American-Eurasian J. Agric. & Environ. Sci., 22 (1): 25-35, 2022
ISSN 1818-6769

DOI: 10.5829/idosi.aejaes.2022.25.35

Impact of Potassium and Nano-Silicon Fertilizers on the Growth and Productivity of Soybean Plants to Overcome Salt Stress

[1]A.A. Yassen, [2]E.A.A. Abou El-Nour, [1]M.A. Abou Seeda and [1]Sahar M. Zaghloul

[1]Plant Nutrition Department, National Research Centre,
33 El-Buhouth St. P.O. Box: 12622. Dokki, Cairo, Egypt
[2]Fertilization Technology Department, National Research Centre,
33 El-Buhouth St. P.O. Box: 12622. Dokki, Cairo, Egypt

Abstract: A field experiment was carried out in Fedymen village at Sannuris province, Fayoum governorate. Egypt to study the effect of combination between three rates of potassium (0, 40 and 80 kg K_2O fed^{-1}) and foliar spray with nano-silicon fertilizers at four rates (0, 0.5, 1and 2 g L^{-1}) on growth parameters, yield and chemical composition of soybean plants grown under salinity soil condition. The results showed that salinity in soil caused a significant reduction in plant growth parameters, yield and chemical composition (N, P, K, protein %, total carbohydrates % and total oil % of seeds). While application of potassium fertilizer significantly increased growth parameters and seed yield as compared to the control treatment (soil salinity). Data also showed that the application of combination between potassium fertilizer and foliar spray of nano-silicon fertilizers significantly increased growth, chemical contents of shoot and seeds and seeds yield of soybean plants as compared to potassium application alone or control treatment.

Key words: Potassium fertilizer · Nano-silicon (Si-NPs) · Growth parameters · Yield · Chemical composition · Soybean plants

INTRODUCTION

Salinization is one of the cruelest environmental factors in agriculture, negatively affecting agriculture development. The soils plagued by salinity are increasing day by day. Salinity is one of the major factors negatively affecting agriculture development in arid and semi-arid regions. Osmotic changes may be induced by salt accumulation in soils, interfering with the process of nutrient uptake, enzymes inactivation and osmotic adjustment is disturbed at the cytosol and vacuoles level. Bad agriculture practices increase senility levels in the soil and in the groundwater by the time to levels that negatively affect the plants growth and productivity. Salinization processes is one of the major abiotic stresses that affect plant growth and development (for example, it alters metabolic processes, induces nutritional disorders, ion toxicity and oxidative stress, disturbs the activity of enzymes, disorganizes cell membranes, reduces cell expansion and division) and negatively affecting crop quality and productively [1-4]. Soybean (*Glycine max* L.) is considered as a leguminous crop that is one of the most important cash crops worldwide. It is considered as an excellent intercropping crop for the human diet (soy sauce, soy milk, tofu, soy meal, soy flour, textured vegetable protein) and feed animal consumption in the developed and developing nation [5-8]. It is the only low-cost plant food source that contains complete protein and provides all essential amino acids, carbohydrates, fatty acids and minerals needed for human health [5, 9, 10]. Its products have also been shown to be useful in the prevention and curing in bone resorption, inhibitor ovarian, breast and carcinoma and other chronic heart and kidney diseases [11-15]. Furthermore, it is utilized in some industrial products, including (oils, biodiesel, soap, cosmetics, resins, plastics, inks, crayons, solvents and clothing). Additionally, with its function within the process of biological N fixation thus, improving soil fertility and structure [16]. Soybean is considered a salt sensitive crop [17, 18]. Several researchers [19-23] reported that under high salinity conditions, growth of soybean is gradually affected; yield was reduced sharply.

Corresponding Author: A.A. Yassen, Plant Nutrition Department, National Research Centre,
33 El-Buhouth St. P.O. Box: 12622. Dokki, Cairo, Egypt.

Potassium, mostly as a cation-K^+, together with calcium-Ca^{2+} are the most abundant inorganic chemicals in plant cellular media, but they are rarely discussed. Potassium is not a component of molecular or macromolecular plant structures, thus it is more difficult to link it to concrete metabolic pathways than nitrogen or phosphorus. Over the last two decades, many studies have reported on the role of K^+ in several physiological functions, including controlling cellular growth and wood formation, xylem–phloem water content and movement, nutrient and metabolite transport and stress responses. These essential roles of K^+ account for its high concentrations in the most active plant organs, such as leaves and are consistent with the increasing number of ecological and agricultural studies that report K^+ as a key element in the function and structure of terrestrial ecosystems, crop production and global food security. Potassium plays several important roles affecting many physiological processes related to stomatal behavior, osmoregulation, enzyme activity, cell expansion, neutralization of no diffusible negatively charged ions and membrane polarization. In addition, potassium has a promising regulatory role in seed germination and emergence [24-28]. The most of the potassium (K) in the soil is not readily available for plant growth and development. Potassium is associated with the movement of water, nutrients and carbohydrates within the plant. These functions stimulate early growth, increase, protein production and improve the efficiency of water use and resistance to diseases and insects. Insufficient K has difficulty absorbing water and N from the soil, which might increase drought stress. Plants conserve water and reduce moisture stress by closing leaf stomata (openings on the undersides of leaves) mechanism, which is regulated by K. Plants with inadequate K may be slower at closing their stomata, which reduces protection from drought stress. Additionally, deficient plants may have reduced energy making capacity via photosynthesis. Rot diseases are among the most common and damaging plant, diseases. The severity of stalk rot can be minimized with an optimum balance between K and nitrogen (N) levels in plant tissue.

Pande *et al.* [29] reported that soybean plant stake up and remove large amounts of potassium from soil than any other nutrient. However, under saline stress, plants suffer from potassium deficiency mainly because of the excess of Na^+ in the rooting medium, which acts as an antagonist and decreases the availability of K. Potassium contributes for tolerance against salinity as it has a competing nature to sodium for binding and maintaining plant water status. [30-33] stated that adequate K nutrition generally enhanced plant growth, biomass production and protein and oil percentage of soybean in saline soil conditions.

Silicon is one of the most prevalent macro elements. It is beneficial for plant growth and crop quality, stimulates photosynthesis, reduces transpiration rate and enhances plant resistance to both abiotic and biotic stresses such as water and nutrient imbalances [34-41], heavy metal toxicities [42], diseases and pests problems [43, 44]. The use of foliage spray of nano fertilizer application on leaves by nanotechnology would be more effective in terms of getting maximum yield and reduce losses to reduce the harmful effect of soil salinity [45]. [46] revealed that faba bean treated with Si and nano–silicon gave bitter seed germination and growth parameters. In addition, [47] showed that the application of silicon in nano and bulk size was beneficial in improving the salt tolerance of tomato plants. Silicon nanoparticle has improved seed germination and seedling growth of tomatoes (*Solanum lycopersicum* L.) under salinity stress. This research aimed to overcome or even alleviated salt stress to ensure sufficient food production by the use of potassium and nano-silicon fertilizer to promote plant growth.

