

Nutrient use Efficiency in Calcareous Soil Amended by the Silicate, Humate and Compost

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Authors' contributions

This work was carried out in collaboration between both authors DHS and RTR. Both authors designed the study, designed the experimentation and managed the laboratory analyses of the study. Author DHS followed up the field-work. Author RTR organized the literature survey, performed the statistical analysis and drafted the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: A study was carried out in the field aims to study the response of a calcareous soil cultivated by soybean to the application of K-silicate (K-Si), K-humate (K-H), and compost at application rates 50% and 100% of the recommended dose.

Study Design: Complete randomized block design with three replicates.

Place and Duration of Study: At El-Nubaryia Agricultural Research Station (latitude of 30° 30'N longitude of 30° 20'E) Agricultural Research Center (ARC), Nubaryia, Egypt (Summer seasons of 2018 and 2019).

Methodology: Compost was mixed with surface soil a week before cultivation at application rates 3.75 and 7.5 kg plot⁻¹ (3.91 and 7.81 t ha⁻¹, respectively). Powder K-H was spread on soil at application rates 7.5 and 15 g plot⁻¹ while aqueous solutions of K-Si; 8 and 16 mL L⁻¹ for plot was sprayed on soil 30, 60, and 90 days after cultivation.

Results: Results showed that soil moisture (SM, %) was increased by the 100% application rate in the order compost (20.6%) > K-Si (19.3%) > K-H (19.1%). A significant increase was found in the seed yield (kg ha⁻¹) by 129.5%, 84.8% and 70.6% by compost, K-H and K-Si, respectively. Compost at 100% application rate showed the most significant increase in the available nitrogen N (mg kg⁻¹) in soil by 104.4% followed by K-H (by 81.8%) then K-Si by 23.4%. Compost also showed

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the most significant increase in the N uptake from soil (kg ha^{-1} soil) by seeds and straw followed by K-H then K-Si. The nutrient use efficiency (NUE, %) and agronomic efficiency (AE) values decreased in the order K-H > K-Si > compost at 50% and 100% application rates.

Conclusion: The quite smaller dose and ease of field application by spraying may make the K-H more agronomically efficient than K-Si and compost.

Keywords: Agronomic Efficiency (AE); soybean; soil moisture; soil amendments.

1. INTRODUCTION

High CaCO_3 percentage along with low organic matter content of calcareous soils often restricts plant nutrient availability [1]. Improving the nutritional status and crop productivity of such soil is an important demand [2]. This type of soil is widely distributed over the desert area at the west Nile Delta of Egypt at the west of Nubaryia, Alex.–Cairo desert road. Reclamation of this region has been started since 1969 to increase its agricultural sustainability and productivity hindered by problems of water logging and salinization [3]. Soil mapping and satellite images have indicated deteriorated surface soil with non-saline calcareous loam deep soils comprise 15.2% unit area [4]. Remote sensing and geographical information systems GIS images of the cultivated land and surface water logging reveal degraded soils [5].

The use efficiency of fertilizers and soil amendments depends on factors related to the fertilizer itself, the growing crop, and mainly to the soil environment. Immediate recovery of a nutrient from a fertilizer by plants after it is applied to low fertility soils is usually less than required. This low initial efficiency of some fertilizers can be attributed to leaching loss, conversion of available form to less available forms in soil, strong retention by soil mineral surfaces (adsorption), precipitation of ionic soluble forms into insoluble ones, etc.

Recovery of an applied plant nutrient, X, could be calculated by the difference between the uptake of X by a crop received the applied amount of X minus the uptake by crop not received the applied amount of X. The method is generally suitable for N fertilizers and more limited for P and K. This is because applied inorganic N fertilizers rarely remains as a residue of in the soil after crop harvest and lost by leaching or denitrification and ammonium by volatilization [6,7].

However, the nutritional status of soils is increased by fertilizers and amendments. Plants

take up nutrients like N, P, and K from seasonal application of fertilizers as well as the residual in the soil from previous fertilization so that apparent nutrient efficiency often increases. Nevertheless, this is not always the case for some soil types such as calcareous soils. Significant increases in fertilizer use efficiency can be achieved by different fertilizer formulations, altering the rate and time of application, altering placement in the soil and matching with suitable crop species or varieties [8].

Soybean (*Glycine max* L.) is an essential crop agriculturally and scientifically [9]. Biotic and abiotic factors negatively affect soybean production in Egypt that was decreased by 57.79% from 1993 to 2008 [10,11]. Foliar application of micronutrients (Fe, Zn, Mn and B) and/or organic manure to soybean has enhanced the seed yield and quality [12,13].

Recent promising studies have showed the impact of Si fertilization using silica amendments on the yield quantity and quality of cereals like soybean. Foliar application of potassium silicates provide highly soluble potassium (K) and silicon (Si) for plants and had showed a bio-simulative effect under salt stress conditions [14] and water deficiency [15]. Sodium meta-silicate (Na_2SiO_3) enhanced K use efficiency and ameliorated symptoms caused by deficiency in essential nutrients [16,17].

Soil applied Si-fertilizers have enhanced Si uptake by plants and increased soybean yields by 7.5–13.6% [18]. Fertilization by potassium meta-silicate (K_2SiO_3 , 12 kg ha^{-1}) has increased the concentration of K^+ in the wheat [19]. Fertilization by Si enhanced plant phosphorus (P) utilization. Absorption through roots may be the only Si-uptake mechanism by some plants [20]. Continuous cultivation of such crops consumes plant-available Si in soils that can be depleted via crop uptake and by leaching [21].

In addition, humic substances (HS) are natural organic fertilizers can improve soil physically,

chemically, and microbiologically [22]. Fertigation by HS along with NPK fertilizer decreased leaching of N and K and increased soil available P [23]. Foliar application of HS is a commonly used agricultural practice because of their hormone-like role in growth promotion and improving plant yield and quality [22]. Humates salts are more soluble component of HS. Commercial K, Ca, B, and Na humates can be used as “soil conditioners” to enhance soil structure and water retention capacity [24]. Iron-humates have been applied to Fe-deficient soybean plants to supply nutritional iron (Fe) in calcareous soils [25]. Potassium humate solutions mitigate the uptake of nutrients by plant [26].

