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Effect of Soil and Foliar Feeding with some Sources of Potassium on Growth, Yield and Quality of Garlic

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ABSTRACT

This study was conducted during two winter successive seasons (2022/2023 and 2023/2024) at El-Gemmeiza experimental farm, Agric. Res., Station (ARC), Gharbya Governorate, Egypt, to study the effect of different potassium sources as soil mineral (MK) or natural feldspar (FS) and foliar spray (spraying with water, potassium fulvate KF (4.5 g/liter) and potassium thiosulfate KTS (1.25 ml/liter) on plant growth, productivity and quality of garlic bulb cv. Balady using clay soil conditions. The interaction between fertilizing garlic plants with 100 % recommended rate (at 96 kg K_2O/fed.) and KTS spraying at 1.25 ml/liter and/or fertilizing with 50% MKR (100 kg KS/fed.) +50% FSR (452.83 kg feldspar/fed.) and spraying with KTS gave the best results for increasing vegetative growth and plant dry weight, N, P and K contents and their leaves uptake, productivity and potassium use efficiency, total soluble solids and pungency. There were no significant differences between two treatments. This means that 50% MKR (100 kg KS/fed.) + 50% FSR (452.83 kg feldspar/fed.) and KTS spraying at was the best treatments for enhancing growth, yield and bulb quality of garlic.

Keywords: Garlic, potassium sulfate, feldspar, potassium fulvate and potassium thiosulfate.

INTRODUCTION

Garlic (*Allium sativum* L.) is regarded as one of the most significant vegetables in Egypt, both for domestic use and export. Second only to onions as a globally important cultivated Allium species is garlic. Garlic has culinary uses, medical value, and is used as a spice and seasoning. Additionally, flavoring food that has both green tips and bulbs (Dufoo-Hurtado *et al*., 2015).

To increase crop production per unit area and offset K-decreases in soils from crop absorption, runoff, leaching, and soil erosion, Egyptian farmers applied huge values of potassium chemical fertilizers such as potassium sulfate or chloride (Sheng and Huang, 2002). Pollution in the environment and increased production costs are caused by these fertilizers' high prices. Natural potassium fertilizer is low-cost methods of giving plants K that can replace the costly K-chemical fertilizers that are used (Labib *et al.,* 2012).

Potassium is essential for improving sugar translocation, which led to an increase in bulb width and weight. Additionally, increased synthesis and photosynthate translocation from the leaves to the bulb may be responsible for the increase in dry matter buildup in the bulb. According to Dilruba *et al.* (2006) higher rate of photosynthesis brought about by a larger potassium dose also improved vegetative development, gathered more food, and boosted overall output. Potassium is also required for a wide range of plant processes, including the activation of enzymes involved in the metabolism of carbohydrates, osmotic control, N absorption, protein synthesis, photosynthesis, and assimilate translocation (Pettigrew, 2008). Usually, chemical fertilizers containing sulfate, chloride, and nitrate are used to apply potassium (Perrenoud, 1993). Potassium is added as sulfate in Egypt. The environment has recently challenged the inclusion of these fertilizers (Badr, 2006). The third option is to make use of other natural resources, such as clay minerals like illite and K-bearing minerals like feldspar, lecuite, and K-mica such as biotite, plogopite, and glauconite (Sanz-Scovino and Rowell, 1988). These substances function as slow-release K fertilizers because they weather gradually, replenishing the natural supply of accessible K. Furthermore, because they are not readily available, K-bearing minerals are ineffective as K-fertilizers in agriculture (Harley and Gilkes, 2000). According to Bakker *et al.* (2004) certain microbes have a significant impact on the weathering processes of silicate minerals by solubilizing nutrients, such as K, from these minerals.

In this regard, Ali and Taalab (2008) showed that the best plant growth, yield and its components were produced form the plants of onion subjected under the mixture of K as potassium sulfate+ feldspar. On the other side there were no significant variation within using potassium sulfate alone and that if mixed with feldspar at rate 50 %+50%. Also, Shams and Fekry (2014) and Saif Eldeen and Baddour (2016) stated that on sweet potato, treating sweet potato plants with 50% potassium sulfate + 50% potassium feldspar and bio-fertilizer gave the best yield and its component. Furthermore, Abou El-Khair and Mohsen (2016) reported that fertilizing Jerusalem artichoke with 75 % mineral K as potassium sulfate) + 25 % natural K as feldspar scored the maximum values of plant growth, mineral contents and its uptake by shoots, total yield /fed. and tuber quality. In addition, Hasan and Ragab (2020) on sweet potato showed that adding 50% from the recommended dose of potassium sulfate plus 50% in the form of feldspar was the best treatment for enhancing vegetative plant growth, productivity and chemical constituents in leaves and tuber roots, followed by adding 100 % RR potassium sulfate. Moreover, Ali *et al.* (2021)

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indicated that the best treatments for enhancing growth, yield and tuber quality of potato were obtained when most of the potassium requirements were covered through mineral fertilizers (50-75%) and the rest via the application of feldspar rock (25-50%).

Foliar fertilization with different sources of potassium is more economical than root potassium fertilization because of its efficiency and higher cost. The foliar technique of fertilizer application is typically preferable since very little fertilizer is applied per hectare. Additionally, it lessens the applicant's pass total, which lessens the compactness of the soil issue. It is also less probable for foliar application to contaminate groundwater (El-Sayed *et al*., 2021).

In light of this, Behairy *et al*. (2015) suggested that spraying onion plants by 2-liter potassium thiosulfate per feddan noticeably improved vegetative growth and productivity than unsprayed plants. According to Shafeek *et al*. (2016), a 2% KTS spray on garlic plants improved the vegetative development, yield, quality of the bulbs, and chemical structure of the cloves. Likewise, Zyada and Bardisi (2018) indicated that the highest values of growth, NPK in leaves and bulbs and total yield of garlic were obtained with foliar spray by potassium silicate as compared to control treatment. Furthermore, Hafez *et al.* (2019) mentioned that the best growth and total yield of garlic were produced by potassium silicate as spraying the plants compared to unsprayed. Moreover, Metwaly *et al*. (2020) indicated that spraying garlic with KTS scored the maximum values of all parameters growth, productivity and quality of bulb as compared to potassium citrate and potassium nitrate. And Yousif *et al*. (2023) showed that spraying garlic plants with KTS produced the maximum growth of plant, productivity and mineral contents as well as the percentages of carbohydrates in garlic cloves than unsprayed plants.

Therefore, the aim of this work was to reduce dependence on mineral potassium fertilizer due to its high price and its harmful impact on the environment by using a natural alternative such as feldspar and some other alternatives in the form of spraying and studying this on the bulb productivity and quality in garlic bulbs.

MATERIALS AND METHODS

This study was conducted during two winter successive seasons (2022/2023 and 20233/2024) at the Experimental Farm of El-Gemmeiza, Agric. Res., Station (ARC), Gharbya Governorate (Middle Delta, Egypt), to study the effect of different sources of potassium as soil and feeding addition on growth of plant, productivity and quality of garlic bulb cv. Balady using under clay soil conditions.

Table 1. The physical and chemical properties of the experimental soil in 2022/2023 and 2023/2024 seasons

Season	Clay (%)	Silt (%)	Sand (%)	Texture class	EC mmohs/ cm	pH	OM (%)	Available (ppm)		
								N	P	K
1st season	66.60	23.80	9.60	Clay loam	1.43	7.82	1.49	8.27	0.048	0.92
2nd season	65.17	26.70	8.13		1.45	7.91	1.51	8.85	0.051	0.99

Soil samples were taken from a 25 cm soil surface.

There were 15 treatments in this experiment, including the following five treatments of potassium sources applied to the soil, and two treatments of potassium sources applied topically, beside unsprayed treatment.

