Sarcouncil Journal of Agriculture

ISSN(Online): 2945-3631

Volume- 02| Issue- 05| 2023

Research Article **Received:** 05-09-2023 | **Accepted:** 19-09-2023 | **Published:** 29-10-2023

Integration of Mineral Fertilization with Chitosan, K-Humate and K-Silicate to Enhance Nutrients Availability and their Uptake by Maize under Sandy Soil Conditions

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Abstract: This study aims to compare the effects of the combination between the mineral N-P-K fertilization and the foliar sprayed chitosan (Chs), potassium-humate (K-H), and potassium-silicate (K-Si) on the nutrients uptake by the maize crop planted in sandy soil. The field experiments were carried at the Ismailia agricultural research station (2022 and 2023 summer seasons). The experiments were conducted in a split-split plot design with three replicates. The main plots were presented as follows; 50%, 75% and 100% of recommended N-P-K doses. While, sub plots were assigned for foliar sprayed (control (CL), Chs, K-H and K-Si). Results have indicated that the most significant increase in the grains yield was by 76.5% for the Chs at the 50% rate and by 56.7% and 48.8% for the K-Si at the 75%, and 100% N-P-K, respectively. The highest significant available N concentration was by 71.4%, 70.5% and 33.1 for the Chs, obtained at the 75%, 50%, and 100% N-P-K rates, respectively. The Chs has showed the highest concentration of the soil-available P by 69.5% and 59% at the 100% and 50% N-P-K rates, respectively. The available K (mg kg^{-1}) in soil was varied significantly. The sprayed K-Si was almost the most significant treatment has increased the uptake (kg ha^{-1}) of the N, P, and K in the ranges 69.9 – 202.6%, 12.6 – 109.1%, and 71 – 99.9%, respectively, within the 50% – 100% range of the N-P-K mineral fertilization.

Keywords: *Chitosan; K-Humate; K-Silicate; Maize; Sandy Soil, Spray fertilization*.

INTRODUCTION

Soil degradation and/or pollution attributable to the concentrated fertilization by the inorganic chemicals usually accompany the crop production increasing requirements. Today, the worldwide orientation towards the agricultural sustainability encourages the use of environment-friendly alternating fertilizers out of the waste (Pandey, *et al*., 2018).

Chitosan (Chs) is a natural biopolymer extracted from the wastes of marines (Ahing and Wid, 2016; Burrows, *et al*., 2007; Ibrahim, *et al*., 2019). It is one of the most useful biodegradable and biocompatible materials widely applied due to the ease of modifications compared with other biopolymers such as starch, gelatine, and cellulose (Takarina and Fanani, 2017). Agriculturally, it has been used as bio-fertilizers and as coating films for seeds since the 1980s. It could be applied as a soil conditioner, foliar spray, and seed treatment to activate plant natural mechanisms. It was also used as a fertilizer to enhance crop growth because of its high nitrogen content and low C/N ratio. Chitosan is emerging as a growth promoter, antimicrobial agent, carrier for nutrients slow-release, increasing water use efficiency and as an absorbent of some heavy metals (Ali, *et al*., 2021; Jayanudin, *et al*., 2021).

The soil-applied Chs increased the content of nitrogen (N), phosphorus (P), potassium (K), total sugars, and soluble proteins as well as the total amino acids of radish. It also increased the leaf chlorophyll content and photochemical efficiency in many crops. Its application as a soil amendment at 0%, 0.05%, 0.10%, 0.15%, 0.20%, or 0.30% (w/w) has enhanced the lettuce (*Lactuca sativa*) growths. Chitosan at 0.05%, 0.10%, and 0.15% has increased the leaf fresh weight from 28.6 to 39.4, 39.1, and 39.8 g, respectively. Chitosan at 0.10%, 0.15%, 0.20%, and 0.30% increased the leaf chlorophyll index from 29.8 to 34.4, 35.4, 37.5, and 41.4, respectively. Chitosan applied in soil is known to be a coagulant that effectively increases the water stability of the soil aggregates with improving the soil water-holding capacity depending on the physicochemical properties of the Chs (Adamczuk, *et al*., 2021).

