J. of Soil Sciences and Agricultural Engineering, Mansoura Univ., Vol. 16 (5):77 - 83, 2025

Journal of Soil Sciences and Agricultural Engineering

Journal homepage & Available online at: www.jssae.journals.ekb.eg

The Efficiency of The Mineral K-Fertilization Combined with Soaking/Spraying by Chitosan Solution to Enhance the Sugar Beet Productivity under Sandy Soil Conditions

Nashwa M. El-Sheikh; M. I. Mohaseb; Marwa A. Ahmed and Rama T. Rashad*

Soils, Water and Environment Research Institute (SWERI), Agricultural Research Center (ARC), P.O. Box: 175 Orman, Area Code: 12112, Giza, Egypt

ABSTRACT

Expanding the sugar beet (*Beta vulgaris* L.) production in sandy soils, as reclaimed soils, is highly recommended. This study aims to evaluate the single and combined effects of soaking and/or spraying with chitosan solution, with the application of mineral K-fertilization on the availability, uptake of the N-P-K nutrients, and the yield of sugar beet cultivated in sandy soil. Two field experiments were carried out in a split-plot design with three replicates. The main factor (F1) was the mineral potassium (K) fertilization applied at the rates of 50%, 75%, and 100% of the recommended dose (RD). The sub-factor (F2) was the chitosan soak and/or spray treatments. The results indicated that increasing the applied K_2O rate from 50% to 100% RD has increased the range of the soil available (mg kg^{-1}) N-P-K by 54.5-106.7%, 60.6-140.1%, and 15.5-101.9%, respectively, relative to the initial soil before the experiment. The sugar beet yield (Mg ha^{-1}) was increased significantly by 18.1% at a significance level $p \leq 0.05$. The combined application of 75% K_2O with soaking seeds has increased the nutrient availability by 26.2% (N), 41.6% (P), and 62.5% (K), relative to the zero-chitosan treatment. The 75% K-fertilization rate combined with repeated spray by the chitosan solution can be recommended to improve the sugar beet yield and quality. Chitosan can be included in the fertilization programs by soaking/spraying the fertilizer solution under sandy soil conditions**.**

Keywords: Bio-fertilizers, Spray Application, Priming Seeds, Reclaimed Soil

INTRODUCTION

Optimal levels of nutrients to be available for plants growing in sandy soil need a continuous recovery by repeating a concentrated fertilization, usually by the quickly dissolved inorganic chemicals, to avoid a diminished crop production. This reduction is usually due to the partial fast loss of the applied fertilizer by quick leaching from the destructive texture of the soil. There is a worldwide interest in using environment-friendly practices and bio-degradable fertilizers out of bio-resources, which enhance the nutrient use efficiency to maintain agricultural sustainability (Pandey *et al*., 2018; El-Sherpiny *et al*., 2023).

The soil capacity for nutrient uptake through the root's activity is sometimes limited because of environmental or plant-related reasons. Stages of the high shoot demand include a competition between roots and shoots that reduce the carbohydrate allocation to roots, restrict root growth and metabolism, and thus reduces the nutrient uptake. The soil nutrient uptake or transport may be restricted during some growth stages, e.g. decreased N uptake following grain set in cereals. Sometimes, there is a decrease in the root growth and activity due to shoot vs. root competition for carbohydrates and metabolites. In addition, plant construction and organ progress generate a local nutrient demand that exceeds the capacity for plant nutrient delivery. Nutrients may be depleted due to rapidly withdrawing mobile nutrients in leaves adjacent to the large, rapidly growing reproductive organs (Fernández *et al*., 2013; Mohamed *et al*., 2023).

Spraying the plant nutrients is a complementary approach to soil fertilization to reduce nutrient loss from soil. Foliar spray affects the shoot-to-root physical and biological equilibrium and consequent root growth and nutrient uptake from the soil. There are increases in the demand for specific elements involved in critical plant functions, e.g. B or Cu, for development and growth, during flowering and fruit set. Shoot demand taking place prior to root development. Nutrients obtained directly by spraying can decrease the plant's dependence on the nutrients' uptake from the soil by roots. Chemical equilibrium of nutrients may be directed towards the soil solution during the transition states of growth stages before the full plant matures. The soil-available nutrients may be unchanged or even increased due to the repetitive and periodic application of the sprayed fertilizers (Fernández *et al*., 2013).