MATERIALS AND METHODS

A field experiment was carried out in Fedymen village at Sannuris province, Fayoum Governorate-Egypt to study the effect of combination between potassium and foliar spray with nano-silicon fertilizers on growth parameters, yield and chemical composition of soybean plants grown under salinity stress. Soil sample from the experimental field was air-dried and passed through a 2-mm sieve and stored for laboratory analysis and recorded in Table (1). The physical and chemical properties of soil were determined according to [48, 49].

Seeds of soybean (*Glycine max* L.) were taken from Legume Crop Department, Ministry of Agriculture, Egypt. Soybean seeds variety “Giza 35” were sown on the 12th of June. The size of each plot was 1/400 feddan (10.5 m^2), 3.5 m long and 3.0 m wide. Soybean seeds were inoculated with a specific strain of *Rhizobium leguminosarum* before planting. After that, five seeds of soybean were sown in a small hole and the distance between the holes was 15-cm. Soybean plants were thinned to three plants after their full germination.

Table 1: Chemical and physical characteristics of the investigated soil

Physical properties							
Sand	Silt	Clay	Texture	pH	EC dSm^{-1}	$CaCO_3$ %	OM %
	%						
28.2	12.6	58.9	Clay	8.4	4.35	2.10	1.02
		Soluble ion sand cation ($meq.L^{-1}$)					
Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4
2.3	2.9	31.8	1.7	-	13.7	15.9	8.5

The recommended doses of nitrogen and phosphorous fertilizers for soybean were applied. The experiment was laid out in a Complete Randomized Block Design with three replicates. Potassium fertilizer was applied as potassium sulphate (48%) at three rates of 0, 40 and 80 kg K_2O fed^{-1}. Foliar spray Nano-silicon fertilizers at four rates (0, 0.5, 1, and $2gL^{-1}$). Four sprays at 3 weeks intervals were applied. The first was after 45 days of cultivation. The control plants were sprayed with tap water. The experimental treatments can be described as follows:

- Control (saline soil)
- 40 kg K_2O/ fed+water foliar spray.
- 40kg K_2O/ fed+0.5 g. L^{-1} foliar spray with Si-NPs
- 40kg K_2O / fed+1g. L^{-1} foliar spray with Si-NPs
- 40kg K_2O / fed+2g. L^{-1} foliar spray with Si-NPs
- 80kg K_2O / fed+ water foliar spray.
- 80kg K_2O / fed+0.5 g. L^{-1} foliar spray with Si-NPs
- 80kg K_2O / fed+1 g. L^{-1} foliar spray with Si-NPs
- 80kg K_2O / fed+2 g. L^{-1} foliar spray with Si-NPs

All agronomic practices other than experimental treatments necessary for growth and development as cultivation, irrigation and pest control were followed whenever it was necessary and were done according to the recommendations of the Ministry of Agriculture, Egypt. Soybean harvesting was performed manually. Ten plants were randomly selected from each plot in order to determine: Plant height(cm), number of branches $plant^{-1}$, number of leaves $plant^{-1}$, stem diameter (mm), number of nodules $plant^{-1}$, shoots dry weight $plant^{-1}$, root dry weight $plant^{-1}$, number of pods $plant^{-1}$, number of seed pod^{-1} (g), the weight of 100 seed (g), Seed yield Kg fed^{-1} and straw yield Kg fed^{-1}. At harvest, seed and straw yields/plot were determined and then converted to yields / feddan.

Chemical Constituents: Samples of soybean shoots and seeds were oven-dried at 60-70°C for 48 h and their dry weights and digested.

- The concentrations of N, P, K, Ca and Na (%) in digested dry straw and seeds were determined according to the methods described by [50].
- Crude protein and carbohydrates contents were determined according to [51].
- Proline percentage in leaves was determined according to [52].
- Oil content; of seed was determined according to [52] using soxhelt apparatus and petroleum ether (40-60°C) as a solvent.
- Nodule assessment was carried out as described by [53].

Statistical Analysis: The obtained data were subjected to statistical analysis of variance according to [54]. The least significant differences (LSD) at $P \leq 0.05$ level was used to verify the difference among means of the treatments.

RESULTS AND DISCUSSION

Effect of different rates of potassium and foliar spray of Si-NPs on some growth parameters of soybean plants under saline soil are presented in Table (2) from which data revealed that in control soil, salinity condition gradually caused a significant reduction the growth parameters as compared to the other treatments. Several researchers [55-58] demonstrated that accumulation of salts particularly in the root zone resulted in a reduction in plant growth and yield production. This phenomenon is attributed to the osmotic effects of salt in plants the uptake of some mineral nutrients dissolved in water is also restricted. They also illustrated that generally, soils contain some water-soluble salts by other irrigation ways. Plants may absorb essential nutrients in the form of soluble salts as added in chemical forms, but excessive accumulation strongly suppresses either plant growth or physical, chemical and biological degradation processes, causing a serious consequence to global natural resources such as compaction, inorganic/organic contamination and diminished microbial activity/ diversity).

Excess of salt (Na^+ and Cl^-) can also, cause the increased expenditure of energy on maintenance respiration or ion transport, reduced energy for the translocation of carbohydrates and diversion of photosynthesis from growth to osmoregulation. Similarly, were noticed by several authors [59-62]. Results revealed that application of either 40 kg or 80 kg K_2O fed^{-1}, markedly increased growth parameters of soybean as compared to control soil (untreated soil).

Table 2: Effect of different rates of potassium and foliar spray of Si-NPs on some growth parameters of soybean plants grown under saline soil

Treatment	Plant height (cm)	Number of branches plant^{-1}	Number of leaves	Stem diameter (mm)	No. of nodules plant^{-1}	Shoots dry matter g plant^{-1}	Roots dry matter g plant^{-1}
Control (saline soil)	42.68	2.89	12.70	3.82	23.02	8.51	0.31
40 K kg fed^{-1} +0 Si-NPs gL^{-1}	46.34	3.42	15.50	5.10	27.42	9.12	0.38
40 K kg fed^{-1} +0.5 Si-NPs gL^{-1}	50.09	3.81	17.40	5.44	30.81	10.89	0.42
40 K kg fed^{-1} +1 Si-NPs gL^{-1}	58.65	4.10	19.70	5.83	33.14	12.89	0.53
40 K kg fed^{-1} +2 Si-NPs gL^{-1}	53.10	4.35	18.70	4.16	35.00	11.52	0.48
80 K kg fed^{-1} +0 Si-NPs gL^{-1}	52.02	3.75	18.00	5.85	30.40	10.88	0.47
80 K kg fed^{-1} +0.5 Si-NPs gL^{-1}	56.31	4.11	20.10	6.08	33.62	11.86	0.51
80 K kg fed^{-1} +1 Si-NPs gL^{-1}	65.62	5.33	25.60	6.70	36.33	15.16	0.72
80 K kg fed^{-1} +2 Si-NPs gL^{-1}	61.60	4.86	22.10	6.44	36.86	12.78	0.66
L.S.D. 5%	6.31	0.67	1.20	2.60	5.97	1.32	0.09