Chitosan foliar application has increased the stomatal conductance, abscisic acid (ABA) content and reduced the transpiration as a crop bio stimulant. It increased the activity of the leaf nitrate reductase in Indian spinach and okra. The foliar fertilizer containing high Chs content and a low concentration of microelements alone or in combination with the soil application has a significant effect on the growth, yield and biochemical characteristics of tomato fruits. Improved macronutrient (N and P) uptake was observed for wheat, potatoes, melon, begonia, chilli fruits and seeds. Chitosan concentration at 2-4 g/L affected the endogenous hormone content, alpha-amylase activity and chlorophyll content in

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DOI- https://doi.org/ 10.5281/zenodo.10063869

the maize leaves (Quynh, *et al*., 2020; Waly, *et al*., 2020; Waly, *et al*., 2019).

The suggested action mechanisms of Chs and its derivatives are metal-chelation interaction that exists between the poly cationic Chs and the poly anionic structures like lipo polysaccharides, proteins, and metal ions present in the cell wall and plasma membrane. The Chs cationic groups can bind the negatively charged phosphate groups of the DNA, which can result in specific modifications in protein expression (Burrows, *et al*., 2007).

On the other hand, fertilization with potassium humate (K-H) and potassium silicate (K-Si) has been well established to enhance the nutrients use efficiency (NUE), plant growth and quality as well as the soil physical and chemical properties (Bocharnikova, *et al*., 2010; Neu, *et al*., 2017; Tubana, *et al*., 2016). Silicon (Si) plays an important role in the nutrients uptake, plant growth and the photosynthetic reaction rate (Wang, *et al*., 2006). Long-term sprayed crops with the K-Si solution had been exhibited increased yield, yield components and all growth parameters (Abd El-Mageed, *et al*., 2016; Laane, 2018). The K-H has been improved the sandy soils' biological, physical, chemical properties, yield components and plant nutrients' content (Hussein and Hassan, 2011). Spraying with 4 cm L^{-1} K-Si and K-H had significantly increased the yield and its components, growth parameters and quality as well as the N-P-K contents in the straw and seeds of pea and maize under plant stress conditions (Ismail, *et al*., 2017).

This study aims to study the effect of the combination between the mineral N-P-K fertilization and the foliar sprayed chitosan (Chs), potassium-humate (K-H), and potassium-silicate (K-Si) on the yield and quality of maize cultivated in sandy soil. The nutrients use efficiency (NUE) was calculated and discussed.

MATERIALS AND METHODS

The chitosan (Chs, 5%), potassium-humate powder (K-H, 60%, 12% K_2O), and potassium-silicate K_2SiO_3 solution (K-Si, 10% K_2O, 25% SiO_2) used in the study were commercial grade solutions handled agriculturally for the crops cultivation.

The mineral N-P-K fertilization was using the ammonium sulphate (N), super phosphate (P), and potassium sulfate (K).

The experimental study (2022 and 2023 summer seasons) has been set at the Ismailia Agricultural Research Station, (30° 35' 30" N 32° 14' 50" E elevation 3 m) Agricultural Research Center (ARC). Testing results before cultivation of the field sandy soil (*Typic Torripsamment*; Entisol [Arenosol AR] (FAO, 2014) are presented in Table 1.

