Journal of Agricultural Science; Vol. 14, No. 4; 2022
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Investigation of the Effect of Sulfonated Silicon Nutrient Solution With Elemental Sulfur S-8 on Agronomic Traits of New Potato Cultivars

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Received: January 14, 2022 Accepted: February 17, 2022 Online Published: March 15, 2022

doi:10.5539/jas.v14n4p90 URL: https://doi.org/10.5539/jas.v14n4p90

Abstract

This objective of this study is to optimize the farm management for improving tuber yield per unit area and improving the quality of potato tubers, which can play an effective role in ensuring food security. One of the most important factors in improving the quantity and quality of the product is the proper application of agricultural inputs such as nutrition and nutrient solution. In this study, the effect of sulfonated silicon nutrient solution with S-8 elemental sulfur on new potato cultivars was investigated in Ardabil Potato Research Station during 2021. This study was performed based on factorial experimental design in three replications. The first factor includes the use of nutrient solution in four levels: (1) spraying with a dose of 3 liter nutrient solution in 1000 liters of water in tuberization start, tuberization and tubers bulking stages; (2) treating with 2 kg per 200 liters of water per hectare in first, third, fifth and seventh irrigation stages; (3) foliar spraying with a dose of 3 per thousand in tuberization start, tuberization and tubers bulking stages and use of 2 kg per 200 liters of water per hectare in the first, third, fifth and seventh stages of irrigation; and (4) control. The second factor included five potato cultivars (Agria, Marfona, Rosa, Rona and Takta). During the growth period, plant height, number of main stems per plant, tuber number and weight per plant and tuber yield were measured. The results indicated that Takta, Rona and Agria cultivars had the highest amount in terms of tuber yield, tuber number and weight per plant, plant height and water use efficiency in foliar sprayed with a dose of 3 per thousand and treated with 2 kg per 200 liters of water. In this study, the use of sulfonated silicon nutrient solution with elemental sulfur S-8 in two forms of foliar spraying at a rate of 3 per thousand and use of 2 kg of solution in 200 liters of water increased tuber yield and water use efficiency.

