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Agronomic Bio-fortification of Egyptian Wheat through Selenium Application in Different Soil Types

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ABSTRACT

Selenium is an essential element for humans, animals and some species of microorganisms. In plants, the role of selenium is still unclear. Agronomic bio-fortification of crops with Se-containing fertilizers provides the best short-term solution for improving Se content. Two experiments were conducted to evaluate the effect of different sources of Se [selenate ($NaSeO_4$) and selenite (NaSeO3)] and different rates (0, 0.75, 1.5 and 3.0 ppm) on Egyptian wheat (Triticumvulogaris) growth, yield, and wheat Se concentration under different soil types (sandy and clay soils). Experiments set up in the greenhouse using plastic pots. Pots were arranged in a completely randomized block design including three replicates for each treatment. Results indicated that soil application of selenate increased plant dry matter production and Se concentrations in wheat plant shoot compared with selenite form. In the second experiment, soil application of selenate at low concentration gave the highest value of dry matter and grains weights. The magnitude of stimulation was remarkably higher in case of clay soil as its yield production (straw and grains) was higher at 0.75 ppm Se level by 56% than those of sandy soils.

Se concentration in plants increased with the amounts of Se added to both soils (sandy and clay soils), also, the selenate form can be used for biofortification of the wheat crop. At the end of experiments, soil selenium concentrations were also significantly higher in sandy soil than in alluvial soil.

This study provides useful information concerning agronomic bio-fortification of wheat which is a staple food and feed for humans and animals.

KEYWORDS: Wheat, Selenate, Selenite and soils.

INTRODUCTION

Oldfield, 2002; Schwarz and Foltz, 1957who'spointed out that the selenium (Se) is an essential trace element for mammals and was the first discovered by the German scientist Jons Jacob Berzelius in1817. The essential role of Se in plant, human and animal nutrition is not clearly (Germ et al., 2007). Lower plants, such as algae, require Se for growth and reproduction; While, Sors et al., 2005 said that, Se is not required for the development and growth of higher plants. Sors et al., 2005 reported the plants absorbed Se from soil in the form of selenate (SeO_4^{-2}) and selenite (SeO_3^{-2}). Then, compounds are transported through the sulfur assimilation pathway and converted into organic Se compounds such as selenomethionine (SeMet), selenocysteine (SeCys), Se-methylselenocysteine and selenocystathionine.
The mostly of the Se absorbed by plants is in organic forms and, thus, should be bioavailable to human.

In biofortification, Se in plant material can be decomposed in agricultural soil which can be used for the increase of food products with Se (Bañuelos et al., 2015). Hence, (Borrill et al., 2014 ; Mayer et al., 2008; Zhao and McGrath, 2009) showed the biofortification is a practice of enriching the agricultural food products with certain nutrients, for example Se, to increase the dietary intake through plant breeding, genetic engineering and manipulation of agronomic practices. Biofortification is an economical safe agricultural technique, which aims to cope up with deficiency of a particular nutrient in diet, and increase the content of Selenium in edible parts of plant. WHO, 2009 reported that, Selenium biofortification increases Se concentration in food products, and can help in alleviation of Se malnutrition to which more than billion people all over the world is suffering. Winkel et al., 2015 found use of Se fertilizers in soil have low rates of Se increased in edible part of plant, whereas, long term use can be toxic to nearby ecosystem, hence use of Se fertilizers should be done carefully to avoid toxic aspects. Researchers round the world are trying to develop Se-enriched food products to minimize Se related deficiency disorders. Selenium fertilization also affects the synthesis of amino acids, protein and phenolics compounds.

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Se mobility in soils as affected by several factors such as type of soil, pH, soil organic matter content and oxi-redox potential (Hlušek et al. 2005). Selenium availability increases with soil pH increase due to the predominance of $SeO4^{2-}$ instead of SeO_3^{2-} and also due to the increase of negative pH dependent charges. However, Se phyto availability decreases on soils with high organic matter content (Eich-Greatorex et al. 2007) and when Fe oxi-hydroxi is present in the clay fraction due to the retention of $SeO4^{2-}$and SeO_3^{2-} (Rajan and Watkinson 1979).

