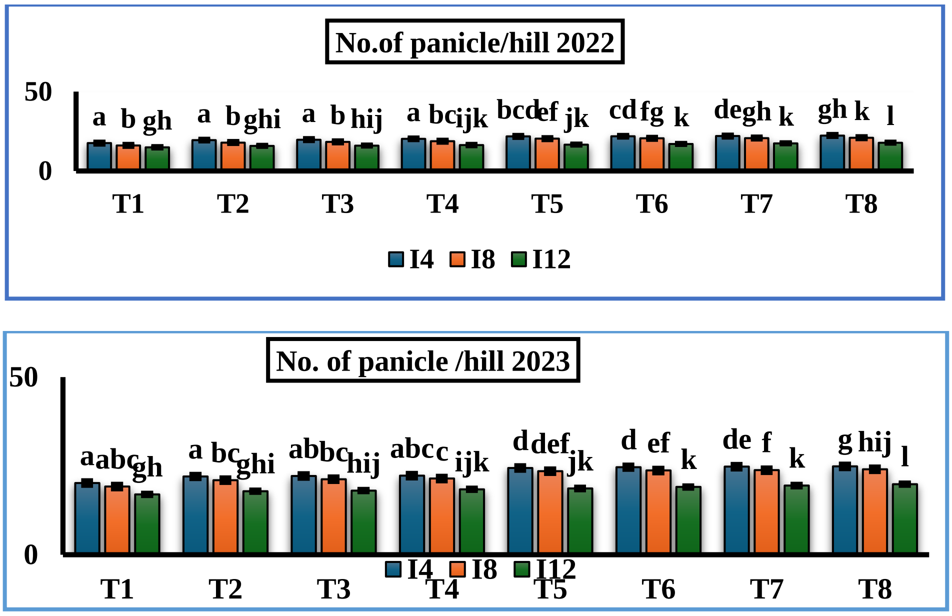

Fig.1. Number of panicle/hill of Sakha 106 rice cultivar as affected by the interaction between the study factors. * = Significant at 0.05 level, ** = Significant at 0.01 level and NS= Not significant. Means having the same letter (s) are not significantly different according to Duncan's multiple range tests. I4= irrigation every 4 days, I8= irrigation every 8days and, I12= irrigation every 12days, T1= 0, T2= 0.5% K_2SiO_3, T3= 1.5% K2SiO3, T4= 3% K_2SiO_3, T5= 5t/ha compost, T6= 0.5% K_2SiO_3+ 5t/ha compost, T7= 1.5% K_2SiO_3+ 5t/ha compost and T8= 3% K_2SiO_3+ 5t/ha compost.

Similar to the findings for panicle number (Figure 1), Figure 2 reveals that the I4 irrigation treatment combined with the T8 fertilizer rate produced the longest panicles across both seasons. Treatment T7 under the same I4 irrigation regime yielded the second-longest panicles. Conversely, the combination of I12 irrigation and T1 fertilizer (without potassium silicate or compost) consistently resulted in the shortest panicles in both growing seasons.