Keywords: agronomic traits, minerals, water use efficiency, potato

1. Introduction

Potato is one of the most important agricultural products in the world. It stands in the fourth place after wheat, rice and maze regarding the nutrition importance (Faberio et al., 2001) and plays an important role in the nutrition and food basket of the world society (Hassanpanah & Akbarlu, 2013). The world population is continuously increasing and as a result, the need for foodstuff growing up every day. FAO has announced that the world population will reach 8 billion in 2030. In fact, supplying the foodstuff for this population needs more attempt and pursuance in the field of agriculture and its related sciences. Despite significant improvements in the recent 3 decades, the world consumption has only increased about 20%. According to the existing statistics, the food production rate should be 70% more than the current rate until 2030 in developing countries so that it can keep up with the increasing population in order to meet their needs. Intense competition in the grains and agricultural products in the international markets will lead to the risk of foodstuff shortage, price fluctuation, and ultimately social chaos in countries with low income. One strategy, which will be helpful in decreasing the above-mentioned risk, is turning the foodstuff production toward basic nutritious products like potato. Iran is ranks 13th in the world in potato production (FAO, 2018). Based on the latest statistics published by the ministry of Agriculture, Jahad, Iran, areas under cultivation of potato in 2019 were about 143,000 hectares producing 5.2 million tons with an average of 37 tons per hectare (Ministry of Agriculture, Jahad, Iran, 2020). At the present time per capita consumption of potatoes for each person is 56 kg which is planned to reach 63 kg in the predicted schedule until 2026 without increasing the area under cultivation (Kazemi et al., 2016). The silicon element will cause the increase in number and quality of the products (Gerami & Torabipoor, 2021; Kaya et al., 2006). Some researchers have reported that silicon element can improve the resistance against environmental cold and heat stress, water scarcity, salinity (Wang et al., 2016; Kaya et al., 2006). It can also increase the production of some antioxidant enzymes (Kaya et al., 2006), the improving of antioxidant system under drought stress (Slinkard & Singleton, 1997), the increase in the activity of SOD and CAT enzymes under drought stress (Guness et al., 2008), the increase in the activity of Chitinase enzyme, Peroxidases and Poly-Phenol Oxidase (Gerami & Torabipoor, 2021). It can also improve the absorption of Potassium and Calcium in the situation of drought stress (Kaplan & Orman, 1998). The results of some researches indicate that silicon element is effective in the increase of chlorophyll (Gerami & Torabipoor, 2021) and also in photosynthesis (Kaplan & Orman, 1998). Other effects of this element are as follow: improving the resistance of the plant against illness and pests, improving germination and plant growth, increasing soil fertility and quality, increasing the activity of terricolous microorganisms, improving the absorption of Calcium and the transfer of food elements, decreasing of accumulation of salt and soil salinity, decreasing the Phosphorus and Potassium leaching existing in the soil (Anonymous, 2021). Sulfur is one of the main elements in plant growing procedure, which helps in protein synthesis and consists a part of some amino acids like Methionine and Cysteine. This element decreases the illness and illness infection, controls and produces sugar, starch and hemicelluloses. Most of the soils of Iran contain sufficient Sulfur although some sandy soils with low organic matters may need Sulfur. Using fertilizers containing Sulfur maybe helpful in the control of potato scab illness if the soil situation is suitable for Sulfur oxidation and affecting the soil acidity (Anonymous, 2021). Sulfur makes the plants more resistant against drought, illness and heat and prevents the nitrate accumulation in the plants (Tate, 1995). Sulfur also improves the function, decreases the soil PH, makes chlorophyll, activates the protein breakdown enzymes and finally resists against biotic and a biotic stresses (Ansouri et al., 2014). The presence of two elements Silica and Potash together, increases photosynthesis, growth of terminal buds, number and strength of stems and plant resistance against sucking insects (Gerami & Torabipoor, 2021). In a suitable nutrient solution, the ratio between different elements should be determined, taking into account the needs of each plant and their different stages of growth (Sajadi, 1983). One of the important points for successful production in these systems is supplying the nutrients required by the plant depending on the type of cultivation bed and the period of plant growth (Ali far et al., 2010). Shahabi Far (2006) has announced that Sulfur is known as an essential and necessary element for the plant nutrition. By examining 3 levels of Sulfur (zero, 250 kg and 500 kg per hectare) which has previously been inoculated with Thiobacillus inoculums, he concluded that the use of Sulfur had a positive and significant effect on plant shrubs, nitrogen concentration, Phosphorus and Potassium of leaves. The highest yield was obtained with the consumption of 500 kg per hectare of Sulfur at the rate of 46,470 kg per hectare which shows an increase of 4,180 kg per hectare in comparisons with control treatment. Golmoradi Marani et al. (2017) studied different amounts of Sulfur fertilizer in the presence or absence of Thiobacillus Thioxidant (biosulfur) on some quality traits and nutrient concentration in potato Agria cultivar. He concluded that the effect of Sulfur fertilizer on the amount of Starch, dry matter and nitrate of the plant was significant. The highest tuber yield per hectare, number of tubers per plant and Phosphorus and Potassium content of tubers were obtained by consuming 400 kg of Sulfur per hectare under the conditions of using Thiobacillus. Also, application of Sulfur fertilizer and biosulfur reduced soil PH. Kafi et al. (2018) reported that the solution to salinity stress is to spray anti-stress solution containing nutrients to mitigate the adverse effects of salinity. They also concluded that foliar application of anti-stress compounds had an effective role in modulating the effects of salinity on tuber operational characteristics, tubers number per plant and tuber dry matter percentage. The use of silicon is an effective way to reduce the effects of salinity.

The goal of this study is to increase the tuber yield of new potato cultivars by consuming sulfonated silicon nutrient solution with elemental sulfur S-8 and to choose the most effective amount for consuming and applying of nutrient solution and also to determine the most suitable potato cultivar.