Compost is one of the humic-rich-amendments sometimes better than humates that are easily leached by irrigation and rainfall. Compost is resulted from the controlled biological decomposition of organic resources. Its organic matter content enhances soil chemical, physical and biological properties [27,28]. Despite compost is not a fertilizer, it can reduce the required dose of fertilizer, suppress soil-borne plant pathogens and efficient in improving plant growth [29].

Use efficiency indices have been suggested to indicate the impact of applied nutrient on productivity. Nutrient use efficiency (NUE) and agronomic efficiency (AE) calculations may refer to the fertilizer/amendment efficiency based on the increase in crop yield per unit nutrient applied [30]. This study aims to answer the question: Which is more efficient for soybean crop cultivated in a calcareous soil; compost, potassium humate (K-H), or potassium silicate (K-Si)? Comparison between the macronutrient use efficiency indices calculated for the mentioned additives may help in answering the question.

2. MATERIALS AND METHODS

2.1 Area of the Study

The field study has been carried out (summer seasons of 2018 and 2019) at El-Nubaryia Agricultural Research Station (latitude of 30° 30'N longitude of 30° 20'E) Agricultural Research Center (ARC), Nubaryia, Egypt. The studied soil is Sandy Clay Loam consists of 48.4% Sand, 28.1% Silt, and 23.5% clay. It is a calcareous soil [Aridisol] [3,31] under an arid climate with hot dry summers and cool winters.

Some properties of the soil of the experiment are presented in Table 1.

2.2 Materials Used in the Study and Planting

The additives under study were potassium silicate (K-Si), potassium humate (K-H) and compost. Potassium silicate (K-Si) was commercial liquid K_2SiO_3 [10% K_2O , 25% SiO_2]. Potassium humate was commercial powder 60% K-H [7% K_2O], while compost was a commercial product for agricultural use (Sharqyia Compost; thermally treated organic fertilizer). Some characteristics of the studied additives are presented in Table 1.

They were applied to the experiment soil at 50% and 100% of the recommended dose by the manufacturer, which is for K-Si: 16.67 L ha^{-1} , K-H: 15.63 kg ha^{-1} , compost: 7.81 t ha^{-1} . Compost was mixed with surface soil a week before cultivation at application rates 3.75 and 7.5 kg $plot^{-1}$ (3.91 and 7.81 t ha^{-1} , respectively). Powder K-H was spread on soil at application rates 7.5 and 15 g $plot^{-1}$ while aqueous solutions of K-Si; 8 and 16 mL L^{-1} for plot was sprayed on soil 30, 60 and 90 days after cultivation. Different treatments including a control (without additives) were added in triplicates with a complete randomized block design.

Three soybean seeds (Giza 111 variety) were hand-sown in each hole along the ridge, in four ridges per plot (on the 1st of June 2018 and 2019) (3.2 m × 3 m = 9.6 m² plot area, 4 ridges). All experimental plots except the control have received 25% N-P-K recommended fertilizer dose. The complete recommended dose of the N-P-K fertilizer was applied to the control plots. Irrigation of the cultivated experiment area was scheduled 30, 60, and 90 days after sowing. Soil moisture (SM, %) was measured before and 48 h after irrigation by core method [32] and calculated according to the Eq. (1):

$$\text{Soil moisture of soil sample (SM, \%)} = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight of soil sample}} \times 100 \quad (1)$$

2.3 Soil and Plant Sampling

At harvesting, representative samples for soil and plant were randomly selected from all experimental plots then air-dried to record the following measurements: plant height (cm),

number of branches/and number of pods per plant, number of seeds per plant, 100-seed weight (g), seed yield plant⁻¹ (g), and shelling (%). The seed yield (t ha⁻¹) has been calculated based on the seed yield per plot area and the mean value of data of the two seasons was recorded. Data were composed by two applications (each year) of the treatments.

2.4 Estimation of N, P and K Content in Soil and Plant Samples

The available concentrations of N, P, and K in soil were extracted by 1% K₂SO₄, 0.5 N NaHCO₃, and 1 N NH₄OAc (pH 7.0), respectively [33,34]. Seeds of soybean were dried at 70°C for 48 h then ground. About 0.5 g of ground seeds was solubilized in 1:1 H₂SO₄/HClO₄ acid mixture [35]. Estimation of the total concentrations of N, P and K in the plant and soil extracts was carried out using Kjeldahl, UV-Vis Spectrophotometer and flame photometer, respectively. Concentrations of Cu, Fe, Mn, Zn, and Si in seeds' extract were measured by the ICP Spectrometry (ICP-*Ultima 2 JY Plasma*). Uptake (kg ha⁻¹) of macro- and micro-nutrients from soil was calculated by multiplying nutrient content (%) by Seed and/or straw yield (kg ha⁻¹).

2.5 Nutrient Use Efficiency Indices

Use efficiency (UE) also expressed as apparent recovery (AR) as well as agronomic efficiency (AE) for applied N, P and/or K were calculated by Eq (2) [36,37]:

$$\text{Nutrient Use Efficiency (UE/AR)} = \frac{(P_{nf} - P_{n0})}{\text{Fertilizer rate (N,P or K, kg ha}^{-1})} \times 100 \quad (2)$$

P_n = seed nitrogen (N, g kg⁻¹), phosphorus (P, g kg⁻¹) and/or potassium (K, g kg⁻¹)

P_{nf} = seed nutrient in fertilized plots f = fertilized plots (by K-Si, K-H, or Compost)

P_{n0} = seed nutrient in non fertilized plots 0 = non-fertilized plots (control treatments)

$$\text{Agronomic Efficiency (AE)} = \frac{Y_f - Y_0}{\text{Fertilizer rate (N,P or K, kg ha}^{-1})} \quad (3)$$

Y = seed yield (kg ha⁻¹)

2.6 Statistical Analysis

The one-way analysis of variance (ANOVA) test was used to calculate the statistical significance

(LSD) of the resulted data at a significance level $P = .05$ using the Co-State software Package (Ver. 6.311) [38].