On another hand, the pre-sowing seed treatments are sometimes recommended to decrease the negative effects of seed storage, causing degradation of their components due to the moisture and the reactive oxygen species (ROS). It is a low-cost practice to alleviate and simulate osmotic stress effects on seed germination. Seed treatment by soaking, coating, pelleting, thermal, and magnetic field MF have been studied (Rashad, 2020; Rashad *et al*., 2022; Mohaseb *et al*., 2023). Studies have used distilled water, dilute salt solutions, nanoparticle suspensions, chitosan, and plant growth regulators (PGRs).

* **Corresponding author.**
E-mail address: rama.mostafa@arc.sci.eg
DOI: 10.21608/jssae.2025.375880.1279

Chitosan is a natural biodegradable and biocompatible polymer studied as a growth promoter, antimicrobial agent, and to increase water use efficiency (Burrows *et al*., 2007; Ahing and Wid, 2016; Takarina and Fanani, 2017; Ibrahim *et al*., 2019; Ali *et al*., 2021; Jayanudin *et al*., 2021). It improves the soil aggregates and water-holding capacity (Adamczuk *et al*., 2021). It could be utilized for bio-fertilization, foliar spray, and seed coating and soaking to activate the plant's natural metabolism for the rice yield, barley (*Hordeum vulgare cv. Reyhan*) and wheat (*Triticum aestivum* cv. *Pishtaz*). The efficiency mechanism may be due to the Chitosan cationic groups that bind the negatively charged phosphate groups of the DNA, which may partially modify the protein expression. A metal-chelation interaction mechanism may exist between the poly-cationic Chitosan and the poly-anionic structures like lipopolysaccharides, proteins, and metal ions in the cell wall and plasma membrane (Burrows *et al*., 2007).

Chitosan-treated seeds have exhibited enhanced germination and stress resistance may be due to the increase in a chitosan-induced catalase activity of the antioxidant role (Faqir *et al*., 2021). It has increased the growth characteristics and yield of barley and soybean plants (Hafez *et al*., 2020) as well as the wheat (*Triticum aestivum* L.). Seeds treated with 0.05–0.4% Chitosan solution showed reduced enzyme activity, stimulated seedling growth, and increased chitinase activity in seedlings in the Safflower (*Carthamustinctorius* L.). Seed treatment with a 40 mg/L solution of oligomeric chitosan induced the drought resistance of rice (*Oryza sativa* L.). Seed treated with 0.2% chitosan increased the shoot and root length and adjusted salt toxicity of the Ajowan (*Carum copticum*), while seed soaked with oligo-chitosan at 0.0625% for 5 h led to a significant increase in proline level (Hidangmayum *et al*., 2019). Seeds priming at low Chitosan nanoparticle concentrations (30 ppm) exhibited positively affected seedling, root and shoot lengths. At high concentrations (e.g. 90 ppm), negative effects were observed on growth features. The application of 1, 3, and 6 g/L of Chitosan resulted in a significant improvement in barley plant height (Kocięcka and Liberacki, 2021).

Foliar sprayed Chitosan has stimulated the stomatal conductance, reduced the transpiration and increased the Indian spinach leaf nitrate reductase activity. The foliar spray with the soil application has significantly affected the tomato fruits' growth, yield and biochemical features. The N and P uptake for wheat, potatoes, melon, begonia, and chilli fruits has improved. Chitosan concentration at 2-4 g/L has affected the endogenous hormone content, alpha-amylase activity and chlorophyll content in the maize leaves (Waly *et al*., 2019; Quynh *et al*., 2020; Waly *et al*., 2020).

Sugar beet (*Beta vulgaris* L.) is one of the most important sugar and sucrose-producing crops in many countries, especially in Egypt (Mohamed *et al*., 2023). It can also be used for animal feed, energy purposes, and is an important part of crop rotations. The sugar beet crop' quantitative, qualitative, and economic improvement is attracting many agricultural and commercial studies (Krzysiak, 2021; Grzanka *et al*., 2023). Improving the yield and quality of the sugar beet cultivated in sandy soil as reclaimed soils is an economic demand to reduce the import of this important crop. Expanding the production is highly recommended in Egypt to satisfy the local sugar needs. This study aims to compare the effects of seed soaking and/or spraying with Chitosan aqueous solution as an organic bio-fertilizer in combination with different application rates of the potassium (K) mineral fertilizer on the yield and quality of the sugar beet plant cultivated in sandy soil.

MATERIALS AND METHODS

The field experiment was carried out in the two successive winter seasons of 2021 and 2022 at the Ismailia Agricultural Research Station (31° 37' 42.8" N and 33°19'52" E, Egypt). The soil sample analysed before sowing (Table 1) has shown a sandy soil texture (*Typic Torripsamment; Entisol*" Arenosol AR") (Jackson, 1973; Black, 1982; Page *et al*., 1982; FAO, 2014).