2. Method

In this study, the effect of sulfonated silicon nutrient solution with elemental sulfur S-8 on new potato cultivars in Potato Research Station of Ardabil Province during 2021 was investigated. This study was performed based on a Factorial experimental design in three replications. The first factor includes the use of nutrient solution in four levels: (1) spraying with a dose of three per thousand in the stages of tuberization start, tuberization and tubers bulking; (2) the amount of 2 kg per 200 liters of water per hectare in stages first, third, fifth and seventh irrigation; (3) foliar spraying with a dose of 3 liter nutrient solution in 1000 liters of water in the stages of tuberization start, tuberization and tubers bulking and use of 2 kg per 200 liters of water per hectare in the first, third, fifth and seventh stages of irrigation; and (4) control. The second factor included five potato cultivars (Agria, Marfona, Rosa, Rona and Takta). During the growth period, plant height, number of main stems per plant, tuber number and weight per plant and tuber yield were measured. S-8 nutrient solution includes 80% sulfur, 2% silicon, 15% Potassium, 2% nitrogen, 2,500 PPM Iron and 200 PPM Zinc. This nutrient solution has a license with registration number 08492 and certificate number 8342/243 dated 15.10.2019 from the Khak-o-Ab {Soil and Water} Institute. The treatments were planted in plots with a length of 5 meters in three rows in the form of a furrow with a density of 75 × 25 cm and a planting depth of 10 cm. The irrigation method was in the form of drip irrigation. After planting and before the potato plants sprouted, Gramaxon (Paraquat) herbicide was used to remove the weeds. The plant earthling up was done in two stages. 250 ml of Confidor (Imidacloprid) insecticide was used to control the Colorado potato beetle pest (*Leptinotarsa disseminate*). Consumption of urea fertilizers was done in three stages in the amount of 250 kg per hectare (one third at planting time, one third at weed weeding and one third at the time of plant earthling up), Ammonium Phosphate fertilizer at two stages in the amount of 150 kg (50% at planting time and 50% at the time of tuberization stage) and Potassium Sulfate fertilizer at a time of 150 kg at planting time was used based on soil test. The project site has a semi-arid and cold climate and the temperature in winter is often below zero.

The average rainfall is 310 mm, the climate is slightly humid, and the altitude is 1,350 meters above sea level and its longitude and latitude are 48°17′35.88″ E and 38°14′59.28″ N, respectively. The average maximum and minimum annual temperatures and absolute maximum temperatures are 1.98, 15.18 and 21.58 °C, respectively. The soil of these lands is loamy clay and is poor in organic matters (0.7%). The PH of these lands is about 7.7 and the PH of water is 7.1. The arable soil (B + A) is about 70 cm deep. The land of the area is flat and its condition is suitable in terms of proper drainage and groundwater aquifer in it is very deep and the condition of soil ventilation is also favorable. The amount of water used was based on different stages of growth and plant needs. To calculate the amount of irrigation water for each time and at each stage of potato growth, the required percentage of field capacity (FC), Percentage of permanent wilting (PWP), specific bulk density (Bd. D), available water (AW) and raw water (RAW) are needed (Rasoolzade & Raoof, 2013). The test site has a specific bulk density of 1 g per cubic centimeter, the field capacity is 29.1% and the permanent wilting is 14.6%. The maximum allowable shortage for potatoes was considered to be 0.35. The maximum allowable deficiency is a part of the amount of available water that the plant easily absorbs. Usually, after this amount of soil moisture, the plant should make more efforts to provide the required moisture, and this will reduce the yield of the crop.

Therefore, the amount of moisture in the soil, which is followed by a decrease in crop yield, is known as the maximum allowable depletion and is expressed as a percentage. The standard value for potatoes is 35%. The amount of available water (AW) and raw water (RAW) of the experimental farm are 18.705 and 6.547%, respectively. Percentage of soil moisture was calculated to determine the start time of irrigation by adding the amount of raw water and permanent wilting. The amount of soil moisture was considered 21.147% for the start of irrigation based on the calculations performed at the test site. The percentage of soil moisture of the test site during the potato-growing period was measured using a portable hygrometer device PMS-714 made in Taiwan.

$$AW = [(\Theta_{FC} - \Theta_{PWP})/100] \times Bd.\ D = [(29.1 - 14.6)/100] \times 1.29 = 18.705\% \quad (1)$$

$$RAW = AW \times MAD = 18.705 \times 0.35 = 6.547\% \quad (2)$$

$$\text{Moisture Percentage of the Soil} = RAW + PWP = 6.547 + 14.6 = 21.147\% \quad (3)$$

2.1 Required Amount of Water

2.1.1 In the Planting Stage

The first stage: Farm capacity × Rooting development in the planting stage × The area of one hectare = percent 29.1 × 0.2 m × 10,000 square meters = 582 cubic meters per hectare