Many studies reported that the application of Se increases plant productivity in straw or grain yield. Use of Se resulted in increases of 14% for straw yield in lettuce (Lactucasativa L.), and 43% for grain production in canola (Brassica napus L.), and 40% for tuber yield in potato (Solanumtuberosum L.) (Lyons et al., 2009. In addition, Boyed (2007) and Hanson et al. (2003) indicated that Se-application increases resistance to aphids, caterpillars, and common Fusarium wilt in Brassica. Se application increased antiox-idant activity of wheat, canola, and sorghum (Sorghum sp. L.) (Djanaguiraman et al., 2010; Smrkolij et al., 2006; Wang, 2011). Increased antioxidant activity of plants with Se application may be help to increase vegetative production and protection from adverse biotic and a biotic conditions. Therefore, identifying correlations among grain yield, antioxidant activity, and disease resistance of food crops

The aim of our study is to increase the Se content in the edible portions of wheat in sandy and alluvial soils and increased wheat yield

MATERIALS AND METHODS

Experiment 1:

The experiment was conducted to compare the effect of selentate (Na_2SeO_4) and selenite (Na_2SeO_3) on the growth and content of Se in wheat plant. The experiment was conducted under greenhouse conditions at the Department of Plant Nutrition, National Research Centre, and Egypt. One kilogram of soil was placed in plastic pots (35 cm height, 12 cm diameter) filled with samples from the 0–20 cm layer of an alluvial soil. The experimental design was a completely randomized as follows: with and without application of Se, soil application at a dose of 0.75 mg kg_{-}^{1} and two sources of Se (selenate and selenite), with five replications. 15 wheat seeds were sown (Triticumvulogaris) per pot, with ten seedlings left in each pot one week after emergence. Wheat plants were harvested after 6 weeks from sowing.

Experiment 2:

The experiment was conducted under greenhouse conditions at the Department of Plant Nutrition, National Research Center, Egypt. The soils were packed in polyethylene pots with a side hole made in the bottom of each pot. The experimental design was a completely randomized block design with three replicates. Soil was divided into two equal portions: the first portion (10kg soil) was placed in the bottom of each pot without any kind of treatments, as a subsurface layer. The second portion (10kg soil) was mixed with different levels of Se as $Na_2SeO_4$and placed as surface layers. The surface layers of groups of pots were treated with 0, 0.75, 1.5 or 3mg Se/Kg soil.

Some chemical properties of investigated soils are presented in Table (1). Twenty wheat seeds (Triticumvulogaris) obtained from Ministry of Agriculture, Giza, Egypt, were sown per each pot on 15th of November (2015). After 21 days from sowing, plants were thinned to 15 seedlings per pot and the soil in the pots were watered to a field capacity limit. Pots were maintained at 70 % of field capacity throughout the experiment with distilled water.

Table (1): Basic physical-chemical soil characteristics and total selenium content in the experimental soil.

	Soil	
	sandy	**Alluvial**
Particle size distribution (%)		
Clay	12	42
Silt	2	30
Sand	86	28
Order	Torripssamments	Torifluvents
Texture	sandy	Clay
CEC (meq/100mg)	11	34
pH (paste)	8.0	7.5
EC (paste ds/m)	2.8	2.1
O.M (%)	0.3	1.7
Soluble cations (meq/L)		
Na^+	19.0	4.5
K^+	0.45	0.8
Ca^{++}	2.8	11.2
Mg++	5.6	0.4
Soluble anions (meq/L)		
CO_3^-	0.0	0.0
HCO_3^-	1.6	1.0
Cl^-	19.0	8.2
Total of Se (ppm)	0.11	0.23

The recommended doses of N, P and K were applied for all treatments. At the end of experiment, Harvested shoots and roots were washed, dried at 70 C and weighed. Air-dried samples of straw and grains were analyzed for Se by digesting with nitric and perchloric acids and measuring Se in the digests. Selenium concentration of the soil extracts by Aqua region (A suspension of 3 g soil and 43 ml of a mixture of HCl and HNO_3 was allowed to stand at room temperature for 16 h, then heated under reflux for 2 h. The cooled extracting was filtered (Whatman Grade 589/2, White ribbon) into a 100-ml volumetric flask, which was filled to the mark with 0.5 M HNO_3). Plant samples was analyzed by a graphite furnace atomic absorption spectrometer (AAS) PerkinElmer Zeeman 5100), using an electro thermal AAS method for food samples (Kumpulainen et al. 1983)

RESULTS AND DISCUSSION

Results of shoot dry matter production in experiment 1 as affected by different Se sources are recorded in Fig. (1). the shoot dry matter production was significantly affected by the application selenate. When the sources of Se were applied to the soil, selenate form gave of about 45% in shoot dry matter. This may be due to Selenate (SeO_4^{-2}) common form of bio -available Se and higher water soluble than selenite (SeO_3^{2}) in agricultural soils, (Sors et al., 2005; Missana et al., 2009). Li et al., 2008 found that selenate mostly existis in alkaline soils, whereas, selenite mostly exists in acidic soils. (Renkema et al., 2012) reported that, translocation of selenium ion to shoot tissue depends on the rate of transpiration and the rate of xylem loading. Both forms of Se differ in terms of their mobility and absorption by the plant and are metabolized to form seleno compounds. Kikkert and Ber kelaar, 2013, studied mobility of selenium in Wheat plant resulting translocation factor were in the following order: selenite/SeCys <selenate < SeMet.

