RESEARCH ARTICLE
Published December 2024
https://doi.org/ 10.21070/nabatia.v12i2.1644

Phosphorus and Silicon Uptake By Corn (Zea Mays L.) In Response To Silicon Application In Calcareous Soil

Jumana A. Jawad Al-rubaie[1], Mohammed A. Abdulkareem[2]
[1,2] University Of Basrah, Department Of Soil Sciences And Water Resources, Basrah,
Corresponding Author : Pgs.jumana.abdulsattar@uobasrah.edu.iq

Abstract: *A field experiment was conducted on clay soil at the Agricultural Research Station, College of Agriculture, University of Basra, Basra, Iraq, to investigate the impact of silicon addition on phosphorus and silicon uptake in corn plants. Silicon was applied as potassium silicate (26.5% Si2O) at 0 and 200 kg Si ha^-1 in two doses: on planting day and two weeks after planting. Phosphorus was applied as concentrated superphosphate or diammonium phosphate at 0, 12.5, 25, and 50 kg P ha^-1 on planting day. Measurements included soil available phosphorus at two stages, leaf phosphorus and silicon concentrations at two stages, grain phosphorus concentration, and the uptake and ratio of the two elements. Results showed that adding silicon increased soil available phosphorus, leading to higher phosphorus and silicon concentrations in leaves and improved uptake of both elements, along with increased grain phosphorus concentration. The Si/P uptake ratio also rose with silicon addition. Higher phosphorus levels boosted soil available phosphorus, enhancing phosphorus and silicon concentrations and uptake, and increased grain phosphorus concentration. The Si/P ratio decreased with rising phosphorus levels. Diammonium phosphate outperformed concentrated superphosphate in all uptake parameters. The study concludes that applying silicon at 200 kg Si ha^-1 can enhance phosphorus and silicon absorption. The Si/P ratio demonstrated that silicon uptake was significantly higher than phosphorus uptake, by nearly four times in some parameters. It is recommended to use silicon to treat corn plants under stress, as the plant accumulates a high amount of silicon, qualifying it as an accumulative species.*
Keywords: Maize, P – Uptake, Si – Uptake, Si/P Ratio, Concentrated Superphosphate, Diammonium Phosphate.

INTRODUCTION

Phosphorus (P) is the key element controlling plant production. P deficiency regards as one of abiotic stress limiting crop growth on approximately half of agricultural soils all over the world [1]. P is highly immobile in soils and generally is fixed near the site of application by precipitation processes with soil including formation of surface – adsorbed complex, dissolution of clay minerals, and slow nucleation, crystallization and recrystallization of P compounds [2]. P is retained, in soil by Fe and Al hydroxides, alumino – silicate minerals, carbonates and organic matter [3]. Hence, inorganic P distribution between Ca, Fe, Al or Si fractions is strongly dependent on soil pH incombination with mineral composition. At soil pH > 6.5, P is immobilized as Ca – P minerals, whereas at pH < 6.5, P tends to adsorbed/bound by Fe, Mn, Al, or their hydrous oxides [4]. For calcareous soils, P interactions with $CaCO_3$ involve two reactions, the first is adsorption by $CaCO_3$

surface which occurs at low P concentration in soil, and the second is formation of Ca – P crystals. Accordingly, P is one of the elements which has led to large amounts of fertilization to achieve acceptable production for farmer. However, the intensive and frequency doses of P fertilizers may cause inbalance of plant nutrients, soil pollution and deterioration of soil properties as well as the high cost of such fertilizers.

Silicon (Si) fertilization may reduce the demand of P fertilizers in soils for crops. A large number of studies pointed to a possibility of Si influencing P availability and consequently nutrient use efficiency [4] Si has been released into soil solution by chemical and physical weathering of silica minerals, followed by interaction with other elements to form clay minerals, released to soil or uptake by plants [5]. The beneficial effects of Si fertilizers on increasing available P in soil can confirmed by many mechanisms involving competitive sorption and exchange on P-slow available compounds [6], increasing soil pH and enhanced soil P availability [7], silicic acid competes with P for binding minerals resulting in a high mobilization of P (25, 3) and enhancement of microbial activity in soil by Si addition resulting in an increase of P availability. Increasing the P – availability in soil resulting in increase the P – uptake and concentration of aboveground P, since the nutrients uptake by plant is a function of the available amount in soil. Many studies have assessed the effect of Si on P – uptake by plant. That N and P uptakes from soil at early and late planting of wheat were clearly increased with the addition of Si at levels ranged 7.8 – 23.4 kg ha^{-1} [8]. That Si can promote shoot P accumulation in rice even without a soil pH change. In wheat, increasing supply of Si consistently increased P and Si concentrations in shoot and root [9]. A significant increase in P and Si shoot as well as in grains of corn plants treated with nanosilicate or potassium silicate at levels of 4.0, 6.0 and 8.0 L ha^{-1}[10]. However, [11] demonstrated a decreased of P-uptake by corn with addition of Si, while Si concentration in plant shoot and root increased.

The ecological mechanisms including the effect of Si on nutrient accumulation in plant tissues in most cases is missing [8]. Si supply might influence the P cycle in soil ecosystems [12] by promoting P nutrient cycles in plant-soil media. In soil, Si might influence the binding of the nutrients to soil particles making them more or less for uptake. Si is well known to decrease soil sorption of P, especially at low pH, thus increases plant available portion of P in soil [13]. Si nutrient may have an indirect effect on P uptake by improving soil microbe communities, which enhancing the immobilization of reserved-P of organic matter as well as promoting the mineralization of P and thus availability in soil [8].

In this study, we aimed to evaluate the effect of adding 200 kg ha^{-1} of Si to improve the availability of P and utilization of P fertilizers and the uptake ratio of Si/P in corn tissues. The results revealed if corn plants, under study conditions, were among the accumulator plant species.

MATERIALS AND METHODS

A. Experiment site

An agricultural experiment was conducted at the Agricultural Research Station affiliated with the College of Agriculture - University of Basra - Basra - southern Iraq (˚30

33′ 44″ N; °47 44′ 40″ E; 3m elevation) and is 9.78 km away from the city center for the growing season of 2023-2024 to study the effect of adding silicon at the concentration that gave the highest available phosphorus in a previously laboratory experiment (200 kg Si ha^{-1}) by interfering with phosphorus treatments on available-P and phosphorus and silicon uptake according to the following:

1. The first factor: Phosphorus levels (0, 12.5, 25, 50) kg P ha^{-1}.
2. The second factor: Silicon levels (0 and 200) kg Si ha^{-1}.
3. The third factor: sources of phosphate fertilizer, including concentrated triple superphosphate (CSP) (20.21% P) and diammonium phosphate (DAP) (21% P).

