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Research Article

Investigation of the role of Potassium Sulfate solution containing zinc chelate in increasing yield and decreasing water consumption in wheat in Kahnooj region (Kerman)

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Abstract

To investigate the role of potassium and zinc fertilizers in increasing yield and reducing the water consumption of wheat (*Triticum aestivum* L.), a field experiment was conducted in the form of a randomized complete block design with five treatments and three replications in November 2017 in Kahnooj city in Kerman province. Experimental treatments in this study included; The first treatment: Control (consumption of all fertilizers except potassium based on the results of soil analysis with 7 irrigations); The second treatment: The conventional fertilizing by the local farmers (NP) with 7 irrigations; the third treatment: First treatment + application of potassium sulfate (SOP) before planting, with 7 irrigations; Fourth treatment: First treatment + application of 33% sulfate-potassium (SOP) before planting and 67% of the remaining source of soluble potassium sulfate (SSOP) as a foliar application with 7 irrigations; Fifth treatment: The first treatment + application of 33% of sulfate-potassium (SOP) before planting and 67% of the remaining source of the sulfate-potassium solution containing chelate (SSOP + Zn-EDTA) as foliar application and irrigation in 5 times. The results showed that A) application of potassium and zinc fertilizers had a significant effect on yield, protein content, phosphorus, potassium, and zinc concentrations and also the molar ratio of phytic acid to zinc (unfavorable nutritional index) Zn) in grain as well as water and potassium use efficiency. B). While the yield and percentage of protein in the grain in the control treatment were 4648 kg/ha and 11.68%, respectively, in the second, third, fourth, and fifth treatments were 4077 and 8.57, 5402 and 69, 12.12, 6137 and 13.62, increased 6022 kg/ha and 13.85%, respectively. C). Unfavorable nutritional index (molar ratio of phytic acid to zinc) - (PA/Zn) in wheat grain in the control treatment was 46, while this ratio in the second, third, fourth, and fifth treatments was 74, 33, 23, respectively. D). While the water use efficiency in the control was equal to 0.62 kg/m^3, the values in the second, third, fourth, and fifth treatments were 0.54, 0.72, 0.82, and 1.11 kg/m^3, respectively. The efficiency of potassium fertilizer in the third treatment was 2.51 kg/kg. In the fourth treatment this value improved to 4.96, and in the fifth treatment to 4.58 kg/kg. E). Despite reducing water consumption from 7560 cubic meters in all four treatments to 5400 cubic meters in the fifth treatment, the yield in the fifth treatment compared to the control treatment had a 31% increase yield, which was significant at the percent probability level. Considering the above results, it was concluded that in soils where the concentration of potassium and zinc was less than the critical limit, it was better to use potassium and zinc fertilizers in several stages.

Keywords: Drought, Chelating agents, Nutrition, Deficiency, Foliar spray

Introduction

According to the Standard Organization of Iran (2017), the per capita consumption of wheat in the country is 334 grams per day per person. Wheat has been reported to provide 47% of a person's daily energy (Aquino *et al*., 2001). By consuming bread, 61 to 78% of calories and 78 to 93% of protein needed by human beings are provided, and considering the increase in world and Iran's population and food shortages, evaluating the possible ways to increase wheat production is one of the most critical and significant issues (Ghorbani *et al*., 2011). Plant nutrition is one of the most important and influential factors in wheat yield. According to the Liebig law of the minimum, if all elements are available to the plant and only one nutrient is deficient, the maximum yield of the plant is limited. Potassium and zinc are essential in improving plants' quantitative and qualitative yield (Malakouti, 2018). In a study conducted by Zhang *et al*. (2011) for 18 consecutive years (1990-2008) on sustainable management of potassium and long-term productivity in interaction with conventional fertilizers (N and P) in five Chinese

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research stations, in response to the addition of potassium in areas with low or non-exchangeable potassium content, a 21% increase in yield was reported for wheat and a 16-172% increase in yield for maize. Keshavarz and Malakouti (2005) showed in an experiment that zinc application positively affecting wheat growth under salinity stress. According to studies by Tariq *et al*. (2014) on corn and Imran *et al*. (2015) on rice, the combined application of zinc and potassium significantly increased plant yield compared to the application of potassium alone.

Potassium is present in the soil in four forms: Mineral, stabilized, exchangeable and soluble (Malakouti *et al*., 2008). The balance between the different forms of potassium in the soil keeps plants supplied with potassium. Soluble and exchangeable potassium equilibrate rapidly. While the balance between structural potassium and solution-stabilized potassium is slow (Havlin *et al*., 2005). Exchangeable potassium and potassium-absorbed potassium are both exchangeable and stabilized. It forms a small part of soil potassium and is about 1%, fixed potassium is up to about 8%, and insoluble or insoluble minerals are up to 90%. The amount of dissolved potassium in soil is negligible compared to the soil potassium. Khavazi *et al*. (2014) reported that 28.10% of the country's soils are deficient in potassium, so a deficiency of this element can be an important factor in limiting plant growth. Potassium nutrition increases crop WUE by utilizing the soil moisture more efficiently than in K-deficient plants. The positive effects of K on water use efficiency may be through promotion of root growth accompanied by a greater uptake of nutrients and water by plants (Waraich *et al*., 2011) and through the reduction of transpirational water loss (Umar and Moinuddin, 2002).