The positive effects of K on dry matter production under saline conditions may be due to the lessening of osmotic and ionic effects on plant growth [63, 64]. Since potassium always associated with the movement of water, nutrients and carbohydrates within the plant, stimulating early growth, increasing protein production and furthermore improving water use efficiency. However, in case of insufficient K plants have difficulty absorbing water and N from the soil, which might increase drought stress. Data also, revealed that application of potassium at a rate of 80 kg K_2O fed^{-1} had more pronounced effects on the growth as compared with the rate of 40 kg K_2O fed^{-1}. Therefore, intensive application of potassium could be helpful for attenuating oxidative cell damage, inhibiting of NADPH oxidase generating O_2 particularly during photosynthesis and reducing harmful effect of salinity in relation to dry matter production in different plant parts in soybean plants. Application of potassium also increased the uptake of K and Ca and decreased the Mg and Na: K and Na: Ca ratio in dry matter. The results of [65-68] revealed that K application stimulated the growth parameters i.e. plant height by 9 and 24%; branch number/plant by 18 and 42%; leaves number/ plant by 22 and 42%; stem diameter by 33 and 53%; the number of nodules/plants by 19 and 32%; shoot dry weight/plant by 7 and 28%; root dry weight/ plant by 23 and 52%, respectively, as compared with control treatment. From the aforementioned results, it could be concluded that increasing the addition of potassium from 40 to 80 kg/ feddan can improve the growth parameters of soybean grown in saline soil.

On the other the hand, application of silicon nano particles Si-NPs at a rate of (0.5, 1 and 2 gL^{-1}) gradually stimulate the growth parameters of soybean plants as compared with potassium fertilizer alone. Several studies reported that nano–silicon treatments could reduce the adverse effects of salinity on faba bean plants by enhancing the activity of antioxidant enzymes [69]. Under salinity stress conditions, nano–SiO_2 might improve leaf fresh and dry weight, chlorophyll content and proline accumulation. It is also reported that an increase in the accumulation of proline, free amino acids, content of nutrients, antioxidant enzymes activity due to the nano–SiO_2, thereby improving the tolerance of plants to abiotic stress [70, 71]. Silicon nanoparticles have been implicated in crop improvements. Many reports indicated that appropriate concentrations of nano–Si increase plant growth [72], plant resistance to hydroponic conditions [73] and alleviation of the adverse effects of salt stress, increased root length and dry weight of some plants, [74], roots length of the lentil and shoots [75]. The importance of Si for improving plant growth was also reported by [76] for faba bean and this is attributed to increase the water use efficiency in the plant [77] and improve the competence of photosynthesis. [78] found that exogenously applied Si significantly enhanced plant water use efficiency and slightly increased photosynthetic rate under saline stress condition in maize. The function of Si and its concentration varies for plant species [79]. Also, Si supplementation helps the formation of secondary and tertiary cells of the endodermis, thus enabling higher root resistance and stronger growth of roots. Several investigators [59, 80-83] noted that the application of 0.5 or 1 mM of nano-SiO_2 enhanced soybean seedling shoot and root growth under salt stress. In addition, [84] found that plants treated with Si are able to maintain a high stomatal conductance and transpiration rate under salt stress, suggesting that a reduction in Na^+ uptake occurs due to deposition of Si in the root resulting in the improvement of plant growth.

They also reported Si-mediated up regulation of aquaporin (PIP) gene expression in relation to increased root hydraulic conductivity and water uptake.

Results revealed that application of high doses of potassium (80 kg K_2O/ fed.) in combining with 1g Si-NPs L^{-1} foliar spray was more pronounced effect for improving growth parameters compared to other treatments and control soil. Meanwhile, combined treatments caused the highest effect in increasing all vegetative growth and yield under study. Concerning the effect of the different rates of nano Si (0.5, 1 and 2gL^{-1}) with potassium fertilizer application (40 and/or 80 kg K_2O fed^{-1}), was presented in Table (2). Data revealed that slightly decreased growth parameters by the application with Si-NPs (2gL^{-1}) in combining with potassium fertilizer at a rate of 40-kg K_2O fed^{-1}. [85] reported that Si gradually increased the availability of Ca, P, S, Mn, Zn, Cu and Mo and that of Cl and Fe tended to increase. The availability of K and Mg was not much affected by Si. It was concluded that, if plants had been cultivated in soil, Si-maintained increased availability of nutrients in the soil solution would probably compensate for the decrease in tissue concentration of those nutrient elements. The study shows that Si also influences nutrient uptake in non-stressed plants [86], observed that a high dose of silicon caused a decrease in plant height. There was no significant difference with increasing Nano Si concentrations except in case of the number of leaves and dry weights of shoot [87, 88], they concluded that high dose of silicon caused a decrease of plant height; suggesting silicon application might exert their favorable effect to counteract the detrimental effects of salinity. Results also showed that application of either 40 or 80 kg K_2O per feddan significantly increased soybean yield and its components i.e. number of pods plant^{-1} by 37 and 59%; number of seeds/pod by 20 and 40 %; weight of seeds/ plant by 16 and 28%; 100 seed weight by 8 and 16%; seed yield fed^{-1} by 45 and 55% and straw yield/ feddan by 43 and 52%, respectively over control treatment. Thus, it could be concluded that applying 80 kg K_2O was better than 40 kg in increasing soybean yield and its components. Moreover, the aforementioned increases showed additional increments when saline affected soil was fertilized with potassium and combined with foliar feeding with silicon nano particles. Application of 80 kg K_2O combined with 1 g Si-NPs/L as foliar spray resulted in the highest increments in both yield and most of its components. The highest number of pods/ plants was achieved by the application of 80 kg K_2O combined with 2 g Si-NPs/l as foliar spray.

Chemical Composition: It is quite clear from the data presented in Tables (4 & 5) that the effect of salinity on the concentration of nutrients, the low values of concentrations of both N, P and K were recorded by soybean plants grown under saline soil conditions. It is important to mention that soil salinity caused by sodium salts may be indirectly implicated in the reduction of K and N concentrations. The increase in Na^+ contents, the reduction of K^+ content in leaves of soybean plant due to competition between Na^+ and K^+ ions on the absorption sites of the plant roots as reported by [89, 90]. Salinity condition could affect total nitrogen in soybean plants causing either reducing nodule number of nodules (specific nitrogenase activity), or diminishing nitrogen uptake by roots and translocation to the upper organs (leaves and seeds) caused by antagonistic effect between the treatments, [29].