Potassium source as soil application

100 % MKR = mineral potassium recommended rate 96 kg K_2O/fed. (200 kg potassium sulfate KS 48% K_2O)

1. 100 % FSR feldspar recommended rate = 96 kg K_2O/ fed (905.66 kg feldspar FS 10.6% K_2O).
2. 75 % MKR +25 % FSR =72 kg K_2O (150 kg KS/ fed.) + 24 kg K_2O (226.41 kg FS/fed.)
3. 50 % MKR + 50% FSR = 48 kg K_2O (100 kg KS/fed.) + 48 kg K_2O (452.83 kg FS/fed.)
4. 25 % MKR +75 % FSR = 24 kg K_2O (50 kg KS/fed.) + 72 kg K_2O (679.24 kg FS /fed.

Potassium sources as foliar spray

1. Spraying with water (control)
2. Spraying with potassium fulvate KF (10 % K_2O and 70 % fulvic acid) at 4.5 g/liter (450 ppm)
3. Spraying with potassium thiosulfate KTS (36% K_2O and 25% sulfur) at 1.25 ml/liter (450 ppm)

Three replications of a split-plot design were used to disperse these treatments. The main plots were randomly assigned to potassium source treatments as soil application, whereas the sub-plots were randomly assigned to potassium source treatments as foliar spray.

The experimental unit area was 13.2 m^2. It contained four ridges with 5.5 m length and 60 cm in width. One ridge was used for the samples to measure plant growth, and the other three ridges were used for yield determination.

Source of potassium for soil application were potassium sulfate KS (48% K_2O) and Feldspar FS (10.6 % K_2O). Al-Ahram Mining and Natural Fertilizer Company in Egypt grinds low-grade rock potassium samples, known as K-feldspar ($KAlSi_3O_8$), into ultrafine powder after extracting them as raw mining from a sedimentary rock materials deposit. 10.6% K_2O is present in rock potassium, a field sparse and little powder.

K-feldspar ($KAlSi_3O_8$) is a low grade rock potassium samples from a sedimentary rock materials deposit as raw mining after grinding to affine powder by Al-Ahram mining and natural fertilizer company in Egypt.

Table 2. Feldspar chemical composition

Feldspar rock	Components (%)
SiO_2	67.94
Al_2O_2	13.92
Fe_2O_2	0.09
CaO	0.32
MgO	8.08
K_2O	10.6
Na_2O	1.94
TiO_2	0.01
MnO_2	0.01
P_2O_5	0.04
Cl	0.03

Feldspar was combined with Bacillus circulanc, a soluble dissolving bacterium (SDB), at a ratio of 20 milliliters per kilogram of feldspar (one milliliter of SDB contains 10^{10} cells). In accordance with Badr (2006), the mixtures were often moistened and covered with a plastic layer to maintain the moisture content at roughly 60–70% for the duration of the composting phase, which lasted for 90 days prior to application treatment. The National Research Center in Egypt's Biofertilizer unit obtained SDB.

Garlic cloves were chosen based on their consistency in size and shape. In both seasons, cloves were planted on either side of the ridge at a distance of 10 cm on October 5 and October 8, respectively.

Potassium fulvate and potassium thiosulfate were produced in China and imported by Technogene Company, Dokki, Egypt, and sprayed on the plants five times at intervals of 45, 60, 75, 90 and 105 days following planting using a manual atomizer, the untreated plants (control) received water only.

The appropriate doses of N and P were applied to each plot at a rate of 120 kg in the form of sulfate ammonium (20.6% N) and 60 kg in the form of super phosphate calcium (15.5% P_2O_5), one third was applied during soil preparation, while the other two thirds of the nitrogen and mineral K_2O were applied in three portions as soil application at 30, 60 and 90 days after planting, the other third of the nitrogen, potassium sulfate, all calcium super phosphate, and various feldspar treatments were added during soil preparation.

In the district, the standard agricultural procedures were followed.

Data recorded

Growth Parameters

Plant height, leaf count per plant, neck, and bulb diameter are the growth characteristics of garlic plants that are measured. In both study seasons, ten randomly selected plants from each plot were collected 135 days after planting. After the leaves and bulb was oven dried at 70 ºC until they reached a constant weight, measurements were taken of the dry weight of the leaves and bulb/plant and the total dry weight of the plant.

Nitrogen, phosphorus and potassium contents

The amounts of nitrogen, phosphorus, and potassium in leaves were measured after 135 days from seeding in both seasons using the techniques outlined by A.O.A.C. (2018), the uptake of N, P and K by leaves was determined.

Yield and Its Components

The bulbs in every plot were taken out at the proper level of bulb maturity, which is about 200 days following sowing. They were then moved that same day to a shady area where they cured for about two weeks before being weighed and converted to show the overall yield (tons/fed.). To find the average bulb weight for each treatment, ten bulbs were randomly selected.

Potassium use efficiency (KUE)

It was calculated, as per Clark (1982), by dividing the bulbs yield/fed. by the potassium quantity/fed. The result was given as kg bulb/kg K.

Bulb Quality at Harvesting Date

Nitrogen, phosphorus and potassium contents

Using the previously described techniques for determining the contents of leaves N, P and K, a sample of one hundred gram of bulbs was oven dried at 70 ºC until it attained a consistent weight.

Using a Carl Zeis refractometer set, the total soluble solids (TSS) and dry matter percentage in the bulb were calculated. Schwimmer and Westen (1961) reported measuring pungency, or pyruvic acid, in bulb tissues at harvest time.

Statistical Analysis:

Snedecor and Cochran (1980) recommended statistical analysis of variance for recorded data, and Duncan (1955) recommended means separation.

RESULTS AND DISCUSSION

1.Growth of Plant

Effect of some sources of potassium as application soil

Data in Tables 3 and 4 show that fertilizing garlic plants with 50% of the recommended rate of mineral potassium (50% MKR) + 50% of the recommended rate of feldspar (FSR) significantly gave the tallest plants and maximum number of leaves/plant, neck and bulb diameter, dry weight of leaves, bulb and total dry weight/ plant at 135 days after planting, followed by fertilizing with 75% MKR +25% FSR and fertilizing with 100% MKR, whereas fertilizing with 100% FSR gave the lowest values in both seasons at 135 days after planting. Fertilizing with 100% FSR gave the lowest values of all plant growth parameters (vegetative growth and dry weight).

Table 3. Vegetative growth parameters of garlic plant after 135 days from planting as affected by potassium sources as soil application during the 2022/2023 and 2023/ 2024 seasons

Treatments	Height of plant (cm)		Leaves number per plant		Diameter of neck (cm)		Diameter of bulb (cm)	
	S1	S2	S1	S2	S1	S2	S1	S2
Effect of soil feeding with potassium sources (SA)								
100 % MKR	108.7 c	116.3ab	11.76 b	12.73 b	1.99 b	2.12 b	4.86 a	5.09 a
100 % FSR	102.9 d	108.5 d	11.14 c	11.88 d	1.85 c	1.98 c	4.17 c	4.40 c
75 % MKR + 25 % FSR	109.5 c	114.9bc	11.99 b	12.75 b	2.00 b	2.12 b	4.67 ab	4.89 ab
50 % MKR + 50% FSR	113.7 a	117.4 a	12.50 a	13.19 a	2.08 a	2.19 a	4.93 a	5.12 a
25 % MKR + 75 % FSR	110.9 b	114.3 c	11.76 b	12.39 c	1.96 b	2.06 b	4.51 b	4.75 b
Effect of foliar feeding with potassium sources (FA)								
Control	104.9 c	108.5 c	11.19 c	11.65 c	1.86 c	1.94 c	4.27 b	4.45 c
KF	109.0 b	115.7 b	11.83 b	12.54 b	1.99 b	2.08 b	4.71 a	4.89 b
KTS	113.5 a	118.6 a	12.46 a	13.58 a	2.07 a	2.26 a	4.90 a	5.21 a

MKR: mineral potassium recommended rate (96 kg K_2O /fed. from potassium sulfate 48% K_2O), FSR: Feldspar recommended rate (905.66 kg from feldspar 10.6 % K_2O), KF: Potassium fulvate (10 % K_2O and 70 % potassium fulvate) at 4.5 g/l and KTS: Potassium thiosulfate (36 % K_2O and 25 % sulfur) at 1.25 ml/l

Table 4. Dry weight of garlic plant after 135 days from planting as affected by potassium sources as soil and foliar feeding during the 2022/2023 and 2023/2024 seasons

