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Effects of Chemical and Biological Potassium Fertilizers in Reducing of Water Stress on Wheat Crop Production in Khuzestan Province (Southwest of Iran)

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ABSTRACT

BACKGROUND: Available water and nutrient management are two important factors that affect yield and quality of wheat production.

OBJECTIVES: Current research was done to assess the effect of chemical and biological potassium fertilizers on growth indices of bread wheat under water stress conditions.

METHODS: This study was done via factorial experiment based on completely randomized block design with three replications during the agricultural year 2015-2016 in Ahvaz region (southwest of Iran). The first factor included irrigation regimes based on the evaporation pan method at 60 (local standard), 90, and 120 mm, and the second factor consisted of the combined use of chemical and biological potassium fertilizers at four levels: 1- 100% chemical fertilizer (potassium sulfate without the use of biological fertilizer) as control, 2- 75% potassium sulfate + Potabarvar2, 3- 50% potassium sulfate + Potabarvar2, and 4- 25% potassium sulfate + Potabarvar2.

RESULT: The results indicated that irrigation after 60 mm of evaporation increased leaf area index, dry matter accumulation, crop growth rate, and net photosynthesis rate, resulting in enhanced yield. The highest grain yield, with an average of 5970 $kg.ha^{-1}$, was obtained from the irrigation treatment based on 60 mm of evaporation with the consumption of 75% potassium sulfate + Potabarvar2. The lowest grain yield was observed in the treatment with irrigation after 120 mm of evaporation and the use of 25% potassium sulfate + Potabarvar2, with an average of 2994 $kg.ha^{-1}$.

CONCLUSION: In general, the study demonstrated that the application of bacteria along with chemical fertilizer influenced plant growth. Moreover, considering the significant increase in grain yield under the conditions of 75% potassium sulfate + Potabarvar2 in all three irrigation regimes compared to the control (no use of biological fertilizers), this fertilizer combination can be recommended under both moisture stress and non-stress conditions in the region.

KEYWORDS: *Biofertilizer, Growth indices, Leaf area index, Macronutrient, Sulfate.*

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1. BACKGROUND

Wheat, as one of the major agricultural crops, plays a crucial role in providing the majority of human nutritional needs, especially in developing countries worldwide. Extensive research has been conducted to enhance its productivity. Ensuring sufficient food at affordable prices for a society is one of the key elements of sustainable development in any country. In the now days, with limited resources, a growing population, and consequently increasing demand for food products, it is imperative to optimize the use of limited resources. Drought is one of the most significant limiting factors in the production of agricultural crops, including wheat, globally and in Iran. This issue is particularly crucial in dry and semi-dry regions worldwide. Iran faces water resource constraints, with an average precipitation of about 250 mm, representing one-third of the world's average precipitation (Heydari Sharifabad, 2004). Therefore, the economic importance of wheat necessitates evaluating any solution to optimize the production system of this crop, especially under dry conditions. One potential solution may involve the use of potassium and biofertilizers containing growth-promoting bacteria. Potassium, like nitrogen and phosphorus, is an essential plant nutrient that plays a dynamic role in the plant. In case of deficiency, it is transferred to young plant tissues, causing symptoms in the plant (Malekouti and Homaee, 2004). Potassium activates around 60 plant enzymes, including those responsible for ATP production, and regulates stomatal opening and closing. Potassium is a crucial element that enhances plant resistance to water scarcity, increases salt stress tolerance, and improves crop storage and quality (Mianab *et al.*, 2013). Fusheng (2006) outlined potassium functions, including enzyme activation, enhancement of the photosynthesis process, synthesis of carbohydrates, and transport of synthesized carbohydrates in the photosynthesis process, protein synthesis, and improvement of plant resistance to stress. In the experiment conducted by Arquero *et al.* (2006) it was reported that water stress leads to a reduction in leaf water absorption, which, in turn, disrupts the potassium release through the cuticle. The term "biofertilizers" is not exclusively applied to organic materials derived from animal manure, plant residues, and green manure; rather, bacteria and fungi, especially plant growth-promoting bacteria (PGPR), and the products of their activity are among the most important types of biofertilizers (Akbariniya *et al.*, 2003). The use of biological fertilizers composed of bacteria and fungi can significantly aid in the optimal utilization of fertilizers. These fertilizers facilitate nutrient absorption by breaking down soil minerals (Vazques *et al.*, 2000). These bacteria, by balancing the uptake of essential and micronutrient elements, secreting amino acids, and producing various antibiotics, promote root and aerial parts' growth and development, leading to increased plant yield (Blak, 2011). Biofertilizer Potabarvar2 contains two potassium-solubilizing bacteria that decompose insoluble potassium compounds in the soil around the roots. By releasing these ions, it enhances the absorption of potassium. Mohseni Mohammadjanlou *et al*. (2023) concluded that application of potassium biological fertilizer combined with 50% of recommended K chemical fertilizer significantly reduce the amount of mineral K fertilizers and production costs and improve product health.