For identifying initial soil properties, a composite sample (0-30 cm) was taken from field, air-dried, ground and sieved through a 2mm sieve, and properties were estimated according to the standard methods mentioned in [14] and [15] and listed in Table 1.

B. Field practices and treatments:

The field was prepared for cultivation by plowing in two perpendicular plows, smoothing and leveling. The experiment was designed according to a Randomized Complete Block Design (RCBD) in a factorial experiment with three replications. field was divided into three blocks, each block containing 6 rows, and the distance between one row and another was 1 m. Each row contained three experimental units, with a length of 3m and a width of 0.5m with an interval distance of 0.5m, so the total of the experimental units is 48 units (2×4×2×3) (Si level × P level × type of phosphate fertilizer× replications). The field was fertilized with organic manure (cow waste) at a level of 25 tons ha^{-1} mixing with the top layer (0-20 cm) of the soil, and the drip irrigation method was used with main and subsidiary pipes and dripper stands.

Corn seeds, a local variety, was sowing on August 13, 2023, on one line opposite each dripper, and the distance between one band to another was 0.25 m. Each hole contained 3-4 seeds, then thinned to one plant in the band, so the number of plants in each experimental unit was 8 plants. Chemical fertilizers side dressing along the irrigation pipe. Nitrogen was added in the form of urea (46% N) with a recommended dose of 150 kg N ha^{-1} and in three doses. The first was at planting date and the second dose was added one month after planting, and the third dose added 20 days after the second dose. Potassium was added in the form of potassium sulfate (42% K) with a recommendation of 100 kg K ha^{-1}. The first dose of potassium was added with planting date (10% of the level) and the remaining dose was added at the beginning of the flowering period. Phosphorus was added eithe at concentrated triple superphosphate (20.21% P) or diammonium phosphate (21% P) at one dose at planting day, at levels of 0, 12.5, 25, and 50 kg P ha^{-1}. Silicon was added in the form of potassium silicate in two doses, one dose two days after planting and the other two weeks later [16] at level of 200 kg Si ha^{-1}. Control treatment of Si was also conducted. Plants were sprayed two months after planting with a preventive spray against the corn.

The agriculture operations were employed as commonly practiced in corn fields of southern Basrah region until harvest time.

Table 1. Basic physiochemical properties of the used soil.

Properties		Value	Unite
pH		8.18	-
EC		6.5	dS m^{-1}
CEC		34.27	$Cmol^{+}$ Kg^{-1}
Organic matter		20.85	g Kg^{-1}
Available P		30.4	mg Kg^{-1}
Available N		4.20	mg Kg^{-1}
Available K		115.6	mg Kg^{-1}
Available Si		22.34	mg Kg^{-1}
Dissolved Cations	Ca^{+}	9.4	mmole L^{-1}
	Mg^{+}	7.75	
	Na^{+}	36.5	
	K^{+}	1.65	
Dissolved Anions	CO3	0.00	
	HCO3	5.44	
	$SO4^{-}$	13.33	
	Cl^{-}	34.45	
Soil particles	Sand	13.5	%
	Clay	81.8	
	Silt	4.70	
Soil texture		Clay	

C. Soil and plant analyses:

Soil samples were taken in the vegetative stages and the end of the season by taking a composite sample for each experimental unit from two locations. Sample was taken included the fertilizer addition line and between two plants from the middle of the experimental unit. The samples were air-dried, ground, and sieved through 2mm sieve, then the available phosphorus was determined by extraction with a 0.5M NaHCO3 solution, then determined by the blue color method using ammonium molybdate and ascorbic acid at a wavelength of 700 nm [17].

Two plant shoots were harvested at the end of the season for each experimental unit, cut into small pieces and dried in the oven at a temperature of 65°C for 48 hours, and the dry weights were recorded. The leaf under the ear was taken from two plants per experimental unit at two stages; flowering - early maturity and the end of the season. Leaves were cleaned with distilled water, then dried at 65°C for 48 hours, ground and divided in two parts. First part was digested using the acidic mixture (4% $HClO_4$ + H_2SO_4) according to the method [18]. Total phosphorus in the digest was estimated using the blue color method after adjusting the acidity of the phosphorus mixture. The another part was digested (0.1g) using 3 ml of 50% sodium hydroxide to determine total silicon. The samples were placed in an autoclave at 121°C for 20 minutes. After digestion process, 1 ml of the digest transferred into a 50 cm^3 polyethylene test tube, 30 ml of 20% acetic acid and 10 ml of ammonium molybdate solution were added, shaked for 5 minutes and then add 5 ml of 20% tartaric acid. After that 1 ml of reducing solution was added. Absorbance was measured using a spectrophotometer at a wavelength of 650 nm as described in [19].

The amount of phosphorus or silicon uptake by the plant was calculated from the following formula:

Uptake = dry weight of plant x element (P or Si) concentration.

A sample of corn grains was selected after harvest and digested according to the method of (36). Total phosphorus in the digest was estimated as recorded for leaves sample. The Si/P ratio uptake in shoot was also calculated at the end of season by divided Si uptake by P uptake.

D. Statistical analysis:

The experiment was designed as a factorial experiment with three factors (Si level, P level, and type of phosphate fertilizer). The data were analyzed using GenStat Procedure Library PL 18.2 program, and the means were compared using the least significant difference (LSD) at the probability level of 0.05 according to [20]

RESULT AND DISCUSSION

A. Available phosphorus in the soil:

Table (2) showed the effect of adding silicon and phosphate fertilization on the amount of available phosphorus at the vegetative growth stage and the end of the season of corn. Silicon caused a significant decrease in available phosphorus compared to the control treatment. The average values were 28.74 and 22.54 mg kg^{-1} at the vegetative growth stage and 25.70 and 17.36 mg kg^{-1} at the end of the season at levels of 0 and 200 kg Si ha^{-1}, respectively. The addition of silicon improves the efficiency of nutrient use and also affects the binding of nutrients to soil particles, making them available to the plant [21]. The lack of available phosphorus at the mentioned level resulted from increased phosphorus absorption by plant and thus drop the remaining part into the soil. Taking a soil sample during the plant's vegetative growth period, which is the more active stage of the plant's life, can confirm the role of absorption in reversing the results of this trait. Silicon increased the availability of phosphorus through several mechanisms, as the addition of silicates leads to modifying the acidity of soil and thus increases the availability of phosphorus by displacing the adsorbed phosphorus into the soil solution [22]. Also, silicate complexes with organic and inorganic forms are the mobile forms of silicon in the soil replace the phosphorus present in calcium phosphate, which contributes to converting unavailable phosphorus into plant-available phosphorus [23]. [24] suggested that silicic acid competes with phosphorus present on the surface of minerals, and this exchange depends on their concentration in the soil solution. As for the biological aspect, that the addition of silicon improves the activity of functional microorganisms in soil, especially P-solubilizing bacteria, through its role in improving soil pH, increasing basic ions, accelerating the decomposition of organic matter, phosphorus mineralization, and developing soil structure.