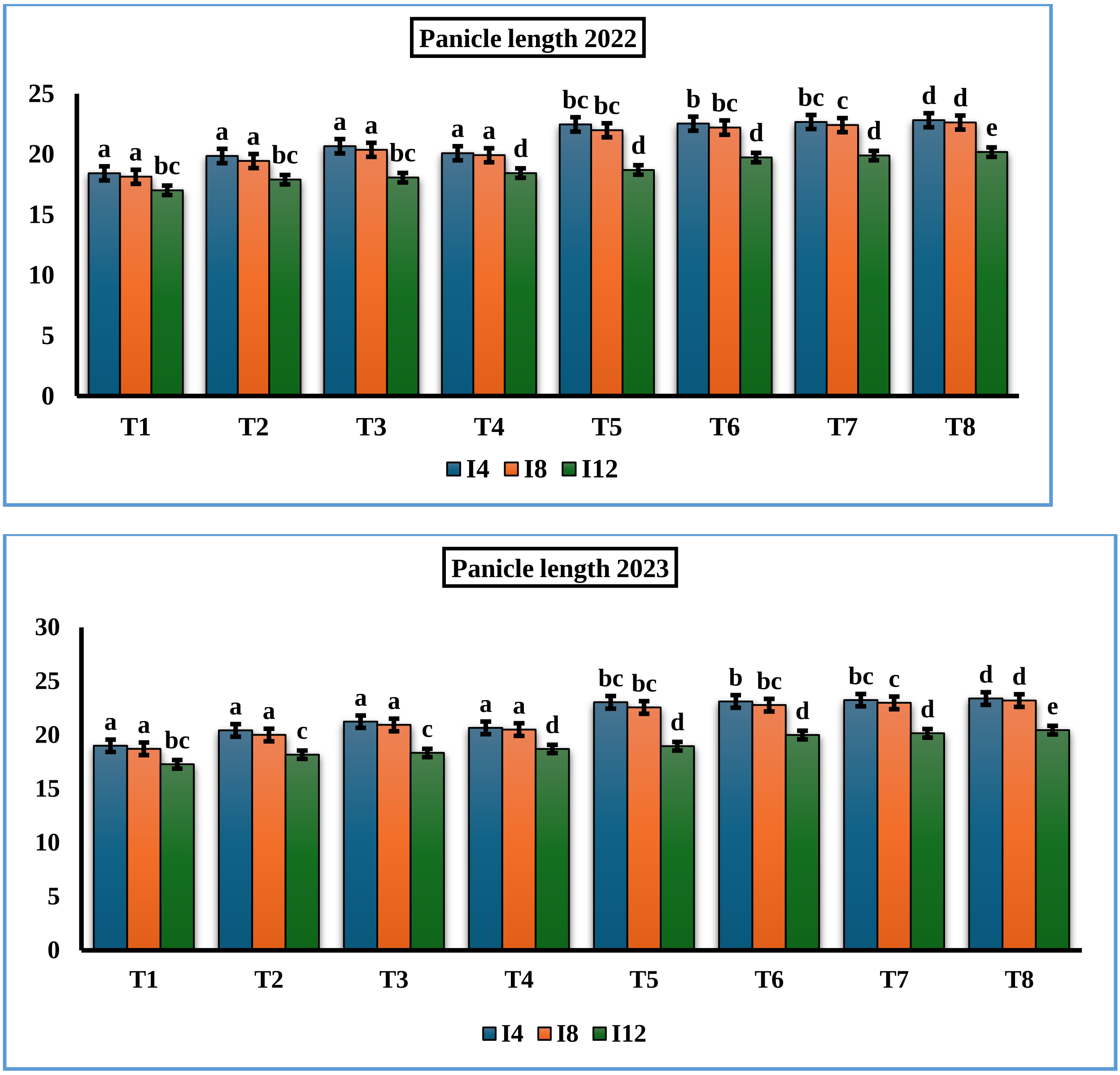

Fig. 2. Panicle length of Sakha 106 rice cultivar as affected by the interaction between the study factors.
*** = Significant at 0.05 level, ** = Significant at 0.01 level and NS= Not significant. Means having the same letter (s) are not significantly different according to Duncan's multiple range tests. I4= irrigation every 4days, I8= irrigation every 8days and, I12= irrigation every 12days, T1= 0, T2= 0.5% K_2SiO_3, T3= 1.5% K_2SiO_3, T4= 3% K_2SiO_3, T5= 5t/ha compost, T6= 0.5% K_2SiO_3+ 5t/ha compost, T7= 1.5% K_2SiO_3+ 5t/ha compost and T8= 3% K_2SiO_3+ 5t/ha compost.**

TABLE 5. Panicle weight, 1000-grain weight, grain yield and straw yield of Sakha 106 rice cultivar as affected by irrigation intervals and fertilizer treatments.