Zinc plays a non-essential role in many physiological processes, including the synthesis of many enzymes, metabolic processes, protein synthesis, and the biosynthesis of chlorophyll in plants, as well as in coordinating the immune response in animals (Huang *et al*., 2019). Calcareous soils of the country, high concentration of bicarbonate in irrigation water, lack of organic matter, and high pH in the soils have caused zinc deficiency in plants (Malakouti, 2018). Wheat is inherently low in zinc; when grown in soil with zinc deficiency, its concentration will naturally decrease further (Cakmak, 2008). In Turkey, it is reported that when wheat grows in soil with sufficient concentration of zinc, it has a concentration of 20 to 30 mg/kg, while wheat grown in soil with zinc deficiency has a concentration of 5 to 12 mg zinc/kg (Cakmak *et al*., 2010). The average zinc concentration in whole wheat grains in different countries has been reported to be 20 to 35 mg/lg (Cakmak, 2008). Hashemi Nasab *et al*. (2021) have reported that the concentration of zinc in wheat grains in the country by 23.80 mg/kg, which is very low due to the optimal level of zinc in wheat grains (40 mg/kg). Considering that bread constitutes the significant share of the community food basket (334 grams per day - Standard Organization of Iran), the lack of zinc in the grain, in addition to reducing yield, will also affect the community's health. According to the report of Khavazi *et al*. (2014), 54.60% of the agricultural soils of the country have a zinc concentration of less than 0.75 mg/kg, which indicates a severe deficiency of this element in Iranian soils. Therefore, zinc deficiency in the soil seems to have caused a lack of zinc in wheat grain (Cakmak, 2008).

Drought stress is the most common environmental stress that limits crop yields in 25% of the world. Among environmental factors, drought stress is the second major cause of yield decline after pathogens (Biglouie *et al*., 2010). Water stress reduces grain weight and yield by reducing growth (Galle *et al*., 2010), decrease in photosynthesis (Urban *et al*. 2017), and accelerating leaf senescence (Martinez *et al*., 2003). Studies have shown a close relationship between nutrient status and water requirements for the plant. Fertilizer application increases crop efficiency with the same water source. This shows that crop yield can be increased by effectively increasing nutrients under moisture restriction. Therefore, this study was designed and conducted to investigate the role of potassium sulfate solution containing zinc-chelate in increasing the yield and reducing the water consumption of wheat in the Kahnooj (Kerman) region.

Materials and methods

Time and location of the project: The present study was conducted during the cropping year of 2019-2020 in the Kahnooj city, south of Kerman province, and in the geographical position of 28º 5'N and 57º 45'E.

Treatments: This experiment was performed in a randomized complete block design with 5 treatments and 3 replications in a wheat field. The area of the plots for each replicate was 100 square meters, and wheat cultivar Chamran 2 with a seed content of 250 kg/ha was selected for this study. Before planting, the soil was sampled from a depth of 0-30 cm, and the physical and chemical properties were determined by conventional laboratory methods (Pansu and Gautherou, 2003)
(Table 1).

Experimental treatments in this study included; the first treatment: Control (consumption of all fertilizers except potassium based on the results of soil analysis with 7 irrigations). The second treatment: The conventional fertilizing by the local farmers (NP) with 7 irrigations; the third treatment: First treatment + application of potassium sulfate (SOP) before planting, with 7 irrigations; Fourth treatment: First treatment + application of 33% sulfate-potassium (SOP) before planting and 67% of the remaining source of soluble potassium sulfate (SSOP) as foliar application with 7 irrigations; Fifth treatment: The first treatment + application of 33% of sulfate-potassium (SOP) before planting and 67% of the remaining source of the sulfate-potassium solution containing chelate (SSOP + Zn-EDTA) as foliar application and irrigation in 5 times.

Fertilization and fertilizer treatments: Micronutrient fertilizers with sulfate sources, including ferrous sulfate, manganese sulfate, zinc sulfate, and copper sulfate, were added to the soil at 100, 80, 50, and 20 kg/ha before planting, respectively. Sulfur at a rate of 300 kg/ha (with *Thiobacillus bacterium* at a rate of 1%)

Table 1- Results of the physical and chemical properties of the soil

OC	pH	EC	Sand	Silt	Clay	P	N	Cu	Zn	Mn	Fe	K	S	TNV
%		dS/m		%					mg/kg					%
0.07	7.3	5.80	68	28	4	6.40	0.007	0.35	0.38	6.13	0.09	86	0.01	11.6

and superphosphate-triple at a rate of 150 kg/ha and 300 kg of sulfate-potassium per hectare were utilized. The urea fertilizer was added to the treatments at the time of tillering and the beginning of stalking as a foliar application. Soluble potassium sulfate and soluble potassium sulfate-containing zinc chelate were added as foliar at the time of stem formation and grain filling.

In the present study, irrigation was conducted as flood irrigation. Water stress was applied to the fifth treatment so other treatments were irrigated seven times as usual in the region. However, the fifth treatment was irrigated five times and included two stages, the first stage at the shoot and the second stage at the grain formation. Plant harvest was performed at the stage of complete physiological maturity. For this purpose, 2 meters from the middle of each plot were harvested to measure wheat yield, and the grains were separated from the cluster and cleaned. Measured traits included total yield, potassium fertilizer efficiency, water efficiency, grain potassium content, grain zinc concentration, grain phosphorus, protein content per grain, and the molar ratio of phytic acid to zinc (PA/Zn) per grain.

Measuring plant dry matter percent: To determine the plant dry matter percentage, the samples were transferred to the laboratory and dried in an oven at 65°C for 48 hours. The dry matter percent was calculated by the distraction of initial sample weight (fresh sample) and oven-dried weight.

Measurement of plant biochemical traits, nitrogen measurement:

Grain nitrogen concentration was determined using the Kjeldahl method (Bremner and Mulvaney, 1982) so that 0.1 g of milled samples adjacent to the catalyst (copper sulfate, potassium, and selenium sulfate) and concentrated sulfuric acid at 380°C for 3 hours of digestion and grain nitrogen concentration were determined using a Kjeldahl apparatus.

Measurement of grain protein: The grain protein concentration was measured using the Kjeldahl method (Bremner and Mulvaney, 1982) so that the amount of 0.1 g of milled samples adjacent to the catalyst (copper sulfate, potassium sulfate, and selenium) and concentrated sulfuric acid at 380°C for 3 hours of digestion and grain nitrogen concentration were quenched using a device. Then, using a coefficient of 6.25, the grain nitrogen concentration was converted to the grain protein (Boulos *et al*., 2020).

Grain phytic acid concentration: Phytic acid with the chemical name cyclohexane is hexylhexa metaphosphate, and its chemical formula is $C_6H_{18}O_{24}P_6$. In order to determine the molar ratio of phytic acid to zinc, it was calculated by first converting the concentration of phytic acid.