3. RESULTS AND DISCUSSION

3.1 Effect of Different Additives on Soil Moisture (SM, %) before and after Irrigation

The moisture content (%) of the calcareous soil under study was affected by soil application of K-Si, K-H, and compost as shown by Fig. 1 (a-c). Soil moisture (SM, %) has increased after 1st, 2nd and 3rd irrigation when application rate was increased from 50% to 100% of the recommended dose. A slight decrease in SM at 50% application rate compared to the control, which may be caused by filling some soil voids and water storing pores by additive particles leading to shrinkage and a change in pore size distribution. At 100% application rate, the increase in SM behaved the order K-Si (48.1%) > K-H (40.4%) > compost (37.1%) in case of the 1st irrigation (30 days after sowing). It may be due to two reasons: one is the application of K-Si and K-H on soil in the form of aqueous solutions while the compost was in a dry form, and the second is the swelling and hydrophilic nature of silicate and humate moieties. Therefore, keeping moisture can be in a faster rate for soil mixed with K-Si and K-H than mixed with compost that is of complex components slowly decomposed. Humate ligand may react with soluble ions in soil solution that can partially block some carboxylic (—COO⁻) and hydroxylic (—OH⁻) and limit their reaction with water compared to the silicate [23].

After 60 days at 2nd irrigation (Fig. 1b), continuous and slow decomposition of compost may exposed many of its hydrophilic constituents so that the SM increased in the order compost (65.9%) > K-Si (55.0%) > K-H (45.1%).

In case of the 3rd irrigation after 90 days of sowing, equilibrium is almost attained with more decomposition of compost and accumulation of silicate and humate in soil near the complete dose of application. Soil moisture increased in the order compost (20.6%) > K-Si (19.3%) > K-H (19.1%). It is worth to mention that the method of application plays a role in the final effect of additives on the estimated properties of soil. Silicate and humate doses were added to soil divided in three consecutive applications due to their fast effect and rapid consumption [20,22]. Compost was added to soil once due to its long-

term effect and slow-decomposition and release behavior [29,39].

3.2 Effect of Different Treatments on Soybean Yield (kg ha^{-1}) and Some Components

Table 2 indicates significant improvement in the parameters of soybean yield at a significance level $P = .05$ compared to the control. Plant length (cm), no. of shoots, no. of pods, no. of seeds, seed yield (kg ha^{-1}), 100-seed wt. (g), and shelling (%) have significantly increased compared to the control as the application rate increased from 50% to 100% of the recommended dose for K-Si, K-H, or compost. At 100% rate, compost resulted in the most significant increase by 100.3%, 147.4%, 212.4%, 129.5%, 68.1% and 27.2% for the no. of shoots, no. of pods, no. of seeds, seed yield (kg ha^{-1}), 100-seed wt. (g) and shelling (%), respectively, compared to control. Seed yield (kg ha^{-1}) has increased significantly by 84.8% and 70.6% by K-H and K-Si, respectively, compared to control. Studies referred to that yield components of soybean enhanced by Si application [19].

Such effect on yield and its components can be attributed to the biocompatible organic nature of compost and K-H, being rich in available nutrients for plant absorption compared to the inorganic K-Si limited to available K and Si. Compost may exhibit a slow release of nutrients as well as improved soil moisture make it succeeds over the K-H [29,40]. Humates and silicates also enhanced water retention capacity of soil as mentioned above but less than the compost [20,24].

3.3 Effect of Different Treatments on Nitrogen (N, mg kg^{-1}) Status in Soil and Uptake (kg ha^{-1}) by Soybean Plant

Table 3 indicates a significant increase in the available N (mg kg^{-1}) in soil, total (g kg^{-1}) in soybean seeds and straw and uptake (kg ha^{-1} soil) compared to the control at significance level $P = .05$ under the effect of different treatments. Compost at 100% application rate showed the most significant increase in the available N (mg kg^{-1}) in soil by 104.4% followed by K-H (by 81.8%) then K-Si by 23.4%, compared to the control. In addition, compost showed the most significant increase in the N uptake (kg ha^{-1} soil) by seeds and straw (by 222.5 and 285.7%)

followed by K-H (by 91.6 and 180.7%) then K-Si (by 63.7 and 151.4%), respectively.

This trend is in agreement with the applied N (kg h^{-1}). Treatments of the studied additives were enriched by 25% of the N-P-K mineral fertilizer recommended dose while the control treatment has received the full dose. Obviously, K-Si, K-H and compost may enhanced the utilization efficiency of the N nutrient with compost being the most effective perhaps due to its long-term stability in soil and greater application dose. Compost can act as a supportive carrier for mineral fertilizers, which increase its efficiency compared to soluble humate and silicate salts quickly lost by leaching from soil [27,28].

3.4 Effect of Different Treatments on Phosphorus (P, mg kg^{-1}) Status in Soil and Uptake (kg ha^{-1}) by Soybean Plant

As observed from Table 4, increasing the application rate of K-Si, K-H, or compost from 50% to 100% increased the available P (mg kg^{-1}), total content in plant (g kg^{-1}) and uptake from soil compared to the control. Non-significant increase in the available P (mg kg^{-1}) in soil was recorded for compost by 54.6%, for K-Si by 18.3% and for K-H by 9.1% at 100% application rate. Also, the compost showed the most significant increase in the total P content in seeds (by 24.8%) and straw (by 169.6%) and its uptake 187% and 516.7% for seeds and straw, respectively. Potassium humate and K-Si have increased the seeds' P by 16.4% and 16%, respectively, compared to the control. Normally, this trend is related to total applied P (kg ha^{-1}) from different additives depending on the P content (g kg^{-1}) in the compost, K-H and K-Si shown in Table 1. Although the applied P by K-H and K-Si is very small compared to the compost, they increased the P content in plant and its uptake from soil. This ensures the role played by the humate and silicate ligands which increase the available N-P-K in soil and enhances the nutrients absorption by plant [18,19,23,26].

3.5 Effect of Different Treatments on Potassium (K, mg kg^{-1}) Status in Soil and Uptake (kg ha^{-1}) by Soybean Plant

Dynamic of the potassium K nutrient is also related to its content in the K-Si, K-H and compost.