Treatments	Panicle weight (g)		1000-grain weight (g)		Grain yield (t/ha)		Straw yield (t/ha)	
	2022	2023	2022	2023	2022	2023	2022	2023
Irrigation intervals (I)								
I4	3.00a	3.28a	25.7a	26.9a	9.90a	10.36a	12.8a	13.0a
I8	2.71b	3.06a	25.3a	26.1b	8.88b	9.21b	12.5a	12.8a
I12	2.18c	2.16b	20.4b	21.2c	7.94c	8.30c	10.3b	10.0b
f. test	**	**	**	**	**	**	**	**
Fertilizer (T)								
T1	1.07g	1.14f	21.8f	22.8f	7.66h	8.05h	8.8f	9.4e
T2	1.70f	1.50ef	22.5e	23.4e	8.02g	8.41g	10.6e	10.9d
T3	1.98e	1.77d	22.9d	23.9d	8.43f	8.81f	11.3d	11.2d
T4	2.34d	2.21d	23.0d	24.0d	8.66e	9.04e	11.1d	11.6c
T5	2.98c	3.66c	24.6c	25.6c	9.19d	9.57d	12.9c	12.8b
T6	3.41b	3.86bc	24.8bc	25.8bc	9.42c	9.81c	13.1bc	13.1ab
T7	3.58b	4.16ab	25.1ab	26.1ab	9.73b	10.11b	13.4ab	13.2ab
T8	3.96a	4.47a	25.4a	26.4a	10.15a	10.53a	13.7a	13.5a
f. test	**	**	**	**	**	**	**	**
Interactions								
I X T	*	*	NS	NS	**	**	NS	NS

* = Significant at 0.05 level, ** = Significant at 0.01 level and NS= Not significant. Means having the same letter (s) are not significantly different according to Duncan's multiple range tests. I4= irrigation every 4days, I8= irrigation every 8days and, I12= irrigation every 12days, T1= 0, T2= 0.5% K_2SiO_3, T3= 1.5% K_2SiO_3, T4= 3% K_2SiO_3, T5= 5t/ha compost, T6= 0.5% K_2SiO_3 + 5t/ha compost, T7= 1.5% K_2SiO_3 + 5t/ha compost and T8= 3% K_2SiO_3 + 5t/ha compost.

Table 5 presents data demonstrating that the I4 irrigation treatment achieved the highest values for all measured yield components across both growing seasons. These include panicle weight (3.00 and 3.28 g), 1000-grain weight (25.7 and 26.9 g), grain yield (9.90 and 10.36 t/ha), and straw yield (12.8 and 13.0 t/ha). The I8 treatment followed closely behind I4 in terms of yield performance. Conversely, water stress imposed by the I12 treatment resulted in significant reductions in yield components. This decline can likely be attributed to tiller death under drought conditions, leading to a lower number of panicles per unit area. In contrast, well-watered treatments I4 ensured adequate nutrient availability, promoting tiller development and ultimately leading to a greater number of panicles with filled grains. These findings align with those reported by **El-Refaee et al. (2021)**. These findings could potentially be attributed to increased soil moisture content during the vegetative stage of rice plant growth. Enhanced soil moisture is well-documented to influence cell division and elongation processes within plants (e.g., **Perumal et al., 2019)**. Furthermore, it may have stimulated various physiological processes such as photosynthesis, enzyme activity, and ultimately, the transport of dry matter to the panicles for grain development. This improved translocation of resources likely contributed to a higher grain yield, characterized by increased grain filling and heavier panicles, as observed in this study. These observations are consistent with the findings reported by **Salgotra and Chauhan (2023)**. Data in Table 5 reveal that fertilizer treatments T7 and T8 achieved the highest values for panicle weight, 1000-grain weight, grain yield, and straw yield across both growing seasons, with no statistically significant difference observed between them. Conversely, the T1 treatment consistently yielded the lowest values for all measured traits. Furthermore, silicon application, as included in T7 and T8, may enhance plant stress tolerance through several mechanisms. It can stimulate antioxidant defense mechanisms, thereby mitigating damage caused by reactive oxygen species produced during various environmental stresses **(Al-Mokadem et al., 2023**). Silicon application can further enhance plant stress tolerance through multifaceted mechanisms. It reinforces cell walls and reduces stomatal size, consequently leading to decreased transpiration rates. This action conserves water content within the plant, thereby optimizing internal physiological processes. Finally, silicon might modulate the influence of phytohormone levels, potentially impacting overall plant growth. **(Al-Mokadem et al., 2023).** Potassium (K) transcends its function as a fundamental plant nutrient. It critically influences cell turgor, a factor directly regulating cellular water content. Moreover, adequate K supply plays a vital role in regulating osmotic potential, consequently enhancing plant water uptake and preventing K^+ depletion. Potassium may also contribute to maintaining a healthy equilibrium between carbohydrates and proteins within the plant. Notably, K serves as a critical nutrient for both photosynthesis and the translocation of assimilates throughout the plant **(Saudy et al. 2023)**. The application of organic matter, particularly rice straw compost, offers a multi-faceted benefit for lowland rice production. Firstly, Rice straw emerges as a valuable source of both potassium (K) and silicon (Si), functioning as a natural organic fertilizer that replenishes essential plant nutrients. Furthermore, compost amendments contribute to improvements in various soil properties, such as water-holding capacity and nutrient retention capacity. This enhanced soil quality can potentially translate to improved drought tolerance in rice plants. These observations align with research conducted by **Ghosh and Devi (2019)** and **Huang et al. (2023)**. As illustrated in Figure 3, the I4 irrigation treatment combined with the T8 fertilizer treatment resulted in the highest panicle weight across both growing seasons (4.95 g and 5.29 g, respectively). Treatment T7 under the same I4 irrigation regime yielded the second-highest panicle weight. Conversely, the combination of I12 irrigation and T1 fertilizer (without potassium silicate) consistently produced the lowest panicle weights in both seasons. These findings align with those reported by **Huang et al. (2023).**

