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The Effect of Spraying with Some Potassium Sources on the Yield, Potassium Use Efficiency, and Potato Tuber Quality Under Different Levels of Potassium Fertilization

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Abstract: This study was conducted at El-Gemmeiza Agric. Res. Station, Gharbeya Governorate, Egypt, over the course of two consecutive winter seasons in 2021/2022 and 2022/2023. The aim was to assess how the potato plants responded to different potassium levels (48, 72, and 96 kg K2O/fad.) and sources such as foliar spraying (applying potassium nitrate, potassium citrate, and potassium silicate), in addition to unsprayed treatment (control), and their interactions with respect to growth, productivity and tuber quality, when grown in clay soil using a furrow irrigation system. Fertilizing potato mondial cultivar grown in clay soil during winter plantations with K_2O at 96 kg /fad. (100 % of the recommended rate) and foliar spray with potassium nitrate at 2.39 g /l followed by fertilizing with the same rate of K_2O and foliar spray with potassium citrate at 2 g /l increased plant height, number of main stems, number of leaves, total chlorophyll, tubers number / plant, weight of tuber, yield / plant and total yield /fad. and efficiency of potassium use, N contents in tubers. The combination between K_2O at 96 kg /fad. and foliar spray with spraying with potassium citrate increased P content in tuber. While, dry weight of shoots/plant, potassium content, dry matter and starch contents in tubers at harvesting date were the highest with the combination between K_2O at 96 kg /fad. and silicate potassium at 9.16 ml/l as foliar spray in the two seasons.

Key words: Potato mondial cultivar, Potassium, fertilization, productivity, growth, nutritional status.

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INTRODUCTION

The Solanaceae family includes potatoes (*Solanum tuberosum* L.). It is one of the most important dicotyledonous tuber crops and has a huge global socioeconomic impact. Potatoes are grown on 49 million

hectares and produce around 377 million tonnes of food per year, making them the fifth most significant crop in the world **(Zia *et al*., 2018)**.

Over the past few decades, Egypt's potato-growing area has grown significantly, reaching around 381379 fed. tonne, yielding approximately 4265178 tonnes, or an average of 11,184 tons/fed. **(Agriculture Economic Bulletin, 2020)**.

Potassium is essential for the meristematic growth of plants as well as their physiological processes, such as the control of gas and water exchange, protein synthesis, enzyme activation, photosynthesis, and the translocation of carbohydrates. According to Wang *et al*. (2013), potassium has positive impacts on the metabolism of proteins, nucleic acids, vitamins, and growth factors. It also helps with energy transfer, phloem transport, cation-anion balance, and the ability to fend off pests and illnesses.

Different potassium fertilisation rates (100 % or 75 % of the recommended dose) increased plant growth, productivity, and tuber quality in potato plants as compared to low rates of potassium **(Ati *et al*., 2012 *;* Helal, and Abd Elhady, 2015; Elhakim *et al*., 2016; Abou Zeid and Abd El-Latif, 2017; Shunka *et al*., 2017; Abdel Naby *et al*., 2018; Elkhatib *et al*., 2018; Yakimenko and Naumova (2018) ; Bera *et al*., 2019; Alkharpotly and Abdelrasheed 2021 ; EL-Sayed *et al*., 2022 and Gabr *et al*. 2022).**

For the purpose of producing potatoes, large applications of fertilisers and soil amendments may lead to the buildup of heavy metals in the tubers, which can eventually become poisonous in the soil environment. Foliar sprays by themselves are useful for addressing foliar deficits for the majority of nutrients; however, they are ineffective for addressing nutritional issues with tubers if the nutrient is not mobile in the phloem **(Westennann, 2005)**. Thus, foliar feeding has developed into a standard practice in crop production to boost crop quality and yield **(Roemheld and El-Fouly, 1999)**. It also reduces pollution to the environment and enhances nutrient utilisation by lowering the amount of fertiliser applied to the soil **(Abou-El-nour, 2002)**. Furthermore, foliar K treatments can enhance tuber quality and yield, particularly in heavy clay soils where plants may not have easy access to K **(Marchand and Bourrie, 1999)**. Potassium nitrate, potassium citrate, and potassium silicate are only a few of the sources of K salts that are employed to nourish plants **(Magen, 2004)**.

According to certain research, spraying with various potassium sources significantly improved in growth, yield and tuber quality of potato as compared unsprayed **(Dkhil *et al*., 2011; Salim *et al*., 2014; Ibrahim *et al*., 2015; Abd El-Gawad *et al*., 2017; Abdel Naby *et al*., 2018; Mohaseb *et al*., 2018; Ewais *et al*., 2020; Ali *et al*., 2021; Baddour and Masoud 2022; EL-Sherpiny *et al*., 2022; Soliman *et al*., 2022).**

The aim of this work is the possibility of reducing the use of mineral potassium fertilizer by using some of its source through foliar spraying with the aim of obtaining the highest productivity with the best quality characteristics of the tubers.

MATERIALS AND METHODS

This work was carried out during two successive winter seasons of 2021/2022 and 2022/2023 at El-Gemmeiza Agric. Res. Station, Gharbeya Governorate, Egypt, to evaluate the response of potato plants to potassium levels and sources as well as their interactions on growth, productivity, potassium use efficiency and quality of tuber using (Mondial cultivar) grown in clay soil under furrow irrigation system. The mechanical and chemical analysis of the used soil are presented in Table (A).