Compost is still showing the most significant increase in the K content and uptake for soybean seeds and straw. Table 5 shows that K-Si applied at 100% of the recommended dose has increased the soil available K (mg kg^{-1}) more than the K-H, but the increase is non-significant compared to the control. This is because of the higher K applied by the K-Si than K-H. Nevertheless, K-H increased the total K (g kg^{-1}) in seeds and straw (by 35.6% and 224.8%, respectively) significantly at $P = .05$ compared to the control more than K-Si (by 24.3% and 215.9%, respectively). Also, K-uptake by seeds has increased by 150.6% and 112.1% for K-H and K-Si, respectively. This may be due to the biocompatibility of the organic K-H that enhances the nutrient utilization and absorption by plant better than the pure mineral K-Si [23,26].

3.6 Effect of Different Treatments on the Uptake (kg ha^{-1}) of Micronutrients from Soil by Soybean Seeds

As it can be seen from Table 6 that the uptake of Cu, Fe, Mn, Zn, and Si (g ha^{-1}) by soybean seeds has increased significantly at $P = .05$

compared to the control as the application rate was increased from 50% to 100% for K-Si, K-H, and/or compost. In 100% doses, the K-H showed the most significant increase in the Fe uptake by 149.9% followed by the compost (by 121.6%) then the K-Si (by 50.7%). It can be attributed to the organic nature of the humate and compost, presence of complexed micronutrients including the Fe in their chemical composition as well as the higher solubility of the humate salt, which enhance the complexation and absorption of Fe by plant. Such results agree with previous studies on calcareous soil [25].

The K-Si has increased the uptake of Si by seeds significantly by 169.7% more than K-H (increased by 128%) but less than the compost (increased by 217.5%) compared to the control. It may be caused by the higher Si content applied from K-Si more than K-H. The readily soluble and more available Si from K-Si perhaps partially lost by leaching or fixed in soil while Si from the compost can be slowly released. The hormone-like role of the silicate and humate is often responsible for the enhanced micronutrient uptake by soybean from soil under study [41].

Table 1. Characteristics of the experiment soil before cultivation and materials applied

	pH	EC (dS m^{-1}) [†]	Organic Matter % OM	CaCO ₃ (%)	Available in soil (mg kg^{-1})					
					N	P	K	Fe	Mn	Zn
Soil	8.3	2.66	1.3	23.66	13.4	4.0	195.0	5.0	1.23	2.9
					Total, g kg^{-1}					
K-Silicate	7.0	7.00	-	-	-	-	83.0			
K-Humate	7.4	19.05	16.89	-	20.20	12	62.0			
Compost	8.5	2.67	11.30	-	13.44	7.0	12.0			

[†] (1:5 soil: Water extract)

Table 2. Soybean yield and yield components under the effect of treatments

Treatment	Application rate	Plant length (cm)	No. of Shoots	No. of Pods	No. of Seeds	Seed yield (kg ha^{-1})	100-seed wt. (g)	Shelling (%)
K- Si	Control	75.16 ^c	3.19 ^d	30.28 ^e	53.05 ^f	1556.44 ^f	11.09 ^d	30.94 ^d
		89.00 ^b	5.02 ^{bc}	37.92 ^d	69.72 ^e	2218.68 ^e	12.04 ^{cd}	33.24 ^{cd}
		98.08 ^b	4.33 ^{cd}	49.55 ^c	75.39 ^e	2436.85 ^d	13.02 ^c	31.31 ^d
K- Si	50%	94.61 ^b	5.11 ^{abc}	52.91 ^c	115.17 ^b	2820.50 ^b	15.52 ^b	34.22 ^{bc}
		95.11 ^b	5.22 ^{abc}	49.28 ^c	95.17 ^c	2655.57 ^c	13.88 ^{bc}	36.45 ^b
		116.22 ^a	6.28 ^{ab}	57.11 ^b	88.97 ^d	2876.31 ^b	15.01 ^b	34.88 ^{bc}
K- Si	100%	109.39 ^a	6.39 ^a	74.92 ^a	165.72 ^a	3571.67 ^a	18.64 ^a	39.35 ^a
		9.51	1.34	3.80	5.71	134.48	1.90	1.76
		L.S.D 5%						
Significance of factors [†]		***	**	***	***	***	***	***

[†]The footnotes (a-h) indicate the non-significance ranges for the different treatments

Table 3. Effect of treatments on the plant available N (mg kg^{-1}) in soil and N content (g kg^{-1}) and uptake (kg ha^{-1}) by soybean seeds and straw

Treatment	App. rate	Applied N (kg ha^{-1})		Available in soil (mg kg^{-1})	Total (g kg^{-1})		Uptake (kg ha^{-1})	
		By Treat. [†]	Total		In seeds	In straw	By seeds	By straw
Control	50%	0.0	41.4	19.16 ^{bc}	25.1 ^e	8.96 ^f	3.91 ^g	3.11 ^c
K- Si		-	10.4	14.68 ^{bc}	23.8 ^g	12.88 ^e	5.28 ^f	5.74 ^b
K-H		0.16	10.5	26.55 ^{ab}	27.8 ^d	13.44 ^d	6.77 ^d	7.19 ^{ab}
Compost		52.5	62.8	16.92 ^{bc}	32.3 ^c	15.12 ^b	9.11 ^c	8.20 ^a
K- Si	100%	-	10.4	23.64 ^{abc}	24.1 ^f	13.26 ^e	6.40 ^e	6.14 ^b
K-H		0.32	10.7	34.84 ^a	26.04 ^d	13.66 ^c	7.49 ^b	7.34 ^{ab}
Compost		104.9	115.3	39.16 ^a	35.3 ^a	16.00 ^a	12.61 ^a	8.81 ^a
		L.S.D ^{5%}		12.3	0.010	0.011	0.005	1.90
Significance of factors [‡]				*	***	***	***	***

[†]Recommended application rates for compost: 7.81 t ha⁻¹, potassium silicate: 16.67 L ha⁻¹, potassium humate: 15.63 kg ha⁻¹, Total applied = Application rate + 25% NPK Recommended (kg ha^{-1} : N= 10.35, P= 3.39, K= 7.47)