The results showed a significant effect ($P \leq 0.05$) of phosphorus levels on available phosphorus in the soil, as it decreased with increasing phosphorus levels due to increasing growth and uptake by plant with increasing levels of phosphorus resulting in a lower amount as a residuals in soil. The average values were 7.61, 38.97, 33.54, and 22.46 mg kg^{-1} soil at the vegetative growth stage, and 7.78, 27.23, 28.18 and 22.93 mg kg^{-1} soil at the end of the season for levels of 0, 12.5, 25 and 50 kg P ha^{-1}, respectively. This is confirmed by the fact that the amount uptake (fig.1) and the phosphorus concentration in the leaves (table 3) increased with increased levels of phosphorus, and this explains the decrease in available phosphorus at high levels of phosphorus. The type of phosphate fertilizer had a significant effect on available phosphorus (table 2). Concentrated superphosphate fertilizer outperformed diammonium phosphate fertilizer with an increase percent of 14.47 and 10.50% at the vegetative growth and the end of season, respectively. This also represented the remaining amounts due to the high absorption at diammonium phosphate compared to concentration superphosphate.

Table 2. Effect of Si application and P fertilization on available – P (mg kg^{-1} soil) in soil at two growth stages of corn plant

Si level (kg Si ha^{-1}), Si	P- fertilizer (F)	P – level (kg P ha^{-1}), P				
		0	12.5	25	50	mean
			Vegetative stage			
0	CSP	8.59	42.63	45.56	25.62	30.60
	DAP	8.59	41.46	33.05	24.45	26.89
200	CSP	6.62	38.52	32.27	19.17	24.15
	DAP	6.62	33.25	23.28	20.59	20.94
	mean	7.61	38.97	33.54	22.46	
LSD0.05: Si = *; P = 3.24; F = *; Si×P = 4.59; Si×F = NS; P×F = 4.59; Si×P×F = NS						
			Post-harvest			
0	CSP	8.20	34.73	32.58	26.45	19.20
	DAP	8.20	31.50	37.04	26.89	25.91
200	CSP	7.36	24.29	24.04	23.20	19.72
	DAP	7.36	18.41	19.05	15.20	15.01
	Mean	7.78	27.23	28.18	22.93	
LSD0.05: Si = *; P = 3.43; F = NS; Si×P = 4.85; P×F = 3.43; Si×P×F = NS						

CSP: concentrated superphosphate; DAP: diammonium phosphate; *: significant; NS: not significant.

This is confirmed by the superiority of diammonium phosphate in the amount uptake (Fig. 1).

The interactions of the experimental factors indicated that available phosphorus was superior when silicon was not added compared to the level of 200 kg Si ha^{-1} and at all levels of phosphorus. The highest value of the interaction was obtained when silicon was not added and at low levels of phosphorus, with a value of 42.04 and 34.81 mg kg^{-1} for vegetative growth and the end of the season, respectively. The results of Table (2) also showed that the interactions including the type of fertilizer referred to the superiority of concentrated superphosphate fertilizer over diammonium phosphate fertilizer in the remaining amount of available phosphorus, and the highest value was obtained when using concentrated superphosphate at the level of 12.5 kg P ha^{-1} (40.58 mg kg^{-1} soil) during vegetative growth, and the highest value was obtained when silicon and diammonium phosphate fertilizer were not added (25.91 mg kg^{-1} soil) at the end of the season.

B. Phosphorus concentration in leaves:

The results of table (3) showed a significant effect of silicon on phosphorus concentration in compared to the control treatment. The values were 3.74 and 4.32 g kg^{-1} at the flowering - early maturity stage and were 3.01 and 3.50 g kg^{-1} at the end of the season for levels 0 and 200 kg Si ha^{-1}, respectively. This is due to the role of silicon in increasing the availability of phosphorus in the soil, which leads to its availability in sufficient quantities for the plant (Table 2). In addition, the role of silicon in improving plant growth, dry mass, and root development leads, as a result, to increased absorption of nutrients from the soil. The study of [9] illustrated the high correlation between the phosphorus metabolism in plants and the accumulation of silicon in the plant, indicating that the high solubility of silicon in soil results in saturate the pore water in the soil and plant tissues with phosphorus due to increasing its availability. Silicon can also develop carriers in the cell walls of the root, which controls the Apoplasmic pathway, followed by the transfer of the element from the root cell walls to the shoot part [25]; [26]. A plant exposed to low phosphorus show a range of physiological processes that modify absorption, such as increasing the density of root hairs, increasing carboxylates exudation into the rhizosphere, and enhancing expression genes considered important to increase Pi uptake, which is present in the plasmalema.

Phosphorus concentration in leaves increased with increasing levels of phosphorus, with an average values of 1.25, 4.39, 4.99 and 5.50 g kg^{-1} at the flowering - early maturity stage and 2.40, 2.25, 3.48 and 3.90 g kg^{-1} at the harvest stage for levels 0, 12.5, 25 and 50 kg P ha^{-1}, respectively. This is consistent with the findings of [27] and [28]. Table (3) showed a significant effect ($P \leq 0.05$) of the type of phosphate fertilizer, where diammonium phosphate outperformed concentrated superphosphate fertilizer by 9.89 and 10.00% for the flowering - early maturity and harvest stages, respectively. This is due to the fact that plant treated with diammonium phosphate fertilizer resulted in high growth leading to an increase phosphorus uptake and an increase in the concentration in leaves. This confirms the decrease in the available amount remaining in the soil (Table 2), as diammonium phosphate fertilizer has a high solubility, a large diffusion in soil, and a lack of immobilized materials resulting from its reaction, in addition to the presence of the ammonium ion in such fertilizer increases the absorption of phosphorus due to modifying the soil pH and increasing the solubility of phosphorus near the plant roots [29]. These results were similar to the results of [30].

