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Using Sulphonated Silicon Nutrient Solution with S8 Elemental Sulfur and Changing Planting Arrangement in Potato Winter Cultivation

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Abstract

This experiment with aims to increase the tuber yield and quality by using sulphonated silicon nutrient solution with S8 and changing the planting arrangement in potato winter cultivation was investigated in Potato Research Station of Ardabil Province, IRAN during 2022. This experiment was carried out based on the factorial experimental design in three factors and three repetitions. The first factor with two levels including: (1) Spring cultivation and (2) Winter cultivation; the second factor consists of two levels: (1) The planting arrangement of one row on one stack, and (2) The arrangement of planting two rows on one stack in a zigzag pattern and the third factor with three levels includes: (1) Spraying on tuber and soil before planting and foliar spraying in three stages of vegetative growth, tuberization and tuber bulking with a dose of 5 liter nutrient solution in 1000 liters of water per hectare, (2) Foliar spraying in three stages of vegetative growth, tuberization and tuber bulking with a dose of 5 liter nutrient solution of S8 in 1000 liters of water per hectare, and 3. Control (without sulphonated silicon nutrient solution of S8) were. The irrigation method was in the form of drip irrigation. During the growth period, plant height, number of main stems per plant, tuber number and weight per plant and tuber yield were measured. By using nutrient solution and changing the planting arrangement (two rows on one stack) increased tuber yield, tuber number and weight per plant, plant height and water use efficiency in winter and spring cultivation.

Keywords: quantitative traits, yield, water use efficiency, siliconated S8, foliar spraying

1. Introduction:

Potato is one of the most important agricultural products in the world and IRAN. It stands in the fourth place after wheat, rice and corn 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). Based on the latest statistics published by the Ministry of Agriculture-JahadIran, areas under cultivation of potato in 2020 were about 142,000 hectares producing 5.3 million tons with an average of 37 tons per hectare (Ministry of Agriculture-Jahad, Iran, 2022).

In tuberous plants, determining the planting row distance is more important, because in addition to tuber yield, it also affects their quality and marketability. Cultivation distance is one of the effective factors on yield and its components in the production of seed, edible and industrial potato tubers. In potato, the density of the main stem per unit area is very important. This density is influenced by factors such as the production potential of the area, variety, growth and production power of each stem, and ultimately the production goal (Samadi & Mohammad-doost-Chamanabad, 2014; Badri, 2016). Reducing the spacing of planting rows is a suitable non-chemical tool in weed management. Many crops are cultivated in wide rows for reasons such as the reduction of the cost of seed consumption, better farm management, less soil destruction, and ease of mechanical and chemical weed control. Reducing the spacing of planting rows increases the ability of plants to compete with weeds, as well as the yield of plants and reduces the need to use herbicides (Rich & Renner, 2007; Samadi & Mohammad-doost-Chamanabad, 2014). Qasim et al. (2013) by studying the planting arrangement (planting on a wide stack covered with soil on one side of the stack width 75 cm, inside the furrow without stack, on the ridge) concluded that the maximum tuber growth (88.7 percent), the number of main stems per plant (3.5 numbers), plant height (45.5 cm), the average number of tubers per plant (10.1 numbers) and the tuber yield in the planting arrangement treatment on a wide stack covered with the soil was on one side. The highest plant height was obtained in the cultivation treatment on the ridge (Fakhari, 2013). With different planting patterns including stack width of 75 cm, two rows of 35 cm on a stack of 150 cm and two rows of 45 cm on a stack of 150 cm and different levels of irrigation, they reported the highest water consumption efficiency in the treatment of 100% and 80% it was related to the treatment of two rows of 45 cm on a stack of 150 cm and in the treatment of 60% irrigation, it was related to the treatment of two rows of 35 cm on a stack of 150 cm. Shiri Janaqard et al. (2007) by examining different cultivation patterns (conventional cultivation with 75 cm row spacing, two row cultivation on a 150 cm wide stack with 35 and 45 cm row spacing) on the yield and yield components of potato showed that there was no significant effect in terms of cultivation pattern in different traits. Baghani (2009) has reported the increase of seed tuber yield and water consumption efficiency in the method of planting arrangement a tape strip for two planting rows at a distance of 35 cm. According to the reports of various researchers of the country, the amount of potato produced per cubic meter of irrigation water is 3 kg (Zare-Mehrjardiet al., 2009), 2.18 kg (Hedari, 2011) and 2.99 kg (Haji Rahimi & Abdul Qozloja, 2012).