Treatments	Leaves dry weight (g)		Bulb dry weight (g)		Plant dry weight (g)	
	S1	S2	S1	S2	S1	S2
Effect of soil feeding with potassium sources (SA)						
100 % MKR	13.90 b	14.59 b	6.80 b	7.17 b	20.70 b	21.77 b
100 % FSR	12.20 d	12.89 c	5.80 d	5.92 d	18.00 d	18.81 d
75 % MKR +25 % FSR	14.00 b	14.70 b	7.03 b	7.38 ab	21.03 b	22.08 b
50 % MKR +50% FSR	14.80 a	15.39 a	7.40 a	7.73 a	22.20 a	23.13a
25 % MKR +75 % FSR	12.73 c	13.31 c	6.36 c	6.65 c	19.10 c	19.96 c
Effect of foliar feeding with potassium sources (FA)						
Control	12.02 c	12.37 c	5.82 c	5.95 c	17.84 c	18.33 c
KF	13.92 b	14.52 b	6.94 b	7.16 b	20.86 b	21.69 b
KTS	14.64 a	15.63 a	7.28 a	7.79 a	21.92 a	23.43 a

MKR: mineral potassium recommended rate (96 kg K_2O /fed. from potassium sulfate 48% K_2O), FSR: Feldspar recommended rate (905.66 kg from feldspar 10.6 % K_2O), KF: Potassium fulvate (10 % K_2O and 70 % potassium fulvate) at 4.5 g/l and KTS: Potassium thiosulfate (36 % K_2O and 25 % sulfur) at 1.25 ml/l

The relative increases in total dry weight/plant due to fertilizing with 50% MKR (48 kg K_2O/fed.) +50% FSR (452.83 kg feldspar/fed.) were about 23.3 and 23.0% over fertilizing with 100% FSR (905.66 kg feldspar/fed.) in both seasons.

Potassium's role in metabolism and other processes that support and encourage vegetative growth and development in plants may help to explain these findings. Additionally, K is required for a number of physiological and metabolic functions, including cell division, elongation, and the metabolism of proteins and carbohydrates (Marschner, 1995). The *Bacillus circulans* bacteria that inoculate feldspar may be responsible for the increases in growth metrics because they can solubilize the feldspar and feed K to plants more quickly and continuously, which is essential for healthy growth (Priyanka and Sindhu, 2013).

These outcomes are consistent with those attained using Ali and Taalab (2008) indicated height plant, leaves number per plant, both neck and diameter of bulb as well as plant dry weight were produced form the plants of onion subjected under the mixture of K as potassium sulfate + feldspar. Furthermore, Abou El-Khair and Mohsen (2016) showed that the maximum values of plant growth were obtained with fertilizing Jerusalem artichoke with 75% mineral K as potassium sulfate) + 25 % natural K as feldspar.

Effect of some sources of potassium as foliar feeding

Spraying with potassium thiosulfate (KTS) at 1.25 ml/l produced the maximum height of plant, leaves number/plant after both diameters of neck and bulb as well as leaves and bulb dry weight and total dry weight per plant followed by spraying with potassium fulvate (KF) at 4.5 g/l in both seasons at 135 days after planting (Tables 3 and 4). While unsprayed plants gave the lowest values of all plant growth parameters in both seasons.

The relative increases in total dry weight / plant due to spraying with KTS at 1.25 ml/l were about 22.9 and 27.8%; 16.9 and 18.3 for spraying with KF at 4.5g/l over control treatment in both seasons.

The significance of KTS spraying for plant growth may be attributed to factors other than potassium's role in protein synthesis, nutrient transport, antioxidant enzymes, root formation, and foliar growth (Chen *et al.,* 2004). Potassium thiosulfate may have the greatest growth-promoting effect because of its formalization, which includes K and S with comparable and consistent synergistic action, congregation with organic moiety, and potent K and S feeding for increased growth of proteins, carbohydrates, enzymes, and energy synthesis (Marschner 1995). Applying K topically on leaves has a significant impact on photosynthesis as well (Huber, 1985). This is because it boosts leaf development and leaf area index right once, which in turn increases CO_2 absorption (Wolf *et al.*, 1976). The external translocation of photosynthesis from the foliate is increased by potassium foliar spray. Ashley and Goodson (1972). These findings are consistent with those of Zhang *et al.* (2006) and Subrahmanyam and Raju (2000).

Similar findings were reported by Metwaly *et al.* (2020), who found that spraying garlic with KTS produced superior results for all plant growth parameters (plant height, number of leaves per plant, neck and bulb diameter, as well as dry weight per plant) when compared to potassium citrate, potassium nitrate, and unsprayed plants. Also, Yousif *et al.* (2023) showed that spraying garlic plants with potassium thiosulfate produced the highest plant growth of garlic as compared to unsprayed plants**.**

Effect of the interaction

The interaction between the fertilization with 50% MKR+50% FSR and spraying with KTS at 1.25 ml/liter and the interaction between the fertilization with 100% MKR and using of 1.25 ml/liter KTS as foliar feeding significantly increased plant height, leaves number per plant both neck and bulb diameter in both seasons with no significant differences with the interaction between 50% MKR+50% FSR and spraying with KF at 4.5 g/l and the interaction between 75% MKR +25% FSR and KTS in the 1st season (Table 5).

The combination between fertilization with 100% FSR and spraying with water (control) gave the lowest values of plant height, number of leaves/ plant both neck and bulb diameter in both seasons.

As for different organs dry weight, data in Table 6 indicate that the combination between fertilization garlic plants with 100% MKR and spraying with KTS at 1.25 ml/liter and the interaction between 50% MKR + 50% FSR and foliar feeding with KTS at 1.25 ml/l produced the highest values of leaves dry weight, bulb and plant dry weight at 135 days after planting in two seasons.

The stimulative effect of the interaction between 50% MKR+50% FSR and spraying with KTS at 1.25 ml/l on total dry weight may be to that this treatment increased height plant, leaves number and diameter of bulb (Table 3).

Table 5. Vegetative growth parameters of garlic plant after 135 days from planting as affected by the combination between sources of potassium as soil and foliar feeding during the 2022/2023 and 2023/2024 seasons

Treatments		Height of plant (cm)		Leaves number per plant		Diameter of neck (cm)		Diameter of bulb (cm)	
Soil	Foliar	S1	S2	S1	S2	S1	S2	S1	S2
100 % MKR	Control	103.0 i	110.3 ef	11.14 e	11.19 h	1.86 e	1.87 c	4.48 ef	4.72 c-e
	KF	106.9 gh	115.8 d	11.57 de	12.54 de	2.03 bc	2.09 b	4.97 a-c	5.02 b-d
	KTS	116.2 a	122.7 a	12.57 ab	14.48 a	2.10 ab	2.41 a	5.13 ab	5.55 a
100 % FSR	Control	97.7 j	104.8 h	10.57 f	11.35 gh	1.76 f	1.89 c	3.75 g	3.89 f
	KF	103.0 i	108.9 fg	11.14 e	11.80 f	1.86 e	1.96 c	4.28 f	4.51 de
	KTS	108.2 fg	111.7 e	11.71 cd	12.51 de	1.95 d	2.09 b	4.49 d-f	4.81 c-e
75 % MKR + 25 % FSR	Control	105.6 h	107.6 g	11.13 e	11.54 fg	1.86 e	1.92 c	4.28 f	4.42 e
	KF	108.2 fg	118.6 c	11.91 cd	12.84 cd	1.99 cd	2.14 b	4.78 b-e	4.93 b-e
	KTS	114.8 b	118.6 c	12.93 a	13.89 b	2.16 a	2.32 a	4.97 a-c	5.34 ab
50 % MKR + 50% FSR	Control	108.9 ef	110.9 ef	11.97 cd	12.40 e	2.00 cd	2.07 b	4.60 c-f	4.75 c-e
	KF	116.2 a	119.9 bc	12.57 ab	12.99 c	2.10 ab	2.16 b	4.93 a-d	5.18 a-c
	KTS	116.2 a	121.4 ab	12.97 a	14.18 ab	2.16 a	2.36 a	5.27 a	5.43 ab
25 % MKR + 75 % FSR	Control	109.6 de	108.9 fg	11.16 e	11.80 f	1.86 e	1.96 c	4.28 f	4.51 de
	KF	110.9 cd	115.4 d	12.00 cd	12.54 de	2.00 cd	2.09 b	4.60 c-f	4.81 c-e
	KTS	112.2 c	118.6 c	12.14 bc	12.84 cd	2.02 cd	2.14 b	4.65 c-f	4.93 b-e