Table 3. Effect of Si application and P fertilization on P concentration (g kg^{-1} dry weight) in leaves at two growth stages of corn plant

Si level (kg Si ha^{-1}), Si	P- fertilizer (F)	P – level (kg P ha^{-1}), P				
		0	12.5	25	50	mean
		Vegetative stage				
0	CSP	0.70	3.70	4.86	5.36	3.65
	DAP	0.70	4.30	4.93	5.40	3.83
200	CSP	1.80	4.53	4.56	5.20	4.02
	DAP	1.80	5.03	5.60	6.03	4.61
	mean	1.25	4.39	4.99	5.50	
LSD$_{0.05}$: Si = *; P = 0.43; F = *; Si×P = NS; P×F = NS; Si×P×F = NS						
		Post-harvest				
0	CSP	2.00	3.06	2.90	3.40	2.84
	DAP	2.00	3.30	3.43	4.00	2.18
200	CSP	2.80	3.23	3.40	4.00	3.35
	DAP	2.80	3.40	4.20	4.20	3.65
	Mean	2.40	3.25	3.48	3.90	
LSD$_{0.05}$: Si = *; P = 0.17; F = *; Si×P = 0.24; P×F = 0.24; Si×P×F = NS						

CSP: concentrated superphosphate; DAP: diammonium phosphate; *: significant; NS: not significant.

Since the addition of silicon has a role in such modifications. These results were similar to those of [31].

The two-way interaction between phosphorus levels and both silicon levels and the type of phosphate fertilizer has a significant effect on the phosphorus concentration at the harvest stage. It is noted that phosphorus values increase with increasing levels of phosphorus at both silicon levels and both types of fertilizer, with a clear superiority of 200 kg Si ha^{-1} level over the control treatment. On the same way diammonium phosphate gave higher values over concentrated superphosphate fertilizer for all treatment.

C. Phosphorus uptake in shoot:

The addition of silicon significantly ($P \leq 0.05$) affected the amount of phosphorus uptake by corn plant, with an increase of 51.25% over control treatment (Fig. 1). This result was similar to the results of [32] who obtained an increase in the uptake amount of phosphorus at the highest level of silicon, and attributed this to increased root growth, increased availability of phosphorus with the addition of silicon, and a decrease in binding of phosphorus. [13] indicated that silicon has a direct effect in improving phosphorus absorption as a result of regulating the transport genes responsible for the absorption of mineral phosphorus. Adding silicon increases the absorption of nutrients, transpiration, exploitation of available moisture resulting in an increase phosphorus absorption by corn. In present study, increasing the concentration of phosphorus in the leaves and increasing the dry weight of the vegetative part results in an increase in phosphorus uptake.

The results of the figure (1) showed a significant effect on phosphorus levels, as the uptake amount increased with increasing levels, with significant differences observed among levels. The average values reached 21.07, 30.10, 36.45, and 45.04 kg P ha^{-1} for levels 0, 12.5, 25, and 50 kg P ha^{-1}, respectively. This increase is due to an increase in the availability of phosphorus in the soil (table 2) and thus an increase in its concentration in the leaves (table 3) by increasing the added levels. This result agreed with the results of [33] As for the type of fertilizer, the results indicated that diammonium phosphate was superior to concentrated superphosphate by a percent of 14.24% (Fig. 1). This result agreed with the findings of who reported that diammonium phosphate was superior to concentrated superphosphate in the amount of phosphorus uptake by eggplant, with an increase of 16.77%. They attributed the reason to the superiority of diammonium phosphate fertilizer in the amount of available phosphorus in soil at the time the plant needs the element, and dividing the dose of fertilizer that reduces contact fertilize with the soil and deposit it. From the results of Figure (1), phosphorus uptake increased with increasing phosphorus levels in both fertilizers, with a superiority of adding silicon compared to control, and a superiority of diammonium phosphate over concentrated superphosphate fertilizer for all treatments. The highest value was 53.22 kg ha^{-1}, with a significant superiority over all interaction treatments.

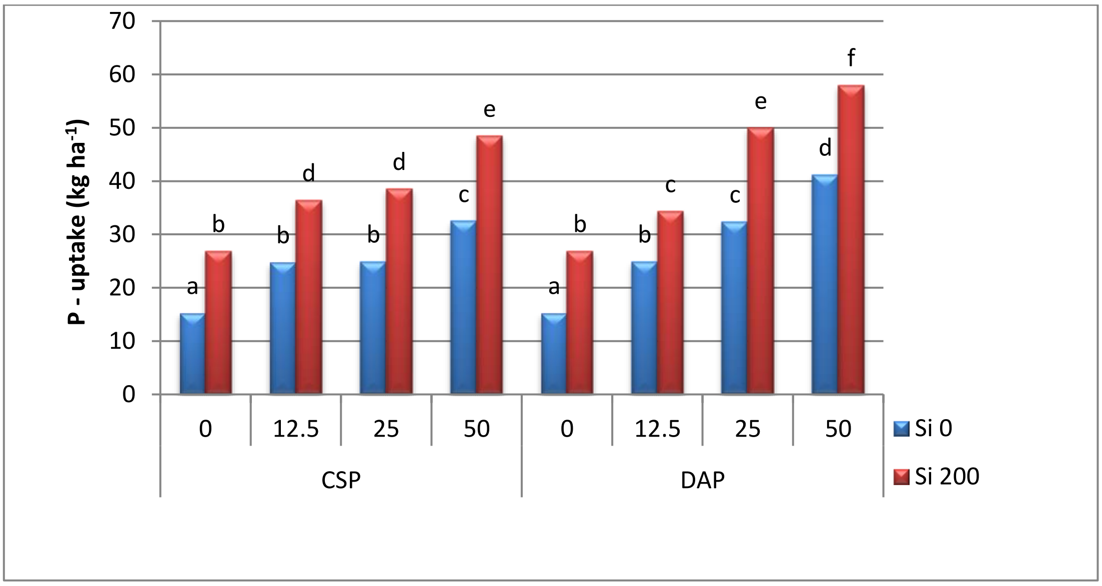

Fig. (1): Effect of Si application and P fertilization on P – uptake in corn shoot (means followed by the same letter are not significantly different at 0.05 level)