Using silicon increased yield and quality (Gerami & Torabipoor, 2021; Kaya et al., 2006), resistance to cold and heat stress (Wang et al., 2016; Kaya et al., 2006), improve the antioxidant enzymes production (Kaya et al., 2006). Tate (1995) announced that sulfur is one of the main essential elements for plant growth, which is involved in protein synthesis and forms a part of some amino acids such as methionine and cysteine. Sulfur increases the resistance of plants to diseases, drought and cold, and also prevents the accumulation of nitrates in plants. Ansuri et al. (2014) reported sulfur element increases yield, reduces soil pH, forms chlorophyll, activates protein-degrading enzymes, and creates resistance to biotic and abiotic stresses. Golmoradi Marani et al. (2017) concluded that the highest tuber yield, tuber number per plant and tuber phosphorus and potassium content were obtained by using Sulfur with Thiobacillus. Grami and Tarabipour (2021) reported the presence of the two elements silicon and potash together increases photosynthesis, the growth of terminal buds, the number and strength of stems, and the plant's resistance to sucking insects. Hassanpanah et al. (2022) by examining the effect of sulphonated silicon nutrient solution with elemental sulfur S8 on potato cultivars, they concluded 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. Increased tuber yield by Shahabifar (2006) has also been reported.

The purpose of this investigation were increase of tuber yield and quality and saving water consumption by using sulphonated silicon nutrient solution and changing the planting arrangement in winter and spring cultivation.

2. Material and Methods

This study was done based on the factorial experimental design with three factors and three repetitions in Potato Research Station of Ardabil Province, IRAN during 2022. The first factor consists of season cultivation with two levels (spring and winter), the second factor including planting arrangement with two levels (one row on one stack and two rows on one stack in a zigzag pattern) and the third factor contains with three levels (1) Spraying on tuber, soil and foliar, (2) Foliar spraying, and (3) Controls (without sulphonated silicon nutrient solution) were. The sulphonated silicon nutrient solution used in three stages of vegetative growth, tuberization and tuber bulking with a dose of 5 liter nutrient solution in 1000 liters of water per hectare. Agria potato cultivar was used in this experiment. The planting date spring cultivation 2 May and winter cultivation 10 March was. 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 10 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

(*Leptinotarsadecemlineata*). Consumption of urea fertilizers was done in three stages in the amount of 200 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 100 kg (50% at planting time and 50% at the time of tuberization stage) and Potassium Sulfate fertilizer at a time of 100 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 physicochemical properties of the soil and water of the experimental site is shown in Table 1.

Table 1. Physicochemical properties of the soil and water of the experimental site

Description	Soil	Analysis	Water
Salinity	1.25 ds m^{-1}	Salinity	1500 µs cm^{-1}
pH	7.64	pH	7.66
Saturation (%)	29	Carbonate	0
Lime (%)	7.50	Bicarbonate (mg kg^{-1})	382
Texture	Clay-loam	Sulfate (mg kg^{-1})	155
Organic carbon	0.97	Chlorine (mg kg^{-1})	195
Total nitrogen (%)	0.10	Sodium (mg kg^{-1})	123.98
Absorbable P (mg kg^{-1})	3.40	Calcium (mg kg^{-1})	118
Available nutrients it is proper potassium (mg kg^{-1})	230	Magnesium (mg kg^{-1})	44.2
Zinc (mg kg^{-1})	1.22	SAR	2.46
Iron (mg kg^{-1})	3.22	TDS (mg l^{-1})	75
Copper (mg kg^{-1})	3.20	Total hardness	480
Manganese (mg kg^{-1})	4.20		

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 and 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.

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

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

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

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;

The first stage − The second stage = 582 − 423 = 159 cubic meters per hectare.

2.1.2 In the Planting Stage Until the Start of Tuberization

The first stage: Farm capacity × Rooting development in the planting stage until the start of tuberization × 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 until the start of tuberization × The area of one hectare = percent 21.147 × 0.3 m × 10,000 square meters = 634 cubic meters per hectare;

The first stage − The second stage = 873 − 634 = 239 cubic meters per hectare.