Data in Table (4 & 5) showed that application of both rates with different concentration of nano Si (0.5, 1 and 2 gL^{-1}) stimulate N, P and K content (%) and uptake (mg/plant) except for Ca and Na content and uptake decreased as compared to the control, in both shoots (including leaves and stems and petioles) and seeds of soybean plants as compared with the control and other treatments under soil salinity conditions [73, 91, 92] they found that the reduced uptake of sodium and calcium by plants could be explained at least partly by the inhibitory effect of silicon on the transpiration. The increase in N, P and K might be attributed to the positive effect of foliar application of SiO_2 nanoparticle, which consequently increased the absorption of different nutrients and alleviating the harmful effects of salinity [93]. In addition, data showed that the application of SiO_2 nanoparticle as foliar application may be avoided leaching loss of N and helped in more accumulation of nitrogen in leaf. Similarly were reported by [94], they concluded that, silicon rendered more P available to the plants reversing its fixation as silicon, itself competed for P fixation and thus slowly released P helped in more accumulation of P content in leaf. However, as treatment 80 kg K_2O fed^{-1} + 1gL^{-1} foliar spray with Si-NPs gave the best significant percentage of N and K in shoots and seeds under soil salinity conditions. Data also showed that the addition of Si nanoparticle with K significantly decreased sodium and calcium contents and uptake under salt stress.

Table 3: Effect of different rates of potassium and foliar spray of Si-NPs on yield of soybean plants under saline soil

Treatment	Number of pods plant^{-1}	Number of seed pod^{-1}	Weight of seed g plant^{-1}	Weight of 100 seed (g)	Seed yield Kg fed^{-1}	Straw yield Kg fed^{-1}
Control (saline soil)	20.67	1.67	8.33	11.89	438.21	973.10
40 K kg fed^{-1} +0 Si-NPs gL^{-1}	28.33	2.00	9.67	12.90	637.63	1391.81
40 K kg fed^{-1} +0.5 Si-NPs gL^{-1}	30.33	2.67	10.00	13.78	690.19	1469.28
40 K kg fed^{-1} +1 Si-NPs gL^{-1}	32.89	3.00	11.33	14.15	754.22	1543.43
40 K kg fed^{-1} +2 Si-NPs gL^{-1}	35.22	3.00	11.67	14.18	796.52	1557.08
80 K kg fed^{-1} +0 Si-NPs gL^{-1}	32.77	2.33	10.67	13.75	680.47	1477.00
80 K kg fed^{-1} +0.5 Si-NPs gL^{-1}	34.52	3.33	12.00	14.60	735.40	1550.66
80 K kg fed^{-1} +1 Si-NPs gL^{-1}	37.18	4.00	12.67	15.50	812.82	1660.38
80 K kg fed^{-1} +2 Si-NPs gL^{-1}	39.41	3.67	12.00	14.73	798.81	1574.24
L.S.D. 5%	1.93	1.12	2.22	1.27	64.38	69.89

Table 4: Effect of different rates of potassium and foliar spray of Si-NPson N, P, K, Ca and Na contents (%) and uptake (mg/plant) in shoots of soybean plants under saline soil

	%					Uptake (mg/plant)				
Treatment	N	P	K	Ca	Na	N	P	K	Ca	Na
Control (saline soil)	1.15	0.13	1.77	1.68	1.47	98.15	10.78	142.12	142.97	130.77
40 K kg fed^{-1} +0 Si-NPs gL^{-1}	1.43	0.18	2.04	1.56	1.21	130.72	16.42	186.35	141.97	110.35
40 K kg fed^{-1} +0.5 Si-NPs gL^{-1}	1.64	0.21	2.14	1.50	1.11	178.96	22.87	233.05	163.35	120.88
40 K kg fed^{-1} +1 Si-NPs gL^{-1}	1.89	0.24	2.38	1.42	0.91	243.19	31.37	306.35	182.61	117.73
40 K kg fed^{-1} +2 Si-NPs gL^{-1}	1.65	0.22	2.44	1.40	0.99	190.08	25.34	281.47	161.28	114.43
80 K kg fed^{-1} +0 Si-NPs gL^{-1}	1.36	0.16	2.20	1.42	1.12	147.61	17.04	239.00	154.13	121.49
80 K kg fed^{-1} +0.5 Si-NPs gL^{-1}	1.54	0.20	2.50	1.37	0.83	182.25	23.32	296.90	162.48	98.04
80 K kg fed^{-1} +1 Si-NPs gL^{-1}	1.78	0.22	2.71	1.25	0.65	269.34	32.85	411.34	189.50	99.05
80 K kg fed^{-1} +2 Si-NPs gL^{-1}	1.50	0.22	2.64	1.21	0.57	192.12	27.69	336.96	154.21	72.42
L.S.D. 5%	0.15	0.04	0.17	0.09	0.11	21.65	4.83	22.66	10.07	12.77

Table 5: Effect of different rates of potassium and foliar spray of Si-NPson N, P, K, Ca and Na contents (%) and uptake (mg/plant) in seeds of soybean plants under saline soil

	%					Uptake (mg/plant)				
Treatment	N	P	K	Ca	Na	N	P	K	Ca	Na
Control (saline soil)	1.90	0.18	1.22	0.70	0.55	117.06	12.30	74.83	45.05	33.62
40 K kg fed^{-1} +0 Si-NPs gL^{-1}	2.35	0.24	1.40	0.54	0.32	167.08	16.85	99.92	38.68	22.78
40 K kg fed^{-1} +0.5 Si-NPs gL^{-1}	2.58	0.28	1.67	0.45	0.28	203.56	22.88	132.03	35.77	22.09
40 K kg fed^{-1} +1 Si-NPs gL^{-1}	2.81	0.30	1.85	0.31	0.26	250.95	28.54	164.72	27.36	23.49
40 K kg fed^{-1} +2 Si-NPs gL^{-1}	2.69	0.30	1.77	0.35	0.26	246.64	23.56	162.18	32.13	23.87
80 K kg fed^{-1} +0 Si-NPs gL^{-1}	2.49	0.25	1.63	0.54	0.31	182.76	18.35	119.40	34.81	23.00
80 K kg fed^{-1} +0.5 Si-NPs gL^{-1}	2.69	0.29	1.80	0.40	0.26	232.15	27.04	155.34	35.79	22.44
80 K kg fed^{-1} +1 Si-NPs gL^{-1}	3.17	0.32	2.10	0.37	0.21	309.07	30.26	205.28	38.00	20.82
80 K kg fed^{-1} +2 Si-NPs gL^{-1}	2.90	0.30	1.96	0.40	0.21	275.82	28.50	186.20	34.81	19.63
L.S.D. 5%	0.12	0.03	0.11	0.05	0.03	11.42	4.39	8.75	4.10	3.26

