*Original Research Article*

THE IMPACT OF IRRIGATION INTERVALS, POTASSIUM SILICATE, AND ORGANIC ACIDS ON IMPROVING WATER RELATIONSHIPS AND WHEAT CROP YIELD IN SANDY SOILS

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ABSTRACT

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| Wheat production in hot, arid climates demands a lot of water; thus, it needs to be drought resistant. Irrigation management and supplementation are critical, and accumulative pan evaporation (APE) evaluation is a useful way. The goal of this study was to determine how varied irrigation schedules, utilizing various APE and both inorganic and organic conditioners, affect wheat crop yield and plant drought tolerance. We carried out a field experiment at the Ismailia Agricultural Research Station in Egypt's Ismailia Governorate. The split-plot design was used with three replications, and wheat was grown across two winters (2021-2022 and 2022-2023). The main plot received three irrigation treatments (2, 1.5, and 1 based on APE). The sub-main plots had five different treatments: a control group (T1), 1000 mg SiO₂ L-1 as potassium silicate (T2), T2 plus 50 mM citric acid (T3), T2 plus 20 mM acetic acid (T4), and T2 with both 50 mM citric acid and 20 mM acetic acid (T5).Water consumptive use (WCU) and water usage efficiency (WUE) were calculated for seasons, as well as wheat crop yield, total nutrient content, and some soil chemical properties. The study indicated that WCU varied between 1365 to 2067 m³fed-1 and 1371 to 2051 m³fed-1 for wheat crop in 2021/2022 and 2022/2023, respectively. Also, interaction between coefficients of APE and adding KSi with organic acids significantly boosted wheat production, improved how well water was used, increased the total nutrients in the wheat, enhanced the soil's chemical properties, and made nutrients more available during both growing seasons In conclusion, using irrigation treatment 2 APE in conjunction with T5 was the optimum treatment and is suggested when wheat Giza 171 is planted in sandy soil with spray watering in northeast Egypt. |

*Keywords: Irrigation Intervals, Water consumptive use, Potassium Silicate, Citric Acid, Acetic Acid, wheat*

1. INTRODUCTION

Climate change is reducing global food crop yields, and current climatic trends suggest that food production may further deteriorate (Eckstein et al., 2019). Changes in rainfall patterns may cause drought and floods, and as temperatures rise, more land may become arid or semi-arid (Guzzetti et al., 2020). Through 2050, higher temperatures and less frequent precipitation will raise irrigation needs by 10% (Khan et al., 2019). All of these factors will eventually accelerate drought. Dry stress is expected to affect more than 50% of arable land by 2050 and reduce grain yield by 10% over the following 50 years (Jochum et al., 2019). World population growth and climate change have exacerbated drought, disrupting agricultural production and food supplies (Leng and Hall, 2019). Plants exposed to water scarcity often exhibit metabolic abnormalities and disturbed physiology, including cell shrinkage, loss of cell turgor, limited water uptake, decreased photosynthesis capacity, nutrient distribution imbalance, and ROS excess (Yang et al., 2019). Water-scarce plants adapt morphologically and physiologically to survive and thrive.

Wheat is a key food crop that must be adapted to water constraints to maintain yield. Wheat is most commonly grown in the hot earth zone, which receives less rainfall. Consequently, its water consumption is high. So, irrigation management using regulating chemicals is required for rational water use and decent wheat production in these conditions. One of the most effective approaches is to determine irrigation intervals using accumulative pan evaporation measurements. El-Nady and Shalaby (2014) found that repeated irrigation increased wheat water consumptive use (ETa) values, with equivalent results for wheat yield. In a field experiment conducted by Ragheb et al. (2017), it was discovered that wheat crop production improved with shorter irrigation intervals, with the highest yield recorded after 15 days of irrigation followed by 21 days of irrigation. Long irrigation periods cause stress conditions, resulting in reduced yields, as seen with 28 days of irrigation. Furthermore, a study conducted by Gameh et al. (2017) found that small irrigation times boosted wheat grain yield and water efficiency. Abdou and Emam (2018) looked at how different irrigation schedules, based on cumulative pan evaporation (APE) values of 1.0, 0.8, and 0.6, affected wheat yields and some crop-water relationships, finding that lower (APE) values led to longer irrigation intervals, which decreased all measured factors. The study resulted in the diminution of all assessed parameters. Singh et al. (2018) demonstrated that regular irrigation enhanced seasonal water utilization in wheat and improved both grain and straw yield at reduced crop water productivity efficiency (APE) in contrast to elevated (APE). Also, Verma et al. (2021) demonstrated that an irrigation schedule of 0.9 irrigation water to cumulative pan evaporation resulted in the maximum grain and straw yield of wheat. This therapy was administered at brief irrigation intervals and the maximum water quantities utilized by wheat.

In addition, exogenous different treatment is an uncomplicated and cost-effective approach to improve the resistance of plants to the adverse effects of environmental stressors, such as drought. Regardless of the abundance of silicon in the soil, plants are unable to utilize it. Exogenous foliar supplementation of Si has been demonstrated to be advantageous in the mitigation of drought damage in a variety of plant species, such as maize, rice, wheat, and sorghum (Wang et al., 2019 and Ning et al., 2020). Si controls drought stress tolerance mainly through crop root growth and water absorption (Hameed et al., 2013). Additionally, Silica helps plants by increasing substances that protect them, boosting their water content to avoid damage, improving the activity of protective enzymes, and enhancing gas exchange and photosynthesis. Also, it helps plants manage water loss, hold onto more water, reduce the opening of their pores, and slow down the loss of chlorophyll, which helps them keep making food even when they are short on water, according to Ma et al. (2004). As well as, Silicon improves hydraulic conductivity and water absorption during drought, according to Sonobe et al. (2009). Also, Saud et al. (2014) found that silicon deposition in pretenses leaves keeps them erect, which increases canopy light penetration and decreases transpiration, boosting photosynthesis. Reduced drought stress may depend on this morphological change.

Several experiments have shown that organic acids can reduce drought effects. These include weak organic acids like citric acid, which regulates pH and is an antioxidant (Soroori et al., 2021). This compound is important for the Krebs cycle because it provides carbon and energy, helps keep cell membranes stable, activates transport enzymes, and supports the metabolism and movement of carbohydrates in plant cells, according to Omar et al. (2018). It also helps plants grow and chelate free radicals (Da Silva, 2003). Also, foliar application of citric acid during drought stress boosts shoot weight, reduces oxidative stress, boosts phosphorus uptake, reduces H₂O₂ accumulation, and boosts leaf RWC and Chl, leading to increased growth and productivity (El-Tohamy et al., 2013). Furthermore, the organic acids have been shown to play significant functions in soils, including the microbial chemotaxis of soil microorganisms, the uptake of nutrients by roots, and the production of root exudates (Adeleke et al., 2017).

Exogenous acetic acid therapies also boost plant adaptation pathways to abiotic stresses like drought. Over a decade of research has shown that acetic acid can boost plant resilience to abiotic stressors. Kim et al. (2017) identified a novel yet straightforward function of acetic acid in the improvement of drought resistance by subjecting numerous plant species to diluted acetic acid (0, 10, 20, 30, and 50 mM). Acetic acid (AA) has been demonstrated to enhance crop survival in drought stress at low exogenous AA concentrations as a result of its low toxicity and low cost (Allen and Allen, 2021; Rahman et al., 2021). Furthermore, acetic acid can enhance a plant's resistance to abiotic stresses by improving various physiological and biochemical processes, such as root and shoot growth and development, net photosynthetic rate, water use efficiency, stomatal conductance, chlorophyll biosynthesis, leaf water status, nutrient use efficiency, and the activation of antioxidant defenses (Rahman et al., 2021, and Hossain et al., 2020). In addition to Dong et al. (2018) propose that natural acetic acid might help plants withstand drought by affecting the pressure in guard cells through a process that involves peroxisomes. There is a limited understanding of the roles that AA plays in drought tolerance mechanisms related to improved water usage efficiency, osmoprotective acquisition, nutrient absorption, and the detoxification of reactive oxygen species through antioxidant defense. Additionally, exogenous acetic acid may be taken and transformed into acetyl-coenzyme A (acetyl-CoA) in plants. Acetyl-CoA also catalyses the manufacture of malate to control drought tolerance by adjusting the guard cells' turgor pressure, according to Kong et al. (2022).

A study by Brodribb et al. (2013) demonstrated that plants often thicken and enhance their leaf structures to reduce water vapour evaporation from their surfaces during drought conditions. Also, a greater quantity of smaller vessels per unit area of stem xylem facilitates more efficient water transport. As well as, Laxa et al. (2019) showed that the formation of reactive oxygen species (ROS) due to drought is believed to hinder plant growth by disrupting photosynthesis. Sun et al. (2022) found that adding acetic acid from outside the plant helped lower oxidative stress and prevent damage from too much light in many plant species during drought stress. On the other hand, sandy soils are often deficient in nutrients, arid, and poorly water-retaining. Physiological and biochemical processes are impaired in these regions by moisture stress, which subsequently reduces crop growth and output.

The objective of the present investigation was to evaluate the productivity and total nutrient content of wheat crops at different irrigation intervals in the presence of drought tolerance substances, specifically potassium silicate (KSi), citric acid (CA), and acetic acid (AA), when employing various coefficients of accumulative pan evaporation (APE). Water relationships, nutrient availability, and soil chemical properties were also assessed.

