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Original Research Article

Relationship between iron and silicon absorption behavior and the macronutrients in sandy soil affected by some different soil additives

ABSTRACT

Aims: A field experiment was carried out to study the relationship between iron (Fe) and silicon (Si) absorption behavior and the macronutrients in sandy soil in presence of soil additives different in their effect on the nutrient' availability.
Study design: Single levels of rice straw, cellulose, silica, and K-humate were applied in a randomized complete block design.
Place and Duration of Study: A field experiment for two successive seasons (summer season 2015 and winter season 2016) in sandy soil of the Ismailia Agricultural Research Station - Egypt.
Methodology: Separate single rates of 1190.48 kg/ha for rice straw, cellulose, silica and 4.76 kg/ha for K-humate were mixed with the soil surface before cultivation and then covered with a thin layer of soil. Sesame seeds and/or wheat grains were hand sown and planted as recommendations. At harvest, the seeds and grains were analyzed for N, P, K, Si and Fe, as well as the soil available N, P, K after harvesting each crop.
Results: Treatments decreased the absorbed Fe by seeds in the order control > silica > rice straw > K-humate > cellulose. Oppositely, Fe% of grains was enhanced by treatments compared to the control in the direction: K-humate > silica > rice straw > cellulose > control.

Si absorbed by sesame seeds is inhibited affected by treatments compared to the control in the order: Control > rice straw > K-humate > silica > cellulose.
Conclusion: Excess fertilization by NPK and excess availability in sandy soil may have adverse effect on the absorption of Fe and Si even if they were available. Enough NPK fertilization is sometimes ideal for the utilization of Fe and Si. Their absorption was positively correlated with total NPK for sesame seeds and with total NP for wheat grains. But it was negatively correlated with total K.

Keywords: Iron; nutrients' behavior; Silicon; Sandy soil; Soil additives

1. INTRODUCTION

Deficiencies in micronutrients of some crops lead deficient diets of a large proportion of the world's population especially for Fe and Zn, which have a strong negative impact on human health. Little is known about the relation between Si and micronutrient (Fe, Zn and Mn) deficiencies in some types of plants [1].

All plants grown in soil contain Si from 0.1% to 10% by weight of plants in their tissues. Silicon uptake by plants varies greatly between species and cultivars, i.e., gramineous vs leguminous plants, and plants are classified as high-, intermediate-, and non-Si-accumulators. Si concentration in plant tissues depends upon the characteristics of Si uptake and transport, variability between species and genotypes within a species. Plant roots take up Si in the form of un-dissociated H_4SiO_4 and Si uptake mechanisms differ between plant species. Transporters responsible for Si uptake by roots have been identified in different plant species such as rice, barley, maize, wheat, and cucumber [2, 3].

Silicon nutrition increased the accumulation of both organic acids and phenolic compounds in cucumber tissues was exclusively related to Fe nutrition but without effect on the mobility and tissue distribution of Zn or Mn. The biological importance of Fe is a result of its reversi-ble changes of oxidation state over a wide range of redox potentials. Iron (Fe) is a component of a number of enzymes involved in various biological processes, including respiration and photosynthesis [1].

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Studies on the Fe hyper-accumulator plants such as Imperata cylindrica have been indicated that the metabolism in plants is much more complex than has been reported. Jarosite ($KFe_3(OH)_6(SO_4)_2$) and ferrihydrate-ferritin, accumulate in the different tissues like roots and rhizomes while in the leaves most of the Fe^{3+} is stored in ferritin as the main Fe managing structure of the plant [1]. Ferritins are a class of ubiquitous Fe storage proteins, found in all living kingdoms and their presence is related to the beneficial effect of Fe on seed production. Zea mays treatment by Fe induced ferritin protein accumulation in the roots and leaves [4, 5].

Cucumber, pumpkin, and soybean demonstrate Si-induced increase of the apoplastic Fe pool, with the enhanced expression of genes involved in biosynthesis of Fe-mobilizing com-pounds in roots of Fe-deficient cucumber. A probable mechanism might involve the chelation of Fe by Si-induced biosynthesis of chelating compounds [1]. For soybean, presence of Si in the Fe deficient nutrient solution, prevented the chlorophyll degradation, delayed the Fe chlorosis symptoms appearance, slowed down the growth decrease due to the Fe deficiency, and maintained the Fe content in leaves. In cucumber, Si addition delayed the decrease of stem dry weight, stem length, node number, and Fe content in stems and roots, but no-effect was observed in chlorosis symptoms alleviation in leaves. The effect of Si in plants grown under Fe deficiency was plant-specific and different responses were observed for soybean and cucumber [5]

Si mediates the heavy metal toxicity by the accumulation of As, Cr, Cd and Fe^{+2} in Ly-copersicon esculentum, Brassica chinensis, Avicennia marina, and O. sativa respectively [6]. Addition of Si along with Fe^{+2} in the solution significantly ameliorated Fe^{+2} toxicity to root cells as the ameliorative effect of Si on rice plants under Fe toxicity [2, 3].