2. OBJECTIVES

This study was conducted in order to investigate the combined effects of chemical and biological potassium fertilizers in order to reduce the effect of soil moisture deficiency on yield and improve the physiological growth indicators of wheat.

3 .MATERIALS AND METHODS

3.1 .*Field and Treatments Information*

This research was conducted in the agricultural year 2015-2016 in the Salami farm located in Ahvaz city (Southwest of Iran), with a geographical latitude of 31 degrees and 20 minutes north, a longitude of 48 degrees and 40 minutes east, and an elevation of 23 meters above sea level. Before conducting the experiment, soil samples were taken from the field at a depth of 0-30 centimeters for physical and chemical soil analysis (Table 1). The research was conducted in a factorial design within the framework of a complete randomized block design with three replications. The first factor included irrigation regimes based on the evaporation pan method at 60 (I60), 90 (I90), and 120 (I120) mm. The second factor involved the simultaneous use of chemical and biological potassium fertilizers at four levels: 1- 100% through chemical fertilizer (potassium sulfate according to the local standard) (K100), 2- 75% through potassium sulfate + biological fertilizer Potabarvar2 (K75), 3- 50% through potassium sulfate + biological fertilizer Potabarvar2 (K50), 4- 25% through potassium sulfate + biological fertilizer Potabarvar2 (K25).

Table 1. Physical and chemical properties of studied soil

K (mg kg^{-1})	EC (ds.m^{-1})	O.C (%)	pH	EC (ds m^{-1})
123	5.9	0.45	7.5	5.9
P (mg kg^{-1})	**Sand (%)**	**Silt (%)**	**Clay (%)**	**ρb (gr.cm^{-3})**
6.8	33	38	27	1.5

The first irrigation was carried out immediately after sowing, and subsequent irrigations were performed based on the plant's visual appearance. The irrigation treatments were applied from the beginning of the tillering stage and continued until the final harvest. For seed priming with biological fertilizer Potabarvar2, the seeds were first moistened and then spread on a plastic surface. Potabarvar2 was applied at a rate of 100 gr.ha^{-1}, according to the manufacturer's recommendation, relative to the amount of seeds used.

3.2 .*Farm Management*

Potassium fertilizer, based on the treatment type, was applied at a rate of 100 kilograms of pure potassium per hectare from potassium sulfate before planting. Nitrogen fertilizer, at a rate of 130 kilograms of pure nitrogen per hectare from urea, was applied in two stages: as a base before planting and as a topdressing at the beginning of the stem elongation stage. Each plot consisted of 7 planting rows, each 5 meters long, with a row spacing of 0.2 meters.

3.3. *Measured Traits*

3.3.1. *Leaf Area Index (LAI)*

To measure the leaf surface index, sampling was conducted six times at 14-day intervals. The first sampling occurred 40 days after planting. Each sampling included the collection of five plants from each treatment, and the leaf surfaces of the samples were measured using the copy method on A4 paper. The Leaf Area Index was calculated using the following formula based on the area of land (SA) and leaf surface area (LA) (Tarighaleslami *et al*., 2013): LAI = LA/SA

3.3.2. *Total Dry Weight (TDW)*

To determine the total dry weight per unit area of the plant, samples were placed in an oven at 75 degrees Celsius for 48 hours. Subsequently, the samples were weighed using a digital scale with an accuracy of 0.001/0 grams.

3.3.3. *Crop Growth Rate (CGR)*

The Crop Growth Rate was determined by calculating the difference in dry weight of samples between two consecutive sampling times (from booting to beginning of flowering stages) divided by the time interval between these two samplings Tarighaleslami *et al*., 2013): CGR $(gr.m^{-2}.day) = (W_2-W_1)/(GA(T_2-T_1))$

Where W_1 and W_2 are the dry weights of samples at two consecutive sampling times and T_1 and T_2 are the time intervals between the two samplings.

3.3.4. *Net Assimilation Rate (NAR)*

The net assimilation rate was calculated in grams per square meter of leaf surface per day between two consecutive sampling times (from the booting to the beginning of the flowering stages) using the following formula:

NAR $(gr.m^{-2}.d^{-1}) = (\text{Ln}\ (LAI_2) - \text{Ln}\ (LAI_1)/(\ LAI_2 - LAI_1) \times CGR_2$

CGR = crop growth rate $(gr.\ m^{-2}.\ d^{-1})$

LAI = leaf area index

Final harvest was conducted at the fully ripened stage, after complete yellowing and drying of the plants. Grain yield was determined after threshing and winnowing in four middle rows covering an area of 2 square meters in each experimental unit.