Results in Fig. (2) Shows the concentration of Se in the dry matter of wheat plant shoots as affected by different Se sources. The highest content of Se element in wheat plants was found with selenate form, this may be due to the specific adsorption with selenate on Aluminum (AL) and Iron (Fe) oxidize surfaces, which are common in tropical soils (Rovira et al., 2008), reducing selenium in the soil solution, and thus its uptake by plants. Also, (Ramos et al., 2010) showed that selenate is little translocation in plants when compared with selenate. The increase in straw and grain yield at low doses of Se applied to the Soil. This may be due to the beneficial effect of selenium.

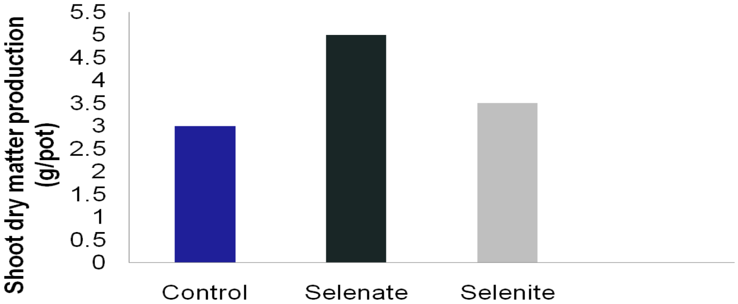

Fig. (1). Shoot dry matter production of wheat plants depending on Se sources

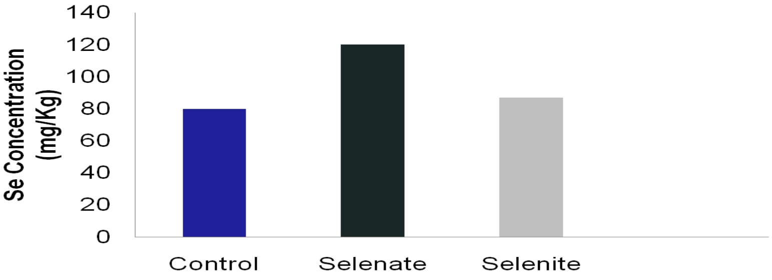

Fig. (2). Se concentration in wheat plants depending on Se sources

Results of straw and grains yield of wheat as affected by different selenate rates in different soil types (sandy and alluvial soil) are recorded in Table (2).

At low levels of Se addition, the yield (straw and grains) was stimulated in all soils. The magnitude of stimulation was remarkably higher in case of alluvial soil as its yield production was higher at 0.75 ppm Se level by 56% than those of sandy soils. The increase in straw and grain yield when Se was applied in the soil can be related to the beneficial effects of Se at low doses. This result are similar with those found by Djanaguiraman et al. (2005) for soybean, Rios et al. (2008) for lettuce, and Boldrin et al. (2012) in rice, which found increase yield at low Se content. Furthermore, recent studies indicate beneficial effects of Se, because it increases the enhance antioxidant activity in plants, leading to health plant yield (Hartikainen et al., 2000; Lyons et al., 2009). Selenium indicate significantly increase the nutritive value of winter wheat grain (Ducsay et al. 2006). Also, during the vegetative growth of wheat in the greenhouse toxicity symptoms were not observed at any Se rate applied for wheat plants. Boldrin et al. (2012) reported applied of selenium up to1.5 mg/kg soil increase rice roots dry matter of rice plants to a clay loamy soil, while decrease in shoot dry matter in all rates applied of selenium.

Furthermore, Yield production at all Se levels in alluvial soil was higher than the amount produced in the sandy soil. This could be rendered to the high reactivity and buffering capacity of alluvial soil compared to sandy soils. By increasing Se-level beyond 3.0 ppm remarkable reductions in straw and grains yield were recorded in sandy soils, while the reductions were not significant in alluvial soils.

Table (2). Grain and straw yield of wheat depending on Se application sources in sandy and alluvial soils.