Table 1: Some characteristics of the studied experiment soil before cultivation

	Particle size distribution (%)			
Coarse sand		Fine sand	Silt	Clay
70.14		20.86	5.36	3.64
Texture class	$CaCO_3$ (%)	Organic Matter OM (%)	pH[†]	Electrical Conductivity EC (dS m^{-1})[‡]
Sandy	0.68	0.26	8.00	0.40
	Available nutrients (mg/kg)			
	N		P	K
	18.50		4.50	75.10

[†] (1:2.5 soil : water suspension) [‡] (1:5 soil : water extract)

The experiment layout and cultivation practices

The experiment area was laid out in a split-plot design with three replicates. Mineral N-P-K fertilization (main factor F1) i.e. 50%, 75%, and/or 100% fo the recommended doses (RD) of N-P-K (285.6 kg ha^{-1}, 16.1 kg ha^{-1}, and 95 kg ha^{-1}, respectively) .The sub-factor (F2) was the sprayed solutions Chs, K-Si, (4 ml L^{-1}) and K-H (4 g L^{-1})

Sowing of the maize grains (hybrid III - 321 white maize variety) was on the 1st of May (2022 and 2023) in ridges per plot (35 m^2) with 25-30 cm plant spacing. Irrigation was scheduled to meet the

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water requirements for maize (7865 m^3 ha^{-1}) at the field capacity of soil with its saturation percentage 18.7%. Fertilization and agronomic practices were following the Ministry of Agriculture recommendations.

The first spray on the soil and plants was done at 21 days after the cultivation and repeated every 10 days until the 80-day plant age. Each spray contained an applied dose of 4 ml L^{-1} (4 L per plot contained 16 ml from the stock solution) for the Chs, K-H, or K-Si.The total applied dose from each solution was 112 ml for the 7 sprays.. Harvesting of the maize crop was done at the 130-day plant age.

Sampling soil and plant

Representative samples from all plots were picked up after harvesting for testing and analysis (Black, 1965; Black, 1982). The yield (Mg ha^{-1}) of cobs and stover, grain yield (Mg ha^{-1}), cob weight (g), grains weight/cob (g) and the 100-seeds weight (g) were calculated based on the plot area data and the average of the two seasons was obtained.

Analysis of soil and plant N-P-K content

The available N-P-K in soil were extracted by 1% K_2SO_4, 0.5 N $NaHCO_3$, and 1 N NH_4OAc (pH 7.0), respectively (Jackson, 1973). Maize grains and Stover were dried at 70 ºC for 48 h and ground. A half gram of the ground grains and/or Stover was wet digested using the acid mixture (1:1 H_2SO_4/$HClO_4$) (Chapman and Pratt, 1961). Total concentrations of the N, P and K in plant and soil extracts were measured (by distillation: Kjeldahl apparatus, colorimetric: the UV-Vis Spectrophotometer, and by flame photometer, respectively) (Piper, 2019; Rayment and Lyons, 2010).

Nutrient Use Efficiency was calculated regarding the mineral N-P-K fertilization (Craswell and Godwin, 1984; Roozbeh, *et al*., 2011):

$$\textbf{Nutrient Use Efficiency (UE)} = \frac{(Pn_f - Pn_0)}{\textit{Fertilizer rate}\ (N, P\ or\ K, kg\ ha^{-1})} \times \mathbf{100}$$

$\mathbf{P_n}$ = grain N and/or P and/or K (g kg^{-1})

$\mathbf{P_{nf}}$ = grain N and/or P and/or K in fertilized plots — **f** = sprayed plots

$\mathbf{P_{n0}}$ = grain N and/or P and/or K in non fertilized plots — **0** = non- sprayed plots (CL treatments)

STATISTICAL ANALYSIS

The statistical significance (LSD) of the treatments effect was estimated at a significance level $P \leq .05$ by the two-way analysis of variance (ANOVA). The Correlation Coefficient ('r') as a measure of the linear association of two independent variables was also calculated using the Co-State software Package (Ver. 6.311), a product of Cohort software Inc., Berkley, California (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Effect of the studied treatments on the maize yield and some yield components