3.4. *Statistical Analysis*

Analysis of variance and mean comparisons were done via Minitab software (Ver.14) and Duncan multiple range test at 5% probability level. Graphs were plotted using Microsoft Excel 2010.

4. RESULT AND DISCUSSION

4.1. *Total Dry Weight (TDW)*

The present of drought stress in various growth stages while minimizing the impact on yield has been a key focus for water management in arid and semi-arid regions. The growth pattern of plants typically follows a sigmoidal curve (S-shape), illustrating the comprehensive trajectory of plant growth and its components over time. The results of this study reveal that, at different irrigation levels, the highest total dry weight was associated with 60 mm evaporative irrigation treatment, reaching 13,963 kg.ha^{-1}, while the lowest was recorded in the 120 mm evaporative irrigation treatment, averaging 8,044 kg.ha^{-1} (Fig. 1).

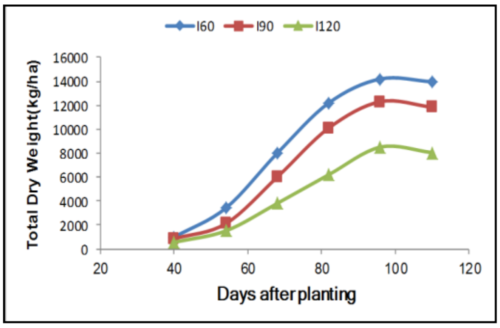

Fig.1. Changes in total dry weight of wheat affected different irrigation regime, included evaporation pan method at 60 (I60), 90 (I90), and 120 (I120) mm.

Notably, the treatment with 75% potassium sulfate fertilizer and 25% biological fertilizer (Patabor2) exhibited the maximum total dry weight at 13,017 kg/ha, whereas the treatment with 25% potassium sulfate fertilizer and 75% biological fertilizer (Patabor2) showed the minimum at an average of 9,633 kg.ha^{-1} (Fig. 2). Zarei *et al*. (2014) emphasized the significant impact of water stress at different growth stages on wheat's total dry matter, with the highest in the control group (normal irrigation) and the lowest during the water-cut treatment in the stem elongation stage. The reduction in irrigation at the 60 mm evaporative level resulted in a notable increase in total biomass (Farahdahr, 2011). Analyzing Fig. 1 suggests that the reduction in total dry weight under the 120 mm evaporative irrigation treatment is attributed to decreased irrigation, leading to diminished stomatal conductance and net photosynthesis, ultimately influencing dry weight. Concurrently, water stress accelerates leaf senescence, diminishes current photosynthesis, and shortens the duration of plant growth stages.

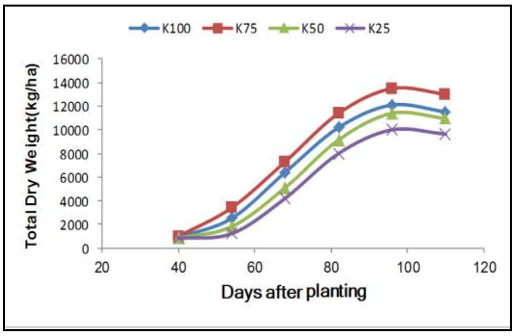

Fig.2. Changes in total dry weight of Wheat affected different level of potassium fertilizer, included 1- 100% through chemical fertilizer (potassium sulfate according to the local standard) (K100), 2- 75% through potassium sulfate + biological fertilizer Potabarvar2 (K75), 3- 50% through potassium sulfate + biological fertilizer Potabarvar2 (K50), 4- 25% through potassium sulfate + biological fertilizer Potabarvar2 (K25).

This aligns with existing research indicating that water deficiency induces premature aging of photosynthetic organs and a decline in current photosynthesis, contributing to a reduction in total biomass (Emam, 2011). Results indicated that in all fertilizer treatments, the dry matter of wheat increased with the progression of days after planting. In all fertilizer treatments, the accumulation of dry matter showed an increasing trend until 95 days after planting, stabilized afterward, and then decreased (Fig. 2). In the early growth stages, the highest total dry matter was associated with the treatment of 75% potassium sulfate fertilizer and 25% biological fertilizer (Patabor2), while the lowest total dry matter was related to the treatment of 25% potassium sulfate fertilizer and 75% biological fertilizer (Patabor2) (Fig. 2). This experiment aligns with the findings of Ghafouri *et al*. (2013) on sorghum, Mianab *et al*. (2013) on barley, demonstrating that an increase in potassium sulfate fertilizer leads to an increase in total dry weight. The reason for this could be the enhanced plant growth, resulting in increased vegetative growth and more nutrient transfer to the plant. As a result, the plant experiences more significant growth, leading to increased dry weight. It has been reported that increasing potassium levels enhance carbon dioxide fixation, consequently boosting photosynthesis and carbohydrate production, leading to an increase in dry weight (Kholdbarin and Islamzadeh, 2005). Stancheva *et al*. (1992) investigated the effect of corn fertilization with biological fertilizers and observed an increase in the dry weight of plant biomass. They attributed this to improved nutrient accessibility and absorption, ultimately resulting in an increase in dry matter accumulation.