2. methodology

**2.1 Description of experimental**

A field experiment was carried out on sandy soil at the Ismailia Agriculture Research Station in the Ismailia Governorate of Egypt. The coordinates are 30° 36' 56.4'' N, 32° 23.7'' E 14 m elevation. Wheat (Triticum sativa var. Giza 168) was cultivated during the two winter seasons of 2021–2022 and 2022–2023. Soil samples were collected from depths of 0–20, 20–40, and 40–60 cm in the research area before planting to examine various physical properties as described by Jackson (1973), the results are presented in Table 1. Also, the surface soil sample (0-30 cm) underwent analysis of its chemical properties and nutrient availability, as outlined by Page et al. (1982), with results displayed in Table 2.

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| **Table 1. Some physical properties and soil moisture constants for the experimental site** | | | | | | | | | |
| **Soil depth (cm)** | **Soil particles fraction (%)** | | | | | **Bulk density,**  **(g cm-3)** | **Field Capacity (ɵv %)** | **Wilting point,**  **(ɵv %)** | **Available water**  **(mm/ 20 cm)** |
| **Coarse** | **Fine sand** | **silt** | **clay** | **texture** |
| 0-20 | 69.2 | 23.2 | 4.4 | 3.2 | Sandy | 1.66 | 14.5 | 3.5 | 22.0 |
| 20-40 | 71.8 | 22.8 | 3.5 | 1.9 | Sandy | 1.71 | 10.3 | 3.1 | 14.4 |
| 40-60 | 79.7 | 17.6 | 1.9 | 0.8 | Sandy | 1.72 | 9.7 | 2.8 | 13.8 |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Table 2. Soil chemical properties and nutrients Availability before cultivation** | | | | | | | |
| **Chemical properties** | | **Soluble cations (meq L-1)** | | **Soluble anions (meq L-1)** | | **Available nutrients (mg Kg-1)** | |
| OM% | 0.36 | Ca2+ | 1.02 | CO32- | - | N | 80.0 |
| \*pH | 7.73 | Mg2+ | 0.99 | HCO- | 1.92 | P | 8.00 |
| \*\*EC | 0.44 | Na+ | 1.30 | Cl- | 1.20 | K | 50.0 |
|  |  | K+ | 1.00 | SO42- | 1.19 | Si | 200 |
| *\*soil: water suspension (1:2.5) \*\* soil: water extract (ds m-1) (1:5)* | | | | | | | |

**2.2 Experimental design and treatment details**

Field studies were done to assess how different irrigation schedules and the use of potassium silicate, acetic acid, citric acid, and their mix affect wheat crop yield, nutrition, and nutrient availability in sandy soil. The experimental design is a split-plot with three replications. The main plot depicted three irrigation treatments (2, 1.5, and 1 coefficient based on the accumulative pan evaporation (APE)). The sub-main plots comprised five treatments: control (T1), potassium silicate 1000 mg SiO₂ L-1 (T2), T2 + 50 mM citric acid (T3), T2 + 20 mM acetic acid (T4) and T2 combined with citric acid (50 mM) and acetic acid (20 mM) (T5). These treatments were applied three times at 30, 45, and 60 days from the sown date in both seasons.

**2.3 Construction of irrigation system:**

A fixed-sprinkler system, including underground laterals, is installed at a depth of 50 cm, with only the riser pipe and sprinkler head above the surface. A valve was fitted on each sprinkler riser to control the activation or deactivation of the sprinkler during irrigation periods. An impact sprinkler (R.C. 160-S, produced in Spain), equipped with a 4 mm nozzle and operating at 3.45 bar, was employed. It discharges at a rate of 1.14 m³ h-1 (9.5 mm h-1) and is configured with parallel laterals. The system has a spacing of 10 by 12 meters, with 10 meters separating the sprinklers along the lateral and 12 meters between the parallels.

**2.4 Irrigation practice**:

An open pan evaporation standard, Class A, was utilized to record daily evaporation using an evaporimeter. Irrigation time is calculated by taking the total daily evaporation from the pan and multiplying it by certain factors, and irrigation is done when this calculation matches the total moisture available in the soil at the depth where the crop roots are grown. The coefficients of accumulative pan evaporation (APE) were 2, 1.5, and 1.0. The total available soil moisture was regulated by gradually increasing effective root depth (see Table 1). As a result, the water regime began 20 days after the wheat sowing date. The total available soil moisture was 22, 36.4, and 50.2 mm in December, January, and February, respectively, until the end of the season. The dates and counts of irrigation for various treatments evaluated in both seasons are presented in Table 3.

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| Table 3. Accumulative pan evaporation and irrigation time | | | | | | | | | | |
| First season (2021- 2022) | | | | | | | | | | |
| Date | Ep, mm  /7day | | Irrigation time for every treat. | | | Date | Ep, mm  /7day | Irrigation time for every treat. | | |
| 2APE | 1.5APE | 1APE | 2APE | 1.5APE | 1APE |
| 1/12/2021 -7/12/2021 | 23.3 | |  |  |  | 1/3/2022 -7/3/2022 | 23.6 | 6/3 |  |  |
| 8/12/201 - 14/12/2021 | 18.7 | |  |  |  | 8/3/202 - 14/3/2022 | 21.9 | 14/3 | 8/3 | 8/3 |
| 15/12/2021 -21/12/2021 | 15.7 | | 20/12 | 20/12 | 20/12 | 15/3/2022 -21/3/2022 | 16.4 |  | 20/3 |  |
| 22/12/2021-28/12/2021 | 13.4 | | 27/12 | 28/12 |  | 22/3/2022-28/3/2022 | 9.5  Rainfall=5 | 23/3 |  |  |
| 29/12/2021-31/12/2021 | 2.2  Rainfall  =10.2 | |  |  |  | 29/3/2022-31/3/2022 | 11.6 |  |  | 29/3 |
| 1/1/2022 -7/1/2022 | 11.3 | |  |  | 4/1 | 1/4/2022 -7/4/2022 | 42.1 | 2/4-6/4 | 2/4-7/4 | 6/4 |
| 8/1/2022 - 14/1/2022 | 16.0 | | 8/1 | 11/1 |  | 8/4/2022 – 14/4/2022 | 41.5 | 10/4-14/4 | 12/4 | 14/4 |
| 15/1/2022 -21/1/2022 | 13.7 | | 16/1 |  | 19/1 | 15/4/2022 -21/4/2022 | 51.1 | 18/4 | 17/4 |  |
| 22/1/2022-28/1/2022 | 14.4 | | 25/1 | 23/1 |  | 22/4/2022-28/4/2022 | 52.8 |  |  |  |
| 29/1/2022-31/1/2022 | 7.3 | |  |  |  | 29/4/2022-30/4/2022 | 15.1 |  |  |  |
| 1/2/2022 -7/2/2022 | 15.4 | | 2/2 | 3/2 | 4/2 |  |  |  |  |  |
| **continue** | |  |  |  |  |  |  |  |  |  |
| 8/2/2022 - 14/2/2022 | 22.8 | | 11/2 |  |  |  |  |  |  |  |
| 15/2/2022 -21/2/2022 | 16.9 | | 18/2 | 15/2 | 22/2 |  |  |  |  |  |
| 22/2/2022-28/2/2022 | 22.2 | | 28/2 | 28/2 |  |  |  |  |  |  |
| 29/2/2022 | 3.0 | |  |  |  |  |  |  |  |  |
| Second season (2022- 2023) | | | | | | | | | | |
| Date | Ep, mm  /7day | | Irrigation time for every treat. | | | Date | Ep, mm  /7day | Irrigation time for every treat. | | |
| 2APE | 1.5APE | 1APE | 2APE | 1.5APE | 1APE |
| 5/12/2022 -7/12/2022 | 7.4 | |  |  |  | 1/3/2023 -7/3/2023 | 40.6 | 4/3 | 2/3 | 6/3 |
| 8/12/2022 - 14/1/2022 | 18.8 | |  |  |  | 8/3/2023- 14/3/2023 | 32.2 | 8/3-14/3 | 8/3 |  |
| 15/12/2022 -21/12/2022 | 20.0 | |  |  |  | 15/3/2023 -21/3/2023 | 32.6 | 19/3 | 16/3 | 17/3 |
| 22/12/2022-28/12/2022 | 16.0 | | 25/12 | 25/12 | 25/12 | 22/3/2023-28/3/2023 | 37 | 25/3 | 23/3 |  |
| 29/12/2022-31/12/2022 | 10.7 | | 30/12 | 31/12 |  | 29/3/2023-31/3/2023 | 17.4 | 29/3 | 29/3 | 27/3 |
| 1/1/2023 -7/1/2023 | 16.4 | | 2/1 | 5/1 | 2/1 | 1/4/2023-7/4/2023 | 44.1 | 2/4-6/4 | 4/4 | 5/4 |
| 8/1/2023 - 14/1/2023 | 14.9 | | 12/1 |  |  | 8/4/2023– 14/4/2023 | 34.4 | 11/4 | 10/4 |  |
| 15/1/2023 -21/1/2023 | 16.6 | | 20/1 | 17/1 | 20/1 | 15/4/2023 -21/4/2023 | 46.7 | 15/4 | 16/4 | 15/4 |
| 22/1/2023-28/1/2023 | 23.4 | | 26/1 | 26/1 |  | 22/4/2023-28/4/2023 | 47.3 |  |  |  |
| 29/1/2023-31/1/2023 | 12.9 | | 30/1 |  | 30/1 | 29/4/2023-30/4/2023 | 13.4 |  |  |  |
| 1/2/2023 -7/2/2023 | 26.3 | | 3/2 | ½ |  |  |  |  |  |  |
| 8/2/2023 - 14/2/2023 | 18.6 | | 10/2 | 10/2 | 8/2 |  |  |  |  |  |
| 15/2/2023 -21/2/2023 | 24.2 | | 19/2 | 21/2 |  |  |  |  |  |  |
| 22/2/2023-28/2/2023 | 24.5 | | 27/2 |  | 25/2 |  |  |  |  |  |

**2.5 Crop - water relations**

**2.5.1 Water consumptive use**:

For determining the crop water consumptive use (WCU), volumetric moisture content v /v % of soil was measured before and after irrigation using a sensor (moisture sensor S-345, china made) which directly records the reading on a digital screen, as well as at harvesting time, and the WCU between each two successive irrigations was calculated according to the following equation (Israelsen and Hansen, 1962).