Table 6: Effect of different rates of potassium and foliar spray of Si-NPs on crude protein (%), total carbohydrates (%), oil % of dry matter in seeds and proline (%) in leaves of soybean plants under saline soil

	Seeds			
Treatment	Crude protein (%)	Total carbohydrates (%)	Oil % of dry matter	Proline (%) in leaves
Control (saline soil)	11.90	17.64	12.11	13.85
40 K kg fed^{-1} +0 Si-NPs gL^{-1}	14.67	18.60	14.43	12.55
40 K kg fed^{-1} +0.5 Si-NPs gL^{-1}	16.13	19.78	14.89	11.67
40 K kg fed^{-1} +1 Si-NPs gL^{-1}	17.58	20.54	15.27	10.63
40 K kg fed^{-1} +2 Si-NPs gL^{-1}	16.79	20.11	14.82	9.89
80 K kg fed^{-1} +0 Si-NPs gL^{-1}	15.56	19.39	15.00	11.65
80 K kg fed^{-1} +0.5 Si-NPs gL^{-1}	16.81	20.89	16.14	10.13
80 K kg fed^{-1} +1 Si-NPs gL^{-1}	19.79	22.21	17.57	8.92
80 K kg fed^{-1} +2 Si-NPs gL^{-1}	18.15	25.75	16.71	8.14
L.S.D. 5%	0.78	1.16	0.89	1.00

Data in Table 5 showed seed NPK (concentrations and uptake) of which were significantly decreased in control soil compared to the other treatments. While both Ca and Na showed marked increments. Application of potassium either at rate of 40 or 80 kg K_2O/feddan resulted in marked increments in NPK (concentration and uptake) as compared with control one. On the other hand, both Ca and Na showed markedly decreased. Combination treatments resulted in additional increase in NPK. However 80 kg K_2O treated soil in combination with 1g Si-NPs/l gave the highest increased of nutrients; concerning increments for both Ca and Na were gradually achieved, because combination treatments were more pronounced effect compared with control.

Data presented in Table 6 show that soil salinity significantly reduced seed crude protein, carbohydrates and oil contents as compared with the other experimental treatments. Application of potassium at rate of 40 and 80 kg K_2O/ feddan significantly increased the aforementioned traits. The increments reached to 23 and 31%; 5 and 9% and 19 and 24% over control by applied 40 and 80 kg K_2O for crude protein; total carbohydrates and oil contents, respectively. It is also clear that combination between potassium application and silicon nano particles foliar feeding resulted in marked additional increments in these traits. Combination between applied 80 kg K_2O and 1 g /l Si NPs foliar spray resulted in the highest increments in seed protein (66% increase over control treatment) and oil content (45% increase over control treatment). However, application of 80 kg K_2O combined with 2 g/l Si Nps foliar spray resulted in the highest increment in seed total carbohydrates. Abbas *et al.* [97] found that Si application could enhance salt tolerance in plants by adjusting the levels of solutes such as proline and total free amino acids in both shoots and roots of okra.

Moreover, Data in Table 6 show that soil salinity resulted in marked increment in leaf proline as compared with the other treatments. Potassium application treatment showed significant decrements in proline content as compared with control soil. The decrement reached to 9% due to applying 40 kg K_2O and the decrement increased to be 16% due to applying 80 kg K_2O. Additional decrements in leaf proline were noticed due to a combination between potassium application and Si NPs foliar spray.

CONCLUSIONS

Application of potassium fertilizer and foliar spray Nano-Si in soybean plants under salinity stress has been shown to be beneficial for plant growth, chemical composition and reduce the harmful effects for soil salinity and environmental conditions. Foliar application of silicon (Si) is an effective way of supplying this beneficial element to plants. The emergence of new potential liquid sources for foliar application requires studies to assess the effectiveness of supplying Si to plants, as well as its effects on agronomic performance indicators. The application of 1.5 g L^{-1} Si resulted in an improvement in shoot dry weight and grain production, using the treatments can be more effective particularly if treated more times during the plant life cycle or in higher concentration

REFERENCES

1. Araújo, S.S., S. Beebe, M. Crespi, B. Delbreil, E.M. González, V. Gruber, I. Lejeune-Henaut, W. Link, M.J. Monteros, E. Prats and I. Rao, 2015. Abiotic stress responses in legumes: strategies used to cope with environmental challenges. Crit. Rev. Plant Sci., 34(1-3): 237-280.
2. Deinlein, U., A.B. Stephan, T. Horie, W. Luo, G. Xu and J.I. Schroeder, 2014. Plant salt-tolerance mechanisms. Trends in Plant Science, 19(6): 371-379.
3. López-Gómez, M., J. Hidalgo-Castellanos, C. Lluch and J.A. Herrera-Cervera, 2016. 24-Epibrassinolide ameliorates salt stress effects in the symbiosis *Medicagotruncatula- Sinorhizobiummeliloti* and regulates the nodulation in cross-talk with polyamines. Plant Physiol. Biochem., 108: 212-221.
4. Machado, R.M.A. and R.P. Serralheiro, 2017. Soil salinity: effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization. Horticulturae, 3(2): 30.
5. Capriotti, A.L., G. Caruso, C. Cavaliere, R. Samperi, S. Stampachiacchiere, R. Zenezini Chiozzi and A. Laganà, 2014. Protein profile of mature soybean seeds and prepared soybean milk. J. Agric. Food Chem., 62(40): 9893-9899.
6. Shurtleff, W. and A. Aoyagi, 2015. History of Soybeans and Soy foods in Italy (1597–2015). Lafayette, California: Soyinfo Center., pp: 618.
7. Heuzé, V., G. Tran, P. Nozière, M. Lessire and F. Lebas, 2017. Soybean seeds. Feedipedia, a programme by INRA, CIRAD and FAO.https:// www. Feedipedia. org/ node / 42. 10:37.
8. Khojely, D.M., S.E. Ibrahim, E. Sapey and T.F. Han, 2018. History, current status and prospects of soybean production and research in sub-Saharan Africa. Crop J., 6: 226-235.