Table 1. Some physical and chemical properties of the studied initial soil before the experiment

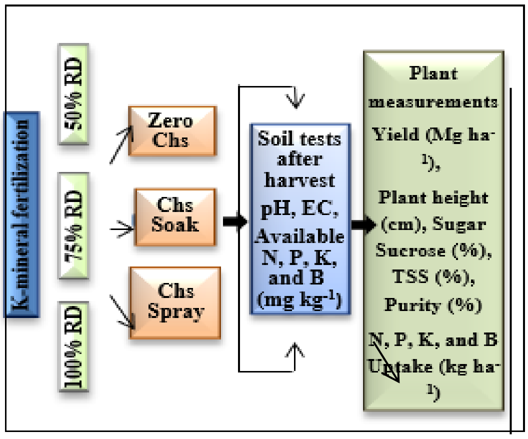
Sand 94%		**Silt 2%**		**Clay 4%**		**Sandy Soil**
pH†	**Electrical Conductivity EC (dS m^{-1})‡**		**$CaCO_3$ (%)**		**Organic Matter OM (%)**	
8.00	2.25		0.68		0.26	
Moisture properties w/w (%)						
SP	Field capacity	Wilting point	Available water	Bulk density (gcm^{-3})	Total porosity (%)	Hydraulic Conductivity (cm h^{-1})
30.00	18.64	3.61	14.83	1.64	37.36	18.64
Soluble ions ($mmol_cL^{-1}$) ‡						
Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}
12.30	0.30	5.90	4.00	1.20	17.20	4.10
Available macronutrients ($mgkg^{-1}$)*						
			N	P	K	B
			22.90	2.97	90.33	0.40

† (1:2.5 soil : water suspension), ‡ (Saturated soil extract i.e. soil paste extract)

***Critical levels of the available nutrient ($mgkg^{-1}$) according to Soltan Pour and Schwab (1977) (Soltan Pour and Schwab, 1977): N ≤ 40.0 Low; 40.0 – 80.0 Medium; >80.0 High, P ≤ 5.0 Low; 5.0 – 10.0 Medium; >10.0 High, K ≤ 85 Low; 85 –170 Medium; >170 High.**

Treatments in triplicates were arranged in a split-plot design. The main factor (F1) was the mineral potassium (K) fertilization in the form of potassium sulphate (48% K_2O) applied at the rates of 50%, 75%, and 100% of the recommended dose RD (114.3 kg ha^{-1}) repeated in two equal application doses 30 and 55 days after sowing. The sub-factor (F2) was the Chitosan soak and/or spray treatments. A control treatment without chitosan application was included. Scheme 1 is a flowchart for treatments examined in the study.

The chitosan used in the study was a commercial liquid product, Chito-Potassium (37% K_2O, pH 6 – 7, density 1.4 g mL^{-1}) contains sea-algae extract aligned with acetate and citrate carboxylic acids. The Chitosan was used for soaking the sugar beet seeds before cultivation and/or for spraying on soil after cultivation. A diluted aqueous solution (3 mL L^{-1}) was prepared by mixing 30 mL of the stock Chitosan solution with 10 L of water. This solution was used for soaking the specified amount of seed to be sown for 24 h, then, the soaked seeds were separated from the soaking solution and air-dried without washing. Another similar solution was prepared, and then sprayed on the soil 50 and 70 days after sowing.



Scheme 1. Flow-chart for the treatments under study

Sugar beet seeds (*Beta vulgaris* L.) Pyramid imported variety obtained from the Sugar Crops Research Institute (Agricultural Research Center) were sown in plots during November 2021 and 2022; the plot area is 21.0 m^2 divided into 6 rows, 7 m long and 50 cm away from each other. Cultural practices and irrigation were applied as recommended by the Ministry of Agriculture. The mineral fertilization by nitrogen (N) was by the ammonium nitrate (NH_4NO_3, 33% N, 714.3 kg ha^{-1}) applied in two equal doses before the 1^{st} and 2^{nd} irrigation. The phosphorus (P) fertilization was added as calcium super phosphate (15.5% P_2O_5, 476.2 kg ha^{-1}) applied during the soil preparation before planting. Harvesting the sugar beet plants was done at maturity after 210 days of planting, and representative samples were chosen for analysis (Black, 1982; Yassin *et al.*, 2021). The yield (ton ha^{-1}) was calculated based on the plot area data, and the mean of the two seasons was obtained.