The second stage: Soil moisture at the beginning of irritation × Rooting development in the planting stage × The area of one hectare = percent 21.147 × 0.2 m × 10,000 square meters = 423 cubic meters per hectare

$$\text{The first stage} - \text{The second stage} = 582 - 423 = 159 \text{ cubic meters per hectare} \quad (4)$$

2.1.2 In the Planting Stage Until the Start of Tuberization

The first stage: Farm capacity × Rooting development in the planting stage × The area of one hectare = percent 29.1 × 0.3 m × 10,000 square meters = 873 cubic meters per hectare

The second stage: Soil moisture at the beginning of irritation × Rooting development in the planting stage × The area of one hectare = percent 21.147 × 0.3 m × 10,000 square meters = 634 cubic meters per hectare

$$\text{The first stage} - \text{The second stage} = 873 - 634 = 239 \text{ cubic meters per hectare} \quad (5)$$

2.1.3 In the Starting Stage of Tuberization Until the Ripping of Tubers

The first stage: Farm capacity × Rooting development in the planting stage × The area of one hectare = percent 29.1× 0.5 m × 10,000 square meters = 1,455 cubic meters per hectare

The second stage: Soil moisture at the beginning of irritation × Rooting development in the planting stage × The area of one hectare = percent 21.147 × 0.5 m × 10,000 square meters = 740 cubic meters per hectare

$$\text{The first stage} - \text{The second stage} = 1{,}455 - 740 = 715 \text{ cubic meters per hectare} \quad (6)$$

During the growth period, plant height, number of main stems per plant, tuber number and weight per plant and tuber yield were measured. For data analysis, the normality test of data distribution was performed by Kolmogorov-Smirnov test. Analysis of variance was performed using SAS 9.1 statistical software. Comparison of mean traits was compared using LSD test at 5% probability level. Minitab16 software was used to calculate factor analysis and cluster analysis by Ward method.

3. Results and Discussion

The results of analysis of variance showed that there was a significant difference between the different levels of nutrient solution, cultivars and the interaction between them at the level of 1% and 5% probability (Table 1). In terms of tuber yield, Takta cultivar in foliar application treatment with nutrient solution at a dose of 3 per thousand in the stage of tuberization start, tuberization, bulking of tubers and the amount of 2 liters per 200 liters of water per hectare in the first, third, fifth and the seventh irrigation stages had the highest value and was placed in group A. In the next group, Takta and Rona cultivars in foliar application treatment with nutrient solution at a dose of 3 per thousand, Takta, Rosa and Rona cultivars in 2 liters per 200 liters of water per hectare and Rosa, Rona and Agria cultivars in foliar application treatment with doses of 3 per thousand and 2 liters per 200 liters of water per hectare (Table 2). The highest tuber weight per plant and plant height in Takta cultivar in foliar application treatment with nutrient solution at a dose of 3 per thousand in the stage of tuberization start, tuberization, bulking and 2 liters per 200 liters of water per hectare in the first, third, fifth and seventh irrigation stages were observed and placed in group A (Table 2). Regarding the number of tubers per plant, Takta cultivar in foliar application with nutrient solution had the highest value at a dose of 3 per thousand in the stage of tuberization start, tuberization, tuber bulking and 2 liters per 200 liters of water per hectare in the first, third, fifth and seventh irrigation stages .Furthermore Rona cultivar in foliar application treatment with nutrient solution at a dose of 3 per thousand had the highest value and were placed in groups a and ab (Table 2). The highest water use efficiency of Takta and Rona cultivars were gained in foliar application treatment with nutrient solution at a dose of 3 per thousand in the stage of tuberization start, tuberization, bulking and 2 liters per 200 liters of water per hectare in the first, third, fifth and seventh irrigation stages. Rosa and Agria cultivars also had the highest amount in foliar treatment with nutrient solution at a dose of 3 per thousand and 2 liters per 200 liters of water per hectare and were placed in the next group (Table 2).

Table 1. Variance analysis of evaluated traits in potato cultivars and agronomic traits

Mean of squares						D.F.	S.O.V.
Water use efficiency	Main stem number per plant	Plant height	Tuber number per plant	Tuber weight per plant	Tuber yield		
0.661	0.317	54.45	1.82	6409.63	16.02	2	Rep.
8.20**	1.733**	2206.95**	7.17**	138495.27**	389.03**	3	Nutrient levels (A)
17.54**	1.392**	1094.48**	21.33**	294722.32**	827.84**	4	Cultivars (B)
4.016**	1.359**	346.8**	0.8655*	87260.56**	240.52**	12	A × B
0.945	0.317	54.45	0.3781	10061.23	25.58	38	Error
15.38	17.23	11.04	8.06	12.21	11.61	C.V. (%)	

Note. * and **: Significant at the 5 and 1%, probability levels, respectively.