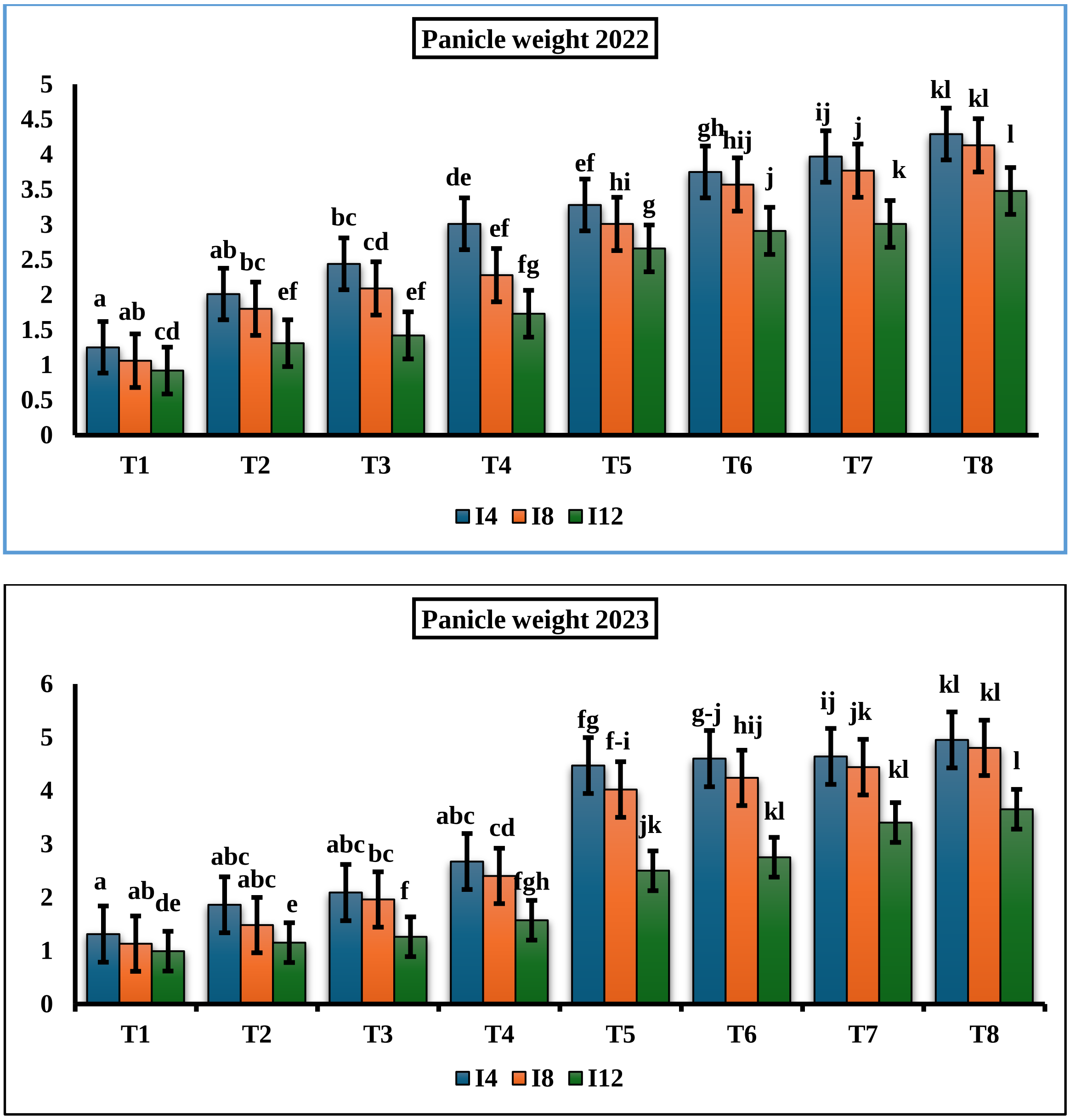

Fig 3. Panicle weight of Sakha 106 rice cultivar as affected by the interaction between the study factors. * = Significant at 0.05 level, ** = Significant at 0.01 level and NS= Not significant. Means having the same letter (s) are not significantly different according to Duncan's multiple range tests. I4= irrigation every 4days, I8= irrigation every 8days and, I12= irrigation every 12days, T1= 0, T2= 0.5% K_2SiO_3, T3= 1.5% K_2SiO_3, T4= 3% K2SiO3, T5= 5t/ha compost, T6= 0.5% K_2SiO_3+ 5t/ha compost, T7= 1.5% K_2SiO_3+ 5t/ha compost and T8= 3% K_2SiO_3 + 5t/ha compost.

As shown in Table 6, there was a significant interaction between irrigation intervals and fertilizer treatment for grain yield across both growing seasons. The treatment combination of I4 irrigation and T8 fertilizer achieved the highest grain yield (10.44 and 10.90 t/ha), followed by T7 fertilizer under the same I4 irrigation regime. Conversely, the I12 irrigation treatment in combination with T1 fertilizer (without potassium silicate) resulted in the lowest grain yield in both seasons (6.24 and 6.60 t/ha, respectively).