The available nutrients in the soil samples were extracted (Jackson, 1973). Plant samples were dried at 70 ºC for 48 h, and ground and a half gram was wet digested using the H_2SO_4/$HClO_4$ acid mixture (1:1) (Chapman and Pratt, 1961). The concentrations of the boron B, N, P, and K in plant and soil extracts were measured by distillation (Kjeldahl apparatus), colourimetric (UV-Vis Spectrophotometer), flame photometer, and the ICP Spectrometry (ICP-Ultima 2 JY Plasma), respectively to calculate the nutrients' uptake by the plant (Piper, 2019; Rayment and Lyons, 2011).

Quality characters, including the juice quality, were determined using an automatic French system (HYCEL). The total soluble solids (TSS, %) of fresh and storage samples were determined using a fully automatic digital refractometer (model ATR-S (04320), 0 -95% Brix temperature compensation 15 - 40ºC) according to the procedure of the Nile Sugar Company Juice quality traits.

The Sucrose percentage (S%) and the root impurities in terms of the Na, K, and α-N (alpha-amino nitrogen) (meq/100 g beet) were estimated in the fresh samples of sugar beet root using a Saccharometer according to the official method described by (A.O.A.C., 2012). The juice purity (%) was calculated by the eq. (1) (Devillers, 1988):

$$\text{Purity (\%)} = 99.36 - \left[\frac{14.27\,(Na+K+\alpha-N)}{S\%}\right] \quad (1)$$

The agronomic efficiency for K-fertilizer (KAE) applied with and without chitosan was calculated where Y = Yield (kg ha^{-1}), f: fertilized by chitosan, 0: zero-chitosan as follows (Roozbeh *et al.*, 2011):

$$KAE = \frac{Y_f - Y_0}{\text{Fertilizer rate (K ,kg ha-1)}} \quad (2)$$

Statistical analysis

The statistical significance (LSD) of the data at P ≤ .05 was calculated by the two-way analysis of variance (ANOVA) test using the Co-State Software Package - Ver. 6.311, Cohort Software Inc., Berkley-California (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Results

Effect of soaking and/or spraying by the Chitosan solution on the N-P-K availability in the experimental soil

The mineral fertilization applied to sandy soil is usually partially lost, inhibiting nutrient use efficiency (NUE) and negatively affecting productivity. Partial substitution of the applied mineral K by an organo-K substrate such as a Chitosan-form may enhance the nutrient immobilization in the sandy soil so that its availability and uptake by plants is improved. Soaking the beet seeds before sowing and spraying after sowing by chitosan solution have significantly affected some characteristics of the cultivated soil as indicated by Table 2 according to the LSD values. The little variation in the soil pH values in Table 2 under the effect of the K_2O and chitosan treatments is often temporary due to mixing the applied fertilizers and their dissolution in the soil solution during the studied cultivation season. The buffering action of soil will return the chemical equilibrium of the soil solution to its stable state so that the soil pH is kept at its control value. The 75% and 100% RD K_2O combined with the chitosan spray have decreased the soil EC (dS m^{-1}) by 16.4% relative to the initial soil before the experiment. This result may be attributed to the interaction between the chitosan ionic groups and ions soluble in soil solution and their uptake and consumption in the plant nutrition processes. So, it decreased the concentrations of soluble ions in the soil solution.

Increasing the applied K_2O rate from 50% to 100% RD has increased the range of soil available (mg kg^{-1}) N-P-K by 54.5-106.7%, 60.6-140.1%, and 15.5-101.9%, respectively, relative to the initial soil before the experiment as shown in Table 2. The combined application of 75% K_2O with soaking seeds has increased the nutrient availability by 26.2% (N), 41.6% (P), and 62.5% (K) relative to the zero-chitosan treatment. These significant increases at $p \leq 0.05$ depend on both the single and combined application of the K-fertilization and/or chitosan, as their single and interactive effects were significant.

Table 2. Effect of the K-mineral fertilization without chitosan (Chs) and with Chs (soak/spray) on the soil pH, EC and available macro-micronutrients content after harvest (mean values of the two seasons)

Treatment			pH[†]	EC ($dS\ m^{-1}$)[‡]	Available nutrients ($mg\ kg^{-1}$)		
					N	P	K
K-mineral fertilization	50% RD	Zero Chs	8.03	1.98	35.37^{b}	4.77^{c}	104.37^{c}
		Chs Soak	8.00	1.9	43.17^{a}	5.40^{b}	122.4^{c}
		Chs Spray	8.01	1.84	36.17^{b}	4.70^{c}	112.43^{c}
	75% RD	Zero Chs	8.01	1.9	36.87^{b}	4.93^{c}	112.50^{c}
		Chs Soak	8.00	1.83	46.53^{a}	6.98^{a}	182.80^{a}
		Chs Spray	8.03	1.88	45.20^{a}	5.83^{b}	162.73^{a}
	100% RD	Zero Chs	8.01	1.86	47.33^{a}	7.13^{a}	182.40^{a}
		Chs Soak	8.07	1.95	43.63^{a}	6.50^{a}	137.3^{b}
		Chs Spray	8.01	1.88	37.47^{b}	6.07^{a}	114.00^{c}
$LSD_{5\%}$		F1	SD = 0.02	SD = 0.14	0.087	0.087	3.02
		SL			***	***	***
		F2			0.097	0.097	1.94
		SL			***	***	***
		F1 * F2			***	***	***