2.1.3 In the Starting Stage of TuberizationUntil the Harvesting of Tubers

The first stage: Farm capacity × Rooting development in the starting stage of tuberization until the harvesting of tubers × 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;

The first stage − The second stage = 1,455 − 740 = 715 cubic meters per hectare.

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 planting season and planting pattern in terms of tuber yield, tuber weight per plant and water use efficiency, between the different levels of nutrient solution in terms of tuber yield, tuber weight per plant, tuber number per plant, plant height, main stem number per plant and water use efficiency and the interaction between planting season and planting pattern in terms of tuber yield, tuber weight per plant and main stem number per plantat the level of 1% and 5% probability (Table 2).

In terms of tuber yield and tuber weight per plant, treatment of spring cultivation and two rows on one stack in a zigzag pattern and in terms of water use efficiency, treatment of winter cultivation and two rows on one stack in a zigzag pattern had the highest value and were placed in group A (Table 3).

Traits of tuber yield, tuber weight per plant, tuber number per plant, plant height, main stem number per plant and water use efficiency had the most value in treatments of the spraying with nutrient solution at a dose of 5 per thousand on tuber and soil before planting and foliar spraying in three stages and foliar spraying in three stages (Table 4).

Table 2. Variance analysis of evaluated traits in planting season, planting pattern and nutrient solution levels

S.O.V.	D.F.	Mean of squares					
		Tuber yield	Tuber weight per plant	Tuber number per plant	Plant height	Main stem no. per plant	Water use efficiency
Rep.	2	33.45	11866.4	0.68	800.12	0.27	4.31
Planting season (A)	1	1722.25**	613115.1**	0.25	702.25	0.22	229.7**
Planting pattern (B)	1	4288.94**	1526872.1**	0.34	42.25	0.25	258.73**
Nutrient levels (C)	2	306.85**	109240.18**	24.25**	30027**	1.75*	18.74*
A × B	1	210.25*	74847.84*	0.26	56.25	2.25*	5.04
A × C	2	19.00	6765.43	0.34	211.00	0.21	0.917
B × C	2	10.15	3614.63	2.25	28.00	0.19	0.363
A × B × C	2	7.00	2492.38	0.33	27.00	0.77	0.168
Error	22	33.33	11866.4	0.75	833.33	0.334	4.31

C.V. (%)	12.33	14.23	13.15	21.19	16.89	17.56

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

Table 3. Mean of quantitative traits in planting seasonand arrangement levels

Planting season	Planting arrangement	Tuber yield (ton per ha)		Tuber weight per plant (gr)		Water use efficiency (kg/m^3)	
Winter cultivation	One row on one stack	31.40	d	592.57	d	11.29	b
	Two rows on one stack in a zigzag pattern	48.40	b	913.27	b	17.40	a
Spring planting	One row on one stack	40.40	c	762.39	c	6.98	c
	Two rows on one stack in a zigzag pattern	67.07	a	1265.47	a	11.60	b

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

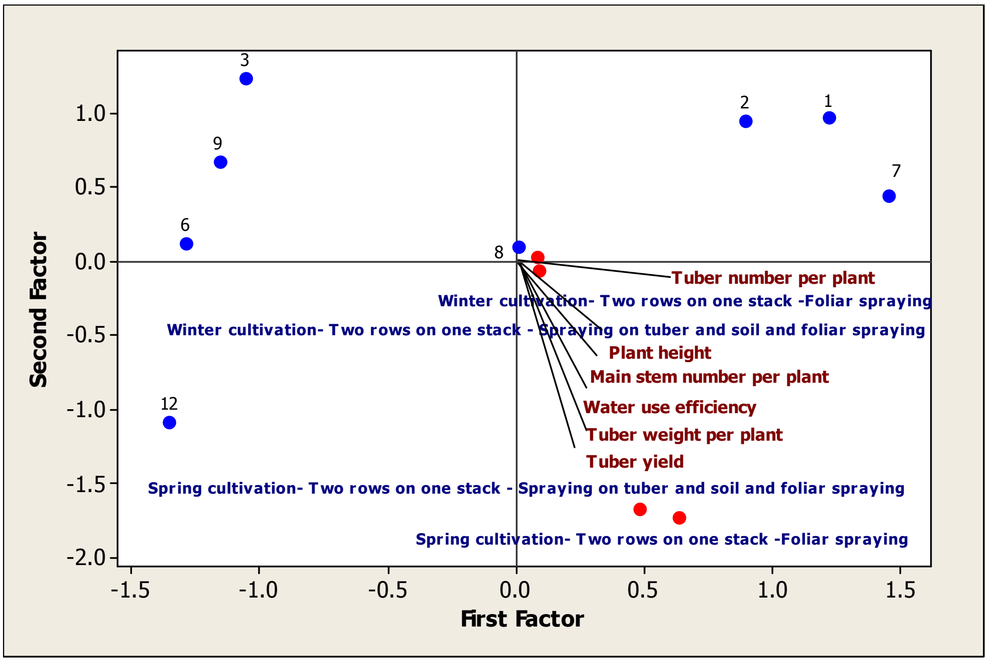
Table 4. Mean of quantitative traits in nutrient solution levels