Table (A). The mechanical and chemical analysis of the experimental soil

Parameters	Values	
1. Mechanical analysis	**First season**	**Second season**
Sand (%)	14.62	14.96
Silt (%)	37.2	35.85
Clay (%)	48.18	49.19
Organic matter (%)	1.57	1.80
Texture class	Silty clay loam	
2. Chemical analysis		
Available nitrogen (ppm)	36.18	35.29
Available phosphorus (ppm)	8.25	8.62
Available potassium (ppm)	432	449
Available boron (ppm)	0.10	0.12
Soluble calcium (Ca^{++})	6 meq/l	
Soil reaction (pH) in 2.5 soil suspension	8.0	8.0

This experiment included 12 treatments, which were the conjugation between three levels of potassium (50 %, 75 % and 100 % of the recommended rate equal (48,72 and 96 kg K_2O/fad., respectively) and 3 sources as foliar spray of potassium (potassium nitrate , spraying with potassium citrate and spraying with potassium silicate) , beside unsprayed treatment (control) . These treatments were arranged in a split plot design with three replicates. The levels of potassium were randomly arranged in the main plots, while the potassium sources were randomly distributed in the sub plots. Tuber seeds of potato were sown at 20 cm apart on 1st October in the both seasons.

The experimental unit area was 14 m^2. It contained four ridges with 5 m length each and 70 cm distance between each two ridges. One ridge was used to measure the morphological and chemical traits and the other three ridges were used for yield determinations. In addition, One ridge was left between each two plots without spraying as a gourd row to avoid the overlapping of spraying salutation.

Potassium sulphate (K_2SO_4) was added at 3 portions (monthly) beginning one months after planting. Different sources of potassium, potassium nitrate (13 %N and 46% K_2O) and added at 2.39 g/l , potassium citrate in the form of Green Gold (55 %K_2O) produced by Germany and added at 2g/l and potassium silicate (12% K_2O and 25% SiO_2) and added at 9.16 ml/l . All sources of potassium were sprayed using a manual atomizer into five times at 30, 45, 60, 75 and 90 days after planting.

All experimental units, received 120 kg N and 80 kg P_2O_5 as ammonium sulfate (20.6 % N) and calcium superphosphate (15.5 % P_2O_5), respectively. 40 kg N and all P_2O_5 were added at soil preparation time with farmyard manure at the rate of 20 m^3/feddan. The rest amount of nitrogen (80 kg N) was applied in three equal split applications after 30 days from planting and 15 days intervals.

The typical farming methods were applied as they are typically done in the district.

Data Recorded

1. Plant Growth

At 110 days after planting in both seasons, a random sample of five plants was picked at random from each plot to measure the following growth characteristics of potato plants: Plant height; quantity of leaves and aerial stems per plant; and dry weight of shoots (leaves + aerial stems).

2. Photosynthetic Pigments

Discs sample from the fourth upper leaf of potato plant was randomly taken from every experimental unit at 110 days after planting, in the two growing seasons, to determine chlorophyll (a+b) according to the method described by **Wettestein (1957**).

3. Contents of N, P, and K and their uptake

For the purpose of determining N, P, and K, the dry weight of the shoots at 110 days after planting were finely crushed and wet digested. The amounts of potassium, phosphorus, and nitrogen were measured using the procedures outlined by **A.O.A.C (2018)**. Shoot uptake of N, P, and K was measured.

4. The components of yield

Tubers from each plot were measured, weighed, and numbered at harvest, or 130 days after planting. The following parameters were computed: Total yield (ton/fad.), tuber yield per plant (g), average tuber weight (g), and number of tubers/plant are all given.

5. Potassium use Efficiency (NUE): According to **Clark (1982)**, it was calculated by dividing the yield/fad by the potassium quantity/fad and expressed as kg tuber / kg K2O.

6. Tuber Quality

NPK Contents: Total nitrogen, phosphorous and potassium were determined as previously mentioned in the dry weight of shoots.

Dry matter (%): One hundred grams of the grated mixture were dried at 105 ^{0}C till constant weight and DM (%) was recorded.

Starch content*:* It was determined by the method described by **A.O.A.C. (2018)**.

Statistical analysis

According to **Snedecor and Cochran (1980)**, the data were properly subjected to statistical analysis of variance. Duncans' multiple range test **(Duncan, 1958)** was used to compare the differences among treatments, with means having different letters being statistically significant and means following the same letter being statistically insignificant.

RESULTS AND DISCUSSION

Plant growth

Effect of K_2O levels

Fertilizing potato plants cv. Mondial grown in clay soil during winter plantation with 96 kg K_2O/fad. (100 % of the recommended rate) increased plant height, number of main stems, number of leaves / plant and dry weight of shoots at 110 days after planting in both seasons (Tables 1 to 4).

The increases in dry weight of shoots / plant were about 2.41 and 3.64 g/plant for 72 kg K_2O/fad and 3.1 and 4.55 g/ plant for 96 kg K_2O/fad. over the 48 kg K_2O/fad. in the 1st and 2nd seasons , respectively.

Since potassium is necessary for the completion of numerous physiological and metabolic processes in plants, it is needed in high quantities for the optimal growth of potato plants **(Oosterhuis *et al*., 2014)**. In addition, **Trehan *et al.* (2001)** thus reported that K treatment led to an increase in plant height and leaf area. Furthermore, it was found that greater K levels increased the potato crop's height and leaf area **(Khan *et al*., 2010)**.

Our findings are consistent with those of **Ati *et al*. (2012), Helal and Abd Elhady (2015) and Shunka *et al*. (2017)**.

Effect of potassium sources

In comparison to spraying water (control) at 110 days after planting in both seasons, spraying potassium nitrate at 2.39 g/l, potassium citrate at 2 g/l, and potassium silicate at 9.16 ml/l increased plant height, number of main stems, number of leaves / plant, and dry weight of shoots. (Tables 1 to 4).

Foliar spray with potassium nitrate significantly increased plant height, number of main stems, number of leaves / plant, whereas foliar spray with potassium silicate significantly increased dry weight of shoots/plant.

The increases in dry weight of shoots / plant were about 2.41 and 3.38 g/plant for spraying with potassium nitrate and 4.64 and 6.27 g/ plant for spraying with potassium citrate and 6.26 and 7.29 g/plant for spraying with potassium silicate over spraying with water in the 1st and 2ndseasons, respectively.