† (1:2.5 Soil: Water suspension),‡ (Soil paste extract)
F1: Main factor (the mineral potassium (K) fertilization), F2: sub-factor (the Chitosan soak and/or spray treatments), LSD: Least significant difference, SL: Significance of level, SD (Standard Deviation)

Effect of the studied treatments on the macro-nutrients uptake (kg ha^{-1}) by the sugar beet

The single and combined fertilization by the K_2O and/or the chitosan solution (soaking/spraying), has significantly increased the macro-nutrient uptake (kg ha^{-1}) by the sugar beet compared to the control. The 100% RD K_2O has shown a significant increase by 36.2% (N), 48.1% (P), and 20.1% (K) relative to the 50% RD, as presented in Table 3. Moreover, the 75% K_2O rate combined with chitosan-soaked seeds has raised the N-P-K uptake by the sugar beet plant relative to the zero-chitosan treatment by 32.9, 48.5, and 19.9%, respectively. The mentioned significant increases are affected by both the single and combined application of treatments because their interaction was significant. The enhanced uptake of nutrients reflects their enhanced availability in soil due to the fertilization treatments.

Table 3. Effect of the K-mineral fertilization without chitosan (Chs) and with Chs (soak/spray) on the uptake of macro nutrients by sugar beet plant after harvest (average values of the two seasons)

Treatment			Uptake ($kg\ ha^{-1}$)		
			N	P	K
K-mineral fertilization	50% RD	Zero Chs	102.15^{c}	12.91^{c}	62.08^{c}
		Chs Soak	119.22^{b}	16.11^{b}	67.19^{c}
		Chs Spray	107.95^{c}	14.63^{c}	67.94^{c}
	75% RD	Zero Chs	104.80^{c}	13.74^{c}	65.50^{c}
		Chs Soak	139.24^{a}	20.40^{a}	78.57^{a}
		Chs Spray	127.28^{b}	18.18^{a}	71.73^{b}
	100% RD	Zero Chs	139.08^{a}	19.12^{a}	74.53^{a}
		Chs Soak	126.10^{b}	17.35^{b}	71.07^{b}
		Chs Spray	111.59^{c}	15.13^{c}	67.50^{c}
$LSD_{5\%}$		F1	1.11	0.44	1.18
		SL	***	***	***
		F2	0.71	0.48	1.07
		SL	***	***	***
		F1 * F2	***	***	***

F1: Main factor (the mineral potassium (K) fertilization), F2: sub-factor (the Chitosan soak and/or spray treatments), LSD: Least significant difference, SL: Significance of level

Boron (B) Uptake and availability

The sugar beet plant is highly sensitive to the boron micro-nutrient since its quality and productivity are suppressed by the B stress. The studied treatments have significantly enhanced the B availability in soil and uptake by plants, as illustrated in Figure 1. The 75% RD K_2O combined with the chitosan-soaked seeds has increased the available B (mg kg^{-1}) by 17.3% and the uptake by 38.3% compared to the zero-chitosan treatment. On the contrary, the 100% K_2O rate combined with chitosan-soaked seeds has exhibited a relative decrease by 9.8% and 8.4% for the available and uptake B, respectively.

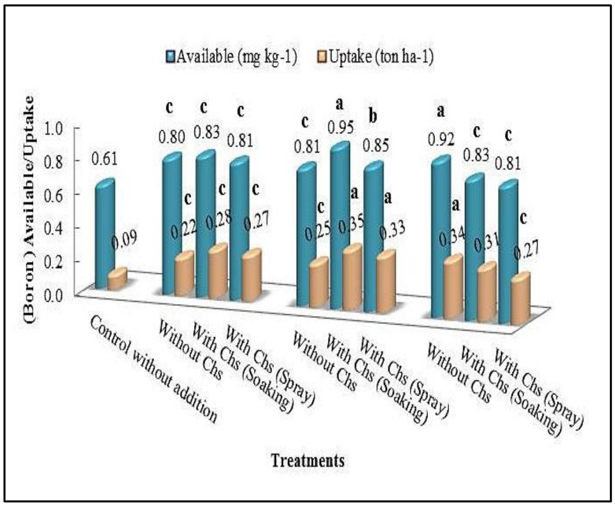


Figure 1. Effect of the studied treatments on the boron (B) availability in soil and uptake by sugar beet after harvesting (initial available B = 0.4 mg kg^{-1} before cultivation)