Grain phytic acid percent= grain P content × 3.55

According to the molar mass of phytic acid (660.04 g/mol) and the molar mass of the element zinc (65.38 g/mol), their concentrations were calculated in moles, and the molar ratio of phytic acid to zinc was calculated according to the following equation.

The molar ratio of phytic acid to zinc = molar ratio of phytic acid/molar concentration of zinc

Water use efficiency: According to the following equation, water use efficiency was calculated based on biological consumption and economic yield of grain in terms of kg/kg (water consumption).

$$WUE = \frac{D}{W}$$

Where, water use efficiency in kg/kg, D is the yield in the treated plot in kg/ha, and W is the amount of water used in kg/ha. Considering the time of water consumption and water consumption, the amount of water consumed for the first to fourth treatments was 7560 cubic meters and for the fifth treatment was 5400 cubic meters.

Fertilizer use efficiency: Fertilizer efficiency is defined as the yield produced per unit of input consumed. The efficiency of fertilizer or elements is the amount of yield production per kilogram of fertilizer or applied element, expressed in kilograms of yield per kilogram of fertilizer or desired element (Malakouti, 2018). The efficiency of potassium fertilizer was calculated from the following formula.

$$KUE = \frac{(Kf)-(Kc)}{R}$$

Where, KUE is the fertilizer use efficiency in kg/kg, Kf is the yield in the treated plot in kg/ha, KC is the yield in the control plot in kg/ha, and R is the amount of potassium applied in kg/ha.

The data were statistically analyzed using SAS software (Ver. 9.0). Also, the mean of the data was compared using LSD test at 5%.

Results and discussion

This study was conducted to investigate the effect of optimal application of potassium fertilizer and water consumption on wheat's quantitative and qualitative yield. The results of this study were presented as traits related to grain yield and quality traits.

Yield traits: According to Table 2, the analysis of variance showed that the effect of different treatments on the studied parameters was statistically significant ($P<0.01$).

Grain yield: According to the results, the lowest and highest grain yields were obtained in the second and fourth treatments, which were 4648 and 6137 kg/ha, respectively (Figure 1). The results showed that in the control where all fertilizers (except potassium) were applied based on the soil test, grain yield was 14%

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Table 2- results of analysis of variance of the effect of the fertilizer and irrigation treatments on studied parameters (first to fourth treatments)

S. O. V.	df	Grain Yield	Water Use Efficiency	Potassium Use Efficiency	P	K	Zn	Protein	Molar ratio of phytic acid to zinc
Treatments	4	2357339**	0.148**	5.2**	0.011**	0.011**	198.22**	13.78**	13.78**
Error	10	3388	0.000072	0.0186	0.000073	0.000073	0.6	0.0076	0.0076
C.V. (%)		2	2	4	3	3	3	3	3

**** significant at 1 percent probability level**

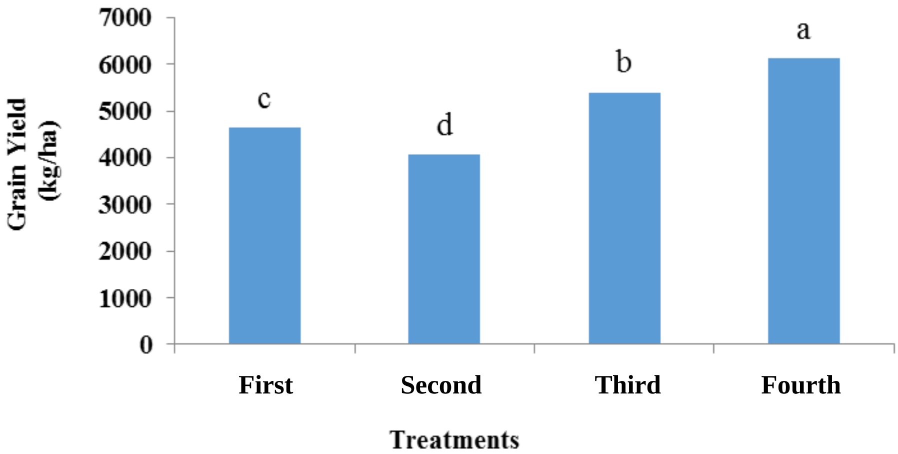

Figure 1- effect of different fertilization treatments on grain yield (T1 (First): Control, T2 (Second): conventionl fertilizing by the local farmers, T3 (Third): first treatment + application of potassium sulfate, T4 (fourth): first treatment + application of 33% sulfate-potassium, before planting and 67% of the remaining source of soluble potassium sulfate (SSOP) as foliar application, T5 (fifth): first treatment + application of 33% of sulfate-potassium (SOP) before planting and 67% of the remaining source of sulfate-potassium solution containing chelate (SSOP + Zn-EDTA) as foliar application)

higher than in the second treatment, which was done according to the farmer's conventional fertilization plan. The difference between the two treatments were statistically significant.

The results showed that the grain yield in the fifth treatment was 6022 kg/ha. According to Table 3, the difference between the grain yield in the fifth treatment and the first to fourth treatments (group comparison) was statistically significant (P<0.01).

The the mean comparison between the first to fourth treatments compared to the fifth treatment showed that the grain yield in the fifth treatment was higher than the first to third treatments and was statistically significant. The results also showed that the grain yield in the fourth treatment was 1.90% higher than in the fifth treatment, whereas the difference was not statistically significant (Table 3).

These results were consistent with the results of Khan *et al*. (2014). They reported that the application of potassium fertilizers in soils with potassium content less than the critical level of initial potassium, mainly sandy soils or highly aerated soils, led to a significant increase in grain yield. Fornari *et al*. (2020) also reported that the application of potassium fertilizer not only increased wheat yield in control but also reduced water consumption, which was consistent with the results of the present study. The positive effect of potassium on increasing grain yield has also been reported by Iqbal *et al*. (2010) for maize and Asgharipour and Heidari (2011) for sorghum. Fan *et al*. (2021) reported an increase in dry matter production and yield of maize using potassium, which was attributed to the increase in photosynthesis and the transfer of more photosynthetic materials to the grain by providing moisture.