The studied Chs, K-H and K-Si have increased the maize yield (Mg ha^{-1}) both the grains and Stover significantly at $P \leq .05$ compared to the control (CL) as indicated by Table (2). This applies to the three application rates 50, 75, and 100% N-P-K mineral fertilization. The most significant increase in the grains yield was by 76.5% for the Chs at the 50% rate and by 56.7% and 48.8% for the K-Si at the 75%, and 100% N-P-K, respectively. The Stover yield has also increased most significantly by 128.5% for the Chs at 50% N-P-K and by 62.3% and 62.9% for the K-Si at the 75%, and 100% N-P-K, respectively. The individual effect of the mineral N-P-K or the sprayed solutions was independent of each other as their interaction was non-significant for the grains yield. On the other hand, the obtained significant variation in the stover yield was dependent on both factors F1 and F2 as their interaction was significant.

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Table 2: Effect of the mineral N-P-K fertilization and the foliar sprayed chitosan, K-humate and K-silicate on yield (Mg ha^{-1}) and its components of the maize crop (average of two seasons)

Treatment		Grains Yield (Mg ha^{-1})	Stover Yield (Mg ha^{-1})	Cob wt. (g)	Grains wt./Cob (g)	100-Grain wt. (g)
		50% N-P-K				
CL		2.00 ^{c}	2.53 ^{c}	141.78 ^{d}	124.88 ^{c}	41.39 ^{b}
Chs		3.53 ^{c}	5.78 ^{c}	191.08 ^{b}	162.17 ^{b}	43.31 ^{b}
K-H		2.63 ^{c}	3.16 ^{c}	170.95 ^{c}	165.79 ^{ab}	37.39 ^{c}
K-Si		3.17 ^{c}	4.03 ^{c}	186.16 ^{c}	159.23 ^{b}	40.83 ^{b}
		75% N-P-K				
CL		4.18 ^{b}	6.45 ^{b}	152.13^{d}	132.02 ^{c}	35.24 ^{c}
Chs		6.02 ^{a}	9.64 ^{a}	214.60 ^{a}	180.74 ^{a}	46.20 ^{a}
K-H		5.15 ^{a}	7.67 ^{b}	181.40 ^{c}	157.11 ^{b}	45.32 ^{a}
K-Si		6.55 ^{a}	10.66 ^{a}	198.73 ^{b}	168.40 ^{ab}	43.39 ^{b}
		100% N-P-K				
CL		4.65 ^{a}	7.01 ^{b}	178.82 ^{c}	154.13 ^{b}	45.49 ^{a}
Chs		6.12 ^{a}	9.51 ^{a}	227.89 ^{a}	190.94 ^{a}	42.71 ^{b}
K-H		5.16 ^{a}	8.51 ^{a}	196.97 ^{b}	167.08 ^{ab}	43.14 ^{b}
K-Si		6.92 ^{a}	11.42 ^{a}	209.08 ^{a}	177.41 ^{a}	41.58 ^{b}
F1	LSD	0.78	0.78	4.15	0.78	0.99
	SL	***	***	***	***	**
F2	LSD	0.62	0.76	4.85	0.62	1.86
	SL	***	***	***	***	*
F1*F2		ns	ns	*	*	***

F1: main factor (application rates of the N-P-K fertilizers), F2: sub-factor (spray treatments), LSD: least significant difference at $p \leq 0.05$, SL: Significance of Level, ns: non-significant.

However, the variations in the weights (g) of the cobs, grains in the cob, as well as the 100-grain were significant under the effect of the N-P-K mineral rates as well as by the effect of the sprayed Chs, K-H, and K-Si. The Chs has produced the maximum relative increase values of the cob weight and the grains weight per cob (g) by 34.8% and 29.9% at the 50% N-P-K rate and by 27.4% and 23.9% at the 100% N-P-K rate, respectively. At the 75% rate, the Chs has produced the maximum relative increase in the weight (g) of cob, grains per cob, and the 100-grain by 41.1%, 36.9%, and 31.1%, respectively.