MKR: mineral potassium recommended rate (96 kg K_2O /fed. from potassium sulfate 48% K_2O), FSR: Feldspar recommended rate (905.66 kg from feldspar 10.6 % K_2O), KF: Potassium fulvate (10 % K_2O and 70 % potassium fulvate) at 4.5 g/l and KTS: Potassium thiosulfate (36 % K_2O and 25 % sulfur) at 1.25 ml/l

Table 6. Dry weight of different organs of garlic plant after 135 days from planting as affected by the combination between sources of potassium as soil and foliar feeding during the 2022/2023 and 2023/2024 seasons

Treatments		Leaves dry weight (g)		Bulb dry weight (g)		Plant dry weight (g)	
Soil	Foliar	S1	S2	S1	S2	S1	S2
100 % MKR	Control	11.40 g	12.12 g	5.20 h	5.64 i	16.60 h	17.77 g
	KF	14.90 bc	15.05 cd	7.50 ab	7.52 b-e	22.40 bc	22.57 cd
	KTS	15.40 ab	16.62 a	7.70 ab	8.36 a	23.10 ab	24.98 a
100 % FSR	Control	10.30 h	10.66 h	4.70 h	4.49 j	15.00 i	15.15 h
	KF	12.80 f	13.59 ef	6.20 fg	6.27 hi	19.00 f	19.86 f
	KTS	13.50 e	14.42 d	6.50 ef	7.00 e-g	20.00 e	21.42 e
75 % MKR + 25 % FSR	Control	12.80 f	13.27 f	6.40 e-g	6.69 gh	19.20 f	19.96 f
	KF	14.30 cd	14.84 cd	7.20 b-d	7.42 c-f	21.50 d	22.26 de
	KTS	14.90 bc	15.99 ab	7.50 ab	8.05 a-c	22.40 bc	24.04 ab
50 % MKR + 50% FSR	Control	13.80 de	14.32 de	6.90 c-e	7.21 d-g	20.70 e	21.53 e
	KF	14.80 bc	15.57 bc	7.40 a-c	7.84 a-d	22.20 cd	23.41 bc
	KTS	15.80 a	16.30 ab	7.90 a	8.15 ab	23.70 a	24.45 a
25 % MKR + 75 % FSR	Control	11.80 g	11.50 g	5.90 g	5.75 i	17.70 g	17.24 g
	KF	12.80 f	13.59 ef	6.40 e-g	6.79 f-h	19.20 f	20.38 f
	KTS	13.60 e	14.84 cd	6.80 de	7.42 c-f	20.40 e	22.26 de

MKR: mineral potassium recommended rate (96 kg K_2O /fed. from potassium sulfate 48% K_2O), FSR: Feldspar recommended rate (905.66 kg from feldspar 10.6 % K_2O), KF: Potassium fulvate (10 % K_2O and 70 % potassium fulvate) at 4.5 g/l and KTS: Potassium thiosulfate (36 % K_2O and 25 % sulfur) at 1.25 ml/l

The relative increases in total dry weight/ plant due to the interaction between fertilizing with 50% MKR +50% FSR and spraying with KTS at 1.25 ml/l were about 58.0 and 61.4 % over the interaction between fertilizing with 100% FSR and spraying with water in both seasons.

2. Nitrogen, phosphorus and potassium percentages and its uptake by leaves

Effect of some sources of potassium as application soil

Fertilizing with 50% MKR+50% FSR increased N, P and K leaves percentages (Table 7) and leaves uptake of N, P and K (Table 8) after 135 days from planting in two seasons. Fertilizing plants with 100 % FSR gave the lowest values of N, P and K contents in leaves and N, P and K uptake by leaves.

These results are harmony with those obtained with (Abdel-Salam and Shams, 2012) they indicated that the combination of potassium sulfate and K-feldspar may improve macro nutrient uptake (N, P and K) in shoots of potato. Also, Mohamed *et al.* (2015) on garlic, they found that applied 50% potassium sulfate +50% K-feldspar + solubilizing dissolving bacteria and obtained high yield as well as N, P and K uptake in shoots and leaves. Also, Abou El-Khair and Mohsen (2016) reported that fertilizing Jerusalem artichoke with 75% mineral K) + 25 % natural K as feldspar scored the maximum values of nitrogen, phosphorus and potassium percentages and its uptake by shoots.

Effect of some sources of potassium as foliar feeding

Potassium thiosulfate and KF as foliar feeding increased nitrogen, phosphorus and potassium percentages and their uptake by leaves than spraying with water, as shown in Tables 7 and 8. Foliar spray with KTS at 1.25 ml/liter increased N, P and K contents and their uptake by leaves followed foliar feeding with KF at 4.5 g/l in both seasons.

Table 7. Nitrogen, phosphorus and potassium percentages in leaves of garlic plant after 135 days from planting of garlic plant as affected by potassium sources as soil and foliar feeding during the 2022/2023 and 2023/2024 seasons

Treatments	N (%)		P (%)		K (%)	
	S1	S2	S1	S2	S1	S2
	Effect of soil application with potassium sources (SA)					
100 % MKR	3.47 b	3.65 b	0.409 b	0.429 b	2.35 bc	2.51 ab
100 % FSR	2.84 d	2.96 d	0.335 d	0.348 d	2.11 d	2.16 c
75 % MKR +25 % FSR	3.50 b	3.67 b	0.412 b	0.433 b	2.46 ab	2.53 a
50 % MKR +50% FSR	3.63 a	3.82 a	0.427 a	0.449 a	2.57 a	2.65 a
25 % MKR +75 % FSR	2.98 c	3.08 c	0.350 c	0.362 c	2.24 cd	2.34 bc
	Effect of foliar feeding with potassium sources (FA)					
Control	2.80 c	2.89 c	0.329 c	0.341 c	2.11 c	2.15 c
KF	3.44 b	3.59 b	0.404 b	0.422 b	2.39 b	2.49 b
KTS	3.62 a	3.82 a	0.426 a	0.450 a	2.53 a	2.66 a

MKR: mineral potassium recommended rate (96 kg K_2O /fed. from potassium sulfate 48% K_2O), FSR: Feldspar recommended rate (905.66 kg from feldspar 10.6 % K_2O), KF: Potassium fulvate (10 % K_2O and 70 % potassium fulvate) at 4.5 g/l and KTS: Potassium thiosulfate (36 % K_2O and 25 % sulfur) at 1.25 ml/l

Table 8. Nitrogen, phosphorus and potassium uptake by leaves of garlic plant after 135 days from planting of garlic plant as affected by potassium sources as soil and foliar feeding during the 2022/2023 and 2023/2024 seasons

Treatments	N (%)		P (%)		K (%)	
	S1	S2	S1	S2	S1	S2
	Effect of soil application with potassium sources (SA)					
100 % MKR	491.1 b	518.1 b	57.7 b	64.4 a	330.60 c	355.2 b
100 % FSR	352.1 d	372.8 d	41.4 d	43.8 b	260.80 e	269.3 d
75 % MKR +25 % FSR	492.4 b	520.3 b	57.9 b	61.2 a	346.00 b	358.1 b
50 % MKR +50% FSR	540.0 a	564.4 a	63.5a	66.4 a	382.07 a	391.8 a
25 % MKR +75 % FSR	383.1 c	399.0 c	45.0 c	46.9 b	286.33 d	300.8 c
	Effect of foliar feeding with potassium sources (FA)					
Control	340.6 c	348.9 c	40.0 c	43.1 c	256.20 c	256.8 c
KF	481.7 b	501.0 b	56.6 b	58.9 b	335.06 b	348.0 b
KTS	532.8 a	575.0 a	62.7a	67.6 a	372.22 a	400.4 a

MKR: mineral potassium recommended rate (96 kg K_2O /fed. from potassium sulfate 48% K_2O), FSR: Feldspar recommended rate (905.66 kg from feldspar 10.6 % K_2O), KF: Potassium fulvate (10 % K_2O and 70 % potassium fulvate) at 4.5 g/l and KTS: Potassium thiosulfate (36 % K_2O and 25 % sulfur) at 1.25 ml/l

When nutrient uptake from the soil is inadequate or nonexistent, foliar feeding is optimally suited to supply a multitude of components in circumstances that might be restricting output (Hiller, 1995). One of the richest sources of potassium is thought to be potassium thiosulfate. Given that potassium directly contributes to the process of phloem loading as a counter ion to H^+ in the absorption of nutrients (Komor *et al.*, 1980), increasing the mineral content of plant leaves.