These outcomes could be explained by the antioxidant properties of citric acid, which also include auxin-producing properties that enhance vegetative growth characteristics. These findings are partly consistent with those of **Hagag *et al*. (2012)**, who reported that antioxidants such citric acid exhibit auxin-like effects. Antioxidants are now employed to promote development in place of auxins and other compounds. Additionally, **Sun and Hong (2011)** found that exogenous application of citric acid increased the activity of antioxidant enzymes, which in turn dramatically promoted plant development. However, **Nour *et al*. (2012)** discovered that the greatest values of plant growth and total dry weight of snap bean pods were obtained from spraying citric acid on snap bean plants.

These results agree with those reported by **Dkhil *et al*. (2011); Salim *et al.* (2014), Ibrahim *et al.* (2015) and Mohaseb *et al*. (2018)**. They found that spraying with different potassium sources recorded the best plant growth than unsprayed plants.

Effect of the interaction

The interaction between K_2O at 96 kg /fad. and spraying with potassium nitrate increased significantly plant height, number of main stems, number of leaves / plant, with no significant differences with K_2O at 96 kg /fad. and spraying with potassium citrate with respect to number of main stems and number of leaves / plant, whereas the interaction between 96 kg K_2O/fad. and spraying with potassium silicate significantly increased dry weight of shoots/plant at 110 days after planting in both seasons (Tables 1 to 4).

Based on the previously mentioned findings, it can be inferred that the combination of 96 kg K_2O (which is 100% of the recommended amount) and potassium nitrate foliar spray led to an increase in plant height, main stem count, and number of leaves per plant. This was followed by the combination of 96 kg K_2O/fad and potassium citrate spraying, and the combination of 96 kg K_2O and potassium silicate foliar spray, which resulted in an increase in the dry weight of shoots per plant.

Table (1). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on plant height (cm) at 110 days after planting of potato plants during 2021/2022 and 2022/2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water (control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	2021/2022 season				
48	47.00 f	58.00 c	53.00 d	50.00 e	**52.00 B**
72	49.00 e	63.00 a	59.00 bc	54.00 d	**56.25 A**
96	50.00 e	63.00 a	60.00 b	54.00 d	**56.75 A**
Mean (KFA)	**48.66 D**	**61.33 A**	**57.33 B**	**52.66 C**	
	2022/2023 season				
48	49.00 h	60.00 c	56.00 e	52.00 fg	**54.25 C**
72	51.00 g	66.00 a	62.00 b	57.00 de	**59.00 B**
96	53.00 f	67.00 a	63.00 b	58.00 d	**60.25 A**
Mean (KFA)	**51.00 D**	**64.33 A**	**60.33 B**	**55.66 C**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.
The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Table (2). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on main stem number / plant at 110 days after planting of potato plants during 2021/2022 and 2022/ 2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water (control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	2021/2022 season				
48	2.00 c	3.00 b	3.00 b	3.00 b	**2.75 C**
72	2.00 c	4.00 a	4.00 a	3.00 b	**3.25 B**
96	3.00 b	4.00 a	4.00 a	4.00 a	**3.75 A**
Mean (KFA)	**2.33 C**	**3.66 A**	**3.66 A**	**3.33 B**	
	2022/2023 season				
48	3.32 e	3.74 d	3.60 d	3.60 d	**3.56 C**
72	3.60 d	4.19 bc	3.60 d	3.74 d	**3.78 B**
96	4.03 c	4.47 a	4.47 a	4.33 ab	**4.32 A**
Mean (KFA)	**3.65 C**	**4.13 A**	**3.89 B**	**3.89 B**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.
The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Table (3). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on number of leaves / plant at 110 days after planting of potato plants during 2021/2022 and 2022/2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water (control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	2021/2022 season				
48	14.31 f	15.68 de	15.09 ef	14.90 ef	**14.99 C**
72	15.49 ef	18.43 ab	17.49 bc	16.86 cd	**17.06 B**
96	17.51 bc	19.02 a	18.47 ab	17.84 bc	**18.21 A**
Mean (KFA)	**15.77 C**	**17.71 A**	**17.01 B**	**16.53 B**	
	2022/2023 season				
48	16.38 g	17.95 de	17.28 ef	17.05 fg	**17.16 C**
72	16.76 fg	21.10 ab	20.02 c	18.32 d	**19.05 B**
96	20.04 c	21.77 a	21.14 a	20.42 bc	**20.84 A**
Mean (KFA)	**17.72 D**	**20.27 A**	**19.48 B**	**18.59 C**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance. The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Table (4). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on dry weight of shoots (g/ plant) at 110 days after planting of potato plants during 2021/2022 and 2022/2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water ((control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	2021/2022 season				
48	16.80 h	19.22 fg	21.50 e	22.20 de	**19.93 B**
72	18.50 g	21.22 e	24.32 bc	25.33 ab	**22.34 A**
96	19.95 f	22.33 de	23.35 cd	26.50 a	**23.03 A**
Mean (KFA)	**18.41 D**	**20.92 C**	**23.05 B**	**24.67 A**	
	2022/2023 season				
48	17.50 f	21.30 de	22.13 d	23.50 c	**21.10 C**
72	20.13 e	23.50 c	27.22 b	28.12 ab	**24.74 B**
96	21.22 de	24.17 c	28.30 ab	29.10 a	**25.69 A**
Mean (KFA)	**19.61 D**	**22.99 C**	**25.88 B**	**26.90 A**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance. The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Total chlorophyll, N, P and K uptake and total carbohydrates

Effect of K2O levels

Data in tables 5 to 9 show that total chlorophyll (a+b) in leaf tissues, nitrogen, phosphorus and potassium uptake by shoots increased with increasing K_2O up to 986 kg /fad. and 96 kg K_2O/fad. gave the highest values of total chlorophyll (a+b) in leaf tissues, nitrogen, phosphorus and potassium uptake by shoots and total carbohydrates after 110 days after planting in both seasons.