Nutrient levels	Tuber yield (ton per ha)		Tuber weight per plant (gr)		Tuber no. per plant		Plant height (cm)		Main stem no. per plant		Water use efficiency (kg/m^3)	
Spraying on tuber and soil before planting and foliar spraying in three stages	49.89	a	941.23	a	7.75	a	169.75	a	3.75	a	12.58	a
Foliar spraying in three stages	49.60	a	935.76	a	7.00	b	160.25	a	3.50	a	12.51	a
Control	40.99	b	773.30	b	5.00	c	78.75	b	3.00	b	10.38	b

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, treatments of spring cultivation, two rows on one stack and spraying on tuber and soil and foliar spraying in terms of tuber yield, tuber weight per plant, tuber number per plant, plant height, main stem number per plant and water use efficiency had the highest amount (Figure 1). In the next stage, treatments of winter cultivation, two rows on one stack and spraying on tuber and soil and foliar spraying in terms of tuber yield, tuber weight per plant, tuber number per plant, plant height, main stem number per plant and water use efficiency had the highest amount (Figure 1). According to Table 5, number of tubers per plant, plant height and main stem number per plant with the first factor with 40.9% variance, tuber yield and tuber weight per plant with the second factor with 33.8% variance and the water use efficiency with the third factor was justified with 19.1% variance (Table 5).

Based on the results of cluster analysis by Ward method, the grouping were placed as follow: in the first group of treatments of winter cultivation, one rows on one stack and spraying on tuber and soil and foliar spraying, foliar spraying in control and treatments of spring cultivation, one rows on one stack in control. The second group was placed as follow: treatments of winter cultivation, two rows on one stack and spraying on tuber and soil and foliar spraying, foliar spraying and control and treatment of spring cultivation, two rows on one stack in control. In the third group, treatments of spring cultivation, two rows on one stack and spraying on tuber and soil and foliar spraying (Figure 2). In the third group treatments of spring cultivation, two rows on one stack and spraying on tuber and soil and foliar spraying had the highest amount (Figure 2). The treatments of spring cultivation, two rows on one stack and spraying on tuber and soil and foliar spraying had the highest amount in the third 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 6).