WCU = {(Q2-Q1) / 100} ×D×10

Where:

WCU = crop water consumptive use (mm).

Q2= soil moisture percentage after irrigation.

Q1= soil moisture just before irrigation.

D = soil layer depth (cm).

**2.5.2 Water use efficiency (WUE)**

The obtained yield for each cubic unit of water used is referred to as water use efficiency (WUE).

**2.6 Agricultural practices and fertilizing systems**

Disc tillage was utilized to plow the experimental soil. To prepare the soil for wheat plant culture, topdressing with superphosphates (P₂O₅ 15%) at a rate of 200 kg fed-1 was performed. Potassium sulfate (48% K₂O) was given at a rate of 50 kg fed⁻¹ in two equal doses at sowing and 30 days after planting. Thereafter, it was tilled with a rotavator to prepare it for the automatic planter. Wheat variety Giza 171 was chosen as the testing crop and planted on the first and fifth of December 2021 and 2022, respectively. The grain rate was 60 kg fed-1, and it was buried in the soil at a depth of 3 cm and 15 cm between rows. Furthermore, wheat plants received 100 kg N fed-1 in the form of ammonium nitrate (33% N), divided into five doses. Wheat plants were also treated with chelated micronutrients such as Fe, Mn, Zn, and Cu. Spraying occurred 45 and 65 days after sowing. Furthermore, typical agricultural procedures were used in accordance with crop-specific requirements.

**2.7 Plant and soil measurements**

Following 151 and 146 days, one square meter of standing wheat crop was collected from each plot at the harvested stage on 30/4/2022 and 30/4/2023 in the first and second seasons, respectively. The collected material was used to determine the wheat yield components, which included biological yield, straw, and grain yield (Kg fed-1). Plant samples from each treatment were dried in an oven for 48 hours at 700C, ground in a stainless-steel mill, and then digested using a mix of sulfuric acid and hydrogen peroxide. Finally, small portions were taken and tested to measure total nitrogen, phosphorus, potassium and silicon as described by (Pag et al., 1982). Also, after plant harvest, 0-30 cm soil samples were taken from the experimental location. After air-drying, these samples passed through 2 mm sieve pores. Soil samples were subject to analysis soil chemicals properties (EC, pH, OM %) and nutrients availability (N, P, K and Si) as described by (Pag et al., 1982).

**2.8. Statistical analysis**

All data were statistically analysed over the seasons using the Snedecor and Cochran (1980) approach. To assess the significance of changes between treatments, the least significant difference (LSD) test was used, with a probability threshold of 0.05. In the end, the "MSTAT-C" computer program was used for all statistical analyses, as described in the research by Freed et al. (1989). Using the Microsoft Excel software, Matrix correlations were performed.

3. results and discussion

**3.1 water relationships**

**3.1.1 Water consumptive use**

Tables 4 and 5 present the monthly, daily, and total WCU values for wheat during the 2021/22 and 2022/23 winter, respectively. WCU of wheat generally increases gradually until reaching an optimum value in March, followed by a decline in April. The occurrence aligns with the crop development stages from the sowing date in December to the harvest date in April. This increase aligns with the climate change observed during the same prior period. Wheat crops utilized 2067–2051 m³fed-1, 1713–1654 m³fed-1, and 1365–1371 m³fed-1 for 2, 1.5, and 1APE irrigation intervals during the 2021/22 and 2022/23 winter, respectively. The results indicated a reduction corresponding to decreased APE. Each APE treatment received five pre-applied irrigations, followed by 17, 13, and 9 additional irrigations for the 2, 1.5, and 1 APE treatments during the first season, respectively. Also, 2021/2022, 10.2 mm of rain fell from 29/12–31/12/2021 and 5 mm from 22/3–28/3/2022. In the second season, when there was no rainfall at all, the number of irrigations included five pre-applied irrigations, followed by 21, 16, and 11 irrigations for 2, 1.5, and 1 APE treatments, respectively. As a result, there was an opposite connection between how often irrigation was done based on APE treatments and the WCU. Therefore, WCU increased when wheat was irrigated at 2 APE, which probably facilitated soil water availability. The results confirmed El-Nady and Shalaby (2014), who observed that watering wheat more often enhanced its water use WCU and yield. According to Ragheb et al. (2017), wheat crop productivity rose with decreasing watering intervals, peaking at 15 days and then 21 days. Crops under irrigation stress for 28 days result in reduced yields. In the study by Abdou and Emam (2018), irrigation schedules based on accumulative pan evaporation (APE) values of 1.0, 0.8, and 0.6 affected wheat yields and water utilization. It was shown that lower APE values extended watering intervals. All examined parameters decreased after analysis. Compared to higher crop evapotranspiration, Singh et al. (2018) found that more frequent irrigation increased seasonal WCU and wheat grain and straw yields.

Furthermore, the WCU for wheat decreased from 1804–1784 m³fed-1 to 1620–1604 m³fed-1 as a result of the applied conditions (KSi mixed with organic acids) during the two winter of 2021/22 and 2022/2023, respectively. The highest value was observed in the control treatment while the lowest values were observed at T5 when KSi was applied in conjunction with citric acid and acetic acid. The treatment resulted in a water savings of 11.35% during the 2021/2022 and 10.03% in the 2022/2023 winter, respectively. Obtained results due to foliar application of mixed treatments included silicon and organic acids. Hameed et al. (2013) showed that silica regulates drought stress tolerance by enhancing crop root development and water uptake along with elevates protective compounds, and augments water content. Moreover, silicon aids in the regulation of water loss, diminishes pore opening, and decelerates chlorophyll degradation, facilitating food production in dry conditions (Ma et al., 2004). Sonobe et al. (2009) found that in dry conditions, silicon helps plants take in more water and improves how light reaches the leaves while also reducing water loss, which leads to better photosynthesis (Saud et al., 2014).

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| **Table 4. The monthly, daily, and total water consumptive use (WCU, mm) of wheat is influenced by different irrigation intervals and various conditions during the winter season (2021-2022)** | | | | | | | | | | | | | | |
| **Treatment** | | **Months** | | | | | | | | | | **Total** | | |
| **Irrigation intervals** | **conditioners** | **December\*** | | **January** | | **February** | | **March** | | **April\*\*** | |  | |
| **Monthly**  **mm** | **Daily, mm** | **Monthly**  **mm** | **Daily, mm** | **Monthly**  **Mm** | **Daily, mm** | **Monthly**  **mm** | **Daily, mm** | **Monthly**  **mm** | **Daily, mm** | **mm** | **M3 fed1-** |
| 2 APE | T1 | 70.6 | 2.35 | 92.0 | 2.97 | 125.6 | 4.33 | 153 | 4.92 | 89.6 | 2.99 | 530 | 2227 |
| T2 | 70.6 | 2.35 | 90.0 | 2.90 | 118.2 | 4.08 | 143 | 4.62 | 85.3 | 2.84 | 507 | 2131 |
| T3 | 70.6 | 2.35 | 89.4 | 2.88 | 117.6 | 4.06 | 138 | 4.44 | 82.4 | 2.75 | 498 | 2090 |
| T4 | 70.6 | 2.35 | 86.5 | 2.79 | 112.3 | 3.87 | 122 | 3.94 | 81.2 | 2.71 | 473 | 1985 |
| T5 | 70.6 | 2.35 | 85.0 | 2.74 | 105.0 | 3.62 | 111 | 3.59 | 80.8 | 2.69 | 453 | 1901 |
| Mean | |  |  |  |  |  |  |  |  |  |  | 492 | 2067 |
| 1.5 APE | T1 | 69.0 | 2.30 | 85.0 | 2.74 | 92.0 | 3.17 | 115 | 3.71 | 63.5 | 2.12 | 425 | 1783 |
| T2 | 69.0 | 2.30 | 83.0 | 2.68 | 90.0 | 3.10 | 115 | 3.70 | 61.3 | 2.04 | 418 | 1755 |
| T3 | 69.0 | 2.30 | 82.0 | 2.65 | 86.0 | 2.97 | 107 | 3.46 | 61.1 | 2.04 | 405 | 1702 |
| T4 | 69.0 | 2.30 | 80.5 | 2.60 | 85.0 | 2.93 | 107 | 3.45 | 60.5 | 2.02 | 402 | 1688 |
| T5 | 69.0 | 2.30 | 80.0 | 2.58 | 82.0 | 2.83 | 98 | 3.16 | 60.0 | 2.00 | 389 | 1634 |
| Mean | |  |  |  |  |  |  |  |  |  |  | 408 | 1713 |
| 1 APE | T1 | 60.0 | 2.00 | 70.0 | 2.26 | 74.1 | 2.56 | 85 | 2.75 | 44.0 | 1.47 | 334 | 1401 |
| T2 | 60.0 | 2.00 | 70.0 | 2.26 | 73.0 | 2.52 | 86 | 2.77 | 43.0 | 1.43 | 332 | 1394 |
| T3 | 60.0 | 2.00 | 70.0 | 2.26 | 73.0 | 2.52 | 84 | 2.71 | 37.0 | 1.23 | 324 | 1361 |
| T4 | 60.0 | 2.00 | 68.0 | 2.20 | 72.0 | 2.48 | 83 | 2.66 | 37.0 | 1.23 | 320 | 1342 |
| T5 | 60.0 | 2.00 | 67.0 | 2.20 | 70.0 | 2.40 | 82 | 2.63 | 37.0 | 1.23 | 316 | 1326 |
| Mean | |  |  |  |  |  |  |  |  |  |  | 325 | 1365 |
| Mean of conditioners | T1 | 66.5 | 2.22 | 82.3 | 2.66 | 97.2 | 3.35 | 118 | 3.79 | 65.7 | 2.19 | 429 | 1804 |
| T2 | 66.5 | 2.22 | 81.0 | 2.61 | 93.7 | 3.23 | 115 | 3.70 | 63.2 | 2.10 | 419 | 1760 |
| T3 | 66.5 | 2.22 | 80.5 | 2.60 | 92.2 | 3.18 | 110 | 3.54 | 60.2 | 2.01 | 409 | 1718 |
| T4 | 66.5 | 2.22 | 78.3 | 2.53 | 89.8 | 3.09 | 104 | 3.35 | 59.6 | 1.99 | 398 | 1672 |
| T5 | 66.5 | 2.22 | 77.3 | 2.51 | 85.7 | 2.95 | 97 | 3.13 | 59.3 | 1.97 | 386 | 1620 |
| *\*Sowing date: 1/12/2021 \*\* harvest date: 30/4/2022* | | | | | | | | | | | | | | |