In this concern, Zyada and Bardisi (2018) indicated that the highest values of N, P and K in leaves of garlic were obtained with foliar spray by potassium silicate as compared to control treatment. Also, although spraying with potassium citrate scored the highest N contents, spraying with monopotassium phosphate recorded the highest values of P and K contents in shoots. Ali *et al*. (2021) demonstrated that there were significant differences between different potassium sources (potassium citrate, potassium silicate, and monopotassium phosphate) as foliar application regarding N, P, and K in shoots and their uptake in potatoes.

Effect of the interaction

The combination between fertilization with 100% MKR and KTS at 1.25 ml/liter as foliar feeding and the combination between 50% MKR+50% FSR and KTS at 1.25 ml/liter increased N, P and K contents (Table 9) and N, P and K uptake by leaves (Table 10) in both seasons at 135 days after planting.

Ali *et al.* (2021) in potato showed that there were significant differences between different potassium sources (potassium citrate, potassium silicate, and monopotassium phosphate) as foliar application regarding N, P and K in shoots and their uptake; however, spraying with potassium citrate scored the highest N contents, while spraying with monopotassium phosphate recorded the highest values of P and K contents in shoots.

Table 9. Nitrogen, phosphorus and potassium percentages in leaves of garlic plant after 135 days from planting of garlic plant as affected by the combination between potassium sources as soil and foliar feeding during the 2022/2023 and 2023/2024 seasons

Treatments		N (%)		P (%)		K (%)	
Soil	Foliar	S1	S2	S1	S2	S1	S2
100 % MKR	Control	2.85 f	3.03 i	0.335 h	0.356 h	2.04 gh	2.16 f-h
	KF	3.73 bc	3.76 d	0.439 bc	0.443 cd	2.46 a-d	2.61 b-d
	KTS	3.85 ab	4.16 a	0.453 ab	0.489 a	2.55 a-c	2.76 ab
100 % FSR	Control	2.36 g	2.31 j	0.278 i	0.272 i	1.84 h	1.90 h
	KF	3.00 f	3.19 h	0.353 g	0.375 gh	2.09 f-h	2.22 fg
	KTS	3.18 e	3.40 efg	0.374 f	0.399 ef	2.41 b-e	2.36 d-f
75 % MKR +25 % FSR	Control	3.20 e	3.32 g	0.376 f	0.391 fg	2.22 d-g	2.30 e-g
	KF	3.58 c	3.71 d	0.421 d	0.437 d	2.50 a-d	2.55 b-e
	KTS	3.73 bc	4.00 bc	0.439 bc	0.471 ab	2.66 ab	2.75 ab
50 % MKR +50% FSR	Control	3.25 de	3.48 ef	0.382 f	0.410 ef	2.36 b-f	2.35 d-g
	KF	3.70 bc	3.90 c	0.435 cd	0.459 bc	2.64 ab	2.68 a-c
	KTS	3.95 a	4.08 ab	0.465 a	0.480 a	2.72 a	2.92 a
25 % MKR +75 % FSR	Control	2.35 g	2.35 j	0.276 i	0.277 i	2.11 e-h	2.05 gh
	KF	3.20 e	3.40 fg	0.376 f	0.399 ef	2.29 c-g	2.42 c-f
	KTS	3.40 d	3.50 e	0.400 e	0.412 e	2.33 c-g	2.55 b-e

MKR: mineral potassium recommended rate (96 kg K_2O /fed. from potassium sulfate 48% K_2O), FSR: Feldspar recommended rate (905.66 kg from feldspar 10.6 % K_2O), KF: Potassium fulvate (10 % K_2O and 70 % potassium fulvate) at 4.5 g/l and KTS: Potassium thiosulfate (36 % K_2O and 25 % sulfur) at 1.25 ml/l

Table 10. Nitrogen, phosphorus and potassium uptake by leaves of garlic plant after 135 days from planting of garlic plant as affected by the combination between potassium sources as soil and foliar feeding during the 2022/2023 and 2023/2024 seasons

Treatments		N (%)		P (%)		K (%)	
Soil	Foliar	S1	S2	S1	S2	S1	S2
100 % MKR	Control	324.9 i	351.5 i	38.19 h	51.7 fg	232.6 h	250.9 g
	KF	555.7 c	541.7 d	65.41 b	63.8 b-e	366.5 c	376.2 d
	KTS	592.9 b	661.3 a	69.76 a	77.7 a	392.7 b	438.6ab
100 % FSR	Control	243.0 k	235.5 j	28.63 j	27.7 h	189.5 i	193.9 i
	KF	384.0 h	414.3 h	45.18 g	48.7 g	267.5 f	288.0 f
	KTS	429.3 f	468.6 fg	50.49 ef	55.0 e-g	325.4 d	325.9 e
75 % MKR + 25 % FSR	Control	409.6 g	422.0 h	48.13 fg	49.6 g	284.2 e	291.9 f
	KF	511.9 d	526.7 d	60.20 c	62.0 c-f	357.5 c	362.0 d
	KTS	555.7 c	612.3 b	65.41 b	72.1 a-c	396.3 b	420.5 b
50 % MKR + 50% FSR	Control	448.5 e	476.7 ef	52.72de	56.1 e-g	325.7 d	322.1 e
	KF	547.6 c	580.7 c	64.38 b	68.3 a-d	390.7 b	398.5 c
	KTS	624.1 a	635.7ab	73.47 a	74.8 ab	429.8 a	454.7 a
25 % MKR + 75 % FSR	Control	277.3 j	258.6 j	32.57 i	30.4 h	249.0 g	225.3 h
	KF	409.6 g	441.5gh	48.13 fg	51.8 e-g	293.1 e	315.1 e
	KTS	462.4 e	497.1 e	54.40 d	58.4 d-g	316.9 d	362.0 d

MKR: mineral potassium recommended rate (96 kg K_2O /fed. from potassium sulfate 48% K_2O), FSR: Feldspar recommended rate (905.66 kg from feldspar 10.6 % K_2O), KF: Potassium fulvate (10 % K_2O and 70 % potassium fulvate) at 4.5 g/l and KTS: Potassium thiosulfate (36 % K_2O and 25 % sulfur) at 1.25 ml/l

3. Total yield and potassium use efficiency

Effect of some sources of potassium as application soil

Fertilizing garlic plants with 100% MKR (96 kg K_2O/fed.) or with 50% MKR (48 kg K_2O/fed.) +50% FSR (452.83 kg feldspar/fed.) increased average bulb weight, total yield and potassium use efficiency (KUE) in both seasons (Table 11). Total yield was about 8.523 and 9.044 ton /fed. for fertilizing with 100% MKR and 8.541 and 9.021 ton/fed. for 50% MKR (48. kg K_2O/fed.) +50% FSR in both seasons.

This means that 50% MKR (48 kg K_2O/fed.) +50% FSR (452.83 kg feldspar/fed.) was the best treatment for enhancing total yield /fed. fertilizing with 100% FSR (905.66 kg feldspar/fed.) gave the lowest average bulb weight, total yield and potassium use efficiency.

The relative increases in total yield/fed. due to fertilizing with 50% MKR (48 kg K_2O/fed.) +50% FSR (452.83 kg feldspar/fed.) were about 30.5 and 31.3%; 30.2 and 31.6 for fertilizing with 100% MKR (96 kg K_2O/fed.) over fertilizing with 100% FSR (905.66 kg feldspar/fed.) in both seasons.