Water use efficiency: The lowest and highest water use efficiencies were related to the second and fourth treatments, whose values were 0.54 and 0.82 kg/m^3, respectively (Figure 2). According to the results, water use efficiency in the first treatment, in which fertilization was performed based on the soil test, was 0.62 kg/m^3 of water, which was 14% higher than the second treatment, which used only nitrogen and phosphorus. Also, the results showed that the water use efficiency in the third treatment was 0.72 kg/m^3, which was 13.60% lower than the fourth treatment, which differed only in the method of fertilizer application.

According to the results, water use efficiency in the fifth treatment was 1.11 kg per cubic meter of water. Although the amount of water used in this treatment was lower compared to other treatments, water use efficiency in this treatment compared to the first treatments was higher, which was statistically significant (group comparison of the first to fourth treatments with the fifth treatment) was also significant at the level of 1% (Table 2). The amount of water use efficiency in the fifth treatment compared to the other

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Table 3- results of t-test between grain yield of fifth treatment compared to the other treatments (first to fourth treatments)

Experimental Treatments	Grain Yield (kg/ha)	Grain Yield in T5 (kg/ha)	Water Use Efficiency (kg/m^3)	Water Use Efficiency in T5 (kg/m^3)
T 1	4648	6022**	0.62	1.11**
T 2	4077	6022**	0.54	1.11**
T 3	5402	6022**	0.72	1.11**
T 4	6137	6022^{ns}	0.82	1.11**

*** and ** significant at 5 and 1 percent probability level, respectively, and ns non-significant. (T1 (First): Control, T2 (Second): conventionl fertilizing by the local farmers, T3 (Third): first treatment + application of potassium sulfate, T4 (fourth): first treatment + application of 33% sulfate-potassium, before planting and 67% of the remaining source of soluble potassium sulfate (SSOP) as foliar application, T5 (fifth): first treatment + application of 33% of sulfate-potassium (SOP) before planting and 67% of the remaining source of sulfate-potassium solution containing chelate (SSOP + Zn-EDTA) as foliar application)**

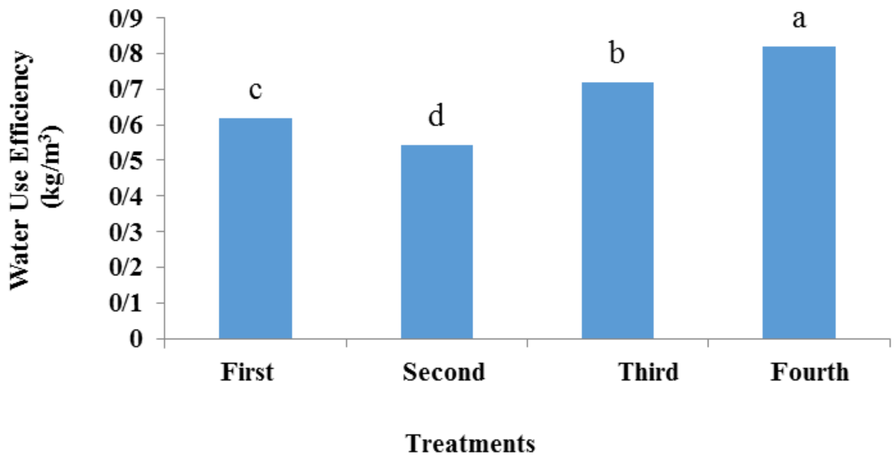

Figure 2- effect of different fertilization treatments on water use efficiency. (T1 (First): Control, T2 (Second): conventionl fertilizing by the local farmers, T3 (Third): first treatment + application of potassium sulfate, T4 (fourth): first treatment + application of 33% sulfate-potassium, before planting and 67% of the remaining source of soluble potassium sulfate (SSOP) as foliar application, T5 (fifth): first treatment + application of 33% of sulfate-potassium (SOP) before planting and 67% of the remaining source of sulfate-potassium solution containing chelate (SSOP + Zn-EDTA) as foliar application)

treatments (first to fourth treatments) was statistically significant (t-test), which indicated that consuming less water in the fifth treatment while achieving maximum yield equivalent to the fourth treatment, water use efficiency was also maximized (Table 4).

Water use efficiency showed a slight relationship between plant growth and water consumption. It is defined as the amount of dry matter produced per unit of water consumed. Fornari *et al*. (2020) reported that the application of potassium fertilizer at 300 kg/ha led to a reduction in water consumption and increased corn yield from 7650 kg/ha to 8700 kg/ha compared to the control. Considering the role of potassium in the stomatal functions and cell turgor, it seems that potassium has increased water efficiency in the plant by regulating water consumption in the plant while reducing the amount of water consumed in the soil (Malakouti *et al*., 2008). The results of the present study showed that the application of zinc with potassium fertilizers had a synergistic effect on the absorption of other cationic nutrients such as potassium, iron, manganese, and copper, which in turn led to increased plant resistance to the drought stress and not only reduced the effects of environmental stresses but also reduced the water vapor pressure fraction by regulating photosynthesis, stomatal conductance, and fluorescence indices, thus prevents water loss, results in a reduction in the plant's water requirement and increases relative yield (Rizwan *et al*., 2019).

Potassium use efficiency: In the present study, potassium fertilizer was not used in the first and second treatments. In the third, fourth, and fifth treatments, potassium-containing fertilizer (application by different methods and amounts) was used. The results showed that potassium application had higher efficiency in the fourth treatment compared to the third treatment, and this difference was significant at 1% probability (Figure 3). Reducing the effects of environmental stresses and increasing yields (increasing the potassium fertilizer efficiency) in tomato, pepper, eggplant, clove, and cereals such as rice has been demonstrated (Grewal and Graham, 1999; Hakerlerler *et al*., 1997; Haque, 1988).