Effect of the studied treatments on the macronutrients availability in soil

The variations in the N, P, and K concentrations (mg kg^{-1}) available in soil were significant regarding both the mineral N-P-K and the sprayed fertilizers compared to the CL. The highest available N concentration was by 71.4%, 70.5% and by 33.1% for the Chs, obtained at the 75%, 50%, and 100% N-P-K rates, respectively. Additionally, the Chs has showed the highest concentration of the soil-available P by 59% and 69.5% at the 50%, and 100% N-P-K rates, respectively. The available K (mg kg^{-1}) in soil was varied significantly because of the mineral N-P-K and the sprayed fertilizers. The K-Si has increased the available K significantly by 55.8%, 31% and by 12.3% at the 50%, 100%, and 75% N-P-K rates.

The increase/decrease of the available N, P, and K in the soil is dependent on the nutrient concentration released from the fertilizer and its uptake by the plant. The more efficient fertilizer provides the enough plant needs with sufficient concentration to maintain the nutritional status of the soil and avoid the disturbance in the nutrient equilibrium in the soil solution. Sometimes, the decreased available remaining after harvesting may refer to an improved uptake by the crop. The chemical composition of the Chs, K-H, and K-Si strongly controls the availability and uptake of the nutrients. The exact mechanism within the soil and plant matrices is not easy to define. But generally, the chemical structure enriched by the hydroxyl (-OH) and carboxyl (-COOH) in the Chs and that enriched by additional aromatic and phenolic groups in the humate offers a bio-compatible

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nutrients, which facilitate and improve their uptake by plant roots. Although the K-Si is mainly a mineral inorganic fertilizer, the Si role in improving the nutrients uptake can be comparable with that of the Chs and K-H.

Impact of the applied treatment on the N, P, and K uptake (kg ha^{-1}) by the maize plant

Increasing the rate of the N-P-K mineral fertilization has increased the uptake of the macronutrients by the maize grains significantly at *P≤ .05* in a comparison with the CL (Table 3). The sprayed K-Si was almost the most significant treatment has increased the uptake (kg ha^{-1}) of the N, P, and K in the ranges 69.9 – 202.6%, 12.6 – 109.1%, and 71 – 99.9%, respectively, within the 50% – 100% range of the N-P-K mineral fertilization. The second most significant treatment was the sprayed Chs that has increased the N and K uptake in the ranges 43.5 – 192.6% and 41.8 – 79.7%, respectively. The K-H has also increased the uptake of the N, P, and K in the ranges 31.5 – 68.9%, 16.9 – 19.9%, and 14.9 – 62.5%, respectively. Both factors F1 and F2 as well as their interaction F1 × F2 showed a significant effect on the nutrients uptake by the maize grains. Hence, their effects may be complementary to each other.

Table 3: Effect of the mineral N-P-K fertilization and the foliar sprayed chitosan, K-humate and K-silicate on macronutrient availability (mg kg^{-1}) and their uptake (kg ha^{-1}) in maize grains and Stover (average of two seasons)