TABLE 6. Grain yield (t/ha) of Sakha 106 rice cultivar as affected by the interaction between by irrigation intervals and fertilizer treatments.

Treatments	Grain yield (t/ha)					
	2022			2023		
	Irrigation intervals					
Fertilizer (T)	I4	I8	I12	I4	I8	I12
T1	9.06fg	7.70gk	6.24n	9.52e	8.03i	6.60l
T2	9.49def	8.00ij	6.58m	9.95d	8.33h	6.94k
T3	9.72b-e	8.40hi	7.16l	10.18cd	8.73g	7.52j
T4	9.76b-e	8.74gh	7.48kl	10.22cd	9.07f	7.84i
T5	10.13abc	9.17fg	8.27i	10.59abc	9.50e	8.63g
T6	10.22ab	9.29ef	8.76gh	10.68ab	9.62e	9.12f
T7	10.41a	9.66cde	9.12fg	10.87a	9.99d	9.48e
T8	10.44a	10.13abc	9.89bcd	10.90a	10.46bc	10.25cd

I4= irrigation every 4days, I8= irrigation every 8days and, I12= irrigation every 12days, T1= 0, T2= 0.5% K_2SiO_3, T3= 1.5% K_2SiO_3, T4= 3% K_2SiO_3, T5= 5t/ha compost, T6= 0.5% K_2SiO_3 + 5t/ha compost, T7= 1.5% K_2SiO_3 + 5t/ha compost and T8= 3% K_2SiO_3 + 5t/ha compost.