4.2. *Leaf Area Index* (LAI)

Based on the trend chart of changes in the leaf area index, the highest LAI was observed in the 60 mm evaporation irrigation treatment during the flowering stage with 7.4, while the lowest LAI was associated with the 120 mm evaporation irrigation treatment with 4 (Fig. 3). Furthermore, in the trend chart of changes in the LAI under potassium fertilization, the highest LAI during the flowering stage was related to the application of 75% potassium sulfate fertilizer and 25% Pata Barur2 with 6.4, and the lowest LAI was attributed to the application of 25% potassium sulfate fertilizer and 75% Pata Barur2 with 1.4 (Fig. 4).

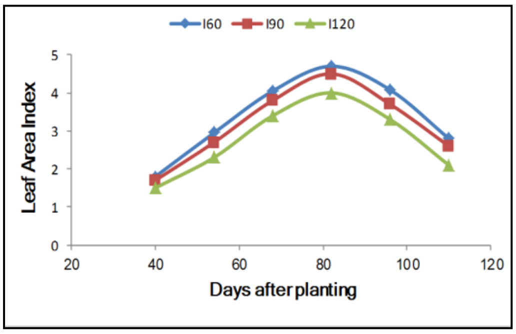

Fig.3. Changes in leaf area index of wheat affected different irrigation regime, included evaporation pan method at 60 (I60), 90 (I90), and 120 (I120) mm.

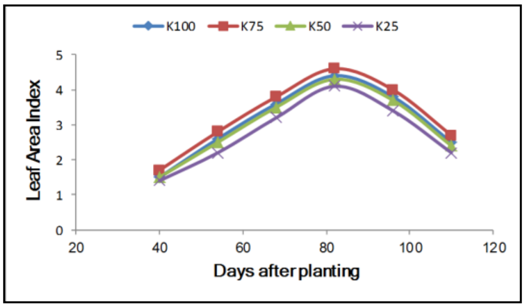

Fig.4. Changes in leaf area index of Wheat affected potassium fertilizer, included 1- 100% through chemical fertilizer (potassium sulfate according to the local standard) (K100), 2- 75% through potassium sulfate + biological fertilizer Potabarvar2 (K75), 3- 50% through potassium sulfate + biological fertilizer Potabarvar2 (K50), 4- 25% through potassium sulfate + biological fertilizer Potabarvar2 (K25).

The results of this experiment align with the findings of Zarei *et al*. (2015), who reported an increase in the Leaf Area Index (LAI) with increased irrigation in crop plants. In the study by Lak *et al*. (2008), the highest LAI was associated with the desirable irrigation treatment in maize plants. Chakir (2004) reported that moisture deficiency, through reduced production and growth and increased leaf senescence, decreases the Leaf Area Index. Pandey *et al*. (2000) applied deficit irrigation at various growth stages of maize and reported that severe water deficit leads to a reduction in the leaf area of the plant. It seems that by reducing the irrigation interval to 120 mm evaporation, the intensity of stress in the plant increases. Competition for water absorption between aerial and underground parts of the plant intensifies, and in this competition, the plant allocates a greater share of photosynthetic materials to the roots. As a result, fewer photosynthetic materials reach the aerial part, including the leaves, leading to a reduction in the Leaf Area Index. The impact of varying levels of potassium sulfate fertilizer on wheat's Leaf Area Index (LAI) revealed an ascending trend in LAI up to 85 days post-planting, followed by a subsequent decline over time. The highest and lowest LAI values corresponded to the treatment with 75% potassium sulfate and 25% Potabarvar2, and 25% potassium sulfate and 75% Potabarvar2, respectively (Fig. 4). Broadly speaking, the rise in potassium usage resulted in increased vegetative growth and, consequently, an elevation in the Leaf Area Index. The decrease in LAI during the later stages of plant growth might be attributed to leaf senescence. Findings from the research by Ghafouri *et al*. (2013) on sorghum and Mianab *et al*. (2013) on barley similarly demonstrated an augmentation in the Leaf Area Index with heightened potassium fertilizer application. The rationale behind the augmented leaf area with increased potassium lies in improved plant growth, leading to expanded surface coverage. In essence, heightened potassium fertilizer application fosters augmented photosynthetic rates per unit area, thereby contributing to increased plant growth and subsequently elevating the Leaf Area Index (Kholdbarin and Islamzadeh, 2005). The influence of the biofertilizer Potabarvar2 in increasing wheat leaf area at higher potassium sulfate levels compared to lower levels was more pronounced (Fig. 4). This could be attributed to the enhanced effectiveness of the microbial activity in biofertilizers in soils with higher absorbable potassium. These findings align with the results of Pouryousef *et al*. (2010), who observed a significant increase in leaf surface area in sorghum by simultaneously applying biofertilizer Barvar 2 compared to its absence. The results of this study are consistent with the findings of Singh *et al*. (2003) and Mohseni Mohammadjanlou *et al*. (2013). Furthermore, the application of bacteria in biofertilizers on barley and sugar beet by Fikrettin *et al*. (2004) resulted in a significant increase in leaf growth and leaf area index across all fertilizer and inoculation treatments compared to the control. Researchers attributed this phenomenon to an increase in nutrient absorption, particularly phosphorus and potassium.