Silicon applications significantly increased Fe concentrations in Fe plaque of different genotypes. The oxygenation of plant roots by radial oxygen loss ROL and rhizosphere oxy-genation by microbial activities convert Fe^{+2} to Fe^{+3}, leading to the formation of Fe-plaque around roots. Root radial oxygen loss (ROL) rates are considered as the key biotic factor controlling Fe plaque formation. The plaque mainly comprises of ferric hydroxides (63%), goethite (32%) and minor concentrations of siderite (5%), whose structure is characterized as amorphous or crystalline Fe (oxyhydr) oxides. Due to adsorption or co-precipitation mechanisms, Fe plaque can sequester metals, metalloids (e.g. As) and anions such as carbonate and silicate on rice roots [4].

Many factors influencing the formation of Fe plaque such as ROL, genotype, pH, Eh and presence of microorganisms. Iron oxides are able to combine with silicate to form Fe silicate and deposit on root surfaces. Silicon application can significantly increase Fe plaque formation. Silicon acid limited the adsorption of As(III) and As(V) on ferri-hydrite by occupying the absorption sites [4]

The oxidation of Fe^{2+} resulted in the co-precipitation of Si with Fe. Dissolved Si is ad-sorbed preferentially to poorly crystalline Fe rather than crystalline Fe, and a part of the poorly crystalline Fe is reducible in a flooded soil. When the soil Eh decreases to a sufficient level to permit Fe-reducing bacteria to be active, its associated Si becomes available to rice plants. The oxidation of Fe^{2+} following the drainage of floodwater may induce the co precipitation of Si in soil solution [13].

The growth and water status were reduced by K-deficient stress, but Si application significantly alleviated these decreases and alleviated the plant hydraulic conductance. Si mediates K^+ accumulation in xylem, which ultimately alleviates the plant-water status under the K-deficient condition [12]. Some properties of Fe particles could stimulate the soil bacterial community structure that facilitates C and N cycling in soil [13]. Magnetic processes may affect salt movement and solubility of nutrients [14].

The present study aims to evaluate the effect of adding rice straw, cellulose, silica, and K-humate as soil additives on the nutrient' availability and absorption behavior in sandy soil. It focuses on the relationship between the absorption of Fe and Si by sesame and wheat and the available and total macronutrients: N, P, and K.

2. MATERIAL AND METHODS

A field experiment for two successive seasons under sprinkler irrigation were carried out using sesame (*Sesamum indicum L.*) cv. Shandauil-3 (summer season 2015) and wheat (*Triticum sativa*) cv. Sakha 93 (winter season 2016), respectively, under the conditions of sandy soil (TypicTorripsamment; Entisol [Arenosol AR] [15] of the Ismailia Agricultural Research Station, Agricultural Research Center (ARC) - Egypt. Some characteristics of the experiment soil were determined in the upper 30 cm layer according to Page [16] and shown in Table (1).

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Table 1 Some characteristics of the experiments soil before cultivation

Character		
Particle size distribution (%)	**Coarse sand**	72.12
	Fine sand	14.32
	Silt	3.22
	Clay	10.34
Texture class		Sandy
$CaCO_3$ (%)		0.36
Organic Matter (OM, %)		0.23
pH (1:2.5 soil : water suspension)		8.01
Saturation Percent (SP, g water : g soil)		25.00
Electrical Conductivity (EC, dS m^{-1}) (1:5 soil : water extract)		0.30
Available nutrients (mg kg^{-1})	**N**	20.50
	P	2.01
	K	50.13

2.1. Planting

Single applications at a rate of 1190.48 kg/ha for rice straw, cellulose, silica and 4.76 kg/ha For K-humate were applied. Plots (3 × 3 m^2) were prepared for cultivation. Treatments were applied in a complete randomized block design with three replicates consisted of 15 plots. Sesame seeds and/or wheat grains were hand sown and planting and the other agronomic practices were applied as recommendations.

The applied materials were mixed with the soil surface before cultivation and then covered with a thin layer of soil. All treatments received a constant level of nitrogen (i.e. 95.2 kg N/ha for sesame, 238 kg N/ha for wheat, while 119 kg/ha of K_2SO_4 (48% K_2O) for both sesame and wheat was applied in two equal doses after sowing as recommended.

2.2. Analysis of soil and plant samples

A half gram of ground seeds was wet digested using acid mixture (1:1 $H_2SO_4/HClO_4$) [17]. After harvesting, soil available N, P and K were extracted by (1%) K_2SO_4, 0.5 N $NaHCO_3$ and 1 N NH_4OAc (pH 7.0), respectively. Total percentage of N, P and K in digested plant samples and the available in the soil extracts were estimated by distillation using Kjeldahl apparatus, colorimetrically by UV-Vis. Spectrophotometer using $SnCl_2$ indicator and by flame photometer, respectively [18, 19]. Total concentration of Fe and Si was measured for seeds by ICP Spectrometry (*ICP-Ultima 2 JY Plasma*).

2.3. Statistical Analysis

The one-way analysis of variance (ANOVA) was carried out using the Co-State software to determine the statistical significance of the treatment effects at a significance level of 0.05 [20]. Treatments means were compared by using LSD test at 5% of probability. Correlation coefficient (r) was calculated to find

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possible relationship between the percent of Fe and Si in seeds and grains and total and available macronutrients.