Table 2. Mean of agronomic traits in potato cultivars and agronomic traits

Nutrient levels	Cultivars	Tuber yield (ton per ha)		Tuber weight per plant (gr)		Tuber number per plant		Plant height (cm)		Main stem number per plant		Water use efficiency (kg/m^3)	
0	Roza	32.74	Cdefg*	706.43	def	7.33	feg	67	cde	2.33	cd	6.20	cdef
	Rona	33.41	cdefg	719.15	cdef	7.67	def	48	h	3.00	c	6.30	bcde
	Agria	22.89	hi	520.55	hi	6.00	ghi	72	cd	3.00	c	4.77	fgh
	Marfona	17.78	i	424.11	i	5.00	j	52	fgh	5.00	a	4.03	h
	Takta	32.06	efg	693.57	defg	7.67	def	71	cd	3.00	c	6.10	cdefg
2 kg/200 L	Roza	34.78	cdef	744.86	cdef	8.00	cdef	55	efgh	3.00	c	6.50	bcde
	Rona	38.89	bcde	822.43	bcd	9.00	bc	67	cde	3.00	c	7.10	bcd
	Agria	26.00	ghi	579.25	fghi	6.33	ghi	67	cde	4.00	b	5.22	fegh
	Marfona	22.26	hi	508.67	hi	6.00	ghi	48	h	4.00	b	4.68	gh
	Takta	38.75	bcde	819.78	bcd	8.33	bcde	64	def	3.00	c	7.08	bcd
3/1000	Roza	38.11	bcde	807.76	bcd	8.33	bcde	58	efgh	3.00	c	6.98	bcd
	Rona	41.63	bc	874.14	bc	9.33	ab	63	defg	3.00	c	7.49	bc
	Agria	29.22	fgh	640.04	efgh	7.00	fg	73	cd	3.00	c	5.69	defg
	Marfona	22.15	hi	506.57	ih	5.67	ij	51	gh	3.00	c	4.67	gh
	Takta	40.44	bcd	851.78	bcd	8.67	bcd	56	efgh	2.00	d	7.32	bc
2 kg/200 L 2/1000	Roza	41.67	bc	874.84	bc	8.67	bcd	74	cd	4.00	b	7.50	bc
	Rona	44.11	b	920.96	b	9.00	bc	77	bc	3.00	c	7.85	ab
	Agria	36.70	bcdef	781.20	bcde	8.33	bcde	88	b	4.00	b	6.78	bcde
	Marfona	23.67	hi	535.22	ghi	6.00	ghi	66	cde	3.00	c	4.89	fgh
	Takta	49.96	a	1006.8	a	10.3	a	120	a	4.00	b	9.28	a

Note. * Means followed with the same letters in each column are not significantly different at 5% probability level using LSD test.

Based on the results of factor analysis, Takta, Rona and Agria cultivars in terms of tuber yield, number and weight of tubers per plant, plant height and water use efficiency in foliar application treatment at a dose of 3 per thousand in the stage of tuberization start, tuberization itself, tuber bulking and consumption of 2 liters per 200 liters of water per hectare in the first, third, fifth and seventh irrigation stages had the highest amount (Figure 1). According to Table 3, tuber yield, number and weight of tubers per plant and water use efficiency with the first factor with 63.9% variance, plant height with the second factor with 18.4% variance and the number of main stems per plant with the third factor was justified with 17.3% variance (Table 3).