4.3. *Crop Growth Rate (CGR)*

According to the graph illustrating the changes in crop growth rate (CGR) due to different irrigation regimes, the highest crop growth rate occurred in the irrigation treatment with 60 mm of evaporation during the flowering stage, reaching 23 grams per square meter per day. Conversely, lowest CGR was observed in irrigation treatment with 120 mm of evaporation, with a rate of 16 grams per square meter per day (Fig. 5).

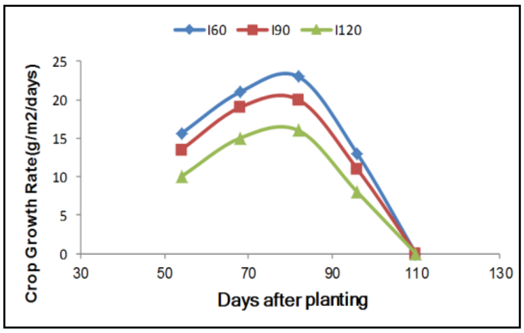

Fig.5. Changes in crop growth rate of wheat affected irrigation regime, included evaporation pan method at 60 (I60), 90 (I90), and 120 (I120) mm.

The maximum crop growth rate during flowering was associated with the application of 75% potassium sulfate fertilizer and 25% Potabarvar2, resulting in 21 grams per square meter per day, while the minimum rate was related to the application of 25% potassium sulfate fertilizer and 75% Potabarvar2, with a rate of 16 grams per square meter per day (Fig. 6). These results align with findings by Hooker *et al.* (1982), indicating that crop growth rate decreases with increased water stress. Pandey *et al.* (2000) reported that deficit irrigation in the early growth stages reduces plant growth rate and dry matter in maize by a certain amount, and the reproductive growth stage leads to a significant decrease in these indicators. Saberi *et al.* (2006) also reported the maximum rate of maize growth between 2-4 grams per square meter per day. Pandey *et al.* (2000) observed a reduction in crop growth rate due to drought stress. It seems that increasing drought stress up to 120 mm of evaporation during plant growth leads to increased competition for water absorption between aerial and soil components in the plant, causing the plant to allocate a greater share of photosynthetic materials to the roots. As a result, fewer photosynthetic materials reach the aerial part, leading to a decrease in crop growth rate. The decline in the crop's growth rate towards the end of the growth period can be attributed to the reduction in dry matter resulting from the shedding of lower leaves.

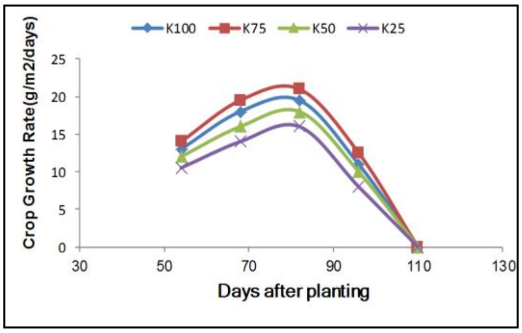

Fig.6. Changes in crop growth rate of Wheat affected potassium fertilizer, included 1- 100% through chemical fertilizer (potassium sulfate according to the local standard) (K100), 2- 75% through potassium sulfate + biological fertilizer Potabarvar2 (K75), 3- 50% through potassium sulfate + biological fertilizer Potabarvar2 (K50), 4- 25% through potassium sulfate + biological fertilizer Potabarvar2 (K25).