3.3 Grain quality

Milling characteristics

Data from Table 7 reveal a significant impact of irrigation regimes on rice grain quality across both growing seasons. Notably, extending irrigation intervals from every 4 days (I4) to every 12 days (I12) significantly decreased milling characteristics. Compared to the I12 irrigation regime, treatments under I4 irrigation (administered every 4 days) consistently achieved superior values for hulling percentage, milling percentage, and head rice percentage. This suggests that increasing water deficit stress (longer intervals between irrigation) negatively impacts milling recovery. These observations align with the findings reported by **Ishfaq et al. (2021).** Water deficit stress possible curtails the grain filling period, potentially leading to reduced grain weight. Since grain filling patterns significantly influence final grain quality, this observation aligns with the documented decline in milling characteristics under water stress conditions. This translates into a decrease in milling recovery, manifested as increased bran yield and a lower head rice percentage. These findings are consistent with those reported by **Prathap et al. (2019)** and **Fuentealba-Sandoval et al. (2020)**, who also documented a similar association between water stress and increased bran yield with a corresponding decrease in head rice output. Potassium silicate application rates (T7 and T8) significantly impacted milling characteristics across both growing seasons. Treatments with the highest potassium silicate rate (T8) consistently yielded the best results, reflected in the highest hulling percentage, milling percentage, and head rice percentage. Conversely, the treatment lacking potassium silicate (T1) resulted in the lowest values for all three milling traits in both seasons. These findings partially support the work of **Ho et al. (2020)**, who suggested that while silicon itself might not directly enhance grain quality, potassium plays a vital role in improving overall crop production and quality. This includes potentially mitigating the negative effects of environmental stresses.

Notably, the interaction between irrigation intervals and fertilizer treatments did not significantly affect hulling percentage, milling percentage, or head rice percentage during growing season (Table 7).

TABLE 7. Hulling, milling and head rice percentages of Sakha 106 rice cultivar as affected by irrigation intervals and fertilizer treatments.

Treatments	Hulling (%)		Milling (%)		Head rice (%)	
	2022	**2023**	**2022**	**2023**	**2022**	**2023**
Irrigation intervals(I)						
I4	79.66a	80.28a	73.52a	74.12a	60.42a	61.22a
I8	75.45b	76.23b	70.75b	71.42b	58.62b	58.90b
I12	72.12c	73.31c	67.11c	67.76c	53.77c	5.06c
f. test	**	**	**	**	**	**
Fertilizer (T)						
T1	73.33f	74.19f	68.05f	68.69f	55.19f	55.65f
T2	74.54e	75.40e	69.25e	69.89e	56.40e	56.85e
T3	75.17d	76.04d	69.89d	70.31d	57.03d	57.49d
T4	74.95d	75.82d	69.67d	70.31d	56.81d	57.27d
T5	76.52c	77.38c	71.23c	71.87c	58.38c	58.83c
T6	76.96b	77.83b	71.68b	72.32b	58.82b	59.28b
T7	77.13ab	77.99ab	71.85ab	72.49ab	58.99ab	59.45ab
T8	77.35a	78.21a	72.06a	72.70a	59.21a	59.66a
f. test	**	**	**	**	**	**
Interactions						
I X T	NS	NS	NS	NS	NS	NS

* = Significant at 0.05 level, ** = Significant at 0.01 level and NS= Not significant. Means having the same letter (s) are not significantly different according to Duncan's multiple range tests. I4= irrigation every 4days, I8= irrigation every 8days and, I12= irrigation every 12days, T1= 0, T2= 0.5% K_2SiO_3, T3= 1.5% K_2SiO_3, T4= 3% K_2SiO_3, T5= 5t/ha compost, T6= 0.5% K_2SiO_3 + 5t/ha compost, T7= 1.5% K_2SiO_3 + 5t/ha compost and T8= 3% K_2SiO_3 + 5t/ha compost.