D. Phosphorus concentration in seeds:

A significant effect of silicon addition on seed phosphorus was obtained compared to control with a mean values of 7.95 and 7.27 g kg^{-1}, respectively (Fig. 2). This result clearly correlated with phosphorus concentration in leaves (table 3) and phosphorus uptake (fig.1). Providing the appropriate level of silicon helping the transfer of phosphorus from flag leaf to wheat grain [9]. [34] explained that phosphorus is transferred in the form of phytin (calcium and magnesium salts of phytic acid) to seeds immediately after pollination. These results agreed with (7) who obtained an increase in phosphorus content of corn seeds with increasing silicon levels. Increasing phosphorus levels increased phosphorus concentration in seeds with no significant differences among treatments which outperformed the control treatment. The value were 5.15, 8.15, 8.43, and 8.72 g kg^{-1} for levels 0, 12.5, 25, and 50 kg P ha^{-1}, respectively, and this increase coincided with the concentration of phosphorus in the leaves (table 3).

Phosphorus source did not have a significant effect on phosphorus concentration in grains, in spite of the superiority of diammonium phosphate over concentrated superphosphate. Moreover, when this fertilizer interacts with phosphorus levels, its superiority over concentrated superphosphate is clear at all levels of phosphorus addition.

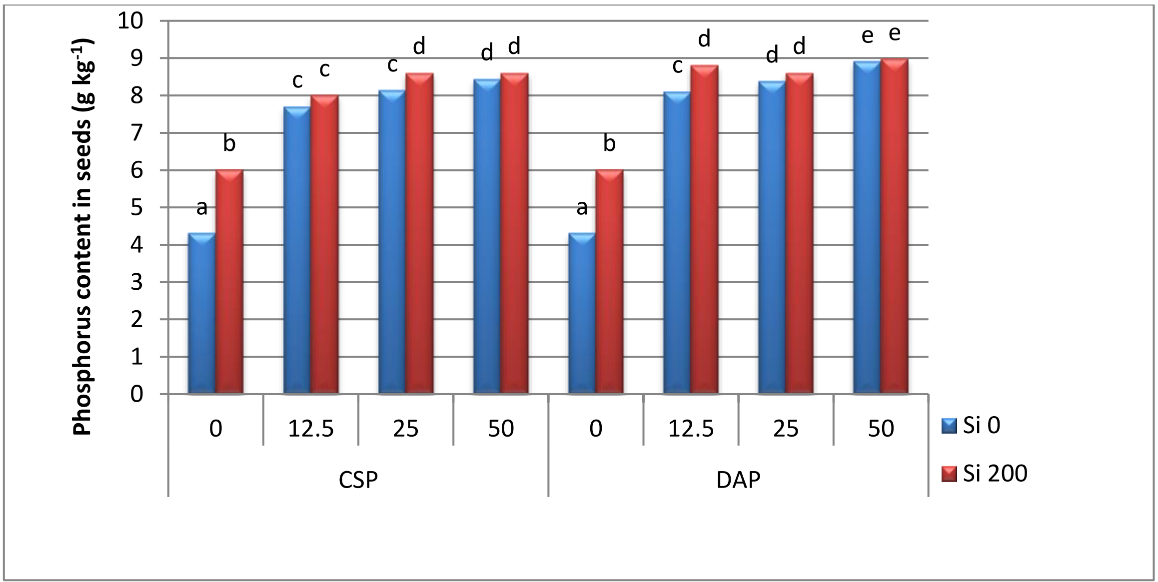

Fig. (2): Effect of Si application and P fertilization on phosphorus concentration in seeds of corn plant (means followed by the same letter are not significantly different at 0.05 level)

Silicon concentration in leaves:

Table (4) showed the effect of silicon and phosphorus fertilization on concentration of silicon in leaves at flowering - early maturity and the end of the season stages. The results showed a significant effect of adding silicon, at the level of 200 kg Si ha^{-1} compared to the control with an a percent of 300.67 and 14.08% for flowering - early maturity stage and the end of season stage, respectively. Adding silicon increased the available amount in the soil, leading to increased absorption by the plant and increased concentration in leaves. [11] obtained similar results for wheat and maize plants. Silicon concentration increased with increasing phosphorus levels, with an average of 5.53, 6.94, 8.17, and 9.21 g kg^{-1} at the flowering-early maturity stage and 10.08, 12.58, 13.63 and 14.48 g kg^{-1} at the end of the season for levels 0, 12.5, 25, and 50 kg P ha^{-1}, respectively. The reason may be due to the role of phosphorus in increasing the availability of silicon, as indicated by [35] who obtained that adding phosphorus at high levels increases the possibility of its absorption on silicate minerals, forming dissolved compounds in the soil. [23] found that silicon-rich sources have the ability to absorb phosphorus, resulting available forms for plant, which leads to plant absorption. Compounds containing phosphorus and silicon, which reflected positively on the concentration of both elements in the leaves (table 3) (table 4), as it is noted that the two elements tend to have the same behavior. In addition the important role of phosphorus in the synthesis and activation of enzymes involved in the absorption and transport of nutrients. In P-deficit soils, imbalance in plant nutrients may occur resulting in toxicity [36]

The type of fertilizer did not have a significant effect at flowering-early maturity stage, but at the end of the season it was noted that diammonium phosphate was superior to concentrated superphosphate with an average values of 13.05 and 12.33 g kg^{-1}, respectively. The improvement in plant growth in the presence of diammonium phosphate and increasing nutrient uptake explains the difference in the effect of the two fertilizers on this trait.

The concentration of silicon in the leaves increased after silicon addition compared to control and at all phosphorus levels. Conversely, the concentration increased with increasing levels of phosphorus at the two silicon treatments, and the highest value were 14.58 and 15.10 g kg^{-1} for interaction of 50 kg P ha^{-1} and 200 kg Si ha^{-1} at the two stages.