Since plant assimilation under moisture stress is primarily governed by two key factors, namely leaf area and photosynthesis per unit leaf area (Edmeades *et al.*, 1996), moisture stress, through a reduction in green leaf area, leads to a decrease in the photosynthetic area and, consequently, a reduction in dry matter production (Boomsma and vyn, 2008). Consequently, the growth rate of the crop consistently proves lower throughout the plant growth period under conditions of water scarcity as opposed to full irrigation conditions (Akbari, 2012). The impact of various levels of potassium sulfate fertilizer on changes in the crop growth rate reveals a linear increase in the growth rate until approximately 85 days after planting, followed by a linear decline. The highest growth rate across all fertilizer treatments was observed at 85 days after planting, with the peak growth rate for the entire growth period attributed to the 75% potassium sulfate fertilizer and 25% Pata Barvar2 treatment (Fig. 6). Similar findings have been reported by Ghafouri *et al*. (2013) for sorghum and Mianab *et al*. (2012). Presumably, the positive effects of potassium on the leaf area index, leading to increased foliage and ultimately higher dry matter production, account for these outcomes. The crop's growth rate hitting zero in the late growth stages may be attributable to decreased dry matter and leaf shedding. El-Nemr *et al*. (2012) reported that biofertilizer such as humic acid increases the absorption of elements by chelating essential elements and increases fertility and production in plants, which can be effective in increasing the growth rate of the crop. Dordas and Siolas (2008) reported that biofertilizers increase the number of enzymes and proteins, especially enzymes and proteins participating in the photosynthetic cycle, such as cytochromes, ferredoxins, plastocyanin, and rubisco enzyme, by improving nitrogen absorption, and in this way, they increase the growth of the plant. The crop growth rate in the final stages of growth was zero, which could be due to the reduction of dry matter and falling leaves. Egilia *et al*. (2005) asserted that the application of potassium fertilizer enhances dry matter production by promoting growth, leading to an increased crop growth rate. The peak crop growth rate coincides with the maximum leaf area index. In plants with limited growth, the expansion of leaf area and, consequently, the growth rate decrease upon entering the reproductive phase. According to the findings of this experiment, the use of 75% potassium sulfate fertilizer and 25% Pata Barvar2 results in a higher leaf area index and increased radiation absorption in the plant community, contributing to an elevated growth rate in wheat (Fig. 6). This underscores the greater impact of the combined application of organic and chemical fertilizers compared to their individual use. The upward trend in the crop growth rate during the continued growth season is associated with the rapid growth and expansion of leaves (LAI), necessitating adequate water and nutrient supply for plant growth and development, particularly during critical growth stages (Latifi *et al*., 2004).

4.4. *Net Assimilation Rate* (*NAR*)

The highest net photosynthetic rate (NAR) was observed in irrigation with 60 mm evaporation in the early growth stage, with 4.5 grams per square meter per day, and the lowest was in irrigation with 120 mm evaporation, with 6.4

grams per square meter per day (Fig. 7). The highest crop growth rate in the early growth stage was associated with the application of 75% potassium sulfate fertilizer and 25% Pata Barvar2, with 3.5 grams per square meter per day, and the lowest was related to the application of 25% potassium sulfate fertilizer and 75% Pata Barvar2, and 50% potassium sulfate fertilizer and 50% Pata Barvar2, with 9.4 grams per square meter per day (Fig. 8).

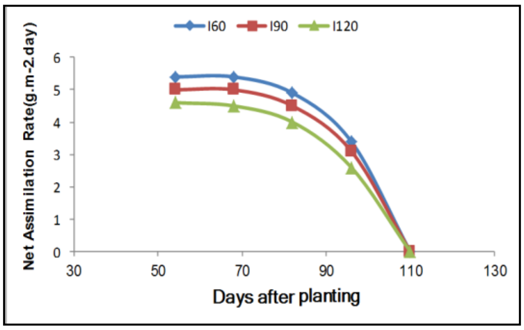

Fig.7. Changes in net photosynthesis rate of wheat affected irrigation regime, included evaporation pan method at 60 (I60), 90 (I90), and 120 (I120) mm.

The highest value of net photosynthetic rate was present in all treatments in the early growth stage, but over time, a declining trend was observed. We attributed this decline in net photosynthetic rate to the increase in plant age, plant density, and greater shading effect, especially due to irrigation with 120 mm evaporation (Fig. 7). These results are consistent with the report by Brevedan and Egli (2003) on the reduction of chlorophyll, leaf aging, decreased leaf area duration, and increased nitrogen transfer from leaves under water stress conditions. Additionally, with increased irrigation in the 60 mm evaporation treatment, the photosynthetic rate increased. This is attributed to the reduction in drought stress, which reduces competition between the aerial and terrestrial parts, leading to increased leaf growth. This increase in leaf area index and greater light interception resulted in increased photosynthesis. As the leaf age increased, photosynthesis decreased, leading to an increased downward slope in net assimilation rate (Javadi *et al*., 2007).