3. RESULTS AND DISCUSSION

Four types of soil additives were used to study the relation between Fe and Si absorption from sandy soil and the total and available macronutrients. Rice straw (1), cellulose (2), silica (3) and K-humate (4) were used for their different effects on nutrients absorption either enhancing or inhibiting. Sesame and wheat were grown for two successive seasons in order to follow the residual effect of additives on the Fe and Si absorption.

3.1. Behaviour of Soil available NPK

Figure 1 (a-c) shows the behavior of soil available NPK in presence of the different additives for the first season and their residual effect. For the 1st season, cellulose enhanced the available N while silica and K-humate enhanced the available P and K compared to the control. Their residual effect sharply decreased compared to the control and to their effect of the 1st application except for the residual effect of cellulose on the available K and P and silica and K-humate on the available P. The legumes crops like sesame increase the N availability in soil more than wheat due to the effect of root nodules.

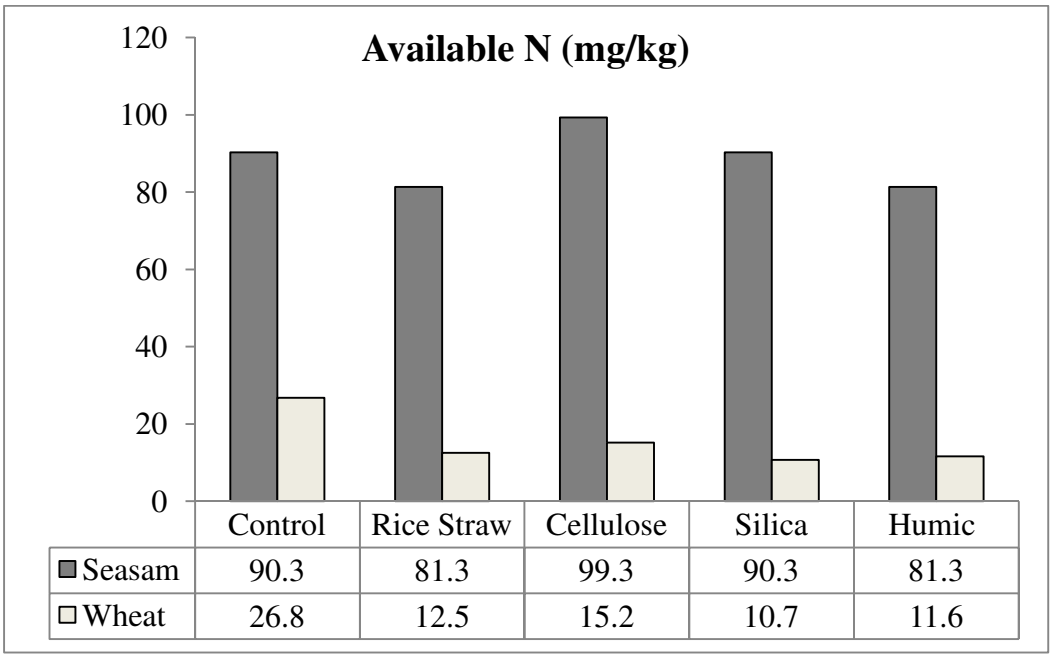

Figure 1a Effect of the studied soil additives on the soil available N (mg/kg) during two successive seasons

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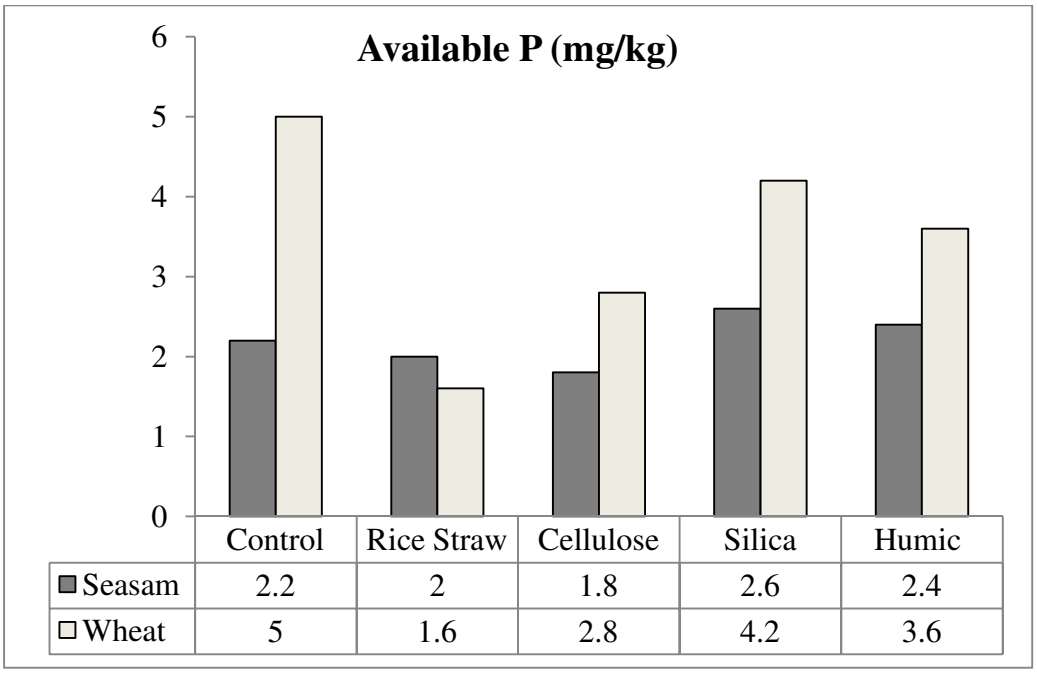