As shown in table (4), silicon values ranged 2.00 and 14.80 g kg^{-1} dry matter during the flowering and early maturity stage, and ranged 3.10 and 16.23 g kg^{-1} dry matter at the end of the season. This clearly indicated that the values exceeded the threshold of 10 g kg^{-1} (1%) when adding silicon, which indicates that corn (of the variety grown in the Present study) can be classified as a silicon-accumulating plant, and thus this property can be exploited to improve the growth of this plant when exposed to various biotic and abiotic stresses. This result is also confirmed the low silicon content in the study soil. [36] indicated that the response of wheat to the addition of silicon increases in soils with low available silicon. Plants differ greatly in their ability to accumulate Si and the concentrations in shoot parts ranged from 1 to 100 g kg^{-1} that accumulate Si higher than 1% are considered as accumulators, while those in which the percentage of Si is lower than 0.5% are considered as non-accumulators of Si. [37] indicated that the concentration of silicon is normally present in concentration of some major elements such as calcium, magnesium, and phosphorus. As shown by [38] that corn is one of the accumulator species of cereals in its organs. These results were similar to those of [39] who indicated that corn was superior to lettuce, wheat, carrots, and pea plants in the silicon content in shoot part and root, noting that the concentrations in the root were higher than in the shoot part reaching, 14702 and 10294 $\mathcal{M}$g g^{-1} dry matter, respectively.

Table 4. Effect of Si application and P fertilization on silicon concentration (g kg^{-1} dry weight) in leaves at two growth stages of corn

Si level (kg Si ha^{-1}), Si	**P- fertilizer (F)**	**P – level (kg P ha^{-1}), P**

		0	12.5	25	50	mean
			Vegetative stage			
0	**CSP**	**2.00**	**3.20**	**2.80**	**3.90**	**2.97**
	DAP	**2.10**	**3.30**	**2.80**	**3.86**	**3.02**
200	**CSP**	**9.00**	**12.20**	**12.70**	**14.37**	**12.07**
	DAP	**9.00**	**9.07**	**14.40**	**14.80**	**11.82**
	mean	**5.53**	**6.94**	**8.17**	**9.21**	
$LSD_{0.05}$: Si = *; P = 0.90; F = NS; Si×P = 1.27; P×F = NS; Si×P×F = NS						
			Post-harvest			
0	**CSP**	**7.27**	**12.33**	**13.50**	**13.70**	**11.7**
	DAP	**7.27**	**13.00**	**13.80**	**14.00**	**12.01**
200	**CSP**	**12.90**	**11.50**	**13.50**	**13.97**	**12.97**
	DAP	**12.90**	**13.50**	**13.70**	**16.23**	**14.08**
	Mean	**10.08**	**12.58**	**13.63**	**14.48**	
$LSD_{0.05}$: Si = *; P = 0.95; F = *; Si×P = 1.35; P×F = NS; Si×P×F = NS						

CSP: concentrated superphosphate; DAP: diammonium phosphate; *: significant; NS: not significant.

When comparing the concentrations of silicon and phosphorus in the leaves and for the two stages, it can be showed that there is a clear superiority of the silicon content of the leaves compared to phosphorus, with an increase of 1.8 and 2.6 times for the stages of flowering - early maturity and the end of the season, respectively. When comparing the available amounts of the two elements in the incubation experiment (unpublished data), it is noted the available phosphorus was more than available silicon at all stages, so this confirms that absorption was linked to factors related to the plant, but not to the available amounts in soil, such as a difference in the nature of absorption for the two elements, (active or passive) as well as interactions between the two elements in soil and plants tissues. Similar results were obtained by [16] on tomato plants, however [10] obtained an increase in the concentration of phosphorus compared to silicon at vegetative growth stage, and the two concentrations were approximately equal at the silking and harvest stages of the corn plant. In general, the concentration of the two elements inside the leaves at the two stages is over the critical level, except for the concentration of phosphorus at the level of 0 kg P ha^{-1} at the flowering - early maturity stage. [35] indicated that the concentration of silicon and phosphorus in well-fertilized cereals and grasses ranged between 2 and 20 mg Si g^{-1} dry matter and 0.3 - 0.4% P, respectively.

E. Silicon uptake in the shoot:

Figure (3) illustrated that silicon uptake increased with addition of 200 kg Si ha^{-1} compared with non-addition with an average values of 154.84 and 33.61 kg ha^{-1}, respectively. This is due to the role of silicon in increasing the concentration in the plant after increasing its availability in soil. These results agreed with [40]. As for the effect of phosphorus, it is noted that silicon uptake increased with increasing phosphorus levels, with a significant difference among levels. This an attributed to the increase in the amount of silicon in the leaves at the two stages (table 4). Diammonium phosphate was superior to concentrated superphosphate in regard to silicon uptake, and the two fertilizers gave an average of 99.84 and 88.61 kg ha^{-1}, respectively. This result was consistent with the silicon concentration in the leaves at the end of the season (table 4). It can be seen from the results of Figure (3) that the treatments including the addition of silicon gave the high values of Si uptake compared to no addition at all levels of phosphorus and type of fertilizer, with a appreciable effect of diammonium phosphate compared to concentrated superphosphate. The highest value reached 223.97 and 43.26 kg ha^{-1} for the two fertilizers, respectively, and each of them outperformed the corresponding values by an increase rate of 80.85 and 82.91%, respectively.

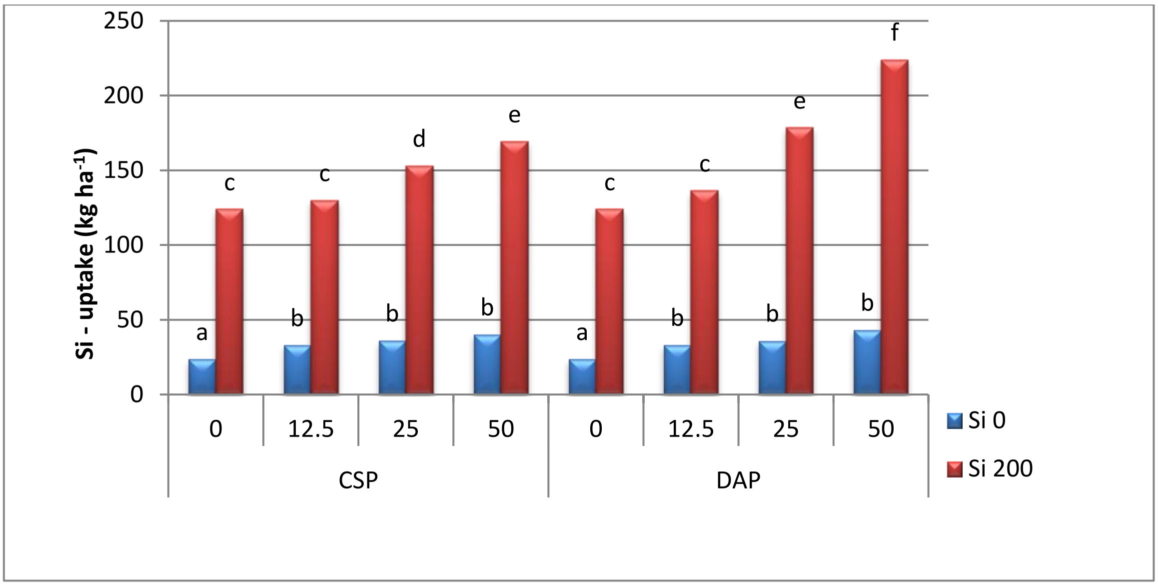

Fig. (3): Effect of Si application and P fertilization on Si – uptake in corn shoot (means followed by the same letter are not significantly different at 0.05 level)