	Sandy soil		Alluvial soil	
Se rates (ppm)	**Straw (g/pot)**	**Grain (g/pot)**	**Straw (g/pot)**	**Grain (g/pot)**
0.00	20.7	23.9	28.2	35.3
0.75	23.8	25.8	33.5	40.9
1.50	18.5	22.0	34.3	42.5
3.00	17.0	21.0	30.5	34.0
L.S.D 0.05	3.1	2.6	4.6	5.1

Selenium content in grains varied in sandy and alluvial soils from 65.2 to 249ug/kg and from 35 to 180ug/kg, respectively (Figure 3). The addition of increasing Se doses significantly increased Se content in both soils under investigation. Selenium content was also significantly higher in sandy soil than in alluvial soil. Data reveal that by increasing the applied Se concentration in the investigated soils, the Se-concentration in grains increased in different manners. The response rate in case of sandy soil was found to be the highest one. At the level of 1.5 or 3 ppm Se, the highest Se concentration was present in the plant grown in the sandy soil followed by that grown in alluvial soils. This could be rendered to the following reasons: 1-The very low buffering capacity of sandy soil which permit higher availability of Se to plant roots; 2- The higher mobility of Se in sandy soil compared to that in alluvial soils; and 3) the retardation of plant growth in sandy soils which cause as an increase in Se- concentration in the small yield of dry matter.

In the alluvial soil, the decrease in availability of Se is associated to its higher adsorption (Mouta et al. 2008), this may be due to presence of competing ion organic matter content, presence of competing ions and microbiological activity which are characteristic of this soil type (Wang and Gao 2001).

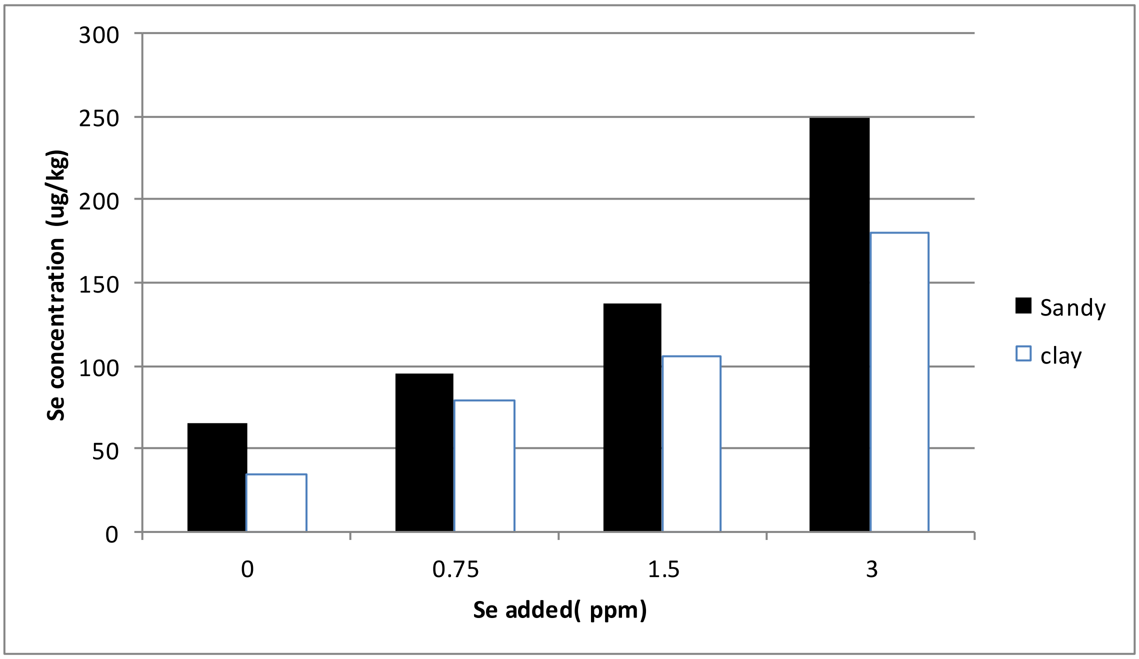

Fig. (3). Selenium (Se) concentration in wheat grains grown in two soils and treated with increasing concentrations of Se.