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| **Table 5. The monthly, daily, and total water consumptive use (WCU, mm) of wheat is influenced by different irrigation intervals and various conditions during the winter season (2022-2023).** | | | | | | | | | | | | | | | |
| **Treatment** | | **Months** | | | | | | | | | | | **Total** | | |
| **Irrigation intervals** | **conditioners** | **December\*** | | **January** | | **February** | | **March** | | **April\*\*** | | |
| **Monthly**  **mm** | **Daily, mm** | **Monthly**  **mm** | **Daily, mm** | **Monthly**  **mm** | **Daily, mm** | **Monthly**  **mm** | **Daily, mm** | **Monthly**  **mm** | **Daily, mm** | **mm** | | **M3 fed-1** |
| 2 APE | T1 | 60.0 | 2.40 | 94.8 | 3.06 | 119.6 | 4.27 | 151 | 4.86 | 100.8 | 3.40 | 526 | | 2209 |
| T2 | 60.0 | 2.40 | 92.9 | 3.00 | 107.0 | 3.82 | 140 | 4.52 | 99.3 | 3.30 | 499 | | 2098 |
| T3 | 60.0 | 2.40 | 90.0 | 2.90 | 105.8 | 3.78 | 131 | 4.23 | 96.1 | 3.20 | 483 | | 2029 |
| T4 | 60.0 | 2.40 | 87.9 | 2.84 | 102.5 | 3.66 | 130 | 4.19 | 96.0 | 3.20 | 476 | | 2001 |
| T5 | 60.0 | 2.40 | 83.9 | 2.71 | 96.0 | 3.43 | 128 | 4.11 | 90.0 | 3.00 | 457 | | 1921 |
| Mean | |  |  |  |  |  |  |  |  |  |  | 488 | | 2052 |
| 1.5 APE | T1 | 58.0 | 2.32 | 71.0 | 2.29 | 78.0 | 2.79 | 130 | 4.19 | 74.1 | 2.50 | 411 | | 1726 |
| T2 | 58.0 | 2.32 | 70.4 | 2.27 | 76.0 | 2.71 | 127 | 4.10 | 74.0 | 2.50 | 405 | | 1703 |
| T3 | 58.0 | 2.32 | 69.0 | 2.23 | 73.0 | 2.61 | 125 | 4.03 | 72.0 | 2.40 | 397 | | 1667 |
| T4 | 58.0 | 2.32 | 68.0 | 2.19 | 72.0 | 2.57 | 118 | 3.81 | 70.0 | 2.30 | 386 | | 1621 |
| T5 | 58.0 | 2.32 | 68.0 | 2.19 | 71.0 | 2.54 | 112 | 3.61 | 61.0 | 2.00 | 370 | | 1554 |
| Mean | |  |  |  |  |  |  |  |  |  |  | 394 | | 1654 |
| 1 APE | T1 | 55.0 | 2.20 | 67.0 | 2.16 | 71.0 | 2.54 | 86 | 2.77 | 58.0 | 1.90 | 337 | | 1415 |
| T2 | 55.0 | 2.20 | 66.0 | 2.13 | 70.0 | 2.50 | 86 | 2.76 | 54.0 | 1.80 | 331 | | 1388 |
| T3 | 55.0 | 2.20 | 66.0 | 2.13 | 69.0 | 2.46 | 83 | 2.68 | 52.0 | 1.70 | 325 | | 1365 |
| T4 | 55.0 | 2.20 | 65.0 | 2.10 | 68.0 | 2.43 | 83 | 2.70 | 51.0 | 1.70 | 322 | | 1352 |
| T5 | 55.0 | 2.20 | 64.0 | 2.06 | 67.0 | 2.39 | 81 | 2.60 | 51.0 | 1.70 | 318 | | 1336 |
| Mean | |  |  |  |  |  |  |  |  |  |  | 327 | | 1371 |
| Mean of conditioners | T1 | 57.7 | 2.31 | 77.6 | 2.50 | 89.5 | 3.20 | 122 | 3.94 | 77.6 | 2.60 | 425 | | 1783 |
| T2 | 57.7 | 2.31 | 76.4 | 2.47 | 84.3 | 3.01 | 118 | 3.79 | 75.8 | 2.53 | 412 | | 1730 |
| T3 | 57.7 | 2.31 | 75.0 | 2.42 | 82.6 | 2.95 | 113 | 3.65 | 73.4 | 2.43 | 402 | | 1687 |
| T4 | 57.7 | 2.31 | 73.6 | 2.38 | 80.8 | 2.89 | 110 | 3.57 | 72.3 | 2.40 | 395 | | 1658 |
| T5 | 57.7 | 2.31 | 72.0 | 2.32 | 78.0 | 2.79 | 107 | 3.44 | 67.3 | 2.23 | 382 | | 1604 |
| *\*Sowing date: 5/12/2022 \*\*Harvest date: 30/4/2023* | | | | | | | | | | | | | | | |

**3.1.2 Water use efficiency**

Table 6 shows the results for water use efficiency in wheat crops, expressed as kg of grain yield per cubic meter of consumed irrigation water, which were affected by irrigation intervals (depending on APE) and different conditioners (KSi, citric acid, and acetic acid) during the 2021/2022 and 2022/2023 winter. The results show that increasing irrigation intervals (by decreasing APE from 2 to 1) considerably reduces water usage efficiency (WUE). The computed average values are 1.113, 0.729 and 0.624 in winter 2021/2022 and -1.104, 0.741 and 0.603 in 2022/2023 season for irrigation treatments 2, 1.5, and 1 APE, respectively. This finding could be explained by the fact that plants had to use a large amount of energy in absorbing soil moisture rather than storing it in grain. Comparable results were found by Abdou and Emam (2016). Berca et al. (2021) found that producing one ton of wheat during the drought years 2019 and 2020 required around 1000 and 1050 m³ of water, respectively. Results of WUE showed substantial variances in response to conditioner treatments. The results indicated that when applied, T5 had the greatest values. Similar results were

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| **Table 6. Water use efficiency of wheat crop in winter 2021/2022 and 2022/2023 as affected by irrigation intervals and different conditioners** | | | |
| **Irrigation treatments** | **Conditioners** | **Water use efficiency** | |
| **First season** | **Second season** |
| 2 APE | T1 | 0.899 | 0.890 |
| T2 | 1.039 | 1.043 |
| T3 | 1.092 | 1.112 |
| T4 | 1.195 | 1.178 |
| T5 | 1.340 | 1.296 |
| Mean | | 1.113 | 1.104 |
| 1.5 APE | T1 | 0.600 | 0.613 |
| T2 | 0.659 | 0.668 |
| T3 | 0.724 | 0.730 |
| T4 | 0.794 | 0.798 |
| T5 | 0.867 | 0.896 |
| Mean | | 0.729 | 0.741 |
| 1 APE | T1 | 0.546 | 0.516 |
| T2 | 0.581 | 0.564 |
| T3 | 0.621 | 0.606 |
| T4 | 0.661 | 0.638 |
| T5 | 0.712 | 0.690 |
| Mean | | 0.624 | 0.603 |
| Mean of conditioners | T1 | 0.682 | 0.673 |
| T2 | 0.759 | 0.758 |
| T3 | 0.813 | 0.816 |
| T4 | 0.883 | 0.871 |
| T5 | 0.973 | 0.960 |
| LSD at 0.05 | APE | 0.032 | 0.032 |
| T | 0.031 | 0.031 |
| APE\*T | 0.053 | 0.053 |
| *APE (accumulative pan evaporation), T1 (control), T2 (KSi), T3 (T2+ citric acid), T4 (T2+ acetic acid), T5 (T2+ citric+ acetic acids).* | | | |

observed by Saudy et al. (2023) and Hassan et al. (2024). The interaction of irrigation treatments and conditioners had a substantial impact on wheat WUE in both seasons. The best interaction occurred between 2APE and T5.

**3.2 Wheat Yield components**

**3.2.1 The impact of irrigation intervals**.

The results in Fig. 1 indicate how wheat crops respond to varied irrigation intervals (2, 1.5, and 1 APE), which were evaluated by accumulative pan evaporation (APE). The metrics for wheat development encompassed biological, straw, and grain yields during two winters' seasons in sandy soil conditions. The average values of irrigation scheduling significantly affect wheat yield (biological, grain, and straw yield) in both growth seasons (Fig. 1). Irrigation at 2.0 APE produced the highest average yields in the 2021/2022 season, with 5911, 3627, and 2283 kg fed-1 for biological, straw, and grain yield. During the 2022/2023 season, the averages remained elevated, recording 5835, 3583, and 2252 Kg fed-1 for biological, straw and grain yield. This phenomenon is related to the importance of water in the metabolic processes of plants, as it not only facilitates the respiration process and enhances photosynthesis but also improves the absorption of water by plants by facilitating its movement within the soil. The productivity of wheat crops is significantly influenced by all of these factors. This finding corresponds with the conclusions of Verma et al. (2023).