F. Si/P uptake ratio:

Table (5) showed that the ratio of uptake silicon/uptake phosphorus in the shoot part of corn gave values higher than (1). This clearly indicated that the uptake amount of silicon over the uptake amount of phosphorus at all treatments and even in the treatment of not adding silicon. This is due to the concentration of silicon in the leaves is higher than the concentration of phosphorus at the end of the season (tables 3,4). Results also showed that this ratio continued to excess over (1) even in the case of high levels of phosphorus (50 kg P ha^{-1}), which had the greatest uptake of phosphorus. This is further confirmation of the ability of the corn used in the present study to accumulate silicon excess than the concentration of phosphorus in the leaves. This is true for adding or not adding silicon treatments For control also, it can be seen that the Si/P ratio at diammonium phosphate did not strongly differ with concentrated superphosphate for adding silicon. This is further evidence of the high ability of corn to absorb silicon even in treatments with diammonium phosphate which have a higher concentration of phosphorus in plant. The Si/P ratio for the treatments including the addition of 200 kg Si ha^{-1} were higher than treatments without the addition of silicon at all interactions, with an increase of 2.99 times. This can confirmed by increasing silicon concentration and dry weight at 200 kg Si ha^{-1} treatments . Therefore, it can be concluded that the ratio of Si/P uptake was not significantly affected by the type of phosphate fertilizer and phosphorus levels, but was greatly affected by the silicon addition.

Table 5. Effect of Si application and P fertilization on Si/P uptake ratio in corn shoot at post-harvest stage

Si level (kg Si ha^{-1}), Si	**P- fertilizer (F)**	**P – level (kg P ha^{-1}), P**			
		0	**12.5**	**25**	**50**
0	**CSP**	1.54	1.33	1.44	1.23
	DAP	1.54	1.33	1.11	1.05
200	**CSP**	4.60	3.57	3.97	3.49
	DAP	4.60	3.97	3.57	3.86

CSP: concentrated superphosphate; DAP: diammonium phosphate

CONCLUSION

It can be concluded that it is possible to use potassium silicate at a level of 200 kg Si ha^{-1} to increase phosphorus availability in calcareous soil and improve the uptake of phosphorus by corn plants. The success of using diammonium phosphate fertilizer as an alternative to concentrated superphosphate fertilizer since we know that the conditions of producing the latter fertilizer are currently not suitable. The results of the study also indicated that corn, of the variety used, is a silicon-accumulator plant, and this phenomenon can be exploited to improve the growth conditions of this plant under different stress conditions prevailing in the region, such as salinity, drought, and infections.

REFERENCE

[1] J. P. Lynch “Root phenes for enhanced soil exploration and phosphorus acquisition: tools for future crops,” Plant physiology, 156(3), 1041-1049, 2011.

[2] O. Talibuddin “Precipitation, in The Chemistry of Soil Processes,” D.J. Greenland and M.H.B. Hayes: Eds., John Wiley and Sons. Chichester, U.K., pp. 81-116, 1981.

[3] J. F. Power and R. Prasad “Soil fertility management for sustainable agriculture,” CRC press, 1997.

[4] J. Schaller; S. Faucherre; H. Joss; M. Obst; M. Goeckede; B. Planer-Friedrich; S. Peiffer; B. Gilfedder and B. Elberling “Silicon increases the phosphorus availability of Arctic soils,” Scientific reports, 9(1), 449, 2019.

[5] F. Guntzer; C. Keller and J.D. Meunier “Benefits of plant silicon for crops: a review,” Agron. Sustain. Dev. 32, 201–213, 2012a.

[6] L. Anggria; H. Husnain; K. Sato and T. Masunaga "Release of silicon from silicate materials and its uptake by rice plant," Indonesian J. of Agric. Sci., 18(2), 69-76, 2017.

[7] Owino-Gerroh and G. J. Gascho "Effect of silicon on low pH soil phosphorus sorption and on uptake and growth of maize," 2004.

[8] M. Liao; Z.P. Fang; Y.Q. Liang; X.H. Huang; X. Yang; S.S. Chen and J.W. Guo "Effects of supplying silicon nutrient on utilization rate of nitrogen and phosphorus nutrients by rice and its soil ecological mechanism in a hybrid rice double-cropping system," Journal of Zhejiang University-science B, 21(6), 474-484, 2020.

[9] S. Pati; B. Pal; S. Badole; G.C. Hazra and B. Mandal "Effect of Silicon Fertilization on Growth, Yield, and Nutrient Uptake of Rice," Communications in Soil Science and Plant Analysis. [Online] 47 (3), 284–290, 2016.

[10] A. M. H. Al-Ameri "Effect of Rate and Source of Applied Silicon to the Soil on its Phyto Availability and Tolerance of Maize to Water Stress,". Dissertation. University of Baghdad, College of Agricultural Engineering Sciences, Iraq, 2022. (In Arabic).

[11] M. Ayman; S. Metwally; M. Mancy and A. Abd Alhafez "Influence of nano–silica on wheat plants grown in salt–affected soil," J. of Prod. and Dev., 25(3), 279-296, 2020.

[12] D. Debona; F. A. Rodrigues; L. E. Datnoff "Silicon's role in abiotic and biotic plant stresses," Annu Rev Phytopathol. 55:85–107, 2017.

[13] L. Kostic; N. Nikolic; D. Bosnic; J. Samardzic and M. Nikolic "Silicon increases phosphorus (P) uptake by wheat under low P acid soil conditions," Plant and Soil, 419, 447-455, 2017.