Treatment		Soil-Available (mg kg^{-1})			Uptake (kg ha^{-1}) in maize grains			Uptake (kg ha^{-1}) in maize Stover		
		N	P	K	N	P	K	N	P	K
		50% N-P-K			50% N-P-K			50% N-P-K		
CL		20.0^{c}	6.1^{c}	93.1^{d}	14.0^{c}	5.1^{c}	5.5^{c}	11.2^{b}	4.9^{b}	12.3^{c}
Chs		34.1^{b}	9.7^{b}	102.6^{d}	20.1^{c}	4.5^{c}	9.1^{c}	25.6^{b}	6.8^{b}	26.8^{a}
K-H		20.2^{c}	7.7^{c}	119.7^{c}	18.4^{c}	6.2^{c}	6.4^{c}	15.4^{b}	3.1^{b}	12.7^{c}
K-Si		27.3^{c}	8.5^{b}	145.0^{a}	23.8^{c}	10.7^{b}	11.0^{c}	14.3^{b}	5.5^{b}	21.1^{bc}
		75% N-P-K			75% N-P-K			75% N-P-K		
CL		21.3^{c}	7.6^{c}	145.0^{a}	23.5^{c}	12.4^{b}	11.2^{c}	40.1^{a}	10.8^{a}	27.1^{a}
Chs		36.5^{a}	9.2^{b}	139.6^{b}	68.7^{a}	13.4^{a}	15.9^{ab}	42.7^{a}	10.3^{a}	16.7^{c}
K-H		22.5^{c}	8.5^{b}	151.5^{a}	37.8^{b}	14.9^{a}	14.5^{b}	34.0^{ab}	9.4^{a}	17.6^{c}
K-Si		26.6^{c}	11.3^{a}	162.8^{a}	53.7^{a}	13.9^{a}	20.7^{a}	56.7^{a}	10.3^{a}	53.7^{a}
		100% N-P-K			100% N-P-K			100% N-P-K		
CL		26.3^{c}	8.2^{b}	135.0^{b}	26.7^{c}	12.8^{b}	13.8^{b}	37.3^{ab}	11.4^{a}	27.1^{a}
Chs		35.0^{a}	13.9^{a}	141.7^{b}	74.1^{a}	18.4^{a}	24.8^{a}	59.1^{a}	6.7^{b}	28.0^{a}
K-H		31.1^{b}	8.5^{b}	154.1^{a}	45.0^{b}	15.0^{a}	22.5^{a}	37.7^{ab}	12.2^{a}	32.6^{a}
K-Si		32.1^{b}	12.3^{a}	176.8^{a}	80.7^{a}	18.5^{a}	23.6^{a}	50.6^{a}	9.9^{a}	23.4^{b}
F1	LSD	2.20	0.81	3.51	2.27	3.46	1.31	1.31	1.31	1.31
	SL	**	**	***	***	**	***	***	***	***
F2	LSD	2.52	1.07	2.99	1.75	1.62	2.19	2.09	1.62	2.09
	SL	***	***	***	***	***	***	***	ns	***
F1*F2		*	*	***	***	**	*	***	**	***

F1: main factor (application rates of the N-P-K fertilizers), F2: sub-factor (spray treatments), LSD: least significant difference at p ≤ 0.05, SL: Significance of Level, ns: non-significant

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Table 4: The Correlation Coefficient ('r') between the yield (Mg ha^{-1}) of maize Cobs and/or Stover with the nutrients use efficiency (NUE)

	NUE	PUE	KUE
Cobs Yield (Mg ha^{-1})	0.293	-0.218	0.012
	ns	ns	ns
Stover Yield (Mg ha^{-1})	0.248	-0.303	-0.046
	ns	ns	ns
PUE	0.068	-	-
	ns		
KUE	-0.135	0.729	-
	ns	*	

The N-P-K uptake by the Stover has been varied significantly under the effect of the studied treatments with an irregular behavior. This can be dependent on the absorption equilibrium of nutrients by the maize plant and their distribution mechanism between the plant organs. Also, both factors F1 and F2 (except for the P vs F2) as well as their interaction F1 × F2 showed the significant effect on the nutrients uptake by the maize Stover.

Economic efficiency

If a unit of fertilizer does not increase the yield enough to pay for its cost, its application will not be gainful. So, calculating the economic efficiency is important to present recommendations based on field experiments results. Efficiency is the general term used to state the condition where the maximum amount of output is produced for a specific amount of input. A process is efficient when it produces the maximum return from a definite bulk of raw material or effort.

Economic Analysis

The first step is calculating the costs for each treatment. The total production costs include variable costs and the fixed costs. The variable costs are the average costs of for example land preparation, purchased inputs, labour, irrigation, employee and machinery. Calculations are based on the average price of inputs during the years of the study. The second step is calculating the gross benefit for each treatment by multiplying the yield quantity by the unit price. The yield consists of two components, seeds and Stover. The gross return is equal to the grain value in addition to the Stover. The third step is calculating the net return using the total approach by subtracting total costs from the gross benefit.