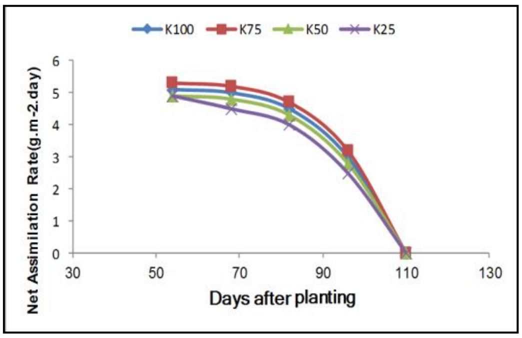

Fig.8. Changes in net photosynthesis rate of Whear affected potassium fertilizer, included 1- 100% through chemical fertilizer (potassium sulfate according to the local standard) (K100), 2- 75% through potassium sulfate + biological fertilizer Potabarvar2 (K75), 3- 50% through potassium sulfate + biological fertilizer Potabarvar2 (K50), 4- 25% through potassium sulfate + biological fertilizer Potabarvar2 (K25).

With a decrease in soil water potential and consequently, Relative Water Content (RWC), stomatal conductance is reduced, limiting the availability of carbon dioxide to the plant. As a result, the rate of photosynthesis in corn decreases (Martinez *et al*., 2007). Water deficit stress leads to a reduction in the leaf area index, and this decrease in leaf area contributes to a decline in photosynthesis levels (Moseki and Dintwe, 2011). Drought stress causes a decrease in the relative water content of leaves and a reduction in the chlorophyll index due to decreased stomatal conductance and restricted carbon dioxide availability, resulting in diminished photosynthesis. The reduced photosynthesis inhibits the optimal development of leaf area and diminishes the accumulation of dry matter per unit leaf area (Fazeli Rostampour and Mohebbian, 2012). The highest net assimilation rate was associated with the treatment of 75% potassium sulfate and 25% Pata Barvar2, while the lowest was related to the treatment of 25% potassium sulfate and 75% Pata Barvar2 (Fig. 8). Ghafouri *et al*. (2013) and Mianab *et al*. (2012) reported a decrease in the net photosynthesis rate over time, and the use of potassium sulfate led to an increase in the net photosynthesis rate, consistent with the results of this experiment. With an increase in the potassium sulfate fertilizer, photosynthesis increased, resulting in an increase in the net assimilation rate. Egilla *et al*. (2005) demonstrated that adequate potassium fertilizer improved leaf moisture content and plant water relations by reducing osmotic potential in the leaf mesophyll. This led to the stability of net photosynthesis, transpiration, and stomatal conductance, consequently increasing net assimilation. Allen *et al*. (1980) reported that the presence of biological fertilizers increases cytokinin levels and chlorophyll content in plants, ultimately leading to enhanced plant growth. It seems that the combined application of Pata Barvar2 with potassium sulfate fertilizer increases the net photosynthesis rate and its absorption process. The bacteria present in this biological fertilizer likely stimulate root growth, leading to increased potassium uptake and stabilization. Consequently, it results in taller plant height, expanding leaf surface, improved chlorophyll synthesis, increased solar radiation absorption, and enhanced assimilation process (Fig. 8). In the early stages of growth, when plants were small and exposed to direct sunlight, a high rate of dry matter accumulation was observed. Simultaneously, with plant growth and an increase in the leaf area index, more leaves became shaded. Instead of being primary producers of photosynthetic substances, these shaded leaves played more of a parasitic role, leading to a decrease in the net assimilation rate. As the age of the leaves increased, photosynthesis was also reduced, contributing to an increase in the downward slope of the net assimilation rate (Javadi *et al*., 2007).

4.5. *Seed yield*

The results of variance analysis of grain yield are shown in table 2.

Table 2. Results of analysis of variance of seed yield

S.O.V	df	Seed yield
Replication	2	12558.33
Irrigation Regime	2	15477.28^{**}
Potassium	3	9466.55^{*}
Irrigation × Potassium	6	6543.77^{*}
Error	22	2301.72
CV (%)		11.2

^{ns}, * and **: no significant, significant at 5% and 1% of probability level, respectively.