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| **Fig. 1. Average values of wheat yield components grown in sandy soil that were impacted by different irrigation intervals (APE) at two successive seasons.** |
| *BY (Biological Yield), SY (Straw Yield), GY (Grain Yield), APE* (*accumulative Pan Evaporation)* |

On the other hand, when irrigation intervals were raised at 1.5 APE, biological, grain, and straw yields were lowered by 40, 36, and 45% in the first season, respectively, and 39, 36, and 44% in the second season. When irrigation intervals were extended by irrigation at 1.0 APE, biological, grain, and straw yields decreased by 58, 55, and 62% in the first season and 58, 55, and 63% in the second season, respectively. This conclusion might be attributed to the influence of water stress on lowering growth characteristics. These findings are consistent with those observed by Abdou and Emam (2018) and Verma et al. (2023). In addition, the results of Fig. 1 indicate that the biological, grain, and straw production yields were the lowest for treatment 1.0 APE. The decrease in yield components may have been caused by unsaturated soil moisture conditions. The turgor pressure of roots is induced by water stress, resulting in a vapor gap that reduces the synthesis of dry matter and the assimilation of nutrients. This decline is due to the reduced interaction between the roots and water particles (Gomaa et al. (2020). Additionally, crop component yields exhibited minor variations between seasons, with the initial season producing greater yields than the subsequent one. Meteorological variations throughout the two seasons influenced both agricultural output and crop responses to irrigation practices.

**3.2.2 The impact of potassium silicate, citric and acetic acid**

The results in Fig. 2 show the effect of tested treatments CR (T1), KSi (T2), T2+ citric acid (T3), T2+ acetic acid (T4), and their combination (T5) on wheat crop metrics (biological, straw, and grain yields) throughout two winter seasons in sandy soil. Overall, all treatments enhanced wheat plant growth indices when compared to T1 therapy. Furthermore, T5 was the superior treatment, boosting wheat biological, straw, and grain yields by 29, 29, and 28% in the first season and 29, 30, and 28% in the second season, respectively. The increase could be due to the positive effects of silicon and organic acids on plant development. Our findings support Ma and Yamaji (2015), who reported that Si fertilization boosts grain output in certain plants. Having enough Si in the cereal husk reduces water loss, which improves grain fertility and plant growth.

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| **Fig. 2. Average values of wheat yield components grown in sandy soil that were impacted by potassium silicate, citric acid and acetic acid at two successive seasons.** |
| *BY (Biological Yield), SY (Straw Yield), GY (Grain Yield), T1 (control), T2 (KSi), T3 (T2+ citric acid), T4 (T2+ acetic acid), T5 (T2+ citric+ acetic acids*). |

Morsy et al. (2024) observed that KSi helps osmoregulation, photosynthesis, respiration, and assimilate translation into sink organs which improve the growth. Also, citric and acetic acid are essential for plants' vital activities, as evidenced by increased wheat output. As a result, acetic acid stimulates specific physiological and biochemical processes that control the growth and development of roots and shoots; hence, it improves plant growth parameters. According to Rahman et al. (2021), these processes involve the rate at which plants make food using sunlight, how well they use water, how easily they take in air, the production of chlorophyll, the moisture level in leaves, how efficiently they use nutrients, and the activation of their defense against damage.

**3.2.3 The interaction between irrigation intervals and potassium silicate, when mixed with citric and acetic acid**

Table 7 shows how wheat yield components responded over two seasons in sandy soil to the interaction of irrigation intervals and tested treatments. Unlike the control treatment, the experimental interaction treatments had a positive effect on wheat growth measures, such as biological yield (BY), straw yield (SY), and grain yield (GY), over two seasons on sandy soil. Also, Table 7 shows that T5+ 2 APE was the most effective treatment, increasing wheat yield components (BY, SY, and GY) by 31%, 33%, and 27% in the first season, and by 32%, 36%, and 27% in the second season, compared to no treatment. One possible explanation for this phenomenon is that silicon, citric acid, and acetic acid can enhance the hardness and durability of plant tissue. This, in turn, protects plants from the adverse effects of drought stress. Additionally, these acids can enhance photosynthetic processes, the efficiency of

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| **Table 7. Response of wheat yield components to the interactions of irrigation intervals and KSi, citric acid, acetic acid, and their combination.** | | | | | | | | |
| **Irrigation treatments** | **Conditioners** | **Yield (Kg fed-1)** | | | | | | |
| **Frist season** | | | **Second season** | | | |
| **BY** | **SY** | **GY** | **BY** | **SY** | **GY** |
| 2 APE | T1 | 5060 | 3057 | 2003 | 4943 | 2977 | 1967 |
| T2 | 5673 | 3460 | 2213 | 5640 | 3450 | 2190 |
| T3 | 5983 | 3700 | 2283 | 5920 | 3663 | 2257 |
| T4 | 6217 | 3847 | 2370 | 6140 | 3783 | 2357 |
| T5 | 6620 | 4073 | 2547 | 6533 | 4043 | 2490 |
| 1.5 APE | T1 | 3107 | 2037 | 1070 | 3077 | 2013 | 1063 |
| T2 | 3343 | 2187 | 1157 | 3285 | 2141 | 1143 |
| T3 | 3487 | 2253 | 1233 | 3437 | 2213 | 1223 |
| T4 | 3733 | 2393 | 1340 | 3673 | 2373 | 1300 |
| T5 | 3980 | 2563 | 1417 | 3907 | 2507 | 1400 |
| 1 APE | T1 | 2177 | 1410 | 767 | 2117 | 1387 | 730 |
| T2 | 2400 | 1590 | 810 | 2347 | 1563 | 783 |
| T3 | 2480 | 1633 | 847 | 2433 | 1607 | 827 |
| T4 | 2557 | 1670 | 887 | 2523 | 1660 | 863 |
| T5 | 2717 | 1773 | 943 | 2683 | 1763 | 920 |
| LSD at 0.05 | | 35.97 | 23.5 | 25.03 | 42.5 | 34.6 | 23.9 |
| *APE (accumulative pan evaporation), BY (Biological Yield), SY (Straw Yield), GY (Grain Yield), T1 (control), T2 (KSi), T3 (T2+ citric acid), T4 (T2+ acetic acid), T5 (T2+ citric+ acetic acids).* | | | | | | | | |

transpiration and evaporation, and the chlorophyll concentration per leaf area. Furthermore, it enhances the manner in which plants are able to absorb and transfer nutrients during their growth. The results match the studies by Ali et al. (2019). Si builds up under the leaf's outer layer, creating a double layer that makes cell walls stronger and helps keep water from escaping. This mechanism mitigates the harmful effects of drought stress on plants, as noted by Ma (2004). Also, Hassan et al. (2019) say silicon influences chlorophyll synthesis, photosynthetic efficiency, antioxidant enzyme activity, plant hormone balance, protein production, and water and nutrient absorption.

Furthermore, Ali and Ibrahim (2021) highlighted that the importance of potassium functions in plant growth and nutrition include regulating metabolic processes, promoting enzymes, and supporting cell division and growth. Therefore, providing wheat plants with potassium silicate is crucial for maintaining production, especially in unfavorable circumstances like droughts. Moreover, Ondrasek et al. (2019) discovered that foliar application of citric acid boosted plant germination rate and root weight by increasing the activity of various antioxidant enzymes. Previous research has demonstrated that foliar application of citric acid greatly increases leaf pigments and chlorophyll content in stressed plants (Farid et al. (2019). Furthermore, Soroori and Danaee (2023) discovered that applying citric acid to leaves can enhance plant growth and yield during arid conditions. citric acid as a natural chelating agent, it facilitates the absorption of water and nutrients in plants and synthesizes hormones that assist them in managing stress. On the other hand, Rahman et al. (2021) discovered that acetic acid could play a role in the synthesis and inhibition of the degradation of photosynthetic pigments, thereby enhancing photosynthetic efficiency. This process is linked to lower water loss, reduced opening of leaf pores, and higher leaf temperature when there is not enough water, which matches with more water in the leaves, thicker leaves, and less wilting of the leaves. Moreover, the data in Table 7 indicate that crop yield components varied seasonally, with the second season yielding less than the first. Seasonal weather fluctuations affected crop reactions to irrigation methods and agricultural output.