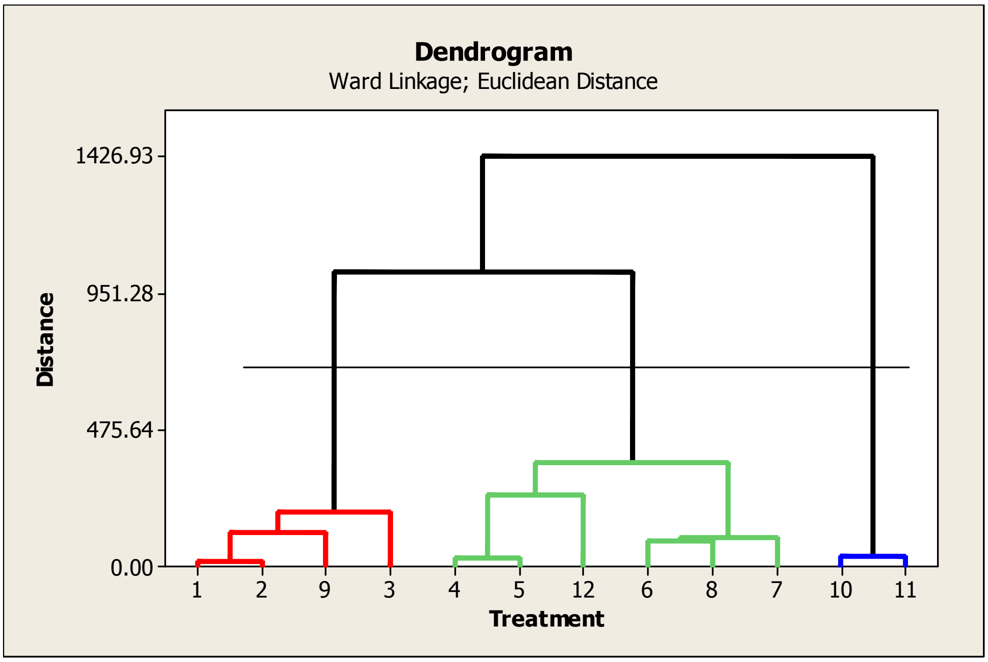


No.	Treatments			No.	Treatments		
1	Winter cultivation	One rows on one stack	Spraying on tuber and soil and foliar spraying	7	Spring cultivation	One rows on one stack	Spraying on tuber and soil and foliar spraying
2			Foliar spraying	8			Foliar spraying
3			Control	9			Control
4		Two rows on one stack	Spraying on tuber and soil and foliar spraying	10		Two rows on one stack	Spraying on tuber and soil and foliar spraying
5			Foliar spraying	11			Foliar spraying
6			Control	12			Control

Figure 1. Biplot of factor analysis in planting season, planting pattern and nutrient solution levels

Table 5. Factors values in evaluated traits in planting season, planting pattern and nutrient solution levels

Traits	Factor 1	Factor 2	Factor 3
Tuber yield	0.091	**0.988**	0.116
Tuber weight per plant	0.091	**0.988**	0.116
Tuber number per plant	**0.960**	-0.004	0.049
Plant height	**0.912**	-0.093	0.318
Main stem number per plant	**0.826**	-0.181	-0.316
Water use efficiency	0.038	-0.185	**0.956**
Eigen value	2.4523	2.0269	1.1436
Variance (%)	40.9	33.8	19.1



No.	Treatments			No.	Treatments		
1	Winter cultivation	One rows on one stack	Spraying on tuber and soil and foliar spraying	7	Spring cultivation	One rows on one stack	Spraying on tuber and soil and foliar spraying
2			Foliar spraying	8			Foliar spraying
3			Control	9			Control
4		Two rows on one stack	Spraying on tuber and soil and foliar spraying	10		Two rows on one stack	Spraying on tuber and soil and foliar spraying
5			Foliar spraying	11			Foliar spraying
6			Control	12			Control

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

Table 6. Deviation of the mean of each group from the total mean in the evaluated traits and studied treatments

Traits	Cluster 1	Cluster 2	Cluster 3
Tuber yield	-14.827	1.908	**23.928**
Tuber weight per plant	-279.75	36.006	**451.481**
Tuber number per plant	-0.333	0.084	**0.417**
Water use efficiency	-1.892	1.123	**0.411**
Plant height	-9.75	-1.25	**23.25**
Main stem number per plant	0.083	-0.25	**0.583**

Based on the results, using sulfonated silicon nutrient solution with elemental sulfur S8with a dose of 5 liter in 1000 liters of water per hectare in the form of spraying on tuber and soil before planting and foliar spraying in three stages of vegetative growth, tuberization and tuber bulking causing an increase tuber yield (7.61 ton per ha), tuber weight per plant (143.58 g), tuber number per plant (2.5 numbers), plant height (91.50 cm) and water use efficiency (2.74 kg/m^3) in winter cultivation and tuber yield (9.61 ton per ha), tuber weight per plant (181.33 g), tuber number per plant (3.00 numbers), plant height (90.50 cm) and water use efficiency (1.66 kg/m^3) in spring cultivation became (Table 7).Changing the planting arrangement from one row on one stack to two rows on one stack in a zigzag pattern increased tuber yield (16.95 ton per ha), tuber weight per plant (319.81 g) and water use efficiency (6.09 kg/m^3) in winter cultivation and tuber yield (25.95 ton per ha), tuber weight per plant (489.62 g) and water use efficiency (4.49 kg/m^3) in spring cultivation(Table 6). By using nutrient solution and changing the planting arrangement increased tuber yield (24.75 ton per ha), tuber weight per plant (466.98 g), tuber number per plant (2.00 numbers), plant height (85.00 cm) and water use efficiency (8.90 kg/m^3) in winter cultivation and tuber yield (37.75 ton per ha), tuber weight per plant (712.27 g), tuber number per plant (2.00 numbers), plant height (92.00 cm) and water use efficiency (6.53 kg/m^3) in spring cultivation(Table 7).