Effect of soaking and/or spraying by the Chitosan solution on the yield (Mg ha^{-1}) and some quality traits of the sugar beet crop

The yield of the sugar beet (Mg ha^{-1}) in Figure 2 has been significantly increased by increasing the K-application rate from 50% to 100% RD by 18.1% at a significance level $p \leq .05$. The 75% rate combined with spraying the chitosan solution has increased the yield by 3.6% relative to the zero-chitosan treatment. The 100% RD K_2O combined with the chitosan-soaked seeds or spraying has decreased the sugar beet yield by 3.6% and 7.7%, respectively, compared to the zero-chitosan treatment.

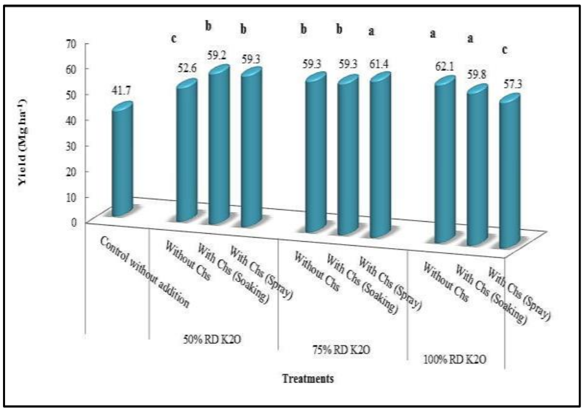


Figure 2. Yield (Mg ha^{-1}) of Sugar beet under the effect of soaking and/or spraying by chitosan with the K-fertilization

The combined application of the chitosan with the K-mineral fertilization has enhanced the estimated quality characteristics of the sugar beet significantly as shown in Table 4.

Table 4. Effect of the K-mineral fertilization without chitosan (Chs) and with Chs (soak/spray) on the some quality characteristics of the sugar beet plant as affected by different treatments after harvest (average values of the two seasons)

Treatment			Plant height (cm)	Sugar Sucrose (%)	TSS (%)	Purity (%)
K-mineral fertilization	50 % RD	Zero Chs	9.18^{c}	16.70^{c}	20.36^{a}	76.33^{c}
		Chs Soak	9.58^{c}	17.90^{c}	20.58^{a}	89.17^{a}
		Chs Spray	9.31^{c}	17.40^{c}	20.45^{a}	82.10^{c}
	75 % RD	Zero Chs	9.25^{c}	17.77^{c}	27.12^{a}	80.37^{b}
		Chs Soak	10.70^{a}	18.96^{a}	21.07^{a}	91.63^{a}
		Chs Spray	9.93^{a}	18.63^{a}	20.69^{a}	91.22^{a}
	100 % RD	Zero Chs	10.34^{a}	18.92^{a}	20.84^{a}	90.39^{a}
		Chs Soak	9.83^{b}	18.41^{a}	20.64^{a}	90.34^{a}
		Chs Spray	9.43^{c}	17.85^{c}	20.51^{a}	88.84^{a}
LSD$_{5\%}$		F1	0.036	0.08	5.04	1.75
		SL	***	***	ns	***
		F2	0.026	0.05	3.95	0.69
		SL	***	***	ns	***
		F1 * F2	***	***	ns	***

F1: Main factor (the mineral potassium (K) fertilization), F2: sub-factor (the Chitosan soak and/or spray treatments), LSD: Least significant difference, SL: Significance of level

The 75% RD K-fertilization rate combined with soaking the seeds in the chitosan solution was almost the most efficient treatment, increased the plant height (cm), sucrose (%), and purity (%) by 15.68, 6.69, and 14.01%, respectively, relative to the corresponding zero-chitosan treatment. Spraying the Chitosan solution was less affecting the beet quality significantly than soaking. Variation in the TSS (%) in the beet samples was non-significant regarding the studied factors: K-fertilization (F1) and chitosan treatments (F2).