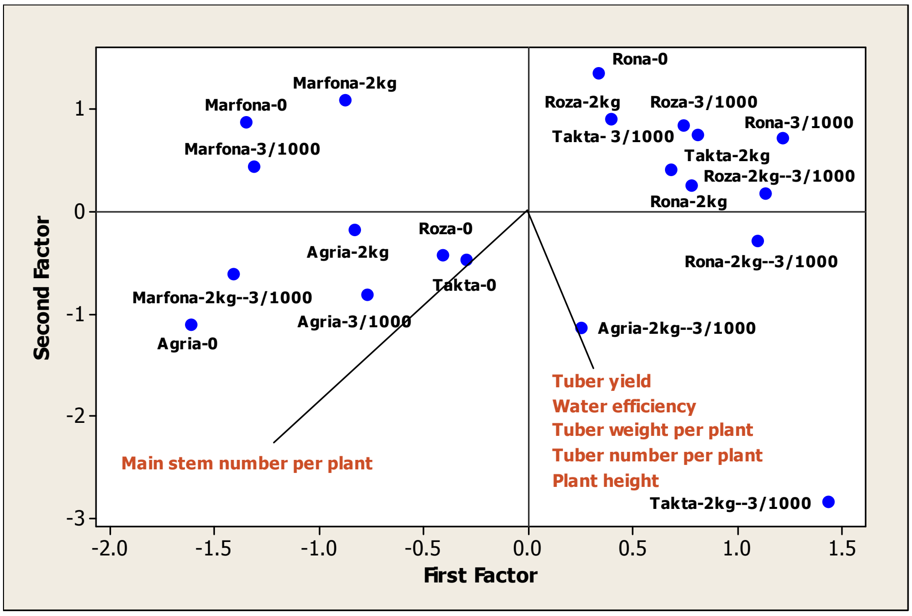
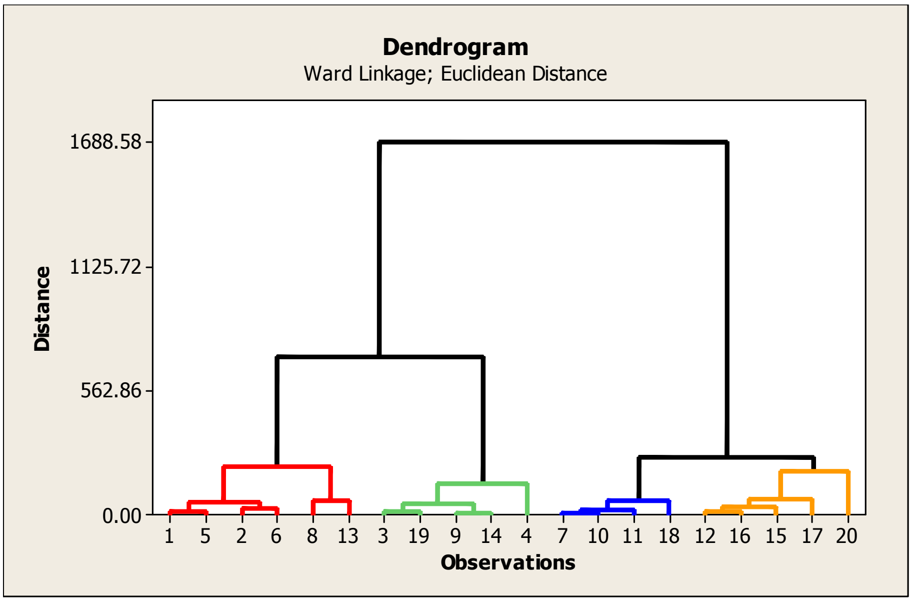


Figure 1. Biplot of factor analysis in potato cultivars and treatments based on all studied traits

Table 3. Factors values in evaluated traits in potato cultivars and studied treatments

Traits	Factor 1	Factor 2	Factor 3
Tuber yield	**0.963**	-0.239	-0.122
Tuber weight per plant	**0.965**	-0.220	-0.131
Tuber number per plant	**0.958**	-0.232	-0.123
Plant height	0.361	**0.919**	0.156
Main stem number per plant	-0.161	-0.120	**0.980**
Water use efficiency	**0.950**	-0.292	-0.094
Eigen value	3.8355	1.1041	1.0399
Variance (%)	63.9	18.4	17.3