The results indicated a significant impact of moisture stress, potassium fertilizer, and the interaction between moisture stress and potassium fertilizer on grain yield (Table 2). When examining the interaction of moisture stress and potassium fertilizer, the highest grain yield was observed in the irrigation based on 60 mm evaporation, coupled with the application of 75% potassium sulfate + Potabarvar2, resulting in 5971 kg.ha^{-1}. Conversely, the lowest yield was associated with the irrigation treatment based on 120 mm evaporation and the application of 25% potassium sulfate + Potabarvar2, yielding 2081 kg.ha^{-1} (Fig. 9).

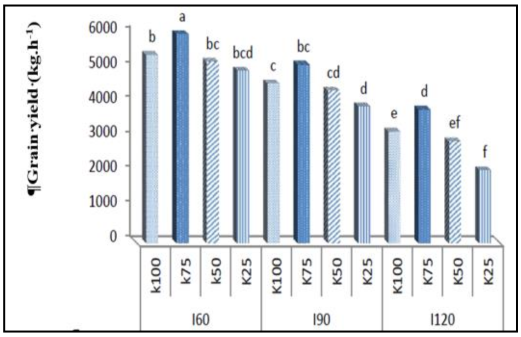

Fig.9. Effect of irrigation regime treatment (I_{60}: 60 mm evaporation from evaporation pan (control), I_{90}: 90 mm evaporation from evaporation pan and I_{120}: 120 mm evaporation from evaporation pan) and potassium treatment (K_{100}: %100 potassium sulfate, K_{75}: %75 potassium sulfate+ potabarvar2, K_{50}: %50 potassium sulfate + potabarvar2 and K_{25}: %25 potassium sulfate+ potabarvar2 on grain yield ($P \leq 0.05$).

According to Nesmith and Ritchie (1992), water deficiency during the flowering and pollination stages negatively affects reproductive organs, leading to a reduction in the yield of agricultural crops. Cox and Jolliff (2000) reported a decrease in grain yield of up to 20% in sunflowers and up to 27% in soybeans due to water deficiency in the soil in their study**.** Alavi Fazel *et al*. (2013) reported that in hybrid corn 704, the combined use of potassium sulfate fertilizer and biofertilizer (Petabarvar2) modified the effects of drought stress and led to an increase in grain yield. Ghaleh Nui *et al*. (2014) reported an improvement in yield with increased irrigation cycles, noting a reduction in the impact of water stress with higher potassium sulfate consumption. Similarly, Salehi *et al*. (2012) highlighted the capacity of sulfur and potassium application to mitigate the effects of moisture stress. Azadi *et al*. (2021) stated that the combined use of biological and chemical potassium fertilizers in corn hybrids reduced the negative effects of drought stress and led to an increase in corn grain yield. The highest grain yield was obtained with the application of 50% potassium sulfate and 50% petabarvar2 in AS71 hybrid under optimal irrigation conditions (12130 kg.ha^{-1}). The results of the interaction between various irrigation treatments and potassium sulfate application revealed an overall increase in grain yield with rising potassium sulfate application across all three irrigation regimes. However, the optimum yield was achieved under the conditions of 75% potassium sulfate + Potabarvar2. It appears bacterial application plays a role in enhancing plant yield by increasing potassium bioavailability and producing growth-regulating hormones (Sturz and Christie, 2003). In line with this, Zahir *et al*. (2010) and Hafiz (2018) found that the integrated use of chemical and biofertilizers leads to the highest grain yield compared to the sole application of either chemical or biological fertilizers. According to the statements of Moradzadeh *et al*. (2021) and Mathur and

Roy (2021), the accumulation of organic matter by bacteria in biological fertilizers in the soil increases root development and more access to nutrients, so that these conditions result in the 1000 grain and increases the number of grains and increases the grain yield.

5. CONCLUSION

The study results demonstrated a reduction in traits such as grain yield with an escalating intensity of moisture stress. This decline in grain yield surpassed that of biological yield, highlighting the heightened sensitivity of reproductive organs to moisture stress conditions relative to vegetative organs. The application of potassium sulfate proved instrumental in creating conducive conditions for plant establishment and, consequently, enhancing overall yield. Optimal yield and functional traits were notably observed under the conditions of 75% potassium sulfate + Potabarvar2. It is plausible that bacterial application, whether through heightened potassium bioavailability or the production of growth-regulating hormones, significantly influences plant dynamics. Furthermore, given the substantial and consistent increase in grain yield under the 75% potassium sulfate + Potabarvar2 conditions across all three irrigation regimes, in comparison to the control (100% via potassium sulfate), it is recommended for adoption in the region. This fertilizer combination exhibits efficacy not only in moisture-stressed scenarios but also in non-stress conditions.

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FOOTNOTES

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