Discussion

Utilizing the chitosan solution as an organic cooperative with the quickly soluble mineral K-fertilizer under sandy soil conditions may enhance the availability and uptake of the N, P, and K nutrients for the sugar beet plant. This effect can be attributed to the fact that the organic moiety of the chitosan acts as a ligand that capture the ionic forms of the nutrients either by an electrostatic attraction or complexation mechanisms and immobilize them from fast leaching within the soil matrix (Faqir *et al*., 2021; Kocięcka and Liberacki, 2021). Moreover, the organic form of nutrients can be more compatible and absorbable by plants than the mineral form. Thus, the plant nutritional role played by the chitosan by soaking and spraying its solution was significantly effective and complementary to the mineral fertilization role as indicated by the present study.

Boron (B) is an essential micronutrient for carbohydrate metabolism and cell division. Its deficiency or toxicity can result in physiological changes in the plants reducing the yield and yield features for the sugar beet. The safe B intake level for adults is 1–13 mg/d, and excessive B concentration in beet may be toxic to human health. Boron stress: toxicity ≈ 30 mg/L or deficiency ≈ 0.05 mg/L significantly inhibited the beet shoot, root growth, and leaf expansion while promoting leaf thickening. The equilibrium of hormones and enzymes is disturbed significantly under B stress. This inhibiting effect on beet growth may relieve B stress-induced oxidative damage (Song *et al*., 2019; Rašovský *et al*., 2022).

A highly significant positive correlation coefficient (r) was found between the B nutrient availability and uptake with the N-P-K uptake, as well as the plant height and sucrose content of the sugar beet plant (Table 5). Boron was weakly correlated with the beet purity, and its dose did not affect its TSS or yield, depending on the present study.

Table 5. The Correlation Coefficient ('r') between the B availability and uptake with the estimated parameters of the sugar beet

	Av. B	B uptake	N uptake	P uptake	K uptake	Plant Height	Sucrose	TSS	Purity	Yield
Av. B	-	-	-	-	-	-	-	-	-	-
B uptake	0.947***	-	-	-	-	-	-	-	-	-
N uptake	0.913***	0.923***	-	-	-	-	-	-	-	-
P uptake	0.926***	0.957***	0.923***	-	-	-	-	-	-	-
K uptake	0.959***	0.982***	0.891***	0.925***	-	-	-	-	-	-
Plant Height	0.985***	0.980***	0.941***	0.958***	0.979***	-	-	-	-	-
Sucrose	0.928***	0.986***	0.939***	0.955***	0.960***	0.964***	-	-	-	-
TSS	0.189 NS	0.167 NS	0.237 NS	0.117 NS	0.198 NS	0.171 NS	0.228 NS	-	-	-
Purity	0.428*	0.431*	0.724***	0.490**	0.369*	0.466**	0.510**	0.315 NS	-	-
Yield	-0.039NS	0.063 NS	0.261 NS	0.089 NS	-0.034 NS	0.021 NS	0.071NS	-0.139 NS	0.514**	-

However, the sugar beet yield was significantly correlated only to the purity parameter strongly correlated to the N-uptake, P- and K-uptake, plant height and sucrose, then the B availability and uptake. So, enhancement of the estimated parameters may enhance the sugar beet yield by an indirect correlation under sandy soil conditions by the single and combined application of the mineral K-fertilization and/or the chitosan solution (seed soaking or spraying).

The calculated KAE in Table 6 and Figure 3 decreases by increasing the K-fertilization rate from 50% to 100% combined with the chitosan treatments except for the 75% RD rate. It may be due to the higher application rate not exactly reflected in the yield, which refers to partial wastage and loss of mineral fertilization. However, combining the 75% rate with the chitosan spraying repeatedly can be more agronomically efficient than soaking. About 25% of the 100% RD mineral fertilization can be replaced by spraying the chitosan solution as a suitable organic alternative without significant loss of the quality or yield attributes of the sugar beet under the studied conditions. The greater AE of spraying may be attributed to repeating the spraying after 50 and 70 days from cultivation during the plant growth stages rather than one soaking stage, which may beneficial for the plant progress. Utilization and uptake of the organic and mineral forms by the developed plant at 50 and 70 days of age perhaps increased the harvested yield more than one soaking stage far from the final mature plant (Waly *et al*., 2019). The seeds soaked in the organic chitosan solution may be subjected to osmotic pressure, which simulates the seeds' chemical and biological content and affects their equilibrium and membrane permeability. The nutrient uptake behaviour during the germination was affected (Waly *et al*., 2020).