The results showed that the efficiency of potassium application in the fifth treatment was 4.60, which was significant compared to other treatments (third and fourth treatments) ($P<0.01$) (Table 2). The results indicated that in light-textured lands, it was necessary to use potassium in wheat in several steps, in proportion to

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Table 4- results of t-test between grain yield of fifth treatment compared to the other treatments (first to fourth treatments)

Experimental Treatments	Potassium Use Efficiency (%)	Potassium Use Efficiency (%) in T5
T 3	2.5	4.6^{**}
T 4	4.96	4.6^{ns}

*** and ** significant at 5 and 1 percent probability level, respectively, and ns non-significant. T3 (Third): first treatment + application of potassium sulfate, T4 (fourth): first treatment + application of 33% sulfate-potassium, before planting and 67% of the remaining source of soluble potassium sulfate (SSOP) as foliar application**

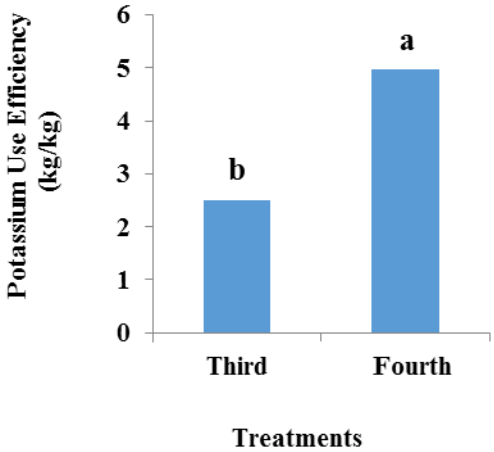

Figure 3- effect of different fertilization treatments on potassium use efficiency, T3 (Third): first treatment + application of potassium sulfate, T4 (fourth): first treatment + application of 33% sulfate-potassium, before planting and 67% of the remaining source of soluble potassium sulfate (SSOP) as foliar application

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wheat's phenological growth stages. Also, the use of all fertilizers containing potassium before planting reduced the efficiency of fertilizer use and its effect. It also reduced yield and increased production costs. The results mentioned above were consistent with the results of Alcoz *et al*. (1993) concerning increasing fertilizer efficiency and in the application of potassium fertilizers.

Increasing the efficiency of potassium fertilizer application in the fifth treatment compared to the third and fourth treatments caused the difference between the fifth and third treatments to be statistically significant at the level of 1%. In contrast, the difference between the fifth and fourth treatments was not statistically significant (Table 4).

Grain quality traits: The analysis of variance of grain quality traits (nitrogen, phosphorus, potassium, zinc, protein concentration and phytic acid to zinc molar ratio) showed a significant difference between the studied treatments at 1% level (Table 2).

Grain phosphorous content: According to the results, farmers obtained the highest grain phosphorus content in the conventional fertilizer application; farmers obtained the highest grain phosphorus content in the conventional fertilizer application (second treatment), which was 0.37%. Phosphorus content in the first, third and fourth treatments were 0.30, 0.26, and 0.23%, respectively (Figure 4). The results also showed that in the application of sulfate-potassium fertilizer, phosphorus concentration decreased compared to the control. In the application of sulfate-potassium fertilizer as a foliar application (fourth treatment), the lowest concentration of phosphorus was observed compared to the other treatments which were also statistically significant.

Remaining source of sulfate-potassium solution containing chelate (SSOP + Zn-EDTA) as foliar application)

The results showed that the concentration of grain phosphorus in the fifth treatment was 0.22%, which is statistically different (group comparison between the first to fourth treatments with the fifth treatment) from the concentration of grain phosphorus in other treatments (first to fourth treatments). According to the results of comparing the mean (t-test) of the first to fourth treatments with the fifth treatment, the difference between grain phosphorus concentrations in the first to third treatments with the fifth treatment was statistically significant. At the same time, there were no differences between the fourth and fifth treatments in terms of the phosphorus concentrations (Table 5).

Grain potassium content: The lowest and highest grain potassium concentrations were obtained in the second treatment (conventional fertilizer application method by farmers) and the fourth treatment (foliar application of soluble potassium sulfate fertilizer) by 0.29 and 0.54%, respectively (Figure 5). The results showed no significant difference in grain potassium concentration between the control and the second treatment (conventional fertilizer application method by farmers). In contrast, the application of potassium sulfate fertilizer completely before planting (third treatment) and as a foliar application (fourth treatment) had a significant difference in grain potassium

Table 5- t-test between nutrient concentrations (percentage) of the fifth treatment with other treatments

Experimental Treatments	P content (%)	P content (%) in T5	K content (%)	K content (%) in T5	Zn content (%)	Zn content (%) in T5
T 1	0.30	0.22^{**}	0.30	0.52^{**}	23.33	37.33^{**}
T 2	0.37	0.22^{**}	0.29	0.52^{**}	17.67	37.33^{**}
T 3	0.26	0.22^{**}	0.42	0.52^{**}	28	37.33^{**}
T 4	0.23	0.22^{ns}	0.54	0.52^{ns}	35	37.33^{**}

*** and ** significant at 5 and 1 percent probability level, respectively, and ns non-significant. (T1 (First): Control, T2 (Second): conventionl fertilizing by the local farmers, T3 (Third): first treatment + application of potassium sulfate, T4 (fourth): first treatment + application of 33% sulfate-potassium, before planting and 67% of the remaining source of soluble potassium sulfate (SSOP) as foliar application, T5 (fifth): first treatment + application of 33% of sulfate-potassium (SOP) before planting and 67% of the remaining source of sulfate-potassium solution containing chelate (SSOP + Zn-EDTA) as foliar application)**