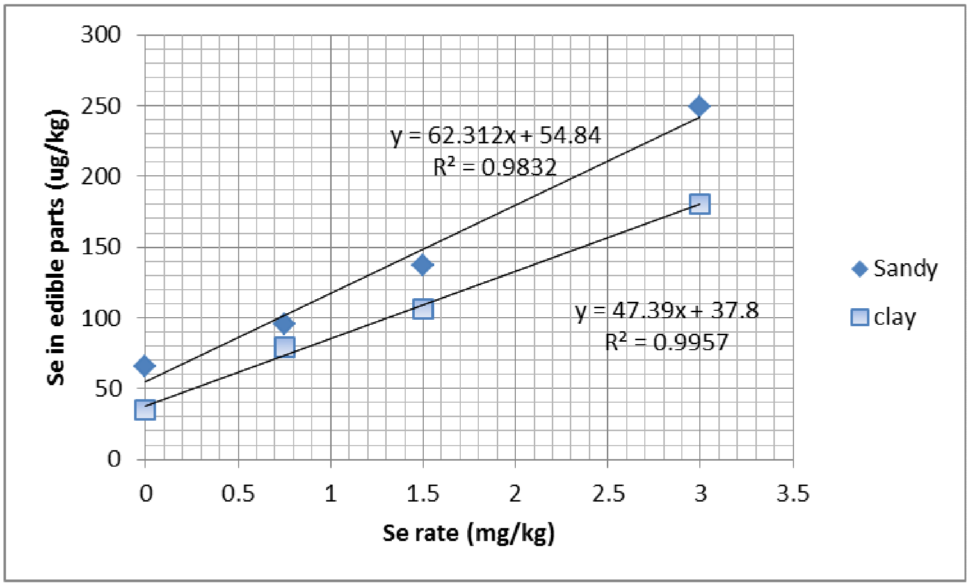

Fig. (4). Selenium (Se) concentration in grains yield of wheat in two soils as affected by Se rates applied.

The regression analysis for Se concentrations in grains of wheat showed a significant linear increase for the Se rates applied (Figure 4) and also for the type of soil. Highest Se content of grains was obtained in the sandy soil than in alluvial soil. These results indicated the Se addition to soil as a biofortification of staple food and vegetable, thus hence, supplement this element to human diet. Furthermore, also indicate that Se applied to soil for food biofortification will be specific for each type of soil and cultivated crop in order to avoid Se phytotoxicity. some authors recently evaluated selenium levels in grain of different genotypes, species and varieties of wheat (spring, emmer and einkorn) with the aim to find wheat accessions with better selenium accumulation (Lachman et al. 2011).

The Se extracted from soil was linearly correlated with the Se rates applied to both soils (Figure 3). The highest Se content from soil treated was recorded in the alluvial soil followed by sandy soils. Taking the control treatment as a reference in each soil, Se extracted in the alluvial soil increased to 37 times its corresponding of control. While the increase was equivalent to 43 times that in the control of sandy soils. This indicated the higher mobility of Se in sandy compared to alluvial soils.

Conclusion, addition selenium as sodium selenate to soil, increased the content of selenium element in grains of wheat indicating its use as a strategy of staple food biofortification. Se concentration in grains of wheat was inversely proportional to soil alluvial content.

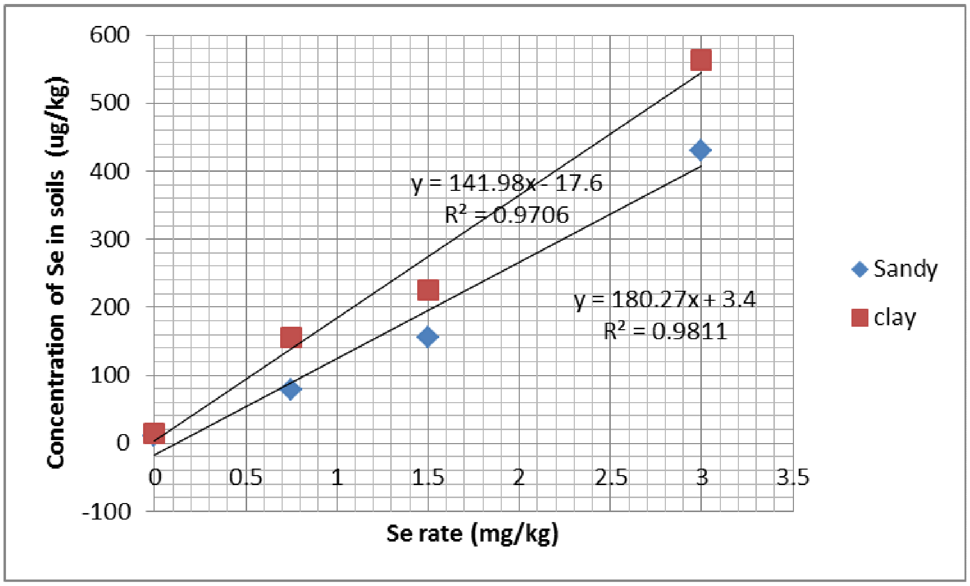

Fig. (5). Selenium (Se) extracted in soils treated with different concentrations of Se as Sodium selenite (mg/kg soil).

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