4. Water management

Table 8 highlights significant variations in water use and productivity across irrigation regimes during both growing seasons. While rice plants under the most frequent irrigation (I4) exhibited the highest total water consumption, this coincided with the greatest grain yield in both seasons compared to less irrigation intervals. Extending irrigation intervals beyond I4 resulted in a significant decrease in water use but also a decline in grain yield. This interplay led to a clear improvement in water use efficiency (WUE). Furthermore, prolonged irrigation intervals proved to be an effective strategy for maximizing water savings in this study. Rice plants subjected to the least frequent irrigation regime (I12) exhibited the lowest total applied water (9627 and 9435 m^3/ha) and grain yield across both seasons. Conversely, these plants achieved the highest mean water saving percentage (25.97% and 25.64%). Notably, the highest WUE values (0.831 and 0.898 kg/m^3) were observed under I8 in the first and second seasons, respectively. In contrast, the most frequent irrigation regime (I4) resulted in the lowest WUE values (0.761 and 0.816 kg/m^3) in both seasons. These findings suggest that extending irrigation intervals promotes greater grain production per unit of water used, thereby enhancing WUE. These observations are consistent with the research by **Gewaily et al. (2019), Me et al., (2019), Darwesh, and Hefzy (2020) and Poddar et al. (2022).**

TABLE 8. Total water used, water saved and water use efficiency as affected by irrigation intervals.

Irrigation interval	Total water use (m^3/ha)		Grain yield (t/ha)		Water saved (%)		Water use efficiency (kg/m^3)	
	2022	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
I4	13005	12689	9.90	10.36	-	-	0.761	0.816
I8	10680	10256	8.88	9.21	17.87	19.17	0.831	0.898
I12	9627	9435	7.94	8.30	25.97	25.64	0.824	0.879

I4= irrigation every 4days, I8= irrigation every 8days and, I12= irrigation every 12days.

Data in Table 9 reveal that across all irrigation intervals, fertilizer treatments T8 and T7 consistently achieved higher water use efficiency (WUE) compared to the control treatment (T1). Notably, the high WUE observed under T8 coincided with high grain yield. Furthermore, the combination of I4 irrigation with T8 fertilizer treatment resulted in the maximum mean WUE in both seasons. Conversely, when evaluated based on WUE, the I12 irrigation regime combined with any fertilizer treatment consistently yielded the lowest WUE and grain yield across both seasons.

TABLE 9. Grain yield and water use efficiency as affected by irrigation intervals and fertilizer treatment.

Irrigation intervals	Fertilizer	Grain yield(t/ha)		water use efficiency (kg/m^3)	
		2022	2023	2022	2023
I4	T1	9.06	9.52	0.697	0.750
	T2	9.49	9.95	0.730	0.784
	T3	9.72	10.18	0.747	0.802
	T4	9.76	10.22	0.750	0.805
	T5	10.13	10.59	0.779	0.835
	T6	10.22	10.68	0.786	0.842
	T7	10.41	10.87	0.800	0.857
	T8	10.44	10.9	0.803	0.859
I8	T1	7.70	8.03	0.721	0.783
	T2	8.00	8.33	0.749	0.812
	T3	8.40	8.73	0.787	0.851
	T4	8.74	9.07	0.818	0.884
	T5	9.17	9.50	0.859	0.926
	T6	9.29	9.62	0.870	0.938
	T7	9.66	9.99	0.904	0.974
	T8	10.13	10.46	0.949	1.020
I12	T1	6.24	6.60	0.648	0.700
	T2	6.58	6.94	0.683	0.736
	T3	7.16	7.52	0.744	0.797
	T4	7.48	7.84	0.777	0.831
	T5	8.27	8.63	0.859	0.915
	T6	8.76	9.12	0.910	0.967
	T7	9.12	9.48	0.947	1.005
	T8	9.89	10.25	1.027	1.086

I4= irrigation every 4days, I8= irrigation every 8days and, I12= irrigation every 12days, T1= 0, T2= 0.5% K_2SiO_3, T3= 1.5% K_2SiO_3, T4= 3% K_2SiO_3, T5= 5t/ha compost, T6= 0.5% K_2SiO_3 + 5t/ha compost, T7= 1.5% K_2SiO_3 + 5t/ha compost and T8= 3% K_2SiO_3 + 5t/ha compost.

Conclusion

It could be concluded that prolonging irrigation from 8 to 12 days could be applied to enhance water and insignificant yield reduction under the case of 3% K_2SiO_3+5 t/ha compost for Sakha 106 rice cultivar.

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