The efficiency indicators are presented in Table 5. The economic return of the study was evaluated depending on the total average costs of the cultivation season versus the total average prices of the yield (Mg ha^{-1}) including the maize cobs and Stover. Data indicates an increased return (L.E. ha^{-1}) with increasing the mineral fertilization from 50% to 100% N-P-K RD. The sprayed Chs can increase the return by 115.5, 52.8, and 35.5% for the 50, 75, and 100% N-P-K RD, respectively. The K-H can increase the return by 9.6, 23.1, and 8.9% for the 50, 75, and 100% N-P-K RD, respectively. The K-Si can increase the return by 90.9, 74.1, and 61.6% for the 50, 75, and 100% N-P-K RD, respectively.

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Table 5: Economic efficiency calculations for the economic variables of the studied treatments for maize cultivation in sandy soils

Treatment	Applied rate (kg or L/ha)	Price of 1 kg or L	Yield (Mg ha^{-1})		Costs (L.E. ha^{-1})				Total Costs (L.E. ha^{-1})	Price (L.E.)		Return (L.E. ha^{-1})
			Cobs	Stover	N-P-K Fertilization	Spray Fertilization	Field Practices	Irrigation		Cobs	Stover	
						50% N-P-K						
CL	-	-	2.29	2.53	3820.2	-	16666.7	7200	27686.9	22900.0	379.5	-4407.4
Chs	32	150	4.16	5.78		4800			32486.9	41600.0	867.0	9980.1
K-H		100	2.72	3.16		3200			30886.9	27200.0	474.0	-3212.9
K-Si		100	3.72	4.03		3200			30886.9	37200.0	604.5	6917.6
	Mean		3.22	3.88		75% N-P-K			30486.9	32225.0	581.3	2319.4
CL	-	-	4.81	6.45	5730.3	-	16666.7	7200	29597.0	48100	967.5	19470.5
Chs	32	150	7.16	9.64		4800			34397.0	71600	1446.0	38649.0
K-H		100	5.95	7.67		3200			32797.0	59500	1150.5	27853.5
K-Si		100	7.76	10.66		3200			32797.0	77600	1599.0	46402.0
	Mean		6.42	8.61		100% N-P-K			32397.0	64200.0	1290.8	33093.8
CL	-	-	5.41	7.01	7640.4	-	16666.7	7200	31507.1	54100	1051.5	23644.4
Chs	32	150	7.29	9.51		4800			36307.1	72900	1426.5	38019.4
K-H		100	6.07	8.51		3200			34707.1	60700	1276.5	27269.4
K-Si		100	8.16	11.42		3200			34707.1	81600	1713.0	48605.9
	Mean		6.73	9.11					34307.1	67325.0	1366.9	34384.8

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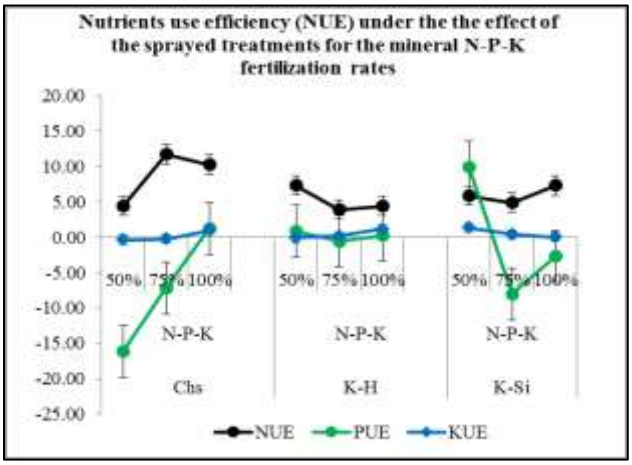

Figure 1: Nutrients use efficiency (NUE) under the effect of the mineral N-P-K fertilization and the foliar sprayed treatments

DISCUSSION

The use efficiency (UE, %) of the N, P and K nutrients that are released from the mineral fertilization with increasing the rate from 50% to 100% RD was calculated and plotted in Fig. 1. The maximum NUE was obtained by Chs at the 75% rate, by K-H at the 50% while by the K-Si it was at the 100% rate. The maximum PUE was obtained by the Chs at the 100% rate, but by the K-H and/or K-Si it was at 50% rate. Additionally, the maximum KUE was obtained at the 100% by the sprayed Chs and/or the K-H and obtained at the 50% rate by the K-Si.