The importance of potassium in potato quality can be attributed to its role in promoting photosynthesis and translocation of photosynthates, as well as enhancing of their conversion into starch and protein **(Koch *et al*. 2019)**.

Obtained results were similar to those reported **Abou Zeid and Abd El-Latif (2017), Abdel Naby (2018) and Yakimenko and Naumova (2018)**. All on potato they mentioned that mineral contents and its uptake by potato plants significantly enhanced by application of the highest and moderate rates of potassium.

Effect of potassium sources

Spraying with potassium nitrate increased the concentration of chlorophyll (a+b) in leaf tissues, whereas spraying with potassium citrate followed by potassium silicate increased N, P and K uptake by shoots and total carbohydrates at 110 days after planting in both seasons (Tables 5 to 9).

The mechanism underlying this impact is unclear, although it is likely related to aqueous solution stomatal penetration. Citric acid-sprayed bean plants displayed increased total chlorophyll content than control plants **(El-Tohamy *et al*., 2013)**.

In this regard, **Ali *et al*. (2021)** discovered that when potassium citrate was sprayed on potato plants, the greatest values of N, P, and K as well as total carbohydrates in leaves were recorded.

Table (5). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on total chlorophyll a+b (mg / gDW) in leaves at 110 days after planting of potato plants during 2021/2022 and 2022/2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water (control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	2021/2022 season				
48	2.45 f	3.90 bc	3.41 d	2.97 e	**3.18 C**
72	2.62 f	4.08 ab	3.76 c	3.36 d	**3.46 B**
96	2.90 e	4.21 a	4.06 ab	3.69 c	**3.71 A**
Mean (KFA)	**2.66 D**	**4.06 A**	**3.74 B**	**3.34 C**	
	2022/2023 season				
48	2.30 i	2.96 fg	2.83 gh	2.69 h	**2.69 C**
72	3.14 ef	3.76 c	3.56 d	3.31 e	**3.44 B**
96	3.71 cd	4.28 a	4.02 b	3.71 cd	**3.93 A**
Mean (KFA)	**3.05 D**	**3.66 A**	**3.47 B**	**3.23 C**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance. The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Effect of the interaction

Chlorophyll (a+b) concentration in leaf tissues was increased by the combination between 96 kg/fad. K_2O and spraying with potassium nitrate; conversely, the interaction between K_2O at 96 kg/fad and potassium citrate foliar spray, and then the combination between K_2O at 96 kg/fad and spraying with potassium silicate increased the uptake of nitrogen , phosphorus and potassium by shoots and total carbohydrates at 110 days after planting in the two seasons (Tables 5 to 9).

Table (6). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on nitrogen uptake by shoot at 110 days after planting of potato plants during 2021/2022 and 2022/2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water (control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	2021/2022 season				
48	346.08 h	572.76 f	567.60 f	557.22 f	**510.91 C**
72	453.25 g	751.19 d	809.86 b	681.38 e	**673.92 B**
96	562.59 f	803.88 bc	784.56 c	871.85 a	**755.72 A**
Mean (KFA)	**453.97 C**	**709.28 AB**	**720.67 A**	**703.48 B**	
	2022/2023 season				
48	369.30 j	615.60 g	566.50 hi	545.20 i	**524.14 C**
72	587.80 gh	834.30 e	958.10 c	916.70 d	**824.23 B**
96	664.20 f	925.70 cd	1061.30 a	1018.50 b	**917.41 A**
Mean (KFA)	**540.41 D**	**791.84 C**	**861.97 A**	**826.80 B**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance. The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Table (7). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on phosphorus uptake by shoot at 110 days after planting of potato plants during 2021/2022 and 2022/2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water (control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	2021/2022 season				
48	59.47 i	91.87 f	128.14 bc	102.56 e	**95.51 C**
72	69.19 h	106.52 e	150.78 a	125.38 c	**112.97 B**
96	76.81 g	116.12 d	147.11 a	132.77 b	**118.20 A**
Mean (KFA)	**68.49 D**	**104.84 C**	**142.01 A**	**120.24 B**	
	2022/2023 season				
48	61.25 i	102.24 h	130.57 e	108.10 g	**100.54 C**
72	118.77 f	166.85 d	195.98 c	194.03 c	**168.91 B**
96	131.56 e	215.11 b	246.21 a	212.43 b	**201.33 A**
Mean (KFA)	**103.86 D**	**161.40 C**	**190.92 A**	**171.52 B**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance. The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Table (8). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on potassium uptake by shoot at 110 days after planting of potato plants during 2021/2022 and 2022/2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water (control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	2021/2022 season				
48	361.20 j	542.00 g	591.25 e	568.32 f	**515.69 C**
72	425.50 i	619.62 d	680.96 bc	671.25 bc	**599.33 B**
96	478.80 h	663.20 c	688.83 b	728.75 a	**639.90 A**
Mean (KFA)	**421.83 C**	**608.27 B**	**653.68 A**	**656.11 A**	
	2022/2023 season				
48	393.75 g	521.85 ef	528.91 ef	540.50 de	**496.25 C**
72	501.24 f	662.70 c	734.94 b	728.31 b	**656.80 B**
96	562.33 d	754.10 b	826.36 a	840.99 a	**745.95 A**
Mean (KFA)	**485.77 C**	**646.22 B**	**696.74 A**	**703.27 A**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance. The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Table (9). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on total carbohydrates content in shoot at 110 days after planting of potato plants during 2021/2022 and 2022/2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water (control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	2021/2022 season				
48	20.91 h	22.25 fg	24.22 de	24.20 de	**22.89 C**
72	21.50 gh	23.30 def	25.50 bc	26.15 ab	**24.11 B**
96	23.20 ef	24.50 cd	26.58 ab	27.13 a	**25.35 A**
Mean (KFA)	**21.87 C**	**23.35 B**	**25.43 A**	**25.82 A**	
	2022/2023 season				
48	20.85 g	22.13 f	24.10 de	24.25 de	**22.83 C**
72	23.55 e	23.89 de	25.60 bc	25.89 bc	**24.73 B**
96	24.99 cd	24.89 cd	26.70 ab	27.55 a	**26.03 A**
Mean (KFA)	**23.13 B**	**23.63 B**	**25.46 A**	**25.89 A**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance. The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Yield and its components