Figure 1b Effect of the studied soil additives on the soil available P (mg/kg) during two successive seasons

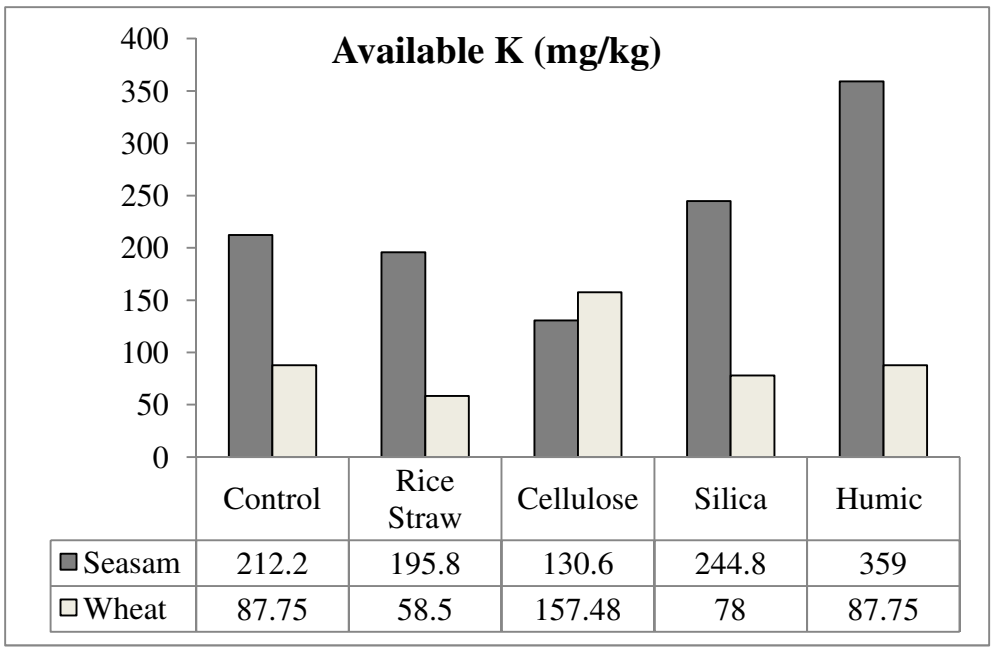

Figure 1c Effect of the studied soil additives on the soil available K (mg/kg) during two successive seasons

3.2. Macronutrients' percent of seeds and grains

Figure 2 (a-c) presents the total NPK of sesame seeds and wheat grains for the different treatments. For sesame seeds, both of the rice straw and cellulose treatments have increased the total N% while silica has increased the total K compared to the control.

Cellulose and K-humate have increased the wheat grains' total N%. Again silica and K-humate have increased the total P, which may be their residual effect on the available P in the previous season. Rice straw and cellulose have increased the total K of the wheat grains compared to the control.

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The residual effect of all treatments on the total NPK was lower than their effect at the 1st application.

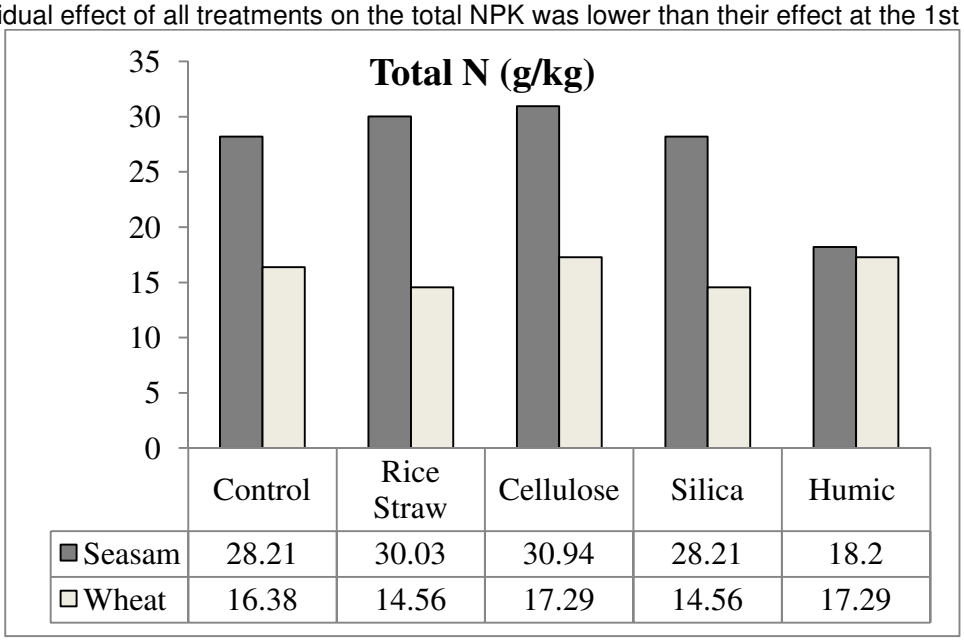

Figure 2a Effect of the studied soil additives on the total N (mg/kg) of both sesame seeds and wheat grains during two successive seasons