[‡]The footnotes (a-h) indicate the non-significance ranges for the different treatments

Table 4. Effect of treatments on the plant available P (mg kg^{-1}) in soil and P content (g kg^{-1}) and uptake (kg ha^{-1}) by soybean seeds and straw

Treatment	App. rate	Applied P (kg ha^{-1})		Available in soil (mg kg^{-1})	Total (g kg^{-1})		Uptake (kg ha^{-1})	
		By Treat. [†]	Total		In seeds	In straw	By seeds	By straw
Control	50%	0.0	13.55	7.33 ^a	4.95 ^g	1.15 ^f	0.77 ^f	0.40 ^d
K- Si		-	3.4	4.00 ^a	5.26 ^f	1.65 ^e	1.17 ^e	0.74 ^c
K-H		0.09	3.5	6.33 ^a	5.29 ^e	1.75 ^d	1.29 ^d	0.94 ^b
Compost		27.3	30.7	9.00 ^a	5.47 ^d	1.9 ^c	1.54 ^b	1.03 ^b
K- Si	100%	-	3.4	8.67 ^a	5.54 ^c	2.15 ^b	1.47 ^c	1.00 ^b
K-H		0.18	3.6	8.00 ^a	5.76 ^b	3.1 ^a	1.66 ^b	1.66 ^a
Compost		54.7	58.1	11.33 ^a	6.18 ^a	3.1 ^a	2.21 ^a	1.71 ^a
		L.S.D ^{5%}		7.62	0.003	0.005	0.047	0.17
Significance of factors [‡]				ns	***	***	***	***

[†]Recommended application rates for compost: 7.81 t ha⁻¹, potassium silicate: 16.67 L ha⁻¹, potassium humate: 15.63 kg ha⁻¹, Total applied = Application rate + 25% NPK Recommended (kg ha^{-1} : N= 10.35, P= 3.39, K= 7.47)

[‡]The footnotes (a-h) indicate the non-significance ranges for the different treatments

Table 5. Effect of treatments on the plant available K (mg kg^{-1}) in soil and K content (g kg^{-1}) and uptake (kg ha^{-1}) by soybean seeds and straw

Treatment	App. rate	Applied K (kg ha^{-1})		Available in soil (mg kg^{-1})	Total (g kg^{-1})		Uptake (kg ha^{-1})	
		By Treat. [†]	Total		In seeds	In straw	By seeds	By straw
Control	50%	0.0	29.88	223.07 ^{ab}	8.03 ^c	3.91 ^c	1.25 ^a	1.36 ^c
K- Si		0.69	8.16	274.27 ^a	8.65 ^{bc}	4.05 ^c	1.92 ^a	1.80 ^c
K-H		0.48	8.0	162.60 ^b	9.49 ^{abc}	9.00 ^b	2.31 ^a	4.81 ^b
Compost		46.9	54.3	292.87 ^a	9.56 ^{abc}	10.26 ^b	2.70 ^a	5.56 ^{ab}
K- Si	100%	1.38	8.85	265.00 ^a	9.98 ^{ab}	12.35 ^a	2.65 ^a	5.72 ^{ab}
K-H		0.97	8.4	223.07 ^{ab}	10.89 ^a	12.70 ^a	3.13 ^a	6.82 ^a
Compost		93.7	101.2	292.87 ^a	11.17 ^a	13.26 ^a	3.99 ^a	7.30 ^a
		L.S.D ^{5%}		91.1	1.9	2.24	2.24	1.90
Significance of factors [‡]				ns	*	***	ns	***

[†]Recommended application rates for compost: 7.81 t ha⁻¹, potassium silicate: 16.67 L ha⁻¹, potassium humate: 15.63 kg ha⁻¹, Total applied = Application rate + 25% NPK Recommended (kg ha^{-1} : N= 10.35, P= 3.39, K= 7.47)

[‡]The footnotes (a-h) indicate the non-significance ranges for the different

Soybean exhibited a high response to Si application being a Si-accumulator plant; contains Si-transporters that facilitate uptake and distribution of Si between leaves and grains [15,42]. In this study, soil application of K-Si, K-H and compost showed a highly significant

increase in seeds' content of Si (mg kg^{-1}) compared to the control. Potassium silicate can be an effective Si-source due to easily soluble Si in soil solution produced by K-Si dissolution. Silicon may partially control the availability and uptake of some nutrients [43,44].

Table 6. Effect of treatments on the seed uptake (kg ha^{-1}) of micronutrients by soybean seeds

Treatment	Application rate	Uptake by Seeds (g ha^{-1})				
		Cu	Fe	Mn	Zn	Si
Control		2.17 ^{bc}	47.79 ^c	6.19 ^d	5.43 ^d	20.96 ^d
K- Si	50%	2.06 ^c	68.59 ^{bc}	8.91 ^{bcd}	7.96 ^{cd}	48.53 ^b
K- H		2.51 ^{bc}	69.00 ^{bc}	7.79 ^{cd}	7.45 ^{cd}	31.16 ^c
Compost		4.09 ^{abc}	88.24 ^{ab}	13.26 ^{ab}	12.87 ^{ab}	52.59 ^b
K- Si	100%	2.91 ^{abc}	72.03 ^b	10.58 ^{abc}	9.92 ^{bc}	56.52 ^{ab}
K- H		4.41 ^{ab}	119.43 ^a	12.88 ^{ab}	11.85 ^{bc}	47.78 ^b
Compost		5.43 ^a	105.90 ^a	14.50 ^a	15.39 ^a	66.54 ^a
L.S.D _{5%}		3.56	28.95	4.99	4.97	13.47
Significance of factors [†]		ns	***	**	**	***

[†]The footnotes (a–h) indicate the non-significance ranges for the different treatments