**3.3 Macronutrients and silicon total content in wheat plant**

**3.3.1 Impact of irrigation intervals**

The data in Fig. 3 show how the total amounts of nitrogen, phosphorus, potassium, and silicon in straw and grain change with different irrigation schedules, based on total pan evaporation measured with different coefficients (2, 1.5, and 1 APE), over two growing seasons in sandy soil. The current data show that irrigation scheduling had a significant impact on wheat straw and grain nutrition total content in both growing seasons. In simple terms, when irrigation was set at 2.0 APE, it resulted in the highest amounts of nitrogen, phosphorus, potassium, and silicon in both the straw and grain during the first season, with straw having 35, 13.6, 33.1, and 26.7 kg fed⁻¹, and grain having 35.5, 10.4, 16.6, and 17.4 kg fed⁻¹. The averages for the second season were also high, measuring 36.1, 14.7, 32.3, and 25.6 kg fed⁻¹ for straw and 38.7, 10.0, 18.8, and 18.0 Kg fed-1 for grain, respectively. This highlights the importance of water in plant metabolism and its role in facilitating nutrient distribution in the soil, thereby improving nutrient absorption by plants. On the other hand,

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| **Fig. 3 Responses of the total amount of N, P, K, and Si in wheat straw and grain in sandy soil as affected by irrigation intervals for two seasons.** |
| *APE (accumulative pan evaporation)* |

increasing the time between irrigation to 1.5 and 1 APE led to a decrease in the amounts of total nitrogen, phosphorus, potassium, and silicon in straw and grain. This decrease may be due to plants absorbing fewer nutrients during periods of unsaturated soil moisture content. The turgor pressure of stressed roots generates a vapor gap surrounding them, diminishing nutrient absorption due to reduced interaction between the roots and water molecules. Furthermore, inadequate soil moisture impedes the transport, distribution, and absorption of nutrients by plants. Our findings support by Verma et al. (2023). In addition, Saudy and El-Metwally (2022) found that a lack of water reduced soluble sugars and leaf colors, which hampered nutrient absorption. As well as, dryness hinders plant development and productivity by negatively affecting the uptake and utilisation of mineral nutrients (Mubarak et al. 2021) and Plant nitrogen absorption capability decreased due to drought (Abd– Elrahman et al. 2022). Along with Ahmad et al. (2007) discovered that the absorption of silicon by wheat plants decreased when soil water content decreased.

**3.3.2 The impact of potassium silicate when combined with citric and acetic acid**

The results in Fig. 4 show how the total content of N, P, K, and Si in straw and grain changed over two wheat growing seasons in sandy soil due to the treatments used. All treatments increased the overall nutritional content of the grain and straw compared to the T1 thereby. Furthermore, the T5 treatment of N, P, K, and Si total content of wheat produced the highest value, with values in the first season of 31, 12, 29, and 22 kg fed-1 for straw and 38, 9, 15, and 14 kg fed-1 for grain; in the second season, the corresponding values were 37, 13, 28, and 23 kg fed-1 for straw and 40, 8, 16, and 14 kg fed-1 for grain. This may be explained by the advantageous effects of silicon and organic acid treatments on improving wheat plant root growth and development, which in turn allowed for increased nutrient absorption and transfer inside the plants. These findings are in excellent accord with those of Morsy et al. (2024) who found that foliar application of potassium silicate considerably raised the total amounts of silicon, potassium, and phosphorus in wheat straw and grains compared

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| **Fig. 4 Total quantity of N, P, K, and Si in wheat straw and grain responses to potassium silicate, acetic acid, citric acid, and their combination across two seasons in sand soil.** |
| *APE (accumulative pan evaporation), T1 (control), T2 (KSi), T3 (T2+ citric acid), T4 (T2+ acetic acid), T5 (T2+ citric+ acetic acids).* |

to the control group. Later on, research by El-Leboudi et al. (2019) showed that higher silicon levels in wheat plants were associated with higher silicon accumulation in the roots and shoots. additionally, findings by Morsy et al. (2023) highlighted that silicon boosts enzymes that help plants absorb and transport potassium, this aligns with Liang's (1999) research, which posits that a cell membrane-based ATP pump actively takes in and moves potassium ions. Silicon may increase potassium absorption by activating H⁺-ATPase. Moreover, Sheng et al. (2018) found that Si deposition altered the cell wall structure, doubling NH+ absorption compared to cells cultivated without Si. Si stabilizes the cell wall, optimizing nutrient intake and boosting growth and development with supplementation. Previously, Singh et al. (2006) found that silicon levels affected grain and straw nitrogen uptake, possibly due to silicon's synergistic effect with other nutrients. Furthermore, Rahman et al. (2021) found that acetic acid considerably improved plant tissue mineral and nutrient absorption, while Miyazawa (2014) found that citric acid increased phosphorus absorption. According to Khan et al. (2018) and Nadeem et al. (2019), acetic acid improved root branching and root-shoot system growth, helping plants reach water and nutrients from deeper soil layers.

**3.3.3 Impact of interaction between irrigation intervals and conditioners treatments**

The results in Table 8 show how wheat straw and grain nutrient total content respond to the combination of irrigation intervals and tested treatments over two seasons in sandy soil. In comparison to the control treatment, the current experimental interaction treatments had a positive effect on total nutritional content. The irrigation treatment 2 APE combined with T5 was the most effective interaction therapy for raising wheat straw and grain N, P, K, and Si total content. This may be due to the ability of silicon, citric acid, and acetic acid to strengthen and harden plant tissues, which protects them from drought stress and enhances essential plant functions related to nutrient absorption and transport. Our results match the studies by Akhtar et al. (2021) who found that wheat that was stressed by drought and exposed to Si absorbed a lot more N, P, and K. This extra nutrition comes from Si, which makes it easier for nutrients to be absorbed and moved around the body. These things improved the plants' nutrition by making the roots longer, wider, and more fluid (Etesami and Jeong, 2018). Mehrabanjoubani et al. (2015) added that Si increased the activity of ion channels and carriers, improved electrochemical gradients, and improved the functionality of membrane transporters. These changes led to better nutrient intake and movement in the steel, which in turn led to plant growth. On the other hand, El-Maddah et al. (2012), which indicated that spraying citric acid on wheat plants greatly affected the levels of nitrogen, phosphorus, and potassium in the grains during both growing seasons, compared to control. The results we saw might be due to adding citric to the leaves, which boost nitrogen, phosphorus, and potassium levels. Moreover, Rahman et al. (2021) demonstrated that acetic acid supplementation significantly enhanced nutrient absorption and tissue mineral ratios in plants. Nadeem et al. (2019) added that acetic acid probably helps plants grow more roots and shoots, which allows them to find more water and nutrients from the soil around them and deeper down as well as Rahman et al. (2024) found that acetic acid enhanced nitrogen absorption in plants, thereby improving their resistance to drought.

**3.4 Some soil chemical characteristics and nutrients availability following wheat harvest**

The data in Tables 9 and 10 show how the EC, pH, OM%, and availability of nutrients (N, P, K, and Si) changed in sandy soil over two wheat seasons. The changes were caused by different amounts of watering and treatments under study.

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| **Table 8. Total content of N, P, K, and Si in wheat straw and grain responses to the interactions of KSi, citric acid, acetic acid, and their combination treatments with irrigation intervals across two seasons in sand soil.** | | | | | | | | | | | | | | | | | | | | | |
| **Irrigation treatments** | **conditioners** | **Nutrients total content (Kg fed-1)** | | | | | | | | | | | | | | | | | | | |
| **First season** | | | | | | | | | | **Second season** | | | | | | | | | |
| **Straw** | | | | | **Grain** | | | | | **Straw** | | | | | **Grain** | | | | |
| **N** | **P** | **K** | **Si** | **N** | | **P** | **K** | **Si** | **N** | | **P** | **K** | **Si** | **N** | | **P** | **K** | **Si** |
| 2 APE | T1 | 27.9 | 7.6 | 24.6 | 17.1 | 29.7 | | 6.6 | 14.9 | 11.9 | 30.8 | | 9.1 | 26.3 | 15.8 | 30.6 | | 6.85 | 16.6 | 13.2 |
| T2 | 33.4 | 10.2 | 30.8 | 23.7 | 32.2 | | 8.3 | 15.9 | 15.1 | 33.2 | | 13.1 | 30.6 | 21.7 | 35.3 | | 9.60 | 17.9 | 15.5 |
| T3 | 34.4 | 13.1 | 34.1 | 27.2 | 32.8 | | 9.9 | 16.4 | 17.9 | 36.4 | | 15.2 | 32.8 | 24.3 | 37.9 | | 9.93 | 18.5 | 18.5 |
| T4 | 38.1 | 17.0 | 35.5 | 29.8 | 35.4 | | 12.4 | 17.2 | 19.7 | 37.1 | | 16.9 | 34.9 | 31.0 | 42.4 | | 10.8 | 19.1 | 20.1 |
| T5 | 41.2 | 20.2 | 40.8 | 35.8 | 47.4 | | 14.6 | 18.6 | 22.4 | 43.3 | | 19.4 | 37.0 | 35.4 | 47.2 | | 12.6 | 22.1 | 22.5 |
| 1.5 APE | T1 | 15.3 | 4.9 | 18.0 | 11.1 | 25.4 | | 3.4 | 12.5 | 5.4 | 28.0 | | 4.9 | 18.2 | 9.9 | 27.7 | | 3.04 | 12.8 | 6.7 |
| T2 | 24.9 | 6.3 | 20.0 | 13.4 | 26.5 | | 4.3 | 12.9 | 7.6 | 29.2 | | 7.5 | 20.7 | 12.0 | 28.1 | | 4.70 | 13.1 | 8.9 |
| T3 | 25.3 | 6.9 | 21.3 | 15.6 | 31.8 | | 4.8 | 13.3 | 8.3 | 31.5 | | 8.8 | 22.0 | 13.4 | 30.7 | | 5.20 | 13.4 | 9.2 |
| T4 | 26.0 | 8.6 | 23.8 | 17.8 | 32.7 | | 5.9 | 13.9 | 10.7 | 33.0 | | 10.1 | 23.8 | 19.1 | 34.5 | | 5.71 | 13.6 | 10.5 |
| T5 | 27.5 | 10.4 | 26.1 | 20.0 | 35.1 | | 6.9 | 14.7 | 11.9 | 37.4 | | 11.8 | 26.1 | 20.6 | 40.6 | | 6.93 | 14.6 | 12.3 |
| 1 APE | T1 | 12.7 | 3.7 | 15.3 | 4.5 | 17.3 | | 2.6 | 11.4 | 3.0 | 17.4 | | 2.9 | 15.2 | 4.4 | 20.0 | | 1.83 | 11.7 | 3.6 |
| T2 | 14.1 | 4.5 | 16.4 | 6.2 | 20.8 | | 3.0 | 11.6 | 4.6 | 18.2 | | 5.3 | 17.6 | 8.5 | 22.2 | | 3.11 | 12.0 | 4.7 |
| T3 | 16.4 | 5.1 | 17.8 | 7.3 | 26.4 | | 3.3 | 11.7 | 5.1 | 21.6 | | 5.7 | 18.6 | 9.3 | 27.4 | | 3.20 | 12.2 | 5.4 |
| T4 | 20.5 | 5.4 | 19.6 | 8.0 | 27.4 | | 3.6 | 12.0 | 5.7 | 24.8 | | 6.3 | 19.0 | 12.3 | 32.2 | | 3.40 | 12.4 | 6.0 |
| T5 | 23.5 | 7.0 | 20.4 | 10.5 | 30.5 | | 4.5 | 12.6 | 6.9 | 30.7 | | 7.8 | 20.7 | 13.9 | 33.4 | | 4.30 | 12.8 | 6.9 |
| LSD at 0.05 | | 2.42 | 1.33 | 1.16 | 2.45 | 3.02 | | 0.77 | 0.47 | 1.2 | 4.57 | | 0.85 | 0.97 | 2.1 | 2.59 | | 0.49 | 1.34 | 1.1 |
| *APE (accumulative pan evaporation ), T1 (control), T2 (KSi), T3 (T2+ citric acid), T4 (T2+ acetic acid), T5 (T2+ citric+ acetic acids).* | | | | | | | | | | | | | | | | | | | | | |