Effect of K_2O levels

Data in tables 10 to 13 show that number of tubers/ plant , average tuber weight, yield / plant and total yield fad. significantly increased with increasing K_2O up to 96 kg /fad. in both seasons. This means that 96 kg /fad. K_2O gave the highest values of average number of tubers/ plant (3.37 and 3.21), average tuber weight (1.669.90 and 176.90 g), yield / plant (565.67 and 5.69.74 g) and total yield /fad. (13.308 and 13.376 ton) in the 1st and 2nd seasons, respectively.

This means that fertilizing with 72 kg/ K_2O (75 % of the recommended rate) increased total yield about 56.43 and 38.80 % over the 48 kg K_2O /fad. (50 % of the recommended rate), whereas 96 kg/ K_2O (100 % of the recommended rate) increased total yield about 178.75 and 166.61 % over the 48 kg K_2O /fad. in the 1st and 2nd seasons, respectively.

As for average tuber weight , data in table 11 show that average tuber weight for Mondial cultivar (as average of the two seasons) were about 111.71 g for 50 % of K_2O (48 kg /fad.) , 139.77 g for 75 % of K_2O (72 kg /fad.) and 171.9 g for 100 % K_2O (96 kg /fad.).

The increases in tuber weight were about 28.06 g for 72 kg K2O and 60.19 g for 96 kg K_2O /fad. over the 48 kg K_2O /fad. This means that fertilizing with 96 kg K_2O /fad. (100 % of the recommended rate) increased average tuber weight about 53.88 % over the 48 kg K_2O /fad. (50 % of the recommended rate) average two seasons.

The increases in total yield were about 2.718 and 1.947 ton/fad. for 72 kg/ K_2O (75 % of the recommended rate) and 8.534 and 8.358 ton/fad. for 96 kg/ K_2O (100 % of the recommended rate) over the 48 kg K_2O /fad. (50 % of the recommended rate) in the 1st and 2nd seasons, respectively.

The stimulative effect of 96 kg K_2O /fad. on total yield may be due to that 96 kg K_2O /fad. increased average number of tubers/ plant and average tuber weight as shown in Tables 10 and 11.

According to **Trehan *et al*. (2001)** potassium activates a number of enzymes involved in photosynthesis, carbohydrate metabolism, protein synthesis, and assists in the translocation of carbohydrates from leaves to tubers, which increases the size of tubers but not their number. K nutrition increases the average size of the tuber significantly **(Moinuddin and Bansal, 2005)**, which could be reflected in enhanced aggregate yield **(Singh and Lal, 2012)**.

In addition, the function of K in facilitating the translocation of assimilates from leaves to tubers, an increase in the volume of tuber and tuber size is expected **(Westermann, 2005)**. Also, **Adhikari and Karki (2006)** reported that an increase in tuber size requires maximum potassium.

These results are in harmony with those reported by **Elkhatib *et al*. (2018), Bera *et al*. (2019), Alkharpotly and Abdelrasheed (2021), EL-Sayed *et al*. (2022) and Gabr *et al.* (2022).** They demonstrated that, compared to low potassium rate, potato yield and its components were considerably impacted by potassium treatment at the highest and moderate rates.

Effect of some potassium sources

The obtained results in Tables 10 to 13 indicate that foliar spray with potassium nitrate, potassium citrate and potassium silicate had significant effect on number of tubers/ plant, average tuber weight, yield / plant and total yield fad. compared to control treatment (spraying with water) in both seasons.

Foliar spray with potassium nitrate increased number of tubers/ plant, average tuber weight, yield / plant and total yield fad. in both seasons with no significant differences with potassium citrate with respect to number of tubers/ plant and yield / plant in the 1st season.

As one of the most significant organic acids in the respiratory routes entering plant cells, potassium citrate is the potassium salt of citric acid. Energy for ATP synthesis, which is necessary for several biochemical and physiological processes, is provided via the mitochondrial citric acid cycle **(Taiz and Zeiger, 2002)**.

These findings are in agreement with the results of **Ewais *et al*. (2020), Ali *et al.* (2021) , Baddour and Masoud (2022) , EL-Sherpiny *et al.* (2022) and Soliman *et al.* (2022)**. They showed that foliar spray with potassium nitrate, potassium citrate and potassium silicate significantly improved the productivity of potato than unsprayed plants.

Effect of the interaction

The interaction between K_2O rates and foliar spray with some potassium sources had significant effect on number of tubers/ plant, average tuber weight, yield / plant and total yield fad. in both seasons (Tables 10 to 13).

Fertilizing with 96 kg K_2O/fad. and spraying with potassium nitrate increased number of tubers/ plant, yield / plant and total yield fad. in both seasons with no significant differences with 96 kg K_2O /fad. and spraying with potassium citrate in the 1st season.

As average tuber weight, data show that fertilizing with 96 kg K_2O /fad. and spraying with potassium nitrate or potassium citrate increased average tuber weight in both seasons.