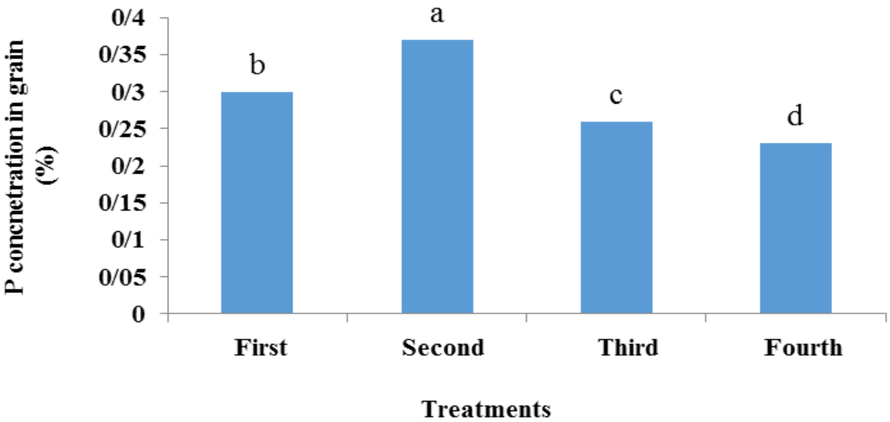

Figure 4- The effect of different fertilizer treatments on grain phosphorus concentration. (T1 (First): Control, T2 (Second): conventionl fertilizing by the local farmers, T3 (Third): first treatment + application of potassium sulfate, T4 (fourth): first treatment + application of 33% sulfate-potassium, before planting and 67% of the remaining source of soluble potassium sulfate (SSOP) as foliar application, T5 (fifth): first treatment + application of 33% of sulfate-potassium (SOP) before planting and 67% of the

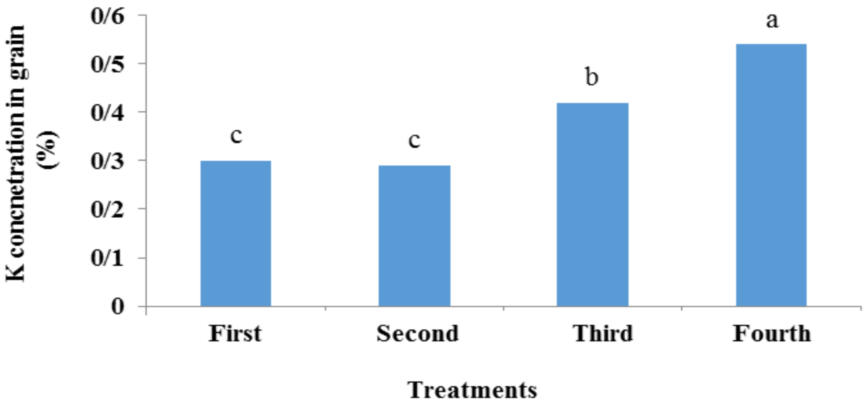

Figure 5- The effect of different fertilizer treatments on grain potassium concentration. (T1 (First): Control, T2 (Second): conventionl fertilizing by the local farmers, T3 (Third): first treatment + application of potassium sulfate, T4 (fourth): first treatment + application of 33% sulfate-potassium, before planting and 67% of the remaining source of soluble potassium sulfate (SSOP) as foliar application, T5 (fifth): first treatment + application of 33% of sulfate-potassium (SOP) before planting and 67% of the remaining source of sulfate-potassium solution containing chelate (SSOP + Zn-EDTA) as foliar application)

concentration compared to the control. Also, there was a statistically significant difference between the third and the fourth treatments in the grain potassium concentration. The grain potassium concentration influenced by these two treatments were 0.42 and 0.54%, respectively. Ma *et al.* (2018) showed that by increasing the application of potassium fertilizer up to 80 kg/ha, leaf potassium concentration increased to 2.7,

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2.5, 1.2, and 1.7% in wheat plant shoots.

The results showed that the potassium concentration in the fifth treatment was 0.52% which was statistically significant compared to the other treatments (first to fourth treatments) (group comparison of first to fourth treatments with the fifth treatment) ($P<0.01$; Table 2).

According to the results, the grain potassium concentration in the fifth treatment was numerically higher than in the first to third treatments, which was also statistically significant (t-test). However, the difference between the fourth and fifth treatments was not statistically significant (Table 5).

Grain zinc content: The lowest and highest grain zinc concentrations were observed in the second and fourth treatments 17.67 and 35 mg/kg, respectively (Figure 6). According to the results, the zinc concentration in the control treatment, fertilizer based on soil test (except potassium), was 23.33 mg/kg. The results also showed that between the third and fourth treatments, which were differences in the application of sulfate-potassium fertilizer, a significant difference was observed in the concentration of zinc in the grain.

The results showed that the zinc concentration in this treatment was 37.33 mg/kg. Group comparison of the first to fourth treatments with the fifth treatment showed a statistical difference between these treatments and the fifth treatment ($P<0.01$; Table 2).

According to the results, the zinc concentration in the fifth treatment was higher than in the other treatments, which was statistically significant with one treatment (first to fourth treatments) (t-test; Table 5).

Based on the results, the amount of zinc uptake from the soil to provide grain zinc concentration in the field has increased, consistent with Soleimanzadeh *et al*. (2010) results in improving the quality of wheat grain. This experiment's results align with the results of Saha *et al*. (2020), who reported that the soil application of zinc fertilizer increased grain enrichment with zinc up to 5 mg/kg (17%) compared to the control. While soil application and zinc foliar application increased zinc enrichment up to 27.8 mg/kg (95%) compared to the control treatment.

Grain protein content: The lowest and highest grain protein content was observed in the second and fourth treatments by 8.57 and 13.85%, respectively (Figure 7). Protein content in the first treatment in which fertilization was based on soil test (except for the application of fertilizer containing potassium) was 11.69%, which was 36.40% higher than the second treatment in which fertilization was based solely on the conventional fertilizer application by farmers. Also, the results showed that the protein concentration in the third treatment was 13.62%, lower than the fourth treatment and higher than the first and second treatments. The rice grain protein content in Saha *et al*. (2020) ranged from 7.91 to 11.18%, with an average of 9.28%. The application of zinc increased the grain protein content compared to the control treatment. For example, a 10% increase in this parameter was reported. Differences in the grain protein content of cereals can depend not only on zinc fertilizer management but also on variation in cereal cultivars. The use of zinc was helpful in increasing protein content in plant parts since zinc was involved in protein metabolism through several enzyme systems (Feng *et al*., 2008). Therefore, increasing the protein content of cereals due to the zinc application can also improve the desired quality characteristics of cereals (Horino *et al*., 1983).