These findings might be explained by the possibility that potassium is directly related to photosynthetic surfaces that are well-developed and to elevated physiological activities that result in the creation of more assimilates, which then translocate and are used in the rapid development and production of bulbs (Marschner, 1995). It can be more affordable to use natural sources of potassium to provide plants enough K and to avoid spending a lot of money on chemical fertilizers. For example, weathering of K-feldspar is the primary source of K for plants cultivated in natural environments (Afifi *et al*., 2016).

These results are in harmony with those reported with, Labib *et al*. (2012) found that applying 50% potassium sulfate and 50% K-feldspar to meet crop potassium requirements produced the greatest results in terms of potato production and its constituent parts, with 100% potassium sulfate coming in second. Also, Shams and Fekry (2014) and Saif Eldeen and Baddour (2016) on sweet potato, stated that treating sweet potato plants with potassium sulfate at 50% + potassium as feldspar at 50% produced the best productivity. Hasan and Ragab (2020) showed that adding 50% from the recommended dose of potassium sulfate plus 50% in the for of feldspar was the best treatment for increasing yield and its components and chemical constituents in leaves and tuber roots, followed by adding 100% of the recommended dose in the form of potassium sulfate on sweet potato.

Effect of some sources of potassium as foliar feeding

KTS at 1.25 ml/liter as foliar feeding increased average bulb weight (75.45 and 80.45 g), total yield (8.614 and 9.199 ton/fed.) and potassium use efficiency (89.731 and 95.75 kg bulb /kg K_2O) in both seasons, followed by spraying with KF at 4.5 g/l (69.63 and 73.39 g), (7.943 and 8.383 ton/fed.) and 82.740 and 87.320 kg bulb/ kg K_2O) for average bulb weight, total yield and potassium use efficiency, respectively in both seasons. (Table 11).

The relative increases in total yield/fed due to spraying with KTS at 1.25 ml/l were about 20.6 and 21.1% and 11.2 and 10.3 for spraying with KF at 4.5g/l over control treatment in both seasons.

Table 11. Yield of garlic and potassium use efficiency of garlic as affected by potassium sources as soil and foliar feeding during the 2022/2023 and 2023/2024 seasons

Treatments	Average bulb weight (g)		Total yield (ton/fed.)		KUE (kg bulb /kg K_2O)	
	S1	S2	S1	S2	S1	S2
	Effect of potassium sources as soil application (SA)					
100 % MKR	74.93 a	79.23 a	8.523 a	9.040 a	88.788 a	94.04 a
100 % FSR	57.56 d	60.09 c	6.545 d	6.868 d	68.180 d	71.54 c
75 % MKR +25 % FSR	72.08 b	77.48 a	8.253 b	8.830 b	85.976 b	91.98 a
50 % MKR +50% FSR	75.12 a	79.30 a	8.541 a	9.021 ab	88.972 a	93.96 a
25 % MKR +75 % FSR	66.76 c	71.69 b	7.634 c	8.210 c	79.524 c	85.52 b
	Effect of potassium sources as foliar application (FA)					
Control	62.78 c	66.82 c	7.141 c	7.599 c	74.394 c	79.15 c
KF	69.63 b	73.39 b	7.943 b	8.383 b	82.740 b	87.32 b
KTS	75.45 a	80.45 a	8.614 a	9.199 a	89.731 a	95.75 a

MKR: mineral potassium recommended rate (96 kg K_2O /fed. from potassium sulfate 48% K_2O), FSR: Feldspar recommended rate (905.66 kg from feldspar 10.6 % K_2O), KF: Potassium fulvate (10 % K_2O and 70 % potassium fulvate) at 4.5 g/l and KTS: Potassium thiosulfate (36 % K_2O and 25 % sulfur) at 1.25 ml/l

The stimulative effect of KTS on total yield/fed., may be due to that KTS increased plant dry weight (Table 4), N, P and K contents and their uptake by leaves (Tables 7 and 8), and average bulb weight (Table 11).

Foliar fertilization with different sources of potassium is more economical than root potassium fertilization because of its efficiency and higher cost. The foliar technique of fertilizer application is typically preferable since very little fertilizer is applied per hectare. Additionally, it lessens the applicant's pass total, which lessens the compactness of the soil issue. It is also less probable for foliar application to contaminate groundwater (El-Sayed *et al*., 2021).

These results agreed with Shafeek *et al.* (2016) indicated that the highest yield and its components of garlic plants were produced from spraying with KTS. Likewise, Zyada and Bardisi (2018) mentioned that the highest values of total yield of garlic were obtained with foliar spray by potassium silicate as compared to the control treatment. Furthermore, Hafez *et al.* (2019) reported that the best yield of garlic was recorded with the plants sprayed with potassium silicate than unsprayed. Moreover, Metwaly *et al.* (2020) showed that spraying garlic with potassium thiosulfate gave the highest values of yield. And Yousif *et al.* (2023) showed that spraying garlic plants with KTS produced the highest yield components in garlic as compared to unsprayed plants.

Effect of the interaction

The combination between 100% MKR (96 kg K_2O/fed.) and KTS at 1.25ml/liter as foliar feeding and the interaction between 50% MKR (48.0 kg K_2O/fed.) +50% FSR (452.83 kg /fed.) and KTS at 1.25 ml/liter as foliar spray increased average weight of bulb, total yield and potassium use efficiency (Table 12). There were no significant differences between two treatments, this means that fertilizing with 50% MKR +50% FSR and spraying with KTS at 1.25 ml/l was the best treatment for enhancing total yield and potassium use efficiency.

The interaction between the fertilizing with 100% FSR and spraying with water (control) gave the lowest values of average bulb weight, total yield and potassium use efficiency.

Total yield was about 9.224 and 10.083 ton/fed. for the interaction between 100% MKR (96 kg K_2O/fed.) and spraying with KTS at 1.25ml/l and 9.465 and 9.824 ton/fed. for the interaction between fertilizing with 50% MKR+50% FSR and spraying with KTS at 1.25 ml/l in both seasons.

The relative increases in total yield/fed. due to the interaction between fertilizing with 50% MKR +50% FSR and spraying with KTS at 1.25 ml/l were about 65.0 and 70.8 % over the interaction between fertilizing with 100 % FSR and spraying with water in both seasons.

The stimulative effect of the combination between fertilizing with 50% MKR+50% FSR and KTS at 1.25 ml/liter as foliar spray on total yield may be due to that these treatments increased total dry weight/ plant (Table 6), the uptake of nitrogen, phosphorus and potassium by leaves (Table 10) and bulb weight (Table 14).

This outcome, which matches our findings, Ali *et al.* (2021) on potato indicated that fertilizing potato plants with (100% or 80% K_2SO_4+20% feldspar) as soil addition and mono-potassium phosphate or potassium citrate as foliar feeding scored the best values of yield and its components.