[14] A. Richards "Diagnosis and improvement of saline and alkali soils," Agris. Hand book No. 60. USDA. Washington, USA,1954.

[15] A. L. Page; R. H. Miller and D. R. Kenney "Methods of soil analysis. Part 2 chemical and biological properties," Amer. Soc. Agron. Inc. Pnnblisher, Madison. Wisconsin, 1982.

[16] A. H. Jabal "Role of Nanosilicon in An Improving the Defence of Tomato Plant (*Solanum lycopersicum* L.) to Salinity of Irrigation Water," Dissertation, University of Basrah, Collage of Agriculture, Iraq, 2022. (In Arabic).

[17] V. V. Matichencov and E.A. Bocharnikova "The relationship between silicon and soil physical and chemical properties," In: Datnoff LE, Snyder GH, Korndörfer GH (eds) Silicon in agriculture. Elsevier, Amsterdam, pp 209–219, 2001.

[18] M. S. Cresser and J.W. Parsons "Sulphuricperchloric and digestion of plant material for the determination of nitrogen , phosphorus , potassium, calcium and magnesium," Anal. Cheam. Acta. 109:431-436, 1979.

[19] Dai Wei-min; K. Zhang; B. Duan; C. Sun; K. Zheng; R. Cai and J. Zhuang "Rapid determination of silicon in rice (China)," Rice.Scie.,12(12):145-147, 2005.

[20] K. M. Al-Rawi and A. M. Khalaf Allah "Design and analysis of agricultural experiments," Ministry of Higher Education and Scientific Research, Dar Al-Kutub for Printing and Publishing, University of Mosul, Iraq. 1980. (In Arabic).

[21] J. Koski-Vähälä; H. Hartikainen and P. Tallberg "Phosphorus mobilization from various sediment pools in response to increased pH and silicate concentration," J. of Env. Quality, 30(2), 546-552, 2001.

[22] S. Neu; J. Schaller and E.G. Dude "Silicon availability modifies nutrient use efficiency and content, C:N:P stoichiometry, and productivity of winter wheat (Triticum aestivum L.)," Sci Rep 7:40829, 2017.

[23] V. V. Matichenkove and Y.M. Ammosova "Effect of amorphous silica on some properties of a sod-podzolic soil," Eurasian Soil Science. 28, 87–99, 1996.

[24] A. Hömberg; M. Obst; K. H. Knorr; K. Kalbitz and J. Schaller "Increased silicon concentration in fen peat leads to a release of iron and phosphate and changes in the composition of dissolved organic matter," Geoderma, 374, 114422, 2020.

[25] M. Vaculik; A. Lux; M. Luxova; E. Tanimoto and I. Lichtscheidl "Silicon mitigates cadmium inhibitory effects in young maize plants. Environ," Exp. Bot. 67, 52–58, 2009.

[26] M. Vaculíková; M. Vaculík; S. Tandy; M. Luxová and R. Schulin "Alleviation of antimonate (SbV) toxicity in maize by silicon (Si)," Environ. Exp. Bot. 128, 11–17, 2016.

[27] A. K. Ibrahim "Effect of level and source of phosphate fertilizer on P availability and growth and yield of corn (Zea mays L.) intercropped with cowpea (Vinga unuiclata L.),". M. Sc. Thesis. University of Basrah, Collage of Agriculture, Iraq, 2021. (In Arabic).

[28] S. J. Volkweiss and B. van. Raij "Retenção e disponibilidade de fósforo em solos," SIMPÓSIO SOBRE CERRADO, BASES PARA UTILIZAÇÃO AGROPECUÁRIA, 4, 317-332, 1976.

[29] J. R. Okalebo and A.F. Mackenzie "A filed control study of ammonium phosphate and superphosphate –urea or ammonium nitrate on corn (Zea mays L.) growth in five quebec soils," Canadian j. of soil sci., 58(2), 221-228, 1978.

[30] M. Mussarat; H. Ali; D. Muhammad; I. A. Mian; S. Khan; M. Adnan; S. Fahad; F. Wahid; K. Dawar; S. Ali; A. Zia; M. Ahmad; S. Khan; W. A. Shah; M. Romman; R. Parvez; M. H. Siddiqui; A. Khan; D. Wang and X. Jiang "Comparing the phosphorus use efficiency of pre-treated (organically) rock phosphate with soluble P fertilizers in maize under calcareous soils," PeerJ, 9, e11452, 2021.

[31] C. H. Li; T. D. Chu; X. B. Liu and Q, Yang "Silicon nutrition effects and its study and application development in China," In Proceedings of Symposium of Plant Nutrition, Shaanxi Science and Technology Press, China (pp. 329-333), 1999.

[32] T. Murphy and J. R. Riley "A modified single solution method for the determination of phosphate in natural waters" Anal .Chem. Acta., 27:31-36, 1962.

[33] M. J. Mustafa "Effect of phosphorus fertilization through integrated nutrient management on some soil properties and growth of sunflower (Helianthus annuus L.)," . M. Sc. Thesis. University of Basrah, Collage of Agriculture, Iraq, 2019. (In Arabic).

[34] K. A. Cherepanov; G. I. Chernish; V. M. Dinelt and J. I. Suharev "The utilization of secondary material resources in metallurgy," Moscow: Metallurgy, 1994

[35] K. A. Cherepanov; G. I. Chernish; V. M. Dinelt and J. I. Suharev "The utilization of secondary material resources in metallurgy," Moscow: Metallurgy, 1994.

[36] B. White; B.S. Tubana; T. Babu; H. Mascagni Jr; F. Agostinho; L.E. Datnoff and S. Harrison "Effect of silicate slag application on wheat grown under two nitrogen rates," Plants, 6(4), 47, 2017.

[37] E. Epstein "Silicon. Annual review of plant biology," 50(1), 641-664, 1999.

[38] N. Mitani; N. Yamaji and J.F. Ma "Identification of maize silicon influx transporters," Plant and Cell Physiology, 50(1), 5-12, 2009.

[39] M. ID. Greger; L. Tommy and V. Marek "Silicon influences soil availability and accumulation of mineral nutrients in various plant species," Plants., 7(41):1-16, 2018.

[40] A. M. Al-Ameri; F. O. Janno and N . S. Ali "Effect of rate and source of applied silicon fertilizer on availability of silicon, N and P in the soil for some growth stage of Maize," Iraqi j. of soil sci., 22, 2022. (In Arabic).

Conflict of Interest Statement*:The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.*