Results showed that the grain protein content in the fifth treatment was 13.85% which was statistically significant compared to the other treatments (first to fourth treatments) (group comparison between the first to fourth treatments with the fifth treatment) at a 1 percent probability level (Table 4).

Similar investigations showed that by pre-planting application of zinc sulfate and also the foliar application of chelated zinc fertilizer, wheat grain protein concentration significantly increased compared to other treatments (Soleimanzadeh *et al*., 2010) high synergistic uptake of zinc, potassium, and nitrogen. There is also an increase in the physiological and morphological characteristics of the plant.

According to the results, the grain protein content in the fifth treatment was higher than in other treatments (first to fourth treatments), where the difference between this treatment and the first to third treatments was statistically significant (t-test). In contrast, the difference with the fourth treatment was not significant (Table 6).

Increasing the grain protein content could be affected by the positive effects of potassium and zinc in providing the nutritional requirements of wheat for these elements and thus the biosynthesis of grain protein. The results obtained in the present study were in line with the findings of and Wang *et al*. (2017) on the combined use of potassium and zinc as foliar application and also the results of Ranjbar *et al*. (2007) on the effect of zinc application in increasing grain zinc concentration, grain protein, 1000-grain weight, and grain yield.

The molar ratio of phytic acid to zinc (unfavorable nutritional index) in the grain: According to the results, there was a significant difference between treatments in terms of PA/Zn ($P<0.01$; Figure 8). The fourth, third, first, and second treatments had the lowest to highest PA/Zn value. The values of this trait in these treatments were 23.44, 32.71, 45.82, and 73.74, respectively.

The results showed that PA/Zn value in the fifth treatment was 20.72, which was statistically significant compared to the other treatments (group comparison of the first to fourth treatments with the fifth treatment) at the 1% probability level (Table 2).

According to Table 6, the PA/Zn value in the fifth treatment was less than other treatments, which is statistically significant (t-test) between the first to third treatments at the level of 1% and with the fourth treatment at the level of 5%. The application of

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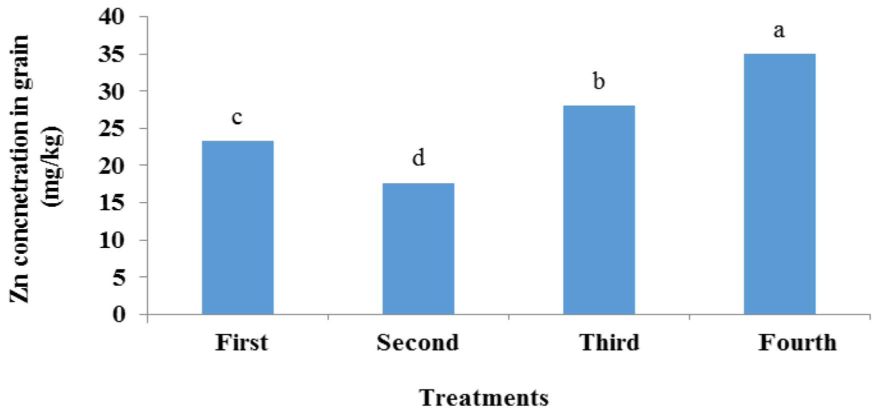

Figure 6- Effect of different fertilizer treatments on grain concentration. (T1 (First): Control, T2 (Second): conventionl fertilizing by the local farmers, T3 (Third): first treatment + application of potassium sulfate, T4 (fourth): first treatment + application of 33% sulfate-potassium, before planting and 67% of the remaining source of soluble potassium sulfate (SSOP) as foliar application, T5 (fifth): first treatment + application of 33% of sulfate-potassium (SOP) before planting and 67% of the remaining source of sulfate-potassium solution containing chelate (SSOP + Zn-EDTA) as foliar application)

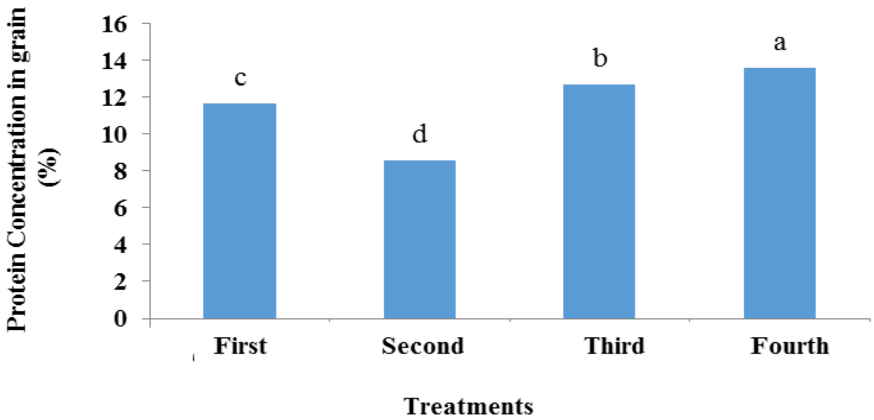

Figure 7- The effect of different fertilizer treatments on grain protein concentration. (T1 (First): Control, T2 (Second): conventionl fertilizing by the local farmers, T3 (Third): first treatment + application of potassium sulfate, T4 (fourth): first treatment + application of 33% sulfate-potassium, before planting and 67% of the remaining source of soluble potassium sulfate (SSOP) as foliar application, T5 (fifth): first treatment + application of 33% of sulfate-potassium (SOP) before planting and 67% of the remaining source of sulfate-potassium solution containing chelate (SSOP + Zn-EDTA) as foliar application)

potassium and zinc fertilizers plays an essential role in decreasing the absorption of phosphorus in soils that are low in potassium and zinc. Zinc and potassium, through primary mechanisms such as inhibition of phosphorus root uptake, transfer of absorbed phosphorus to less-mobile areas such as cell walls and vacuoles, and changes in plant root position, lead to reduced phosphorus transfer to organs where it has more motility. Then its entry into the cytoplasm, thus reducing the transfer of phosphorus to the grain, which leads to a decrease in the unfavorable nutritional index (Malakouti, 2018; Marschner, 1995). Also, the results showed a statistical difference between the fifth treatment and other treatments in terms of the molar concentration of phytic acid at the level of 1% (Table 6).