Under different rates of K_2O, spraying with potassium nitrate, potassium citrate and potassium silicate increased yield and its components compared to spraying with water under the same rates of K_2O, whereas the increases in total yield /fad. were about 28.36 and 22.22 % for the interaction between K_2O at 48 kg /fad. and potassium nitrate over the control (48 kg K_2O /fad. and water), 21.91 and 13.65 % for the interaction between K_2O at 72 kg /fad. and potassium nitrate over the control (72 kg K_2O /fad. and water), and 38.43 and 16.48 % for the interaction between K_2O at 96 kg /fad. and potassium nitrate over the control (96 kg K_2O /fad. and water) in the 1st and 2nd seasons, respectively.

This means that spraying with potassium nitrate increased total yield /fad. under the different K_2O rates compared to K_2O rates with water (control) and potassium nitrate gave the highest values followed by potassium citrate under different rates of K_2O.

Under different rates of K_2O, spraying with potassium silicate increased yield and its components but insignificant compared to control 9 K_2O with water) in both seasons. For all the interaction treatments, average tuber weight of potato mondial cultivar ranged from 104.53 to 179.20 g in the 1st season and 113.53 to 179.20 g in the 2nd season.

Table (10). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on number of tubers / plant of potato plants during 2021/2022 and 2022/2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water (control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	2021/2022 season				
48	1.71 e	2.08 d	2.05 d	1.74 e	**1.89 C**
72	2.13 d	2.23 d	2.25 d	2.19 d	**2.20 B**
96	3.20 c	3.58 a	3.45 ab	3.28 bc	**3.37 A**
Mean (KFA)	**2.34 B**	**2.63 A**	**2.58 A**	**2.40 B**	
	2022/2023 season				
48	1.72 g	1.97 e	1.85 f	1.74 g	**1.82 C**
72	2.18 d	2.23 d	2.22 d	2.22 d	**2.21 B**
96	3.12 c	3.36 a	3.25 b	3.14 c	**3.21 A**
Mean (KFA)	**2.34 C**	**2.52 A**	**2.44 B**	**2.36 C**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.
The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Table (11). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on average tuber weight of potato plants during 2021/2022 and 2022/2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water (control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	2021/2022 season				
48	104.53 f	110.79 e	106.32 ef	105.19 f	**106.71 C**
72	136.48 d	159.20 b	150.24 c	138.17 d	**146.02 B**
96	145.60 c	180.40 a	179.20 a	162.40 b	**166.90 A**
Mean (KFA)	**128.87 D**	**150.13 A**	**145.25 B**	**135.25 C**	
	2022/2023 season				
48	113.53 g	120.79 fg	117.32 g	115.19 g	**116.71 C**
72	126.48 ef	141.20 d	137.24 d	129.17 e	**133.52 B**
96	170.60 c	185.40 a	179.20 ab	172.40 bc	**176.90 A**
Mean (KFA)	**136.87 C**	**149.13 A**	**144.59 B**	**138.92 C**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance. The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Table (12). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on yield / plant (g) of potato plants during 2021/2022 and 2022/2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water (control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	2021/2022 season				
48	178.74 g	230.44 fg	217.96 g	183.03 g	**202.54 C**
72	290.70 ef	355.02 d	338.04 de	302.59 de	**321.59 B**
96	465.92 c	645.83 a	618.24 a	532.67 b	**565.67 A**
Mean (KFA)	**311.79 B**	**410.43 A**	**391.41 A**	**339.43 B**	
	2022/2023 season				
48	195.27 i	237.96 g	217.04 h	200.43 hi	**212.67 C**
72	275.73 f	314.88 d	304.67 de	286.76 ef	**295.51 B**
96	532.27 c	622.94 a	582.40 b	541.34 c	**569.74 A**
Mean (KFA)	**334.42 C**	**391.93 A**	**368.04 B**	**342.84 C**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance. The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Table (13). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on yield / faddan (ton) of potato plants during 2021/ 2022 and 2022/2023 seasons

Potassium rate (KSA) kg /fad.	Potassium sources				Mean (KSA)
	Spraying with water ((control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	**2021/2022 season**				
48	4.199 g	5.390 f	5.171 f	4.336 g	**4.774 C**
72	6.772 e	8.256 d	7.849 d	7.089 e	**7.492 B**
96	11.002 c	15.231 a	14.579 a	12.422 b	**13.308 A**
Mean (KFA)	**7.324 D**	**9.625 A**	**9.199 B**	**7.949 C**	
	2022/2023 season				
48	4.590 h	5.610 g	5.109 gh	4.759 h	**5.017 C**
72	6.517 f	7.420 d	7.200 de	6.718 ef	**6.964 B**
96	12.524 c	14.589 a	13.704 b	12.689 c	**13.376 A**
Mean (KFA)	**7.877 C**	**9.206 A**	**8.671 B**	**8.055 C**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance. The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Potassium use efficiency (KUE)

Effect of K_2O levels

Fertilizing with 96 kg K_2O/fad. (100 % of the recommended rate) gave the highest values of KUE by plants (138.63 and 139.34 kg tuber /1 kg K_2O) in the is and 2nd seasons respectively (Table 14).

The increases in KUE for K_2O at 96 kg /fad. were about 39.17 and 34.82 kg tubers/1 kg K_2O over the 48 kg K_2O /fad. , 34.58 and 42.62 kg tubers/1 kg K_2O over the 72 kg K_2O /fad. in the 1st and 2nd seasons, respectively. This means that fertilizing with 96 kg K_2O /fad. was more KUE by potato plants compared to K_2O at 48 and 72 kg/feddan.

Effect of potassium sources

Spraying with potassium nitrate recorded maximum KUE (128.34 and 123.97 kg tubers/1kg K_2O) followed by potassium citrate in the 1st and 2nd seasons, respectively (Table 14). There were no significant differences between spraying with potassium silicate and control (water) in both seasons.

Effect of the interaction

The interaction between K_2O at 96 kg /fad. K_2O and spraying with potassium nitrate or with potassium citrate gave the highest values of KUE in both seasons (Table 14).