Table 12. Yield of garlic and potassium use efficiency of garlic as affected by the combination between potassium sources as soil and foliar feeding during the 2022/2023 and 2023/2024 seasons

Treatments		Average bulb weight (g)		Total yield (ton/fed.)		KUE (kg bulb /kg K_2O)	
		S1	S2	S1	S2	S1	S2
100 % MKR	Control	69.46 cd	74.06 bc	7.908 e	8.465 ef	82.375 de	88.17 cd
	KF	74.25 b	75.37 bc	8.439 c	8.573 def	87.906 c	89.30 bcd
	KTS	81.08 a	88.28 a	9.224 b	10.083 a	96.083 ab	104.66 a
100 % FSR	Control	50.75 h	50.75 g	5.736 i	5.752 i	59.750 i	59.91 g
	KF	59.87 g	62.94 f	6.795 h	7.227 h	70.781 h	75.28 f
	KTS	62.06 fg	66.59 ef	7.105 g	7.626 g	74.010 fg	79.44 ef
75 % MKR + 25 % FSR	Control	64.59 ef	68.92 de	7.378 f	7.805 g	76.854 f	81.30 e
	KF	72.40 bcd	78.63 b	8.279 cd	8.990 c	86.240 c	93.65 b
	KTS	79.25 a	84.89 a	9.104 b	9.697 b	94.833 b	101.01 a
50 % MKR + 50% FSR	Control	69.13 cd	74.56 bc	7.814 e	8.443 f	81.396 e	87.94 cd
	KF	73.04 bc	77.52 b	8.345 cd	8.797 cd	86.927 c	91.63 bc
	KTS	83.19 a	85.82 a	9.465 a	9.824 ab	98.594 a	102.33 a
25 % MKR + 75 % FSR	Control	59.99 g	65.84 ef	6.873 h	7.533 gh	71.594 gh	78.47 ef
	KF	68.63 de	72.53 cd	7.857 e	8.331 f	81.844 e	86.78 d
	KTS	71.68 bcd	76.70 bc	8.173 d	8.767cde	85.135 cd	91.32 bcd

MKR: mineral potassium recommended rate (96 kg K_2O /fed. from potassium sulfate 48% K_2O), FSR: Feldspar recommended rate (905.66 kg from feldspar 10.6 % K_2O), KF: Potassium fulvate (10 % K_2O and 70 % potassium fulvate) at 4.5 g/l and KTS: Potassium thiosulfate (36 % K_2O and 25 % sulfur) at 1.25 ml/l

4. Bulb quality

Effect of some sources of potassium as application soil

Data in Table 13 indicate that fertilizing with 50% MKR+50% FSR, 100% MKR and 75% MKR +25% FSR increased N, P and K contents in bulbs (Table13), whereas, 50% MKR +50% FSR, 100% FSR increased dry matter (%), total soluble solids and pungency in bulbs in both seasons (Table 14).

The favorable effect of potassium on assimilate translocation may account for the improvement in bulb quality attributes in response to elevated sources of various potassium (Mengel 1997).

These results are in agreement with Abou El-Khair and Mohsen (2016) reported that fertilizing Jerusalem artichoke with 75% mineral K as potassium sulfate) + 25 % natural K as feldspar produced the highest values of all tuber roots quality parameters, also, Hasan and Ragab (2020) on sweet potato showed that adding 50% from the recommended dose of potassium sulfate plus 50% in the for of feldspar was the best treatment for increasing chemical constituents in tuber roots, followed by adding 100% of the recommended dose in the form of potassium sulfate.

Table 13. Nitrogen, phosphorus and potassium percentages in bulb of garlic at harvesting time as affected by potassium sources as soil and foliar feeding during the 2022/2023 and 2023/2024 seasons

Treatments	N (%)		P (%)		K (%)	
	S1	S2	S1	S2	S1	S2
	Effect of soil application with potassium sources (SA)					
100 % MKR	2.39 a	2.48 a	0.600 b	0.636 a	1.80 ab	1.93 a
100 % FSR	1.74 c	1.88 b	0.474 d	0.457 c	1.62 c	1.66 b
75 % MKR +25 % FSR	2.33 a	2.45 a	0.605 ab	0.631 a	1.86 a	1.94 a
50 % MKR +50% FSR	2.39 a	2.56 a	0.621 a	0.643 a	1.91 a	2.00 a
25 % MKR +75 % FSR	1.94 b	1.95 b	0.499 c	0.491 b	1.69 bc	1.76 b
	Effect of foliar feeding with potassium sources (FA)					
Control	1.85 c	1.96 c	0.475 c	0.486 c	1.54 c	1.65 c
KF	2.23 b	2.31 b	0.583 b	0.585 b	1.84 b	1.91 b
KTS	2.39 a	2.52 a	0.621 a	0.643 a	1.94 a	2.01 a

MKR: mineral potassium recommended rate (96 kg K_2O /fed. from potassium sulfate 48% K_2O), FSR: Feldspar recommended rate (905.66 kg from feldspar 10.6 % K_2O), KF: Potassium fulvate (10 % K_2O and 70 % potassium fulvate) at 4.5 g/l and KTS: Potassium thiosulfate (36 % K_2O and 25 % sulfur) at 1.25 ml/l

Table 14. Bulb quality of garlic at harvesting time as affected by potassium sources as soil and foliar feeding during the 2022/2023 and 2023/2024 seasons

Treatments	Dry matter (%)		Total soluble solids (TSS)		Pungency as pyruvic acid (µmol/gm FW)	
	S1	S2	S1	S2	S1	S2
	Effect of soil application with potassium sources (SA)					
100 % MKR	33.86 c	33.33 c	30.88 c	30.26 b	3.11 c	3.09 c
100 % FSR	35.19 a	34.13 b	32.92 a	31.51 a	3.39 a	3.40 a
75 % MKR +25 % FSR	34.37 bc	34.30 b	31.70 b	31.22 a	3.19 b	3.22 b
50 % MKR +50% FSR	34.95 ab	34.85 a	31.69 b	31.39 a	3.45 a	3.41 a
25 % MKR +75 % FSR	33.93 c	34.25 b	31.15 bc	31.25 a	3.15 bc	3.14 bc
	Effect of foliar feeding with potassium sources (FA)					
Control	33.33 c	32.85 c	30.16 c	29.84 c	3.05 c	3.03 c
KF	34.25 b	33.97 b	31.41 b	30.86 b	3.28 b	3.24 b
KTS	35.80 a	35.69 a	33.43 a	32.68 a	3.44 a	3.48 a

MKR: mineral potassium recommended rate (96 kg K_2O /fed. from potassium sulfate 48% K_2O), FSR: Feldspar recommended rate (905.66 kg from feldspar 10.6 % K_2O), KF: Potassium fulvate (10 % K_2O and 70 % potassium fulvate) at 4.5 g/l and KTS: Potassium thiosulfate (36 % K_2O and 25 % sulfur) at 1.25 ml/l

Effect of some sources of potassium as foliar feeding

Foliar spray with KTS at 1.25 mg/l increased N, P and K contents in bulbs, dry matter (%), total soluble solids and pungency contents, followed by spraying with KF at 4.5 g/l than control treatment (water spraying) in both seasons (Tables 14 and 15).

Potassium, the most prevalent cation in plants, might be involved in preserving the ionic equilibrium inside the cells. Additionally, it forms an ionic bond with the pyruvate kinase enzyme, which is essential for both respiration and glucose metabolism. Potassium is therefore essential to the plant's overall metabolism. Additionally, Evans and Wildes (1971) noted that potassium has a role in a number of stages of protein synthesis.

In this regard, Lester *et al*. (2005) and John and Gene (2011) found that total soluble solids of muskmelon fruit were the best with foliar application of potassium thiosulfate as compared to unsprayed. In the same trend, Afzal *et al*. (2015) found similar results for tomato fruits. Moreover, Shafeek *et al.* (2017) showed that foliar feeding with KTS at 2% markedly enhanced seeds chemical constituents of broad bean plants. Furthermore, Metwaly *et al*. (2020) reported that the maximum values of dry matter contents and total soluble solids in cloves were the best with KTS as compared to spraying garlic plants with citrate potassium and nitrate potassium. Also, Yousif *et al.* (2023) showed that spraying garlic plants with potassium thiosulfate produced the highest N, P, K and total carbohydrates percentage in garlic cloves as compared to unsprayed plants.

Effect of the interaction

The interaction between fertilization with 100% MKR and spraying with KTS at 1.25ml/l and the interaction between 50% MKR +50% FSR and spraying with KTS at 1.25 ml/l increased N, P and K contents in bulbs (Table 15), whereas, the interaction between 50% MKR +50% FSR and spraying with KTS at 1.25 ml/l increased dry matter (%), TSS and pungency (Table 16). Fertilization with 100% MKR gave the lowest values of dry matter (%), TSS and pungency as pyrovic acid in both seasons. There was positive correlation among average bulb weight (Table 12), dry matter, TSS and pungency in bulbs (Table 16).