Table 6. Potassium agronomic efficiency (KAE) relative to the mineral K_2O fertilization without chitosan

KAE	50% K_2O		75% K_2O		100% K_2O	
	Chitosan		Chitosan		Chitosan	
	Soak	Spray	Soak	Spray	Soak	Spray
Zero Chitosan (K-Control)	57.48	58.62	0.17	12.42	-9.71	-20.95

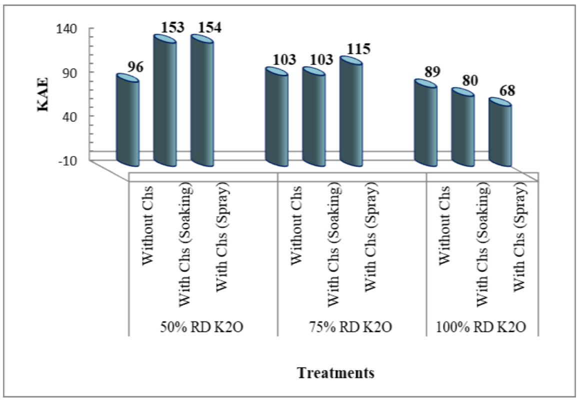


Figure 3. Potassium agronomic efficiency (KAE) compared to the control without addition of K-fertilization or chitosan

CONCLUSION

This study has shown that the single and combined application of the mineral K-fertilization, and soaking and/or spraying by the chitosan solution, has significantly improved the availability and uptake of the N-P-K nutrients under sandy soil conditions. Increasing the applied K_2O rate from 50% to 100% RD has increased the soil available (mg kg^{-1}) N-P-K and the sugar beet yield (Mg ha^{-1}) significantly by 18.1%. The combined application of 75% K_2O with soaking seeds has increased nutrient availability. The studied treatments have enhanced the estimated quality parameters of the sugar beet plant.

ACKNOWLEDGMENT

The authors wish to thank the Staff Members at the Ismailia Agricultural Research Station for their great assistance and support in conducting this experiment.

Conflict of interest

The authors declare that they have no conflict of interest.

Data availability

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study. All data generated or analyzed during this study are included in this published article

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كفاءة التسميد البوتاسى المعدنى مع النقع/الرش بمحلول الشيتوزان لتحسين إنتاجية بنجر السكر تحت ظروف التربة الرملية

نشوى محمد الشيخ ، محمد إبراهيم مُحَسِب ، مروة عبده أحمد و رامـا طلعت رشاد

معهد بحوث الأراضى والمياه والبيئة (SWERI) – مركز البحوث الزراعية (ARC) – الجيزة – مصر

الملخص

إن التوسُع فى إنتاج بنجر السكر فى الأراضى الرملية كأراضى مُستصلَحة مما يُوصَى به إلى حدٍ كبير, وتهدف هذه الدراسة إلى تقييم تأثير المعاملة المنفردة والمزدوجة للنقع و/ أو الرش بمحلول الشيتوزان مع التسميد البوتاسى المعدنى على تيسُر وإمتصاص عناصرالنيتروجين والفوسفور والبوتاسيوم وكذلك على إنتاجية بنجر السكر المُنزرع فى أرض رملية. أُقيمت تجربتان حقليتان فى تصميم قطع منشقة بثلاث مكررات حيث كان العامل الرئيسى هو التسميد البوتاسى المعدنى مُضافاً فى ثلاث معدلات ٥٠٪ و٧٥٪ و ١٠٠٪ من الجرعة المُوصى بها, بينما كان العامل تحت الرئيسى هو معاملات النقع و / أو الرش بمحلول الشيتوزان. بيَنت النتائج أن زيادة معدل البوتاسيوم مُعِبرا عنه بصورة أكسيد البوتاسيوم K_2O من ٥٠٪ إلى ١٠٠٪ أدى إلى زيادة المُيَسر فى التربة (مجم/كجم) من عناصرالنيتروجين والفوسفور والبوتاسيوم بنسبة ٥٤,٥–١٠٦,٧٪ و ٦٠,٦–١٤٠,١٪ و ١٥,٥–١٠١,٩٪ على التوالى, نسبةً إلى مُحتوى التربة الأوَلى قبل الزراعة . زادت إنتاجية بنجر السكر معنوياً بنسبة ١٨,١٪ عند مستوى معنوية $p \leq 0.05$. أدت الإضافة المزدوجة بمعدل ٧٥٪ بوتاسيوم K_2O مع نقع البذور إلى زيادة تيسُر المَغذيات بنسبة ٢٦,٢٪ (نيتروجين) و ٤١,٦٪ (فوسفور) و ٦٢,٥٪ (بوتاسيوم) نسبة إلى المعاملة بدون شيتوزان . يمكن التوصية بإستخدام معدل ال ٧٥٪ تسميد بوتاسيوم معدنى مع تكرار الرش بمحلول الشيتوزان لتحسين جودة وإنتاجية بنجر السكر تحت ظروف الأرض الرملية .