In order to investigate the role of zinc in increasing yield and reducing the molar ratio of phytic acid to rain-fed wheat, Bahrami (2011) experimented by 10 farms near Khodabandeh city located in Zanjan province in the 2010-2011 cropping year. The three treatments of this experiment were the first treatment: control (without fertilizer application), the second treatment: fertilization according to the conventional method of the farmers in the region, and the third treatment: Fertilization based on the results of soil analysis (balanced nutrition) and planting and maintenance operations were conducted according to farmers' conventions in the area. The results showed that while the average yield per hectare in the treatment areas without fertilizer was 975 kg and in the conventional treatment of farmers was 1401 kg/ha, this yield in the

Table 6- t-test between protein content and PA/Zn ratio of the fifth treatment with other treatments

Experimental Treatments	Protein content (%)	Protein content (%) in T5	PA/Zn	PA/Zn (%) in T5
T 1	11.68	33.85**	45.82	20.72**
T 2	8.57	33.85**	73.74	20.72**
T 3	12.69	33.85**	32.70	20.72**
T 4	13.62	33.85ns	23.44	20.72*

*** and ** significant at 5 and 1 percent probability level, respectively, and ns non-significant. (T1 (First): Control, T2 (Second): conventionl fertilizing by the local farmers, T3 (Third): first treatment + application of potassium sulfate, T4 (fourth): first treatment + application of 33% sulfate-potassium, before planting and 67% of the remaining source of soluble potassium sulfate (SSOP) as foliar application.**

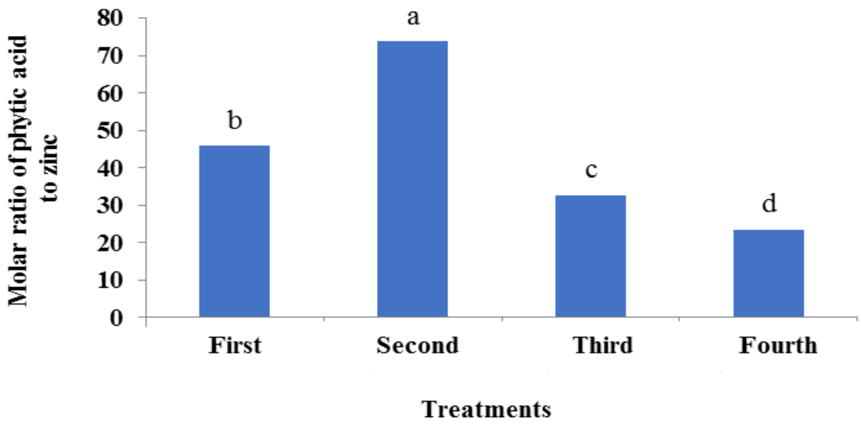

Figure 8- Effect of different fertilizer treatments on the molar ratio of phytic acid on grain. (T1 (First): Control, T2 (Second): conventionl fertilizing by the local farmers, T3 (Third): first treatment + application of potassium sulfate, T4 (fourth): first treatment + application of 33% sulfate-potassium, before planting and 67% of the remaining source of soluble potassium sulfate (SSOP) as foliar application, T5 (fifth): first treatment + application of 33% of sulfate-potassium (SOP) before planting and 67% of the remaining source of sulfate-potassium solution containing chelate (SSOP + Zn-EDTA) as foliar application)

balanced nutrition treatment was 1628 kg/ha. The mean concentrations of phosphorus and zinc in wheat grain compared to the control treatment were 0.26% and 21 mg/kg, respectively, in the conventional treatment of farmers, 0.24% and 25 mg/kg, and the optimal fertilizer application treatment, 0.21% and 30 mg/kg, respectively. While the molar ratio of phytic acid to zinc in the treatment without fertilizer was 30 and in the conventional treatment of farmers was 23, this value decreased to 15 in the balanced nutrition treatment, which was significant at a 5 percent probability level. Considering the results, it was inferred that with balanced nutrition, in addition to a 16% increase in yield per hectare of dryland wheat fields compared to the conventional method of farmers, the molar ratio of phytic acid to zinc decreased from 23 to 15. Therefore, dryland wheat can be prepared without bran being separated from the wheat, which was in line with the current results of our research.

Conclusion

Potassium efficiency in wheat grain varied depending on the source and time of fertilizer application and was obtained in the range of 2.5 to 4.96 kg/kg. Potassium application in several steps at the same time as urea fertilizer application in the shoot and emergence stages compared to a single application at the pre-planting stage. While significantly affecting grain yield and protein, it significantly increased potassium use efficiency. In the study of fertilizer efficiency, based on the presented results, the fourth fertilizer treatment (consumption of soluble potassium sulfate as foliar) with 7 irrigations increased by 98%, and the fifth treatment (consumption of soluble potassium sulfate-containing chelating) with 5 irrigations, increased by 84%. Regarding the optimal fertilizer recommendation treatment of soil analysis laboratory, the third treatment; application of sulfate-potassium, showed that this was a positive result of using the foliar application of soluble potassium sulfate and soluble potassium sulfate-containing zinc chelate, affected fertilizer use efficiency. On the other hand, in this experiment, the preference of applying potassium sulfate fertilizer containing zinc chelate over soluble potassium sulfate (exterior soluble potassium sulfate) was proved, mainly due to the presence of zinc that could be used during flowering. The results indicated that these two elements, potassium, and zinc, had positive interactions and the combination of zinc with potassium application in several steps had a more significant effect on increasing wheat's quantitative and qualitative yield. Therefore, in order to increase grain yield and protein, enrich the grain with potassium and zinc, and improve the efficiency of potassium in wheat, in lands facing potassium and zinc deficiency, it is recommended to use potassium sulfate fertilizer containing Zn-EDTA chelate instead of a single application of potassium sulfate before planting. Further research should be continued to compare potassium and zinc application methods at different phenological stages of wheat growth.

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