9. USDA (United States Department of Agriculture) (2018b) Basic Report: 16108, Soybeans, mature seeds, raw. Agricultural Research Service. National Nutrient Database for Standard Reference Legacy Release. https: //ndb. nal. usda. gov/ ndb/ foods/ show/ 16108 (Last accessed: 8 June 2018).
10. Ayman E.L. Sabagh, Akbar Hossain, Mohammad Shohidul Islam, Celaleddin Barutçular, Disna Ratnasekera, Narendra Kumar, Ram Swaroop Meena, Hany Sobhy Gharib, Hirofumi Saneoka, and Jaime A. Teixeira Da Silva, 2019. Sustainable soybean production and abiotic stress management in saline environments: a critical review. AJCS, 13(02): 228-236.
11. Sacks, F.M., A. Lichtenstein, L. Van Horn, W. Harris, P. Kris-Etherton, M. Winston, American Heart Association Nutrition Committee, 2006. "Soy Protein, Isoflavones and Cardiovascular Health: An American Heart Association Science Advisory for Professionals from the Nutrition Committee". Circulation, 113(7): 1034-44.
12. Dong, Jia-Yi and Qin Li-Qiang, 2011. "Soy Isoflavones Consumption and Risk of Breast Cancer Incidence or Recurrence: A Meta-analysis of Prospective Studies". Breast Cancer Research and Treatment., 125(2): 315-323.
13. Van Die, M.D., K.M. Bone, S.G. Williams and M.V. Pirotta, 2014. "Soy and soy isoflavones in prostate cancer: a systematic review and meta-analysis of randomized controlled trials". BJU International, 113(5b): E119-30.
14. Yu, Yi, Jing, Xiaoli, Li, Hui, Zhao, Xiang and Wang, Dongping, 2016. "Soy isoflavone consumption and colorectal cancer risk: a systematic review and meta-analysis". Scientific Reports, 6(1): 25939.
15. Kahraman, A., 2017. Nutritional value and foliar fertilization in soybean. Journal of Elementology J. Elem., 22(1): 55-66.
16. Maxwell, J. and E. Hauppauge, 2011. Soybeans: cultivation, uses and nutrition. eBook. Science publishers, NY.
17. Ghassemi -Golezani, K., M. Taifeh-Noori, Oustan, Sh., and M. Moghaddam, 2009. Response of soybean cultivars to salinity stress. Journal of Food, Agriculture and Environment, 7(2): 401-404.
18. Kamkar, B., M.A. Dorri and J.A.T. Da Silva, 2014. Assessment of land suitability and the possibility and performance of a canola (*Brassica napus* L.) soybean (*Glycine max* L.) rotation in four basins of Golestan province, Iran. Egyptian J. Remote Sens. Space Sci., 17(1): 95-104.
19. Fernandez, F., 2012. Corn, Soybean Showing Signs of Potassium Deficiency. Corn and Soybean Digest Newsletter.
20. Mannan, M.A., M.A. Karim, M.M. Haque, Q.A. Khaliq, H. Higuchi and E. Nawata, 2013. Response of soybean to salinity: II. Growth and yield of some selected genotypes. Trop. Agr. Develop., 57(1): 31-40.
21. Chen, P., H. Wang, X. Tang, M. Brestic and H. Shao, 2013. Comparative physiological study between cultivated and wild soybean species under salt stress. Jokull J., 63: 1-11.
22. Ghassemi -Golezani K., M. Taifeh-Noori, S. Oustan Sh, M. Moghaddam and S. Seyyed-Rahmani, 2011. Physiological performance of soybean cultivars under salinity stress. Journal of Plant Physiology Breeding, 1: 1-8.
23. Khan, M.S.A., M.A. Karim, M.M. Haque, M.M. Islam, A.J.M.S. Karim and M.A.K. Mian, 2016. Influence of salt and water stress on growth and yield of soybean genotypes. Pertanika J. Trop. Agric. Sci., 39(2): 167-180.
24. Thomas, T.C. and A.C. Thomas, 2009. Vital role of potassium in the osmotic mechanism of stomata aperture modulation and its link with potassium deficiency. Plant Signal. Behav., 4: 240-243.
25. Wang, M., Q. Zheng, Q. Shen and S. Guo, 2013. the critical role of potassium in plant stress response. Int. J. Mol. Sci., 14: 7370-7390.
26. Zorb, C., M. Senbayram and E. Peiter, 2014 Potassium in agriculture-Status and perspectives. J. Plant Physiol., 171: 656-669.
27. Wang, Y. and W.H. Wu, 2017. Regulation of potassium transport and signaling in plants. Curr. Opin. Plant Biol., 39:, 123-128
28. Martineau, E., J.C. Domec, A. Bosc, P. Denoroy, V.A. Fandino, J. Lavres, Jr. and L. Jordan-Meille, 2017. The effects of potassium nutrition on water use in field-grown maize (*Zea mays* L.). Environ. Exp. Bot., 134: 62-71.
29. Pande, M., M.B. Goli and N. Bellaloui, 2014. Effect of Foliar and Soil Application of Potassium Fertilizer on Soybean Seed Protein, oil, fatty acids and minerals. American Journal of Plant Sciences, 5: 541-548.
30. Marschner P. Marschner's, 2012. Mineral Nutrition of Higher Plants. 3rd ed. Academic Press; London, UK, pp: 178-189.
31. Su, Y., W. Luo, W. Lin, L. Ma and M.H. Kabir, 2015. Model of cation transportation mediated by high-affinity potassium transporters (HKTs) in higher plants. Biol. Proced. Online, 17: 1.