Table 15. Nitrogen, phosphorus and potassium percentages in bulb of garlic at harvesting time as affected by the combination between potassium sources as soil and foliar feeding during the 2022/2023 and 2023/2024 seasons

Treatments		N (%)		P (%)		K (%)	
Soil	Foliar	S1	S2	S1	S2	S1	S2
100 % MKR	Control	2.11 de	2.17 ef	0.503 g	0.535 de	1.57 ghi	1.66 ef
	KF	2.49 ab	2.51 bc	0.619 e	0.650 c	1.89 b-e	2.01 ab
	KTS	2.57 a	2.77 a	0.680 ab	0.723 a	1.96 a-d	2.12 a
100 % FSR	Control	1.37 h	1.46 h	0.411 h	0.408 g	1.42 i	1.46 g
	KF	1.85 f	2.02 fg	0.500 g	0.438 g	1.61 fgh	1.70 def
	KTS	2.02 e	2.16 ef	0.511 g	0.526 ef	1.85 cde	1.82 cde
75 % MKR + 25 % FSR	Control	2.13 de	2.22 de	0.524 g	0.534 de	1.61 f-i	1.77 de
	KF	2.39 bc	2.48 bc	0.632 de	0.655 bc	1.92 a-e	1.96 abc
	KTS	2.49 ab	2.66 ab	0.659 bc	0.706 a	2.05 ab	2.11 a
50 % MKR + 50% FSR	Control	2.07 e	2.38 cd	0.523 g	0.541 de	1.62 fgh	1.81 cde
	KF	2.47 ab	2.59 ab	0.653 cd	0.689 ab	2.03 abc	2.06 a
	KTS	2.63 a	2.72 a	0.688 a	0.699 a	2.09 a	2.14 a
25 % MKR + 75 % FSR	Control	1.57 g	1.57 h	0.414 h	0.416 g	1.52 hi	1.58 fg
	KF	1.98 ef	1.95 g	0.514 g	0.494 f	1.76 efg	1.86 bcd
	KTS	2.27 cd	2.33 cde	0.570 f	0.565 d	1.79 def	1.86 bcd

MKR: mineral potassium recommended rate (96 kg K_2O /fed. from potassium sulfate 48% K_2O), FSR: Feldspar recommended rate (905.66 kg from feldspar 10.6 % K_2O), KF: Potassium fulvate (10 % K_2O and 70 % potassium fulvate) at 4.5 g/l and KTS: Potassium thiosulfate (36 % K_2O and 25 % sulfur) at 1.25 ml/l

Table 16. Bulb quality of garlic at harvesting time as affected by the combination between potassium sources as soil and foliar feeding during the 2022/2023 and 2023/2024 seasons

Treatments		Dry matter (%)		Total soluble solids (TSS)		Pungency as pyruvic acid (μmol/gm FW	
Soil	Foliar	S1	S2	S1	S2	S1	S2
100 % MKR	Control	32.16 h	32.21 g	28.94 g	29.53 fg	2.99 ef	2.96 h
	KF	34.01 d-g	33.11 f	30.94 de	30.05 ef	3.08 e	3.00 gh
	KTS	35.42 bc	34.67 de	32.78 c	31.20 d	3.27 d	3.31 cd
100 % FSR	Control	34.08 def	33.06 f	31.15 d	30.23 e	3.10 e	3.01 fgh
	KF	35.42 bc	34.17 e	32.95 bc	31.10 d	3.48 c	3.53 b
	KTS	36.08 b	35.16 cd	34.66 a	33.22 ab	3.60 b	3.67 a
75 % MKR + 25 % FSR	Control	33.07 gh	32.52 g	29.91 fg	29.48 g	3.02 ef	3.13 efg
	KF	34.28 de	34.17 e	32.17 c	31.35 d	3.23 d	3.14 efg
	KTS	35.78 b	36.22 b	33.02 bc	32.85 bc	3.33 d	3.39 bc
50 % MKR + 50% FSR	Control	34.16 def	33.12 f	30.80 def	29.73 efg	3.26 d	3.15 ef
	KF	33.42 efg	34.25 e	30.43 def	30.91 d	3.35 d	3.38 c
	KTS	37.28 a	37.19 a	33.86 ab	33.55 a	3.76 a	3.72 a
25 % MKR + 75 % FSR	Control	33.21 fg	33.35 f	30.00 ef	30.25 e	2.91 f	2.93 h
	KF	34.12 def	34.19 e	30.60 def	30.92 d	3.27 d	3.18 de
	KTS	34.48 cd	35.22 c	32.87 c	32.58 c	3.28 d	3.32 c

MKR: mineral potassium recommended rate (96 kg K_2O /fed. from potassium sulfate 48% K_2O), FSR: Feldspar recommended rate (905.66 kg from feldspar 10.6 % K_2O), KF: Potassium fulvate (10 % K_2O and 70 % potassium fulvate) at 4.5 g/l and KTS: Potassium thiosulfate (36 % K_2O and 25 % sulfur) at 1.25 ml/l

Finally, from the forgoing results, it cloud be concluded that fertilizing garlic plants with 100% MKR (96 kg K_2O/fed.) and KTS at 1.25 ml/liter as foliar feeding as well as, fertilizing with 50% MKR + 50% FSR (48 kg K_2O/fed.) + 452.83 kg feldspar/fed.) and KTS at 1.25 ml/liter as foliar feeding gave the tallest plants and increased number of leaves, neck and bulb diameter, dry weight/ leaves, bulb and total dry weight/ plant, N, P and K contents in leaves, N, P and

K uptake by leaves, average bulb weight, total yield and potassium use efficiency, N, P and K contents in bulb, dry matter %, total soluble solids and pungency. There were no significant differences between two treatments in growth, yield and bulb quality. This means that 50% MKR (48 kg K_2O/fed.) +50% FSR (452.83 kg feldspar) and KTS at 1.25 ml/liter as foliar feeding was the best treatments for enhancing growth, yield and bulb quality of garlic.

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تاثير التغذية الأرضية والورقية ببعض مصادر البوتاسيوم على النمو والمحصول والجودة فى الثوم

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الملخص

اجريت هذه الدراسة خلال موسمى شتاء ٢٠٢٣/٢٠٢٢ و ٢٠٢٣٣/ ٢٠٢٤ بمزرعة محطة الجميزة التجريبية بمحافظة الغربية مصر، مركز البحوث الزراعية، لدراسة تأثير بعض مصادر البوتاسيوم المعدنى والفلسبار عن طريق التربة، و الرش الورقي (الرش بالماء)، فولفات البوتاسيوم وثيوسلفات البوتاسيوم على النمو والإنتاجية وجودة البصلة لنبات الثوم الصنف بلدي النامى فى الأرض الطينية. سجل تسميد نباتات الثوم بالبوتاسيوم ١٠٠% من الموصى به فى صورة بوتاسيوم معدنى والتى تساوى ٩٦ كجم من اكسيد البوتاسيوم/فدان والرش بثيوسلفات البوتاسيوم بمعدل ١,٢٥ مل/لتر وكذلك التسميد ٥٠% من الموصى به فى صورة بوتاسيوم معدنى+ ٥٠% من الموصى به فى صورة بوتاسيوم طبيعى (الفلسبار) والتى تساوى ٤٨كجم من اكسيد البوتاسيوم/ فدان + ٤٥٢,٨٣ كجم فلسبار للفدان والرش بثيوسلفات البوتاسيوم بمعدل ١,٢٥ مل/لتر افضل القيم لزيادة النمو الخضرى ، الوزن الجاف للنبات ، محتوى الأوراق والممتص من النيتروجين والفوسفور والبوتاسيوم، المحصول الكلي وكفاءة استخدام البوتاسيوم، المواد الصلبة الذائبة الكلية والحرافة. ولم تكن هناك فروق معنوية بين هاتين المعاملتين. وهذا يعني أن التسميد بمعدل ٥٠ % من الموصى به فى صورة بوتاسيوم معدنى+ ٥٠% من الموصى به فى صورة بوتاسيوم طبيعى (الفلسبار) والتى تساوى ٤٨كجم من اكسيد البوتاسيوم/ فدان + ٤٥٢,٨٣ كجم فلسبار للفدان والرش بثيوسلفات البوتاسيوم بمعدل ١,٢٥ مل/لتر كانت أفضل المعاملات لتعزيز النمو والمحصول وجودة أبصال الثوم.