**3.4.1 Soil EC**

The results presented in Table 9 demonstrate that irrigation intervals and various treatments (interaction treatments) exerted a negligible influence on the soil EC values although EC increased with increasing of irrigation intervals. The implementation of amendment treatments led to a decrease in soil EC values, with T5 treatment exhibiting the lowest value. Compared to T1 therapy, the reduction percentages were 3.4% and 11.4% in the first and second seasons, respectively. This difference is likely due to the migration of anions from the soil to the roots and the complexes formed between KSi, citric acid, acetic acid, and cations in the soil, which reduces the concentration of ions in the soil. Furthermore, the soil EC readings in the second season were inferior to those in the first season. These results were in line with those of El-Maddah et al. (2012), who found that increasing irrigation intervals in the first and second seasons increased EC values. This could be because the lowest irrigation intervals caused more soluble salts to leach and decreased them in the two seasons. Morsy et al. (2024) found that using silicon treatments slightly lowered soil EC compared to the control, but we still don't know how silicon affects sandy soils on its own. The decline in electrical conductivity of sandy soil in the presence of potassium silicate, citric

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| **Table 9. Soil EC, pH and OM% after harvested wheat responses to irrigation intervals and /or KSi, citric acid, acetic acid, and their combination treatments across two seasons in sand soil.** | | | | | | | |
| **Irrigation treatments** | **Conditioners** | **First season** | | | **Second season** | | |
| **EC dsm-1** | **pH** | **OM%** | **EC dsm-1** | **pH** | **OM%** |
| 2 APE | T1 | 0.258 | 7.61 | 0.373 | 0.251 | 7.69 | 0.542 |
| T2 | 0.254 | 7.51 | 0.383 | 0.250 | 7.68 | 0.580 |
| T3 | 0.254 | 7.44 | 0.392 | 0.247 | 7.66 | 0.641 |
| T4 | 0.250 | 7.34 | 0.400 | 0.242 | 7.66 | 0.665 |
| T5 | 0.246 | 7.27 | 0.530 | 0.235 | 7.61 | 0.673 |
| Mean | | 0.252 | 7.44 | 0.416 | 0.245 | 7.66 | 0.62 |
| 1.5 APE | T1 | 0.260 | 7.65 | 0.284 | 0.254 | 7.73 | 0.471 |
| T2 | 0.259 | 7.53 | 0.328 | 0.251 | 7.71 | 0.562 |
| T3 | 0.255 | 7.50 | 0.336 | 0.249 | 7.70 | 0.586 |
| T4 | 0.254 | 7.49 | 0.410 | 0.244 | 7.68 | 0.653 |
| T5 | 0.248 | 7.42 | 0.447 | 0.237 | 7.57 | 0.663 |
| Mean | | 0.255 | 7.52 | 0.361 | 0.247 | 7.68 | 0.587 |
| 1 APE | T1 | 0.276 | 7.67 | 0.216 | 0.305 | 8.00 | 0.440 |
| T2 | 0.274 | 7.52 | 0.295 | 0.273 | 7.76 | 0.445 |
| T3 | 0.254 | 7.50 | 0.341 | 0.247 | 7.73 | 0.484 |
| T4 | 0.247 | 7.49 | 0.377 | 0.242 | 7.66 | 0.518 |
| T5 | 0.244 | 7.47 | 0.400 | 0.238 | 7.66 | 0.541 |
| Mean | | 0.259 | 7.53 | 0.326 | 0.261 | 7.76 | 0.486 |
| Mean of treatment | T1 | 0.265 | 7.64 | 0.291 | 0.270 | 7.81 | 0.484 |
| T2 | 0.262 | 7.52 | 0.336 | 0.258 | 7.72 | 0.529 |
| T3 | 0.254 | 7.48 | 0.356 | 0.248 | 7.70 | 0.570 |
| T4 | 0.250 | 7.44 | 0.396 | 0.243 | 7.66 | 0.612 |
| T5 | 0.246 | 7.39 | 0.459 | 0.237 | 7.61 | 0.625 |
| LSD at 0.05 | APE | 0.030 | 0.17 | 0.03 | 0.03 | 0.09 | 0.03 |
| T | 0.031 | 0.14 | 0.03 | 0.03 | 0.08 | 0.03 |
| APE\*T | 0.053 | 0.24 | 0.05 | 0.05 | 0.13 | 0.05 |
| *APE accumulative pan evaporation), T1 (control), T2 (KSi), T3 (T2+ citric acid), T4 (T2+ acetic acid), T5 (T2+ citric+ acetic acids).* | | | | | | | |

acid, and acetic acid necessitates more investigation. Also, the control treatment always showed higher EC compared to the treatments that used citric acid, according to Pérez-Labrada et al. (2016).

**3.4.2 Soil pH**

The data in Table 9 indicate that soil pH levels increased with longer irrigation intervals. Irrigation intervals were increased from 2 APE to 1 APE, resulting in soil pH values rising from 7.44 to 7.53 in the first season and from 7.66 to 7.76 in the second season. The research conducted by Soomro et al. (2001) revealed comparable results, demonstrating that extended irrigation intervals marginally elevated soil pH levels. The current study found that the treatments used successfully reduced soil pH levels, with the lowest pH seen in treatment T5 which had decreases of 3.3% in the first season and 2.6% in the second season compared to the T1 treatment. Our results reveal that the T5 + 2 APE treatment led to the lowest soil pH, reducing it by 4.5% in the first season and 1.0% in the second season compared to theT1 treatment with 2 APE. Furthermore, the soil pH values in the second season were higher than those in the first season. The findings align with El-Maddah et al. (2012), who reported that irrigation intervals and citric acid produced negligible changes in soil pH, with peak values of 7.60 and 7.55 observed in the first and second seasons, respectively. This reading indicates a reduction of 1.81% and 1.82%, respectively, in comparison to the control group. The values were derived from irrigation intervals during the first and second seasons, in conjunction with citric acid application.

**3.4.3 Organic matter (OM %)**

Data presented in Table 9 indicate that soil OM% significantly decreased as irrigation intervals increased. Increasing irrigation intervals to 1.5 and 1 APE resulted in a reduction of OM% values by 13.2% and 21.6% during the first season and by 5.3% and 21.6% in the second season, respectively. The implementation of amendment treatments enhanced the OM %, with treatment T5 achieving values of 0.45 and 0.66 in the first and second seasons, respectively. The combination of amendment treatments and different watering schedules showed that the best results for OM% came from T5 used with 2APE. Lowering water levels may adversely affect the movement and activity of microorganisms responsible for the formation and breakdown of organic matter in the soil. In contrast, the addition of potassium silicate, citric acid, and acetic acid enhances both the activity and quantity of these microorganisms, thereby improving the organic matter content in the soils examined. The soil OM% in the second season exceeded that of the first season. Our results align closely with those of Omae and Tsuda (2022), who reported that drought significantly, affected microbial activity, physiology, and habitat, resulting in considerable changes in microbial community compositions. Although there is a lot of research on how acetic acid helps plants, especially their above-ground parts, during drought, we still know little about how acetic acid affects soil microbes and how that, in turn, affects plant growth. A recent study by Kong et al. (2022) provided significant insights into the impact of acetic acid on soil microbial dynamics during drought stress. The physical and chemical features of soil greatly affect soil microbial communities, showing the need to explore how acetic acid affects these features and microbial activity in future research. To determine how reliable and effective silicate and organic acids are for helping plants survive in dry conditions, it is important to carry out organized field experiments that compare situations with and without studied treatments.