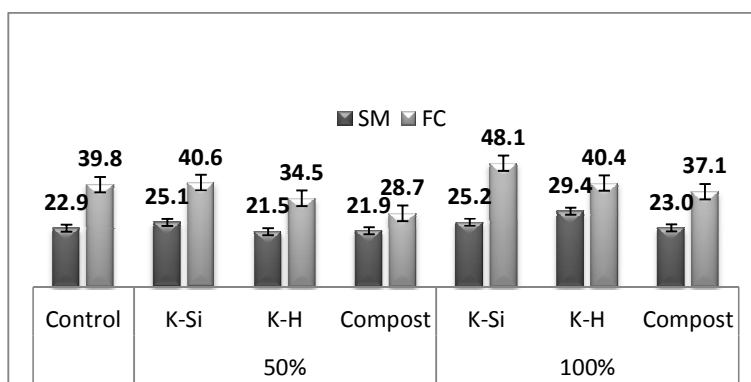


Fig. 1a. Effect of the studied additives on the soil moisture (SM, %) before first (1st.) irrigation and field capacity (FC, %) after it

Error bars refer to the $LSD_{5\%}$ values of the statistical analysis of data

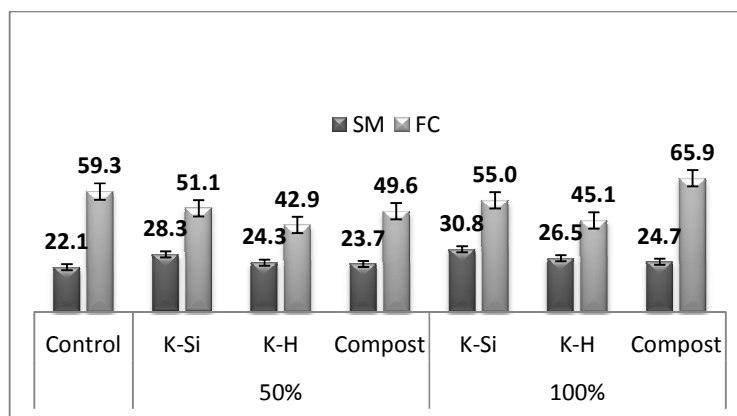


Fig. 1b. Effect of the studied additives on the soil moisture (SM, %) before second (2nd.) irrigation and field capacity (FC, %) after it

Error bars refer to the $LSD_{5\%}$ values of the statistical analysis of data

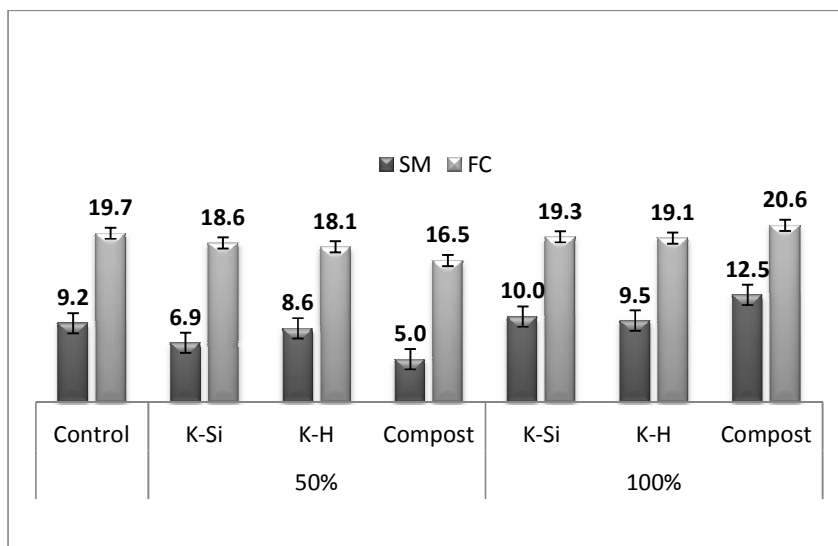


Fig. 1c. Effect of the studied additives on the soil moisture (SM, %) before third (3rd.) irrigation and field capacity (FC, %) after it
 Error bars refer to the $LSD_{5\%}$ values of the statistical analysis of data

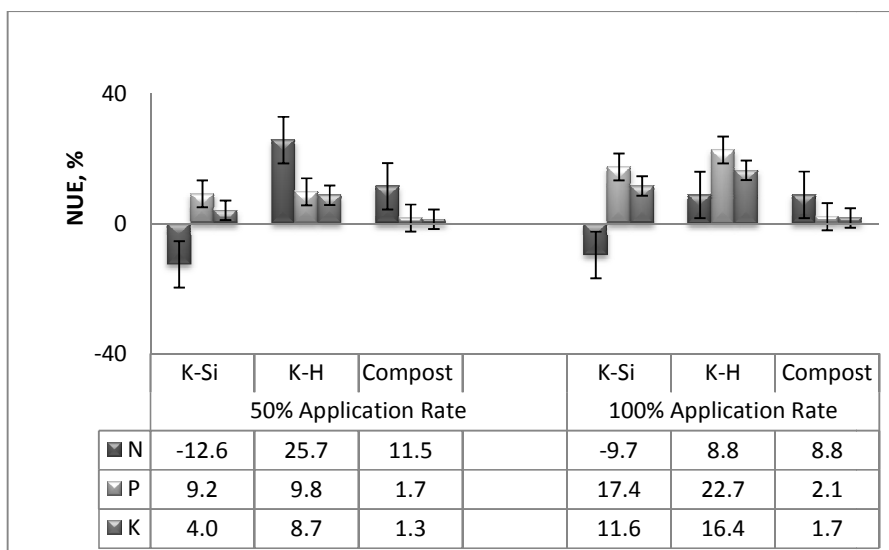


Fig. 2. Nutrient use efficiency (NUE, %) for the studied materials
 Error bars refer to the $LSD_{5\%}$ values of the statistical analysis of data

3.7 Nutrient Use Efficiency (NUE, %) and Agronomic Efficiency (AE) of the Silicate, Humate and Compost Used Applied in the Study

Regarding the applied (inputs) nutrients' dose and the obtained yield (outputs), Figs. 2 and 3 indicate that the K-H may be the most efficient agronomically and for N, P, K nutrient use. Although the highly similar effect of additives in the present study, the nutrient use efficiency

(NUE, %) and agronomic efficiency (AE) follow the order K-H > K-Si > compost at 50% and 100% application rates. High solubility in water and soil solution, organic biocompatibility, richness with macro and micronutrients, complexation ability and quite smaller dose in addition to ease of handling and field application by spraying are many advantages of the K-H may make it more agronomically efficient than K-Si and compost.