Based on the results of cluster analysis by Ward method, the grouping were placed as follow: in the first group of Rona, Rosa and Takta cultivars in conditions without using nutrient solution, Rosa and Agria cultivars in conditions of consumption of 2 kg in 200 liters of water and Agria cultivar in conditions of consumption of nutrient solution in 3 per thousand. The second group was placed as follow: Agria and Marfona cultivars in conditions without using nutrient solution, Marfona cultivar in conditions of consumption of 2 kg in 200 liters of water, Marfona cultivar in conditions of consumption of nutrient solution in the amount of 3 per thousand and in conditions of consumption of 2 kg in 200 liters of water and consumption of nutrient solution was 2 per thousand. In the third group, Rona and Takta cultivars were placed in condition of consumption of 2 kg in 200 liters of water and Rosa cultivar in condition of nutrient solution consumption of 3 per thousand and Marfona cultivar in condition of nutrient solution consumption of 3 per thousand and in condition of consumption of 2 kg in 200 liters of water. In the fourth group, Rona and Takta cultivars had the highest amount of nutrient solution at a rate of 3 per thousand and Rosa, Agria and Tekta cultivars had the highest amount at a rate of 2 per thousand and 2 kg per 200 liters of water (Figure 2). The cultivars and treatments in the fourth group, in terms of tuber yield, number and weight of tubers per plant, plant height and water use efficiency traits have a deviation of the mean of each trait from the total positive average and are selected as a suitable group in terms of yield traits and yield components (Table 4).



No.	Treatments		No.	Treatments		No.	Treatments		No.	Treatments	
1		Roza	6		Roza	11		Roza	16		Roza
2		Rona	7		Rona	12		Rona	17		Rona
3	0	Agria	8	2kg/200L	Agria	13	3/1000	Agria	18	2kg/200L 3/1000	Agria
4		Marfona	9		Marfona	14		Marfona	19		Marfona
5		Takta	10		Takta	15		Takta	20		Takta

Figure 2. Grouping of potato cultivars and treatments based on all studied traits using Ward method

Table 4. Deviation of the mean of each group from the total mean in the evaluated traits of potato cultivars and studied treatments

Traits	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Tuber yield	-2.2	-11.6	**4.7**	**10.2**
Tuber weight per plant	-36	-218	**91**	**189**
Tuber number per plant	-0.3	-1.9	**0.86**	**1.57**
Plant height	-3.4	-9.1	**2.4**	**11.1**
Main stem number per plant	-0.216	**0.334**	-0.016	-0.066
Water use efficiency	-0.321	-1.713	**0.664**	**1.567**

Based on the results, Takta, Rona and Agria cultivars had the highest amount in terms of tuber yield, number and weight of tubers per plant, plant height and water use efficiency in foliar application treatment with a dose of 3 per thousand in the stage of tuberization start, tuberization and bulking and the consumed water was 2 liters per 200 liters per hectare in the first, third, fifth and seventh irrigation stages. In foliar application at 3 per thousand and with the use of 2 liters of nutrient solution in 200 liters of water compared to the control (without foliar application) tuber yield difference of 12.25 tons per hectare (24.48%), tuber weight per plant 231.06 g (25%), number of tubers per plant 1.74 tubers (20.5%), plant height 23 cm (27%) and number of main stems per plant 1.78 tubers (24.52%) was observed. Using sulfonated silicon nutrient solution with elemental sulfur S8 in two forms of foliar spraying at a rate of 3 per thousand in the stages of tuberization stage, tuberization and bulking of tubers and the use of 2 liters of solution in 200 liters of water in the three stages of the first, third, fifth and seventh irrigation, increased tuber function and water use efficiency. Gerami and Torabipoor (2021), and Kaya et al. (2006) also reported that silicon element increases resistance to environmental stresses of heat, cold, dehydration and salinity. It has also been reported that this element can cause the increase of resistance to plant diseases and pests, improve the germination and plant growth (Anonymous, 2020). Ansouri et al. (2014) concluded that the element sulfur increases yield, decreases soil PH, chlorophyll formation, activates protein-degrading enzymes and develops resistance to biotic and abiotic stresses. The presence of two elements Silica and Potash together increases photosynthesis, terminal bud growth, number and strength of stems and plant resistance to sucking insects (Gerami & Torabipoor, 2021) and increases yield (Shahabifar, 2006; Golmoradi Marani et al., 2017; Kafi et al., 2018).

In conclusion, the use of sulfonated silicon nutrient solution with elemental sulfur S-8 in two forms of foliar spraying at a rate of 3 per thousand and use of 2 kg of solution in 200 liters of water increased tuber yield and water use efficiency in Takta, Rona and Agria cultivars.

Acknowledgements

The authors thank from management support of Seed and Plant Breeding Research Institute and assistance the management of Ardabil Agricultural and Natural Resources Research Centre, Iran.

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