Under the different rates of K_2O, spraying with potassium nitrate or with potassium citrate increased KUE compared to spraying with potassium silicate under the same rates of K_2O in both seasons.

This means that potato plants which sprayed with potassium nitrate or potassium citrate were more KUE with different rates of K_2O (48, 72 and 96 kg /fad. K_2O) compared to control (K_2O rates with water).

Table (14). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on potassium use efficiency (kg tubers/ kg K_2O) of potato plants during 2021/2022 and 2022/ 2023 seasons

Potassium rate (KSA) kg /fad.	Potassium sources				Mean (KSA)
	Spraying with water (control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	2021/2022 season				
48	87.48 f	112.29 cd	107.73 cde	90.33 f	**99.46 B**
72	94.06 ef	114.67 bc	109.01 cd	98.46 def	**104.05 B**
96	114.60 c	158.66 a	151.87 a	129.40 b	**138.63 A**
Mean (KFA)	**98.71 B**	**128.54 A**	**122.87 A**	**106.06 B**	
	2022/2023 season				
48	95.63 ef	116.87 c	106.44 d	99.15 def	**104.52 B**
72	90.51 f	103.06 de	100.00 def	93.31 ef	**96.72 C**
96	130.46 b	151.97 a	142.75 a	132.18 b	**139.34 A**
Mean (KFA)	**105.53 C**	**123.97 A**	**116.40 B**	**108.21 C**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance. The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Tuber quality

Effect of K_2O levels

Presented data in Tables 15 to 19 show that K_2O at 96 kg /fad. (100 % of the recommended rate) gave the highest values of N, P and K and starch contents in tuber and dry matter (%). The increases in dry matter percentage were about 2.34 and 2.18 % for K_2O at 72 kg /fad. and 3.29 and 3.47 % for K_2O at 96 kg /fad. over the K_2O at 48 kg /fad. in the 1st and 2nd seasons, respectively.

The enhancement of tuber quality characteristics, such as dry matter and starch contents, in response to elevated mineral potassium levels could be ascribed to potassium's beneficial influence on assimilate translocation **(Mengel 1997)**. Additionally, according to **Mohammad and Naseem (2006)**, the potassium found in plants led to excessive nitrate, which effectively reduced activity and produced molecules with nitrogen in their structures, which are crucial for the creation of proteins and enzymes. Similarly, **Perrenoud (1993)** found that potassium completely activated the system of enzymes responsible for starch production, causing potatoes to synthesise starch more quickly. Furthermore, the findings of **Gerendas *et al.* (2007)** showed that lesser amounts of reducing sugar content are produced by larger doses of potassium.

These findings corroborated those of **Elhakim *et al.* (2016)**, who discovered that potassium fertilisation at rates of 60 or 120 kg K_2O /fed led to considerable increases in the levels of nitrogen and potassium in potato plants. Furthermore, **Abou Zeid and Abd El-Latif (2017)** discovered that potato plants' levels of potassium, phosphorus, and nitrogen rose as potassium rates increased, reaching 120 kg K_2O/ feddan. Also, **Abdel Naby *et al.* (2018)** showed that fertilizing with 100 % of the recommended doses equal 96 kg K_2O/fad. recorded the highest values of total carbohydrates and starch percentages in fresh potato tubers.

Effect of potassium sources

Foliar spray with potassium nitrate or with potassium citrate increased N content, whereas foliar spray with potassium citrate increased phosphorus content , foliar spray with potassium silicate, followed by potassium citrate increased K, dry matter and starch contents in tuber at harvesting time (Tables 15 to 19). In general, spraying with potassium citrate and potassium silicate increased N, P and K, dry matter and starch contents in tubers.

This could be the case because, as noted by **(Ewais *et al*. 2020)**, potassium activates a number of enzymes involved in photosynthesis, protein synthesis, especially the synthesis of sugars and proteins, and carbohydrate metabolism. It also facilitates the translocation of carbohydrates from leaves to tubers and their accumulation in storage tubers. The application of potassium silicate by foliar spray significantly increased total carbohydrates, vitamin C, and total sugar levels, according to the data.

These findings are consistent with those published by **Abd El-Gawad *et al.* (2017)**, who reported that the plants sprayed with potassium silicate at a concentration of 2000 ppm had the highest values of dry matter content and total carbohydrates in tubers when compared to plants that were not sprayed with potassium silicate at 1000 or 3000 ppm. Additionally, **Baddour and Masoud (2022)** found that plants sprayed with potassium silicate had higher chemical content values in their potato tubers that is, higher N, P, and K contents than unsprayed plants.

Effect of the interaction

Regarding N content, the highest values of N content in tuber were obtained by combining K_2O at 96 kg/fad. with either potassium citrate or potassium nitrate spraying (Table 15). Regarding P content, the combination of spraying potassium citrate and K_2O at 96 kg/fad elevated P content in the tuber (Table 16). When it comes to K, dry matter, and starch levels in tubers, the combination of K_2O at 96 kg/fad and spraying with potassium silicate or potassium citrate produced the highest values at the time of harvest (Tables 17, 18, and 19).

Under different rates of K_2O, spraying with potassium nitrate, potassium citrate and potassium silicate increased dry matter and starch contents in tubers compared to spraying with water under the same K_2O rates (control).

Dry matter and starch (%) in tuber of Mondial cultivar, dry matter ranged from 15.14 to 20.80 in the 1st season and 14.80 to 19.89 % in the 2nd season for all the interaction treatments and starch (%) in tuber ranged from 11.83 to 13.96 % in the 1st season and 11.32 to 14.10 % in the 2nd season for all the interaction treatments. There was positive correlation between dry matter and starch contents in tubers. Dry matter was about 17.5 to 19.9%) **(Yaseen *et al.*, 2014)** and starch was about 11.46 to 14.90% **(Leonel *et al*., 2017)**.