32. Capula-Rodríguez, R., L.A. Valdez-Aguilar, D.LO. Cartmill, A.D. Cartmill and I. Alia-Tejacal, 2016. Supplementary calcium and potassium improve the response of tomato (*Solanum lycopersicum* L.) to simultaneous alkalinity, salinity and boron stress. Commun. Soil Sci. Plant Anal., 47(4): 505-511.
33. Yin, X. and T.J. Vyn, 2003. Potassium placement effects on yield and seed composition of no till soybean seed in alternate row widths. Agron. J., 95: 126-132.
34. Muneer, S., Y.G. Park, A. Manivannan, P. Soundararajan and B.R. Jeong, 2014. Physiological and proteomic analysis in chloroplasts of *Solanum lycopersicum* L. under silicon efficiency and salinity stress. Intl. J. Mol. Sci., 15(12): 21803-21824.
35. Xie, Z., R. Song, H. Shao, F. Song, H. Xu and Y. Lu, 2015. Silicon improves maize photosynthesis in saline-alkaline soils. Sci. World J. 2015:245072.
36. Ma, D., D. Sun, C. Wang, H. Qin, H. Ding, Y. Li and T. Guo, 2016. Silicon application alleviates drought stress in wheat throughtranscriptional regulation of multiple antioxidant defense pathways. Journal of Plant Growth Regulation, 35: 1-10.
37. Kim, Y.H., A.L. Khan, M. Waqas and I.J. Lee, 2017. Silicon regulates antioxidant activities of crop plants under abiotic-induced oxidativestress: a review. Frontiers in Plant Science, 8: 510.
38. Aras, S. and A. Eşitken, 2018a. Effects of silicon to salt stress on strawberry plant. Harran Tarımve Gıda Bilimleri Dergisi, 22: 478-483.
39. Zhang, W., X. Yu, M. Li, D. Lang, X. Zhang and Z. Xie, 2018. Silicon promotes growth and root yield of Glycyrrhizauralensis undersalt and drought stresses through enhancing osmotic adjustment and regulating antioxidant metabolism. Crop Protection, 107: 1-11.
40. Conceiç o, S.S., C.F.D. Oliveira Neto, E.C. Marques, A.V.C. Barbosa, J.R. Galvlo, T.B.D. Oliveira, R.S. Okumura, J.T.S. Martins, T.C. Costa and E. Gomes-Filho, 2019. Silicon modulates the activity of antioxidant enzymes and nitrogen compounds in sunflower plants under salt stress. Archives of Agronomy and Soil Science, 65: 1237-1247.
41. Abou Seeda M.A., A.A. Yassen, E.A.A. Abou El-Nour, M. Gad Mervat and Sahar M. Zaghloul, 2020 The Essentiality of Selenium for Plants and Their Role in Plant Physiology. A review.Middle East J. Agric. Res., 9(1): 149. 170
42. Cui, J., T. Liu, F. Li, J. Yi, C. Liu and H. Yu, 2017. Silica nanoparticles alleviate cadmium toxicity in rice cells: mechanisms and size effects. Environ Pollut, 228: 363-369.
43. Wang, M., L. Gao and S. Dong, 2017. Role of silicon on plant-pathogen interactions, Frontiers in Plant Science, 8: 701.
44. Alhousari, F. and M. Greger, 2018. Silicon and mechanisms of plant resistance to insect pests. Plants (Basel), 7(2): 33.
45. Cheng, H.N., K.T. Klasson, T. Asakura and Q.L. Wu, 2016. Nanotechnology in agriculture. In: Nanotechnology: Delivering on the Promise (Vol. 2), ACS Symposium Series, American Chemical Society, Washington, DC, pp: 233-242.
46. Abdul Qados, A., 2015. Mechanism of nanosilicon-mediated alleviation of salinity stress in faba bean (*Viciafaba* L.) plants. American J. Experimental Agriculture, 7(2): 78-95.
47. Haghighi, M. and M. Pessarakli, 2013. Influence of silicon and nano-silicon on salinity tolerance of cherry tomatoes (*Solanum lycopersicum* L.) at early growth stage. Sci. Hortic., 161: 111-117.
48. Klute, A., 1986. Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods 2nd edition. American Society of Agronomy, Madison, Wisconsin, USA.
49. Page, A.I., R.H. Miler and D.R. Keeny, 1982. Methods of Soil Analysis part II. Chemical and Microbiological Methods. 2nd ed. Amer. Soc. Agron., Madison, Wisconsin, USA.
50. Cottenie, A., M. Verloo, L. Kiekens, G. Velghe and R. Camerlynck, 1982. Chemical Analysis of Plant and Soil, pp: 100-129. Laboratory of Analytical and Agrochemistry, State Univ. Ghent. Belgium.
51. AOAC, 1984. Association of Official Analytical Chemists. Official Method of analysis. 14th eds., Washington DC.
52. AOAC, 1990. Official Methods of Analysis. 15th Ed. Association of Official Analytical Chemists, Inc., Virginia, USA, pp: 770-771.
53. Vincent, J.M., 1970. A manual for practical study of root-nodule bacteria. In: IBP Handbook, vol. 15. Blackwell, Oxford.
54. Snedecor, G.W. and W.G. Cochran, 1980. Statistical Methods. 7th ed., Iowa State Univ. Press, Ames, Iowa, USA.
55. Amirjani, M.R., 2010. Effect of salinity stress on growth, mineral composition, proline content, antioxidant enzymes of soybean. Amer. J. Plant Physiol., 5: 350-360.

56. El-Sabagh A., M.S. Islam, A. Ueda, H. Saneoka and C. Barutçular, 2015a. Increasing reproductive stage tolerance to salinity stress in soybean. Int J Agric Crop Sci. 8: 738-745.
57. Agarwal, N., A. Kumar, S. Agarwal and A. Singh, 2015. Evaluation of soybean (*Glycine max* L.) cultivars under salinity stress during early vegetative growth. Intl. J. Curr. Microbiol. Appl. Sci., 4(2): 123-134.
58. Kargar, S.M.A. and S.J. Kareh, 2017. The evaluation of seed germination on 12 soybean cultivars under different salinity stress levels. Plant Breed Seed Sci., 73: 39-51.
59. Munns, R. and M. Tester, 2008. Mechanisms of salinity tolerance, Annu Rev Plant Biol., 59: 651-68.
60. Klein, A.J., 2012. Modulation of Soybean and Maize Antioxidant Activities by Caffeic Acid and Nitric Oxide under Salt Stress Doctoral dissertation. University of the Western Cape.
61. Do, T.D., H.T. Chen, V.T.T. Hien, A. Hamwieh, T. Yamada, T. Sato, Y.L. Yan, H. Cong, M. Shono, K. Suenaga, D.H. Xu, 2016. Ncl synchronously regulates Na+, K+ and Cl. in soybean and greatly increases the grain yield in saline field conditions. Sci. Rep., 6: 19147.
62. Mannan, M.A., M.A. Karim, M.M. Haque, Q.A. Khaliq, H. Higuchi and E. Nawata, 2013b. Response of soybean to salinity: III. Water status and accumulation of mineral ions. Tropical Agr. Dev., 57: 41-48.
63. Hashi, U.S., A. Karim, H.M. Saikat, R. Islam and M.A. Islam, 2015. Effect of Salinity and Potassium Levels on Different Morpho-Physiological Characters of two Soybean (*Glycine max* L.) Genotypes. J. Rice. Res., 3: 143.
64. Parveen, Anwar-ul-Haq, M., J. Akhtar and S.M.A. Basra, 2016. Interactive effect of salinity and potassium on growth, biochemical parameters, protein and oil quality of soybean genotypes. Pak J. Agric. Sci., 53(1): 69-78.
65. Pettigrew, W.T., 2008. Potassium influences on yieldand quality production for maize, wheat, soybean and cotton. Physiologia Plantarum, 133: 670-681.
66. Hendrival, Latifah, Idawati, 2014. Effect of potassiumfertilization on the development of aphids (Aphisglycines Matsumura) and soybean yield. J. Floratek, 9: 83-92.
67. Shin, R. and D.P. Schachtman, 2004. Hydrogen peroxide mediates plant root cell response to nutrient deprivation. Proc Natl Acad Sci. USA, 101: 8827-8832.
68. Shabala, S. and T.A. Cuin, 2008. Potassium transport and plant salt tolerance. Physiol. Plant, 133: 651-669.
69. Abdul Qados, A.M., 2015. Influence of silicon and nano-silicon on germination, growth and yield of faba bean (*Viciafaba* L.) under salt stress. Amer J. Exp. Agric., 5: 509-524.
70. Siddiqui, M.H. and M.H. Al-whaibi, 2014. Role of nano-SiO2 in germination of tomato (*Lycopersicumesculentum seeds* Mill.). Saudi J. Biological Sciences, 21(1): 13-17.
71. Kalteh, M., Z.T. Alipour, S. Ashraf, M. MarashiAliabadi and A. Falah Nosratabadi, 2018. Effect of silica nanoparticles on basil (Ocimumbasilicum) under salinity stress. J. Chemical Health Risks, 4(3): 49-55.
72. Suriyaprabha, R., G. Karunakaran, R. Yuvakkumar, V. Rajendran and N. Kannan, 2012. Silica nanoparticles for increased silica availability in maize (*Zea mays* L.) seeds under hydroponic conditions. Curr. Nanosci., 8: 902-908.
73. Suriyaprabha, R., G. Karunakaran, R. Yuvakkumar, P. Prabu, V. Rajendran and N. Kannan, 2012. Growth and physiological responses of maize (*Zea mays* L.) to porous silica nanoparticles in soil. J. Nanoparticle Research, 14(12): 1294.
74. Haghighi, M., Z. Afifipour and M. Mozafarian, 2012. The effect of N-Si on tomato seed germination under salinity levels. J. Biol. Environ. Sci., 6(16): 87-90.
75. Sabaghnia, N. and M. Janmohammadi, 2015. Effect of nano-silicon particles application on salinity tolerance in early growth of some lentil genotypes. Annals UMCS, Biologia, 69(2).
76. Roohizadeh, G., A. Majd and S. Arbabian, 2015. The effect of sodium silicate and silica nanoparticles on seed germination and growth in the *Viciafaba* L. Tropical Plant Research Journal, 2(2): 85-89.
77. Romero-Aranda, M.R., O. Jurado and J. Cuartero, 2006. Silicon alleviates the deleterious salt effect on tomato plant growth by improving plant water status. J. Plant Physiology, 163(8): 847-855.
78. Parveen, N. and M. Ashraf, 2010. Role of silicon in mitigating the adverse effects of salt stress on growth and photosynthetic attributes of two maize (*Zea mays* L.) cultivars grown hydroponically. Pakistan J. Botany, 42: 1675-1684.
79. Pilon-Smits, E.A., C.F. Quinn, W. Tapken, M. Malagoli and M. Schiavon, 2009. Physiological functions of beneficial elements. Current Opinion in Plant Biology, 12(3): 267-274.