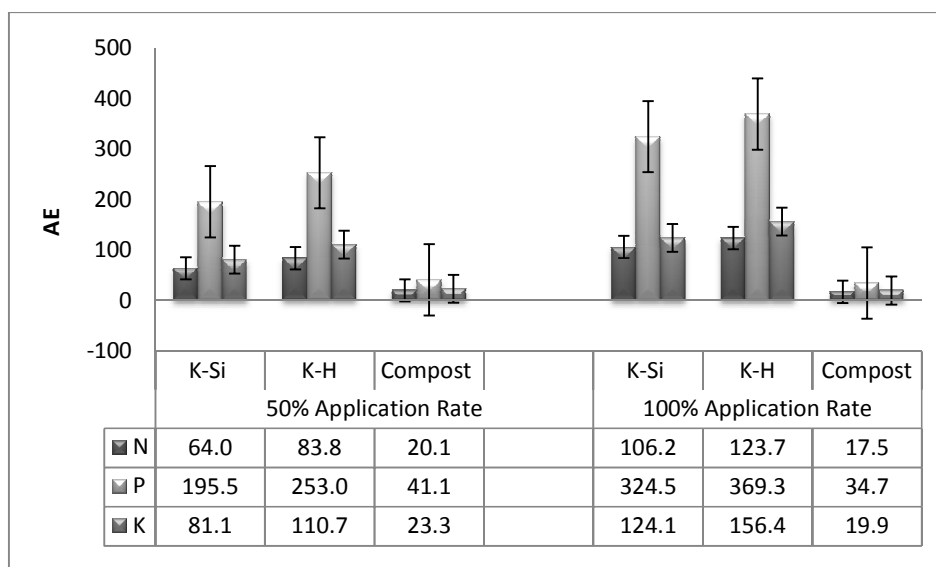


Fig. 3. Agronomic efficiency (AE) of the studied materials
 Error bars refer to the $LSD_{5\%}$ values of the statistical analysis of data

4. CONCLUSION

The nutrient use efficiency (NUE, %) and agronomic efficiency (AE) follow the order K-H > K-Si > compost at 50% and 100% application rates. High solubility in water and soil solution, quite smaller dose and ease of field application by spraying are many advantages of the K-H may make it more agronomically efficient than K-Si and compost.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

- Ibrahim SM, Ali AM. Effect of potassium humate application on yield and nutrient uptake of maize grown in a calcareous soil. *Alex. Sci. Exch. J.* 2018;39(3).
- Eid AR, Bakry BA, Taha MH. Effect of pulse drip irrigation and mulching systems on yield, quality traits and irrigation water use efficiency of soybean under sandy soil conditions. *Agri. Sci.* 2013;4(5):249-261. DOI:<http://dx.doi.org/10.4236/as.2013.45036>
- Khalifa MEA, Beshay NF. Soil classification and potentiality assessment for some rain fed areas at west of Matrouh, Northwestern Coast of Egypt. *Alex. Sci. Exch. J.* 2015;36:4.
- Khalifa MEA, Morsy IM. Land use planning at mechanical farm Sector-west of Nubaryia using parametric models. *J. Agric. Env. Sci. Alex. Univ.* 2007;6(2):159-175.
- Amer R, Moghanm F. Remote sensing for detection and monitoring of the cropland water logging in arid and semi-arid regions. 20th Int. Water Technol. Conf., IWTC20, Hurghada, 18-20 May. 2017;264-276.
- Johnston (Johnny) AE, Syers JK. A new approach to assessing phosphorus use efficiency in agriculture. *Better Crops.* 2009;93(3):14-16.
- Vaneekhaute C, Janda J, Vanrolleghem PA, Tack FMG, Meers E. Phosphorus use efficiency of bio-based fertilizers: Bioavailability and fractionation. *Pedosphere.* 2016;26(3):310–325.
- Ewis AMG, Sobh MM, Amer MH, Gouda M. Rates and methods of rice straw application to wheat and rice crops and the