Hassanpanah et al. (2022) results 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. Increased yield has also been reported by Shahabifar (2006), Golmoradi Marniet al. (2017) and Soltaniet al., (2018). Also, Ansouri et al. (2014) reported element sulfur increases yield and decreases soil PH. Kaya et al. (2006) and Gerami and Torabipoor (2021) reported that silicon element increases resistance to heat, cold, dehydration and salinity stress.

Table 7. Increasing quantitative traits in treatments of planting season and pattern and nutrient solution levels

Treatments		Tuber yield (ton per ha)	Tuber weight per plant (g)	Tuber no. per plant	Plant height (cm)	Water use efficiency (kg/m^3)
Winter cultivation	Nutrient solution spraying on tuber and soil before planting and foliar spraying in three stages	7.61	143.58	2.50	91.50	2.74
	Changing the planting arrangement from one row on one stack to two rows on one stack in a zigzag pattern	16.95	319.81	-	-	6.09
	Nutrient solution + Changing the planting arrangement	24.75	466.98	2.00	85.00	8.90
Spring cultivation	Nutrient solution spraying on tuber and soil before planting and foliar spraying in three stages	9.61	181.33	3.00	90.50	1.66
	Changing the planting arrangement from one row on one stack to two rows on one stack in a zigzag pattern	25.95	489.62	-	-	4.49
	Nutrient solution + Changing the planting arrangement	37.75	712.27	2.00	92.00	6.53

In conclusion, the use of sulfonated silicon nutrient solution with elemental sulfur S8 with a dose of 5 liter in 1000 liters of water per hectare in the form of spraying on tuber and soil before planting and foliar spraying in three stages of vegetative growth, tuberization and tuber bulking and changing the planting arrangement from one row on one stack to two rows on one stack in a zigzag pattern increased tuber yield and water use efficiency.

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Reference

Ansuri, A., Golami, A., Abasdokht, H., Gholipoor, M., Baradaran, M., & Falah Nosratabad, A. R. (2014). Evaluation of mycorrhizal symbiosis, Thiobacillusthiooxidans and sulfur application effects on growth characteristics and yield of Corn (*Zea mays* L.). *Journal of Soil Management and Sustainable, 4*(1), 110-126. https://doi.org/20.1001.1.23221267.1393.4.1.6.0

Badri, A. R. (2016). *Potato cultivation*. Alborz Province Agricultural Jihad Organization, Alborz Province Agricultural Promotion Coordination Management.

Baghani, J. (2009). Effect of planting pattern and water quantity on potato cultivation with drip irrigation in mashhad. *Journal of Water and Soil, 23*(1), 153-159. https://doi.org/10.22067/JSW.V0I0.1547

Faberio, C., Martin de Santa Olalla, F., & de Juan, J. A. (2001). Yield and size of deficit irrigated potatoes. *Agricultural Water Management, 48*, 255-266. https://doi.org/10.1016/S0378-3774(00)00129-3

Fakhari, R., Tobeh, A., Hasanzadeh, N., Barghi, A., & Shiri, M. (2013). Studying effects of different irrigation levels and planting patterns on yield and water use efficiency in potato (*Solanum tuberosum* L.). *International Research Journal of Applied and Basic Sciences, 4*(7), 1941-1945. https://doi.org/10.22077/ESCS.2018.895.1178

Gerami, S. H., & Torabipour, S. H. (2021). *The role of silicon (Si) and its application in plants*. Retrieved from https://alborzbehsam.com

Golmoradi Marani, F., Barmaki, M., Sedghi, M., & Firoozi, M. J. (2017). Effect of sulfur fertilizer and thiobacillus on qualitative traits and nutrients concentration of potato (*Solanum tuberosum* L.). *Journal of Plant Ecophysiology, 9*(29), 113-124. Retrieved from https://jpec.arsanjan.iau.ir/article_597302.html

Grami, S. H., & Tarabipur, S. H. (2021). *The role of silicon (Si) and its use in plants*. Retrieved from https://alborzbehsam.com

Haji Rahimi, M., & Abdul Qozlujah, A. (2012). *Analysis of water input efficiency and calculation of economic value of irrigation water in potato production in Dasht Bahar.* Kurdistan University Research Information Management.