80. Lee, S.K., E.Y. Sohn, M. Hamayun, J.Y. Yoon and I.J. Lee, 2010. Effect of silicon on growth andsalinity stress of soybean plant grown underhydroponic system. Agrofor. Syst., 80(3): 333-340.
81. Mozafarian, M., Z. Afifipour and M. Haghighi, 2011. Effect of nano SiO3 and potassium silicate on priming of tomato seeds. Conference on Modern Technologies in Agriculture, ZanjanUniversity, Zanjan, Iran, pp: 496-498.
82. Parande, S., G.R. Zamani, M.H. Syyari Zahan and M.G. Ghaderi, 2013. Effects of silicon application on the yield and component of yield in the common bean (Phaseolus vulgaris) under salinity stress. International Journal of Agronomy and Plant Production, 4(7): 1574-1579.
83. Farhangi-Abriz, S. and S. Torabian, 2018. Nano-silicon alters antioxidant activities of soybean seedlings under salt toxicity. Protoplasma, 255(3): 953-962.
84. Rios, J.J., M.C. Martínez-Ballesta, J.M. Ruiz, B. Blasco and M. Carvajal, 2017. Silicon-mediated improvement in plant salinity tolerance: the role of aquaporins. Frontiers in Plant Science, 8: 948.
85. Maria Greger, I.D., Tommy Landberg and Marek Vaculík, 2018. Silicon Influences Soil Availability and Accumulation of Mineral Nutrients in Various Plant Species, Plants, 7: 41.
86. Savvas, D., D. Giotis, E. Chatzieustratiou, M. Bakea and G. Patakioutas, 2009. Silicon supply in soilless cultivations of zucchini alleviates stress induced by salinity and powdery mildew infections. Environ. Exp. Bot., 65: 11-17.
87. Bybordi, A., 2014. Interactive effects of silicon and potassium nitrate in improving salt tolerance of wheat. Int. J. Agric., 13: 1889-1899.
88. Zhu, Y. and H. Gong, 2014. Beneficial effects of silicon on salinity and drought tolerance in plants. Agron. Sustain. Dev., 34: 455-472.
89. Essa, T.A., 2002. Effect of salinity stress on growth and nutrient composition of three soybean [*Glycine max* (L.) Merr.] Cultivars. J. Agron. Crop Sci., 188: 86-93.
90. Prakash R. Patel, Sushil S. Kajal, Vinay R. Patel, Vimal J. Patel and Sunil M. Khristi, 2010. Impact of salt stress on nutrient uptake and growth of cowpea. Braz. J. Plant Physiol., 22(1): 43-48.
91. Kardoni, F., S.J.S. Mosavi, S. Parande and M.E. Torbaghan, 2013. Effect of salinity stress and silicon application on yield and component yield offaba bean (*Viciafaba*). Int. J. Agric. Crop Sci., 6: 814-818. 39.
92. Farooqui, A., H. Tabassum, A. Ahmad, A. Mabood, A. Ahmad and I.Z. Ahmad, 2016. Role of nanoparticles in growth and development of plants: A review. Int. J. Pharm. Bio. Sci., 7: 22-37.
93. Trivedi, H.B., T.V.R. Rao, D.L. Bagdi and G.G. Rao, 2004. Influence of silicon on growth and salt uptake in wheat under salinity. Ind. J. Plant Physiol., 9: 360-366.
94. Abdelazim Yassen, Emam Abdallah, Maybelle Gaballah and Sahar Zaghloul, 2017. Role of Silicon Dioxide Nano Fertilizer in Mitigating Salt Stress on Growth, Yield and Chemical Composition of Cucumber (*Cucumis sativus* L.) Int. J. Agric. Res., 12(3): 130-135.
95. Abbasi, M.K., M.M. Tahir, W. Azam, Z. Abbas and N. Rahim, 2012. Soybean yield and chemical composition in response to phosphorus-potassium nutrition in kashmir. Agronomy Journal, 104: 1476-1484.
96. Bellaloui, N., X. Yin, A. Mengistu, A.M. McClure, D.D. Tyler and K.N. Reddy, 2013. Soybean Seed Protein, Oil, Fatty Acids and Isoflavones Altered by Potassium Fertilizer Rates in the Midsouth. American Journal of Plant Sciences, 4: 976-988.
97. Abbas, T., R.M. Balal, M.A. Shahid, M.A. Pervez, C.M. Ayyub, M.A. Aqueel and M.M. Javaid, 2015 Silicon-induced alleviation of NaCl toxicity in okra (Abelmoschus esculentus) is associated with enhanced photosynthesis, osmoprotectants and antioxidant metabolism. ActaPhysiol Plant, 37: 1-15.