Conclusion

From the foregoing results, it could be concluded that fertilizing potato Mondial cultivar grown in clay soil during winter plantations with K_2O at 96 kg /fad. (100 % of the recommended rate) and foliar spray with potassium nitrate at 2.39 g /l followed by fertilizing with the same rate of K_2O and foliar spray with potassium citrate at 2 g /l increased plant height, number of main stems, number of leaves, total chlorophyll, number of tubers/ plant, average tuber weight, yield / plant and total yield /fad. and potassium use efficiency as well as N contents in tubers.

Table (15). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on nitrogen content (%) in tuber of potato plants at harvesting time during 2021/2022 and 2022/2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water (control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	2021/2022 season				
48	1.20 f	1.62 bcd	1.54 cde	1.50 de	**1.46 B**
72	1.42 e	1.75 ab	1.70 ab	1.62 bcd	**1.62 A**
96	1.43 e	1.82 a	1.72 ab	1.65 bc	**1.65 A**
Mean (KFA)	**1.35 C**	**1.73 A**	**1.65 AB**	**1.59 B**	
	2022/2023 season				
48	1.22 g	1.36 ef	1.38 ef	1.32 fg	**1.32 C**
72	1.45 de	1.68 b	1.62 bc	1.55 cd	**1.57 B**
96	1.66 bc	1.88 a	1.80 a	1.68 b	**1.75 A**
Mean (KFA)	**1.44 C**	**1.64 A**	**1.60 A**	**1.51 B**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance. The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Table (16). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on phosphorus content (%) in tuber of potato plants at harvesting time during 2021/2022 and 2022/2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water (control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	2021/2022 season				
48	0.245 e	0.305 bcd	0.320 abc	0.312 abcd	**0.295 A**
72	0.252 e	0.295 d	0.334 a	0.304 bcd	**0.296 A**
96	0.255 e	0.299 cd	0.328 ab	0.308 bcd	**0.297 A**
Mean (KFA)	**0.250 C**	**0.299 B**	**0.327 A**	**0.308 B**	
	2022/2023 season				
48	0.256 f	0.293 e	0.320 d	0.310 d	**0.295 B**
72	0.290 e	0.290 e	0.320 d	0.290 e	**0.297 B**
96	0.310 d	0.370 c	0.490 a	0.450 b	**0.405 A**
Mean (KFA)	**0.285 D**	**0.317 C**	**0.376 A**	**0.350 B**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance. The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Table (17). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on potassium content (%) in tuber of potato plants at harvesting time during 2021/2022 and 2022/2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water ((control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	**2021/2022 season**				
48	2.00 f	2.09 e	2.15 e	2.23 d	**2.11 B**
72	2.32 c	2.44 b	2.50 b	2.60 a	**2.46 A**
96	2.32 c	2.35 c	2.48 b	2.65 a	**2.45 A**
Mean (KFA)	**2.21 D**	**2.29 C**	**2.37 B**	**2.49 A**	
	2022/2023 season				
48	2.05 f	2.15 ef	2.21 e	2.24 de	**2.16 C**
72	2.35 d	2.46 c	2.52 c	2.69 b	**2.50 B**
96	2.72 b	2.89 a	2.90 a	2.96 a	**2.86 A**
Mean (KFA)	**2.37 C**	**2.50 B**	**2.54 B**	**2.63 A**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance. The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Table (18). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on dry matter (%) in tuber of potato plants at harvesting time during 2021/2022 and 2022/2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water (control)	**Potassium nitrate**	**Potassium citrate**	**Potassium silicate**	
(Kg K_2O /fad.)	**2021/2022 season**				
48	15.14 f	15.85 ef	16.20 de	17.20 cd	**16.09 C**
72	16.95 cde	17.86 bc	18.80 b	20.12 a	**18.43 B**
96	17.78 bc	18.54 b	20.40 a	20.80 a	**19.38 A**
Mean (KFA)	**16.62 D**	**17.41 C**	**18.46 B**	**19.37 A**	
	2022/2023 season				
48	14.80 e	15.90 de	15.63 de	15.89 de	**15.55 C**
72	16.40 d	17.10 cd	18.33 bc	18.90 ab	**17.68 B**
96	17.98 bc	18.90 ab	19.34 ab	19.89 a	**19.02 A**
Mean (KFA)	**16.39 C**	**17.30 B**	**17.76 AB**	**18.22 A**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance. The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

Table (19). Effect of potassium rate soil application (KSA) and spraying with different sources of potassium (KFA) and their interaction between them on starch content (%) in tuber of potato plants at harvesting time during 2021/2022 and 2022/2023 seasons

Potassium rate (KSA)	Potassium sources				Mean (KSA)
	Spraying with water (control)	Potassium nitrate	Potassium citrate	Potassium silicate	
(Kg K_2O /fad.)	2021/2022 season				
48	11.83 g	12.47 f	13.23 cde	13.42 bc	**12.74 B**
72	12.43 f	12.90 def	13.45 abc	13.84 ab	**13.16 A**
96	12.74 ef	13.26 cd	13.85 ab	13.96 a	**13.45 A**
Mean (KFA)	**12.33 C**	**12.87 B**	**13.51 A**	**13.74 A**	
	2022/2023 season				
48	11.22 g	12.03 e	11.25 g	11.63 f	**11.53 C**
72	11.77 ef	12.61 cd	12.93 bc	13.09 b	**12.60 B**
96	12.50 d	13.07 b	13.77 a	14.10 a	**13.36 A**
Mean (KFA)	**11.83 C**	**12.57 B**	**12.65 B**	**12.94 A**	

Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance. The concentrations of potassium nitrate (13 percent N and 46 percent K_2O) at 2.39 g/l, potassium citrate (55 percent K_2O) at 2 g/l, and potassium silicate (12% K_2O and 25% SiO_2) at 9.16 ml/l

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