**3.4.4 Nutrients N, P, K and Si availability**

The results in Table 10 shows that the levels of N, P, K, and Si in the soil changed a lot with all the different treatments after two growing seasons, compared to the control with different irrigation intervals. The soil availability of nutrients was decreased with increasing irrigation intervals. When the irrigation intervals were increased to 1.5 and 1 APE, the levels of N, P, K, and Si dropped by 7.8, 8.5, 10.6, and 11.1% (for 1.5 APE) and 13.1, 17.1, 25.7, and 22.9% (for 1 APE) in the first season, and by 8.5, 3.9, 18.4, and 6.5% (for 1.5 APE) and 13.6, 7.3, 33.7, and 14.4% (for 1 APE) in the second season. Additionally, applying the treatments improved the soil availability of N, P, K, and Si, with T5 being the most effective treatment; it resulted in increases of 32.6%, 56.9%, 34.7%, and 38.4% in the first season and 33.6%, 37.0%, 33.5%, and 19.3% in the second season, respectively. Regarding the interaction treatments between amendments and irrigation intervals, the highest nutrient availability in the soil was observed with the treatment T5 combined with 2 APE. Our results

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| **Table 10. Soil nutrient** **availability after harvested wheat responses to irrigation intervals and /or KSi, citric acid, acetic acid, and their combination treatments across two seasons in sand soil.** | | | | | | | | | | |
| **Irrigation treatments** | **Conditioners** | **Nutrient availability in soil (mg Kg-1)** | | | | | | | | |
| **First season** | | | | **Second season** | | | | |
| **N** | **P** | **K** | **Si** | **N** | **P** | **K** | **Si** |
| 2 APE | T1 | 101 | 21.9 | 64.9 | 200 | 97 | 17.5 | 69.6 | 181 |
| T2 | 111 | 24.7 | 71.1 | 243 | 107 | 19.7 | 72.4 | 190 |
| T3 | 117 | 29.4 | 72.4 | 254 | 113 | 21.0 | 76.0 | 206 |
| T4 | 123 | 30.6 | 65.2 | 263 | 119 | 21.7 | 81.3 | 208 |
| T5 | 130 | 33.7 | 81.9 | 307 | 126 | 22.6 | 83.6 | 220 |
| Mean | | 116 | 28.1 | 71.1 | 253 | 113 | 20.5 | 76.6 | 201 |
| 1.5 APE | T1 | 90 | 20.0 | 55.1 | 193 | 86 | 16.5 | 48.8 | 173 |
| T2 | 102 | 23.1 | 59.0 | 200 | 98 | 18.6 | 54.6 | 178 |
| T3 | 108 | 26.6 | 62.6 | 213 | 105 | 19.6 | 67.3 | 191 |
| T4 | 113 | 27.0 | 67.3 | 248 | 109 | 20.5 | 69.1 | 196 |
| T5 | 121 | 31.9 | 74.1 | 271 | 118 | 23.1 | 72.7 | 204 |
| Mean | | 107 | 25.7 | 63.6 | 225 | 103 | 19.7 | 62.5 | 188 |
| 1 APE | T1 | 87 | 18.7 | 43.3 | 177 | 84 | 15.5 | 42.3 | 159 |
| T2 | 93 | 20.9 | 48.2 | 189 | 89 | 16.9 | 48.2 | 162 |
| T3 | 102 | 23.2 | 51.7 | 196 | 98 | 19.4 | 51.7 | 169 |
| T4 | 108 | 24.1 | 57.2 | 201 | 105 | 21.0 | 54.1 | 180 |
| T5 | 115 | 29.5 | 63.9 | 213 | 112 | 22.1 | 58.0 | 188 |
| Mean | | 101 | 23.3 | 52.8 | 195 | 98 | 19.0 | 50.8 | 172 |
| Mean of treatment | T1 | 92 | 20.2 | 54.4 | 190 | 89 | 16.5 | 53.5 | 171 |
| T2 | 102 | 22.9 | 59.4 | 210 | 98 | 18.4 | 58.4 | 177 |
| T3 | 109 | 26.4 | 62.2 | 221 | 105 | 20.0 | 65.0 | 188 |
| T4 | 115 | 27.2 | 63.2 | 237 | 111 | 21.1 | 68.2 | 195 |
| T5 | 122 | 31.7 | 73.3 | 263 | 119 | 22.6 | 71.4 | 204 |
| LSD at 0.05 | APE | 1.88 | 1.43 | 4.55 | 12.3 | 1.81 | 0.66 | 1.52 | 14.8 |
| T | 4.89 | 0.90 | 4.22 | 7.93 | 4.91 | 0.68 | 2.50 | 11.7 |
| APE\*T | 8.47 | 1.57 | 7.31 | 13.7 | 8.50 | 1.17 | 4.33 | 20.3 |
| *APE (accumulative pan evaporation), T1 (control), T2 (KSi), T3 (T2+ citric acid), T4 (T2+ acetic acid), T5 (T2+ citric+ acetic acids).* | | | | | | | | | | |

are consistent with those of Mubarak et al. (2021), who found that arid stress has a significant impact on plants. These effects may encompass insufficient nutrient availability. Moreover, Verma et al. (2023) discovered that plants have a more convenient time accessing N, P and K when irrigation is applied more frequently. Watering encourages the circulation of nutrients through the soil profile, thereby increasing the accumulation of dry matter in plants. Increased irrigation levels have been demonstrated to have a beneficial impact on wheat yield, in addition to enhancing nutrient availability. The soil's mechanical properties are weakened by adequate watering, which facilitates nutrient absorption and root development. In the same vein, Ibrahim et al. (2020) discovered that substantial deficit irrigation led to a decrease in P and K. This decline may be attributed to a decrease in the activity and concentration of P-uptake protein (Bista et al., 2018).

On the other hand, Morsy et al. (2024) report that the application of potassium silicate increased the levels of accessible P, K, and Si in sandy soil. Later on, Greger et al. (2018) found that the incorporation of silicon enhanced mineral availability in the soil. Post-harvest of wheat, the combination of K and Si improved the availability of essential plant nutrients, such as N, P and Si, in sandy soils. This is likely due to their beneficial impact on nutrient availability. Finally, silicon influences soil dynamics due to its significant adsorptive capacity. Schaller et al. (2019) demonstrated a significant correlation between soil silicon levels and P availability in their experiment. Additionally, treated Si demonstrated the ability to facilitate the active mobilization of P within the soil. Babu et al. (2016) highlighted the importance of silicon conversion to the soil solution, as it increases the availability of silicon for plant uptake. Furthermore, foliar application of K₂SiO₃ improved the availability of nitrogen, phosphorus, and potassium under conditions of water stress, as reported by Ibrahim et al. (2020). Before the application of K₂SiO₃, a significant increase in nutrient levels was observed under both extreme and moderate stress conditions. The findings indicate that drought stress significantly affects nutrient absorption in plants.

On the other hand, Santos et al. (2017) demonstrated that citric acid dissociates in soils with a higher negative charge to compete with inorganic P. Wei et al. (2010) discovered that the organic acids produced when citric acid breaks down can help dissolve stuck phosphorus and also compete for places where phosphorus can attach. Soil P availability is controlled by processes apart from citrate-phosphate competition for sorption sites (Duputel et al., 2013). In addition to, Barrow et al. (2018) state that releasing citric acid near plant roots lowers the pH and has at least three immediate benefits. This benefit is accomplished by bringing the pH level closer to the region where the HPO₄ ion is most abundant, facilitating absorption. Low pH alone accelerates P desorption, however. Reduced watering intervals in conjunction with spraying citric resulted in the highest quantities of available nutrients, according to El-Maddah et al. (2012). Values were found to be lowest when irrigation intervals were increased.

3.5 Correlation between studied traits

Fig. 5 Pearson’s correlation coefficients among 13 studied traits (GY, grain uptake of N, P, K, and Si, EC, pH, OM%, soil availability of N, P, K, and Si and WUE) under different irrigation intervals and studied treatments for two seasons in sandy soil. Results showed strong positive correlations between GY and NG, PG, KG, SiG, OM%, SN, SP, SK, SSi, and WUE. While there were strong negative correlations between GY and EC and pH (-0.414 and -0.601 for the first season, respectively as well as -0.428 and -0.491 for the second season, respectively). Also, correlations among water use efficiency were strongly positive with NG, PG, KG, SiG, OM%, SN, SP, SK, and SSi , and they were negative with EC and pH (-0.527 and -0.762 for the first season, respectively) (-0.528 and -0.589 for the second season, respectively). As regards the correlation among different types of traits, highly significant positive correlations were exhibited between SSi and Gy, SiG, SN, SP, SK, and WUE (0.778, 0.896, 0.915, 0.9, 0.903, and 0.886, respectively), but it was negatively correlated with EC and pH (-0.566 and -0.787, respectively).

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| **Fig. 5 Coefficients of correlation between the factors under study during the first (A) and second (B) growth seasons as affected by irrigation intervals and studied treatment.** |
| ***GY (grain yield), NG, PG, KG, SiG (grain uptake of N, P, K and Si), SN, SP, SK, SSi (soil availability of N, P, K, and Si, WUE (water use efficiency.)*** |

4. Conclusion

Identifying strategies to enhance plants' drought resilience is becoming imperative due to global climate change. Consequently, irrigation management is essential alongside the administration of inorganic and organic conditioners for optimal wheat yield and prudent water utilization. Irrigation intervals based on accumulative pan evaporation (APE) are an effective strategy for sandy soil. Also, the use of potassium silicate along with organic acids (citric acid and acetic acid) as conditioners was useful for wheat production. The research showed that the highest water consumptive use (WCU) was 2067 and 2052 m³ fed⁻¹ for the 2021/2022 and 2022/2023 seasons, respectively, with the 2 APE irrigation systems. A similar trend in water use efficiency (WUE) was also noted under the same irrigation treatment. Using T5 (KSi, citric acid, and acetic acid), along with the 2APE irrigation intervals, improved the overall yield, straw, and grain production of the wheat crop compared to the control and other methods. The results indicated that the interaction treatments had no impact on soil EC values and a reduction in pH values. Under all treatments, organic matter content and the availability of macronutrients and silicon increased. Lastly, when wheat Giza 171 is planted on sandy soil with spray watering in northeast Egypt, the best irrigation treatment was to use irrigation interval 2 APE in combination with T5.

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