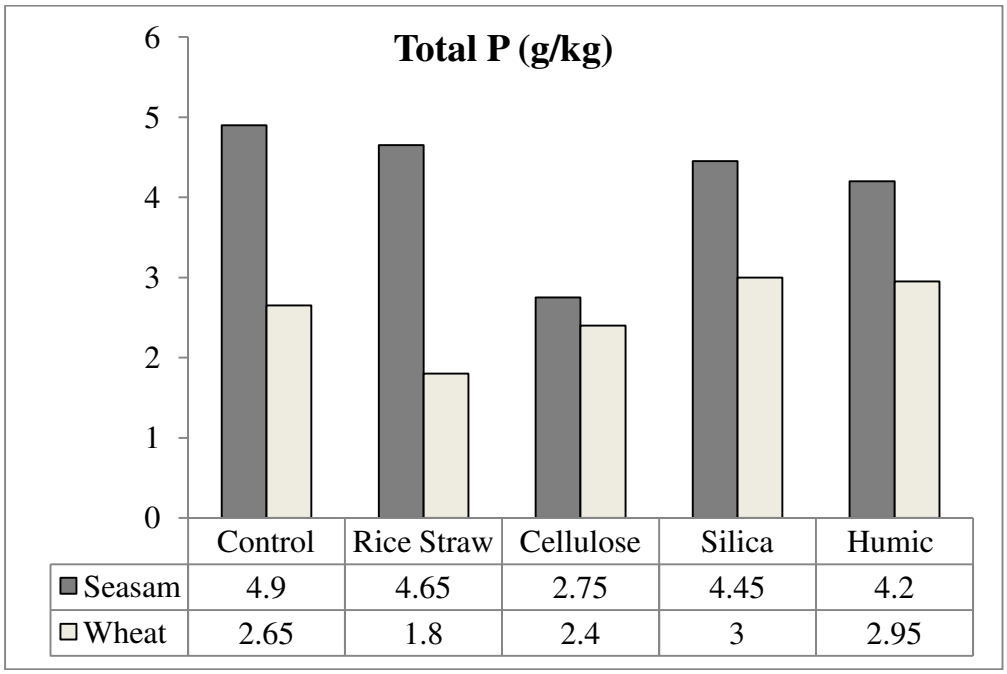

Figure 2b Effect of the studied soil additives on the total P (mg/kg) of both sesame seeds and wheat grains during two successive seasons

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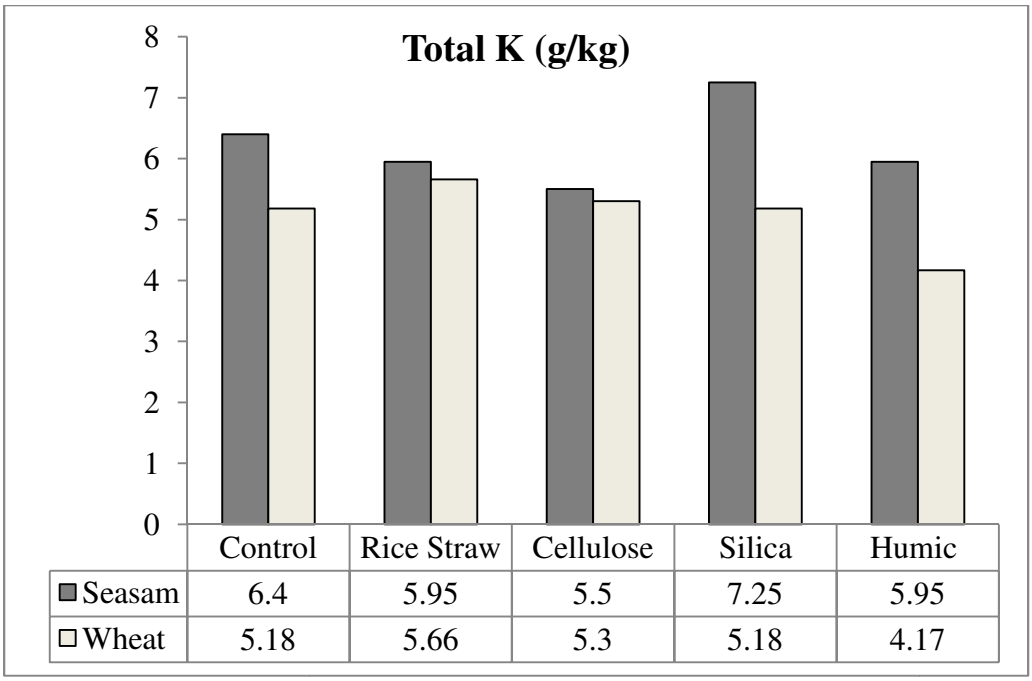

Figure 2c Effect of the studied soil additives on the total K (mg/kg) of both sesame seeds and wheat grains during two successive seasons

3.3. Behavior of the total Fe

According to Fig. 3, the different treatments decreased the absorbed Fe by sesame seeds in the order control > silica > rice straw > K-humate > cellulose.