Hassanpanah, D., & Akbarloo, H. (2013). *Growing and processing edible potatoes and seeds* (p. 224). Danesh Negar.

Hassanpanah, D., ParastarAnzabi, S., Shirinzadeh, P., MousapourGorji, A., & ParastarAnzabi, E. (2022). Investigation of the effect of sulfonated silicon nutrient solution with elemental sulfur s-8 on agronomic traits of new potato cultivars. *Journal of Agricultural Science, 14*(4), 90-98. https://doi.org/10.5539/jas.v14n4p90

Heydari, N. (2011). Determination and evaluation of water use efficiency of some major crops under farmers management in Iran. *Journal of Water and Irrigation Management, 1*(2), 43-57. Retrieved from https://jwim.ut.ac.ir/article_24582.html?lang=en

Kaya, C., Tuna, L., & Higgs, D. (2006). Effect of silicon on plant growth and mineral nutrition of maize grown under water-stress conditions. *Journal of Plant Nutrition, 29*, 1469-1480. https://doi.org/10.1080/01904160600837238

Ministry of Agriculture-Jahad, Iran. (2022). *Agricultural Statistics, Volume One: Crops* (p. 95). Ministry of Jihad-e-Agriculture, Deputy of Planning and Economy, Information and Communication Technology Center.

Qasim, M., Khalid, S., Naz, A., Zafarullah Khan, M., & Ahmad Khan, S. (2013). Effects of different planting systems on yield of potato crop in Kaghan Valley: A mountainous region of Pakistan. *Agricultural Sciences, 4*(4), 175-179. https://doi.org/10.4236/as.2013.44025

Rasoulzadeh, A., & Majid, R. (2013). *Principles and methods of irrigation* (p. 283). Amidi Publications.

Rich, A. M., & Renner, K. A. (2007). Row spacing and seeding rate effects on eastern black nightshade (*Solanum ptycanthum*) and soybean. *Weed Technology, 21*, 124-130. https://doi.org/10.1614/WT-04-220.1

Samadi, F., & Mohammad-doust-Chamanabad, H. R. (2014). Effect of cover crops and row space on weed control and potato yield. *Journal of Plant Protection, 27*(4), 434-441. https://doi.org/10.22067/jpp.v27i4.29881

Shahabifar, J. (2006). *The effect of sulfur and zinc levels on potato yield in Qazvin region*. Paper presented at the 9^{th} Iranian Congress of Plant Science and Plant Breeding, Tehran, Iran.

ShiriJanagard, M., Tobeh, A., Asghari Zakaria, R., Nour-Ganbalani, G., & DehdarMasjedlo, B. (2007). The effects of different levels of drip irrigation and cultivation pattern on yield and yield components of the agria potato. *Pajouhesh & Sazandegi, 75*, 149-157. Retrieved from https://www.sid.ir/paper/19333/en

Soltani, M., Kafi M., Nezami, A., & Taghiyari, H. R. (2018). Effects of silicon application at nano and micro scales on the growth and nutrient uptake of potato mini-tubers (*Solanum tuberosum* var. Agria) in greenhouse conditions. *BioNano Science, 8*(2), 1-11. https://doi.org/10.1007/s12668-017-0467-2

Tate, R. L. (1995). The sulfur and related biogeochemical cycle. *Soil microbiology* (pp. 359-372). John Willey & Sons Inc., New York.

Wang, Y., Hu, Y., Duan, Y., Feng R., & Gong, H. (2016). Silicon reduces long-term cadmium toxicities in potted garlic plants. *Acta Physiologiae Plantarum, 38*, 211-219. https://doi.org/10.1007/s11738-016-2231-6

Zare Mehrjardi, M., Akbari, S. M. R., & Farajzadeh, Z. (2009). *Agricultural water management according to productivity index (case study: Chenaran Mashhad Plain)*. The National Conference on Water Crisis Management, Islamic Azad University, Marodasht Branch. Retrieved from https://www.sid.ir/paper/809703/fa

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