However, the yield values of the maize cobs and/or Stover were not correlated to the nutrients UE as indicated by Table 4. Non-significant correlation coefficient r values were found between the yield (Mg ha^{-1}) with the NUE, PUE, or KUE. A weakly significant correlation was observed between the PUE and the KUE under the effect of the studied treatments.

The macronutrients quickly released by the mineral fertilizers are utilized by the plant under the effect of the sprayed fertilizers. The carboxylic (—COOH), hydroxyl (—OH), humate, and silicate (SiO_4^{-2}) functional groups usually interact with the solubilized nutrients and form bio-compatible chemical forms of the N, P, and K (Pandey, *et al*., 2018; Waly, *et al*., 2019). They are absorbed almost with the same efficiency. The mechanism of the absorption and utilization by plant is often comparable for the Chs, K-H, and K-Si. Although the UE of the macronutrients was not correlated to the yield, their uptake was significantly different between the Chs, K-H, and K-Si. It can be said that the Chs, K-H, and K-Si are similar in their effect on the macronutrients UE depending on the N, P, and K concentrations in the soil as available and the plant (grains and Stover). The significant difference in the yield (Mg ha^{-1}) between treatments may be related to a physiological role of the different functional groups [—COOH, —OH, humate, and SiO_4^{-2}] within the plant matrix. Such physiological action affects the growth steps including the germination percentage and plant development. This in turn, may affect the number of plants in the planted area and the number of cobs in the plant resulting in significant differences in the yield. The intensified maize crop yield (grains and Stover) under the studied treatments almost follows the order: 100% (N-P-K) > 75% (N-P-K) > 50% (N-P-K) and at the rate 100%, the order K-Si > Chs > K-H (Bocharnikova, *et al*., 2010; Neu, *et al*., 2017; Tubana, *et al*., 2016).

CONCLUSION

Three types of commonly used fertilizers that are Chs, K-H, and K-Si were compared for their efficiency in enhancing the yield of the maize crop under sandy soil conditions with the use of the N-P-K mineral fertilization (50%, 75%, 100% RD). Their effect of the soil available N, P, and K was non-significant except for the K (mg kg^{-1}) being an additional soluble dose contained in the K-H and K-Si. Although the N-P-K availability was non-significantly varied, their uptake and consequently the yield of the maize grains and Stover were improved significantly as affected by the studied treatments. Increasing the fertilization rate of the mineral N-P-K from 50% to 100% RD has markedly increased the maize yield. At the 100% rate, the K-Si was the most efficient followed by the Chs then the K-H in increasing the yield both the grains and Stover. This effect can be attributed to the physiological role of the Si as a nutrient that succeeded compared with the organic carboxylic Chs and/or humate. The K-Si and/or Chs may be more recommended than the K-H at the 75% and 100% RD of the mineral N-P-K fertilization for the maize cultivation in sandy soil.

ACKNOWLEDGMENTS:

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

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Source of support: Nil; **Conflict of interest:** Nil.

Cite this article as:

Abd El-Rahman, Z.M., Mohamed, M.S. and Rashad, R.T. "Integration of Mineral Fertilization with Chitosan, K-Humate and K-Silicate to Enhance Nutrients Availability and their Uptake by Maize under Sandy Soil Conditions."*Sarcouncil Journal of Agriculture* 2.5 (2023): pp 1-10.

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