In an opposite trend, Fe% of wheat grains was enhanced by treatments compared to the control in the direction: K-humate > silica > rice straw > cellulose > control. Sensitivity of wheat to Fe indicates that it is a Fe accumulator.

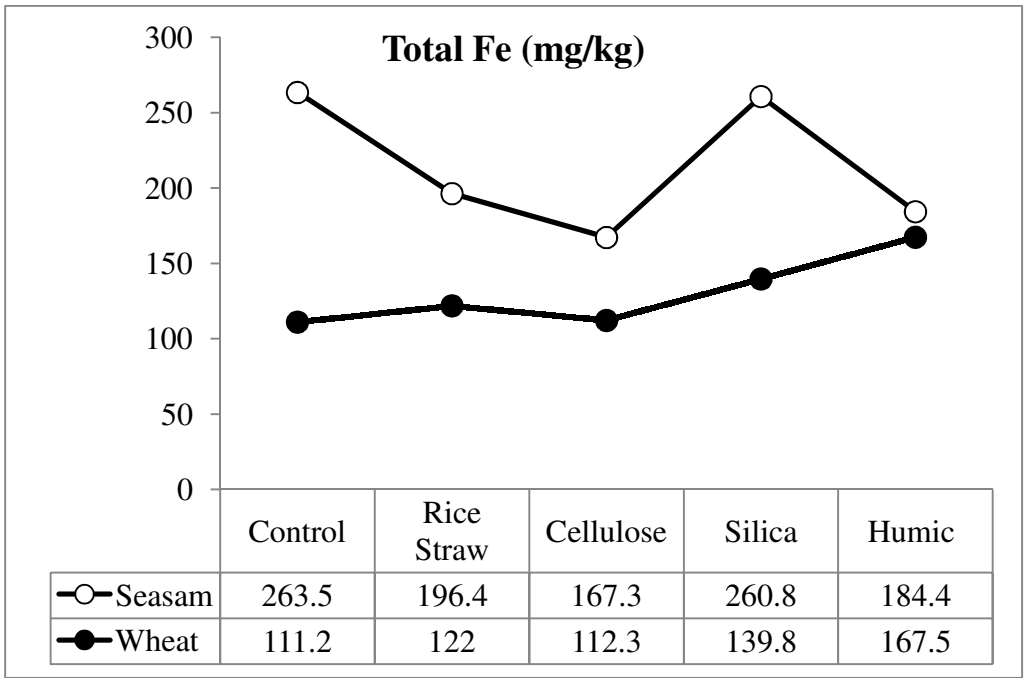

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Figure 3 Effect of the studied soil additives on the total Fe (mg/kg) of both sesame seeds and wheat grains during two successive seasons

3.4. Behavior of the total Si

Figure 4 indicates that Si absorbed by sesame seeds is inhibited affected by all treatments compared to the control in the order: Control > rice straw > K-humate > silica > cellulose.

For wheat grains, the Si% was enhanced compared to the control in the order: K-humate > cellulose > rice straw > silica = control. The sensitivity and affinity of a crop differ from sesame to wheat and play a role in its Si content.

Additionally, the type of a soil additive used has an effect. Silicon from K-humate is an organo form readily available and more compatible for plant nutrition. Cellulose and rice straw are fibrous materials and their fibers mixed with soil particles enhance Si availability or keep Si if available from leaching and/or restrict fixation. Solubilized Si may adsorb on their fibers or chemically bind to the hydroxyl moieties of the rice straw and cellulose to be as Si-exchangers (Si – OH –) or a donor of silicic acid moieties. The soluble form of Si as the weakly acidic orthosilicic acid monomer [$Si(OH)_4$] (or its ionized form, $Si(OH)_3O_2^-$) that allow its uptake by plants from the soil. Weak effects considering the low content of soil OM and degradation of such fibers by microorganisms may occur. Another suggested mechanism is the fibers dissolution under the effect of soil solution conditions (ionic composition and pH).

Although silica is a pure SiO_2, it showed a poor effect on the absorbed Si by seeds or grains. Its Si moiety is either unavailable (insoluble or precipitated) since it is extracted at a pH range 7-8 same as that of soil. However, SiO_2 dissolution is possible under the conditions of soil solution.