- implications on crop productivity as well as some soil properties. Egypt. J. Soil Sci. 2014;54(1):49-68.
9. Ouda SA, Shreif MA, Abou Elenin R. Simulation of the effect of water stress on soybean yield and water use efficiency. 14th Int. Water Technol. Conf., IWTC 14, Cairo, Egypt. 2010;395-406.
 10. El Agroudy N, Mokhtar S, Zaghlol EA, El Gebaly M. An economic study of the production of soybean in Egypt. Agric. Biol. J. N. Am. 2011;2(2):221-225.
 11. Khalil NA, Darwish DS, Safina SA, Ferozy SA. Effect of environmental conditions on the productivity of soybean in Egypt. Egypt. J. Plant Breed. 2011;15(3):33-43.
 12. Mekki BB, Ahmed AG. Growth, yield and seed quality of soybean (*Glycine max* L.) as affected by organic, bio fertilizer and yeast application. Res. J. Agri. Biol. Sci. 2005;1(4):320-324.
 13. Abdel-Latif E, El Haggan MA. Effect of micronutrients foliar application on yield and quality traits of soybean cultivars. Int. J. Agri. Crop Sci. 2014;7(11):908-914.
 14. Ali AM, Ibrahim SM, Abou-Amer IA. Water deficit stress mitigation by foliar application of potassium silicate for sugar beet grown in a saline calcareous soil. Egypt. J. Soil. Sci. 2019;59(1):15-23.
 15. Cruz MFA, Rodrigues FÁ, Diniz APC, Moreira MA, Barros EG. Soybean resistance to *Phakopsora pachyrhizi* as affected by Acibenzolar-S-Methyl, Jasmonic Acid and silicon. J. Phytopathol. 2014;162:133-136.
 16. Miao B-H, Han X-G, Zhang W-H. The ameliorative effect of silicon on soybean seedlings grown in potassium-deficient medium. Ann. Bot. 2010;105:967-973.
 17. Gonzalo MJ, Lucena JJ, Hernández-Apaolaza L. Effect of silicon addition on soybean (*Glycine max*) and cucumber (*Cucumis sativus*) plants grown under iron deficiency. Plant Physiol. Biochem. 2013;70:455-461.
 18. Liang Y, Nikolic M, Bélanger R, Gong H, Song A. Effect of silicon on crop growth, yield and quality. In Silicon in Agriculture; Springer Science + Business Media: Dordrecht, The Netherlands. 2015;209-224.
 19. Artyszak A. Review effect of silicon fertilization on crop yield quantity and quality—A literature review in Europe. Plant. 2018;7:54.
 20. Agostinho FB, Tubana BS, Martins MS, Datnoff LE. Effect of different silicon sources on yield and silicon uptake of rice grown under varying phosphorus rates. Plants. 2017;6:35.
 21. NOSB TAP Review Compiled by UC SAREP. National Organic Standards Board Technical Advisory Panel Review compiled by University of California Sustainable Agriculture Research and Education Program (UC SAREP) for the USDA National Organic Program. Potassium Silicate for Use in Crop Production. September 4; 2003.
 22. Ouni Y, Ghnaya T, Montemurro F, Abdelly Ch, Lakhdar A. The role of humic substances in mitigating the harmful effects of soil salinity and improve plant productivity. Int. J. Plant Prod. 2014;8(3):353-374.
 23. Selim EM, El-Neklawy AS, El-Ashry SM. Beneficial effects of humic substances on soil fertility to fertigated potato grown on sandy soil. Libyan Agri. Res. Cent. J. Int. 2010;1(4):255-262.
 24. Karčauskienė D, Repšienė R, Ambrazaitienė D, Mockevičienė I, Skudienė R, Šiaudinis G. A complex assessment of mineral fertilizers with humic substances in an agro ecosystem of acid soil. Zemdirbyste-Agri. 2019;106(4):307-314. DOI: 10.13080/z-a.2019.106.039
 25. Cieschi MT, Polyakov AY, Lebedev VA, Volkov DS, Pankratov DA, Veligzhanin AA, Perminova IV, Lucena JJ. Eco-friendly iron-humic nano fertilizers synthesis for the prevention of iron chlorosis in soybean (*Glycine max*) grown in calcareous soil. Front. Plant Sci. 2019;10:413. DOI: 10.3389/fpls.2019.00413
 26. Rashad RT. Effect of soaking seeds in some growth regulators on wheat grown in sandy soil. Egypt. J. Soil. Sci. 2020;60(2):99-108.
 27. Abou Hussien EA, Elbaalawy AM, Hamad MM. Chemical properties of compost in relation to calcareous soil properties and its productivity of wheat. Egypt. J. Soil. Sci. 2019;59(1):85-97.
 28. Mohamed SM, Rashad RT. Studying some characteristics of sandy soil amended by

- water hyacinth, bean straw and compost. Egypt. J. Soil. Sci. 2020;60(1):53–65.
29. Badar R, Batool B, Ansari A, Mustafa S, Ajmal A, Perveen S. Amelioration of salt affected soils for cowpea growth by application of organic amendments. J. Pharmacognosy Phytochem. 2015;3(6):87-90.
30. Fixen P, Brentrup F, Bruulsema T, Garcia F, Norton R, Zingore S. Nutrient/Fertilizer use efficiency: Measurement, current situation and trends. Ch. 1 from “Managing Water and Fertilizer for Sustainable Agricultural Intensification” by IFA, IWMI, IPNI and IPI; 2014.
31. FAO. World Reference Base for Soil Resources. A framework for international classification, correlation and communication, Soil Taxonomy, Food and Agriculture Organization of the United Nations, Rome, Italy; 2014.
32. Black CA. Methods of soil analysis. Soil Sci. Soc. Amer., Inc. Pub., Madison, Wisconsin, USA; 1982.
33. Black CA. Methods of soil analysis. Part 2, Series 9, p. 894-1372. Am Soc. Agron. Inst. Publ., Madison, WI; 1965.
34. Jackson ML. Soil chemical analysis. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, USA. 1973;429–464.
35. Chapman HD, Pratt RE. Methods of analysis for soil, plants and water. Department of Soil and Plant Nutrition, California Univ, U.S.A.; 1961.
36. Craswell ET, Godwin DC. The efficiency of nitrogen fertilizers applied to cereals in different climates. Adv. Plant Nut. 1984;1:1-55.
37. Roozbeh M, Sheikhdavoodi MJ, Almassi M, Bahrami H. Effects of tillage intensity and anionic polyacrylamide on sediment and nitrogen losses in irrigated wheat field. Afr. J. Agri. Res. 2011;6(22):5320-5327.
38. Gomez KA, Gomez AA. Statistical procedures for agricultural research. John Wiley & Sons, New York, NY, USA. 1984;8–20.
39. Krull ES, Skjemstad JO, Baldock JA. Grains Research and Development Corporation (GRDC) Project No CSO 00029. Residue management, soil organic carbon and crop performance - functions of soil organic matter and the effect on soil properties; 2012. Seen on 28 Dec. 2012
40. Darlington W. Compost – A guide for evaluating and using compost materials as soil amendments. Consultant Soil & Plant Laboratory, Inc., Orange Office. 2014;714:282-8777. Seen on 16 Feb. 2014
41. Mihara C, Chang X, Sugiur Y, Makabe-Sasakid S, Watanabe A. Relationship between plant-available silicon and reducible iron in irrigated paddy soils. Soil Sci. Plant Nutr. 2017;63(1):67–74.
42. Rashad RT, Hussien RA. Studying the solubility, availability and uptake of silicon (Si) from some ore minerals in the sandy soil. Sains Tanah J. Soil Sci. Agroclimat. 2018;15(2):69-82. DOI: 10.15608/stjssa.v15i2.21430
43. Schaller J, Hodson MJ, Struyf E. Is relative Si/Ca availability crucial to the performance of grassland ecosystems? Ecosphere. 2017;8(3):1-11. e01726. DOI: 10.1002/ecs2.1726
44. Greger M, Landberg T, Vaculik M. Silicon influences soil availability and accumulation of mineral nutrients in various plant species. Plants. 2018;7(41):1-16. DOI: 10.3390/plants7020041 Available:www.mdpi.com/journal/plants

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