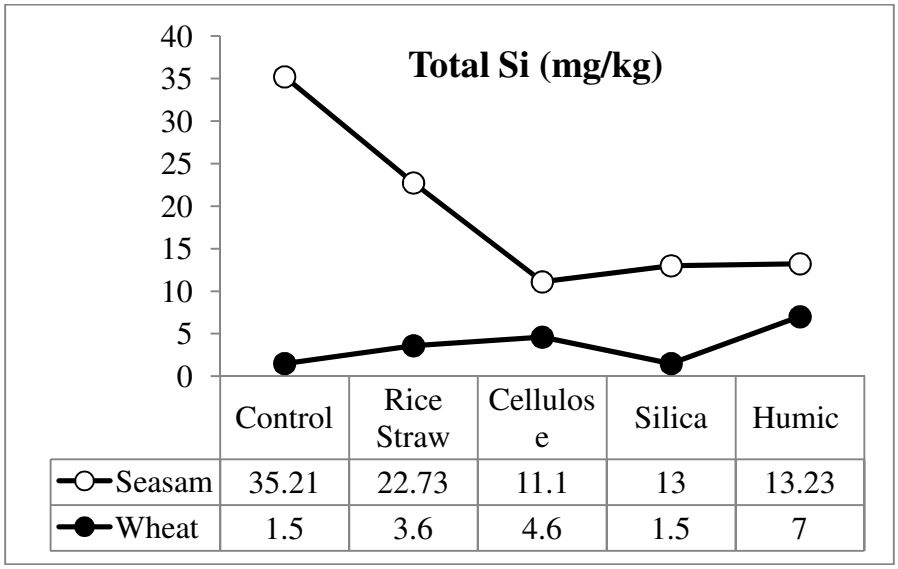

Figure 4 Effect of the studied soil additives on the total Si (mg/kg) of both sesame seeds and wheat grains during two successive seasons

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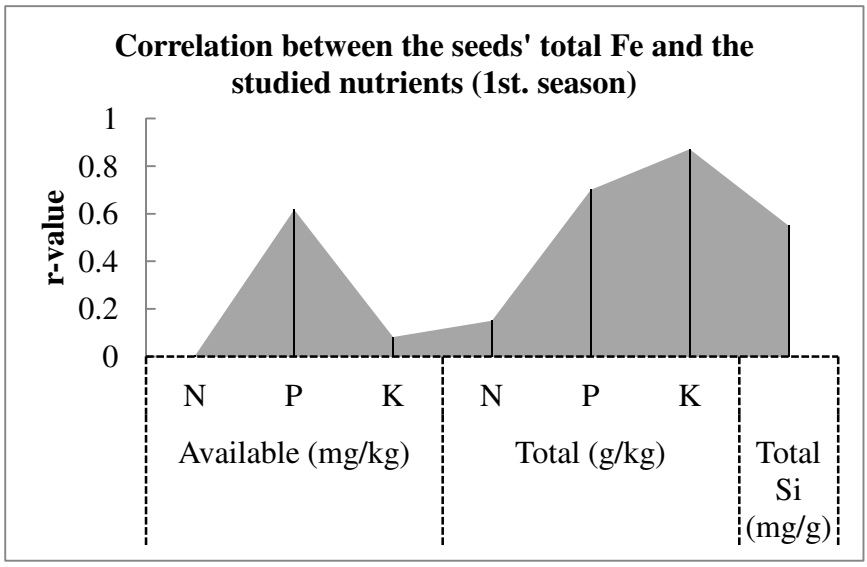
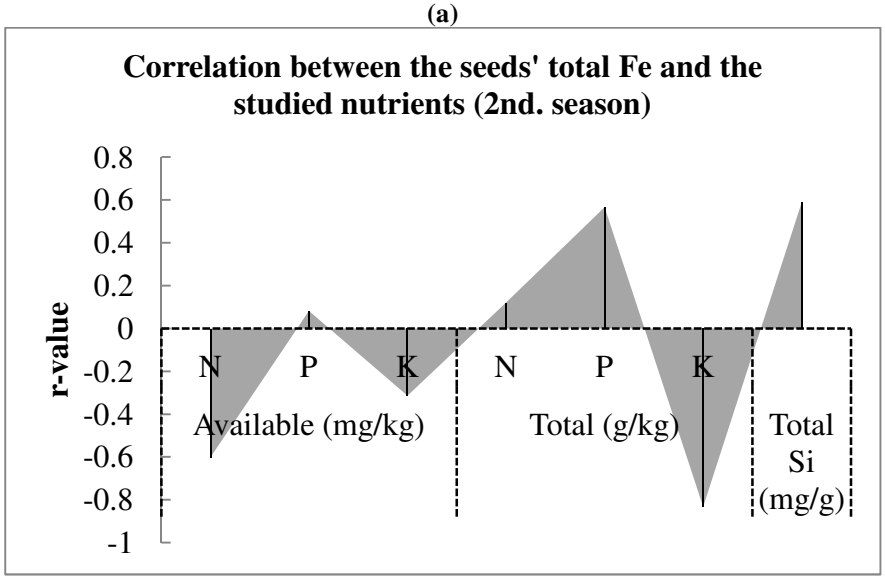
3.5. Correlation between absorption of Fe and Si and macronutrients

Figure 5 (a, b) gives a view of the correlation between Fe and different nutrients. Positive correlation exists between Fe in sesame seeds and both available and total NPK but only with available P and total NP for wheat grains.

Positive correlation exists between Fe and Si percents in both crops the successive seasons. It is higher for wheat than sesame.



(a)



(b)

Figure 5 **Correlation between the seeds' and/or grains' total Fe and the studied nutrients during two successive seasons**

Figure 6 (a, b) for Si absorption correlations indicates positive with available NPK and positive ones with total NPK for seeds. Only positive correlation is with available K and total N and P with a small value.

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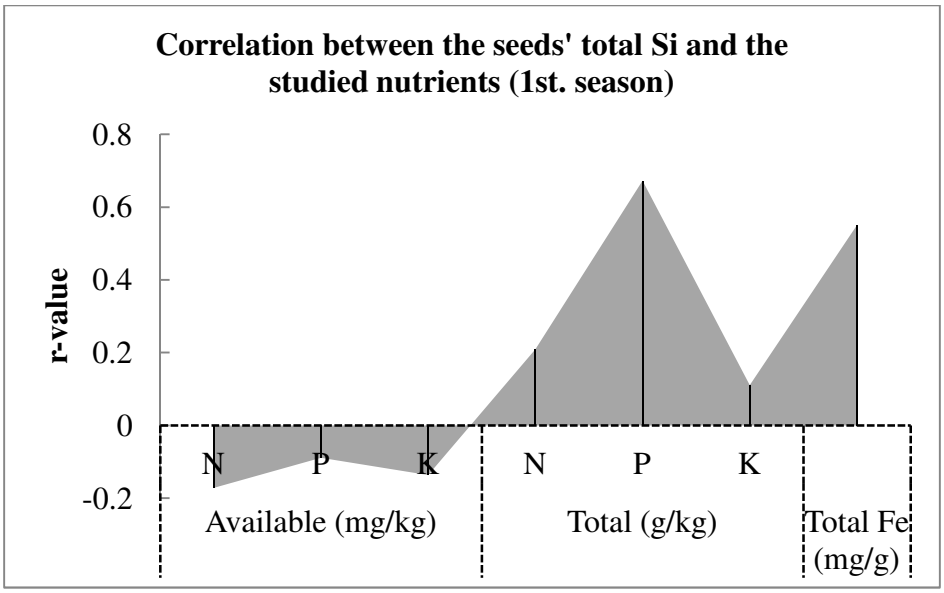
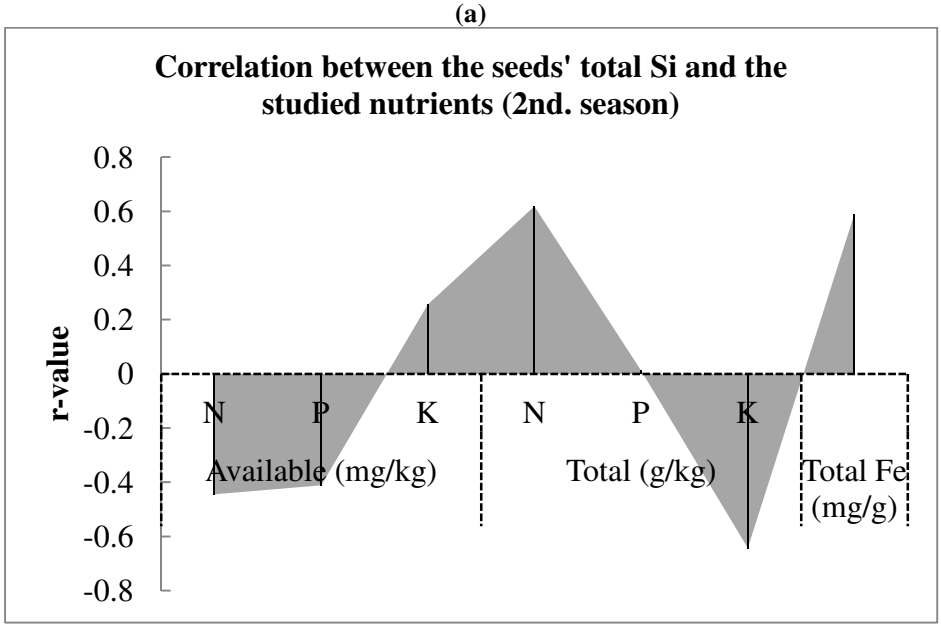


(a)



(b)

Figure 6 **Correlation between the seeds' and/or grains' total Si and the studied nutrients during two successive seasons**

4. CONCLUSION

The results indicate that the applied additives have affected the absorbed Fe and Si by sesame seeds and wheat grains which were related to available and total macronutrients. Although some availability problems related to Si and Fe as plant nutrients, additional factors are to be taken into account. Excess fertilization by NPK and excess availability in sandy soil may have adverse effect on the absorption of Fe and Si even if they were available. On the other hand, enough NPK fertilization is sometimes ideal for the utilization of Fe and Si. Their absorption was positively correlated with total NPK for sesame seeds and with total NP for wheat grains. But it was negatively correlated with total K.

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