The effects of Soil Chemical Characteristics on Accumulation of Native Selenium by Zea Mays Grains in Maize Belt in Kenya

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Abstract

Background: *Selenium which is an-antioxidant is important for human health enters food chain through crops. Both total amount of selenium in soil and its speciation determines the concentration in food crops. In Kenya Zea mays is consumed by 96% of population hence is a cheap and convenient method to provide selenium to large number of population. Soil chemical factors are known to have antagonistic effects on selenium speciation hence the uptake by Zea mays. The objective of this study was to determine the effects of the four soil chemical characteristics (pH, Tcarbon, CEC, Eh) on accumulation of selenium in Zea mays grains in Maize the Belt in Kenya.* ***Research Methods:*** *About 100 Zea mays grain samples together with 100 soil samples were collected from the study site, put in separate labeled Ziplocs and were transported to laboratories at room temperature for analysis. Maize grains were analyzed for selenium while soil samples were analyzed for pH, Cat Ion Exchange Capacity, Total carbon, and Electrical conductivity.* ***Results:*** *The mean selenium in Zea mays grains varied from 1.82 ± 0.76 mg/Kg to2 .11±0.86 mg/Kg.There was no significant difference between selenium levels between different grain batches {χ (Df =76) = 26.04 P= 1.00}. The pH levels varied from 5.43± 0.58   to 5.85± 0.32. No significant correlations between selenium in grains and soil pH (Pearson's correlations = - 0.143) was observed. There was no signicant correlations between selenium levels in grains and the four (pH, Tcarbon, CEC,Eh) soil chemical characteristics {F (4,91) = 0.721 p = 0.579} was observed.* ***Conclusion:*** *Using the native selenium accumulation in Zea mays grains as proxy-indicator of selenium speciation in the soil, it can be concluded that the soil chemical characteristics in the study site did not significantly affect the speciation of available selenium species and hence accumulation of native selenium.*

Introduction

Selenium occurs in various oxidative states in the environment, which include Selenites (SeIV), selenides, selenates (SeVI), and organic selenium (SeMet, SeCyst) (Adriano., 1986). These various oxidative forms determine the forms available to crops in the soil (Jezek *et al.*, 2012). Selenates are easily taken up by the crops due to similarity of its oxidative state with sulphur, through sulphur transporters (Dhilon.,2004; Terry *et al.*,2000).Selenites are strongly adsorbed to soils and the uptake is thought to be through phosphate transporters (Gissel-Nielssen *et al.*,1984).

Selenium uptake by crops depends on a number of bio-physical characteristics of the soil (Mayland *et al*.,1994). These include the soil pH, redox potential, speciation, organic matter, soil texture and presence of competitive ions, soil weathering and climate (Jezek *et al*., 2012). These factors therefore determine the availability of selenium in the food chain (Fordyce.,2007). Relationship between soil selenium and plant selenium has been reported (Roberecht *et al*.,1982). Soltanpour *et al.,* 1982 reported a strong correlation between soil selenium and plant selenium (R^2 = 0.82) while Jump *et al*., (1989) reported a correlations (R^2 between 0.66 and 0.78) among vegetation grown in seleniferous soils.

The objective of this study was to determine the effect of soil chemical characteristics (pH, CEC, Eh, and total carbon) on accumulation of native selenium by *Zea mays* grains in Trans Nzoia, Uasin Gishu, Kakamega and Kisi .

2.0 Materials and Methods

2.1 Sampling and Sites

This study took form of cross sectional survey; a multi-stage sampling method was adopted. The study covered Trans Nzoia, Uasin Gishu, Kisii, Kakamega counties and two Districts, each in the selected counties. These districts had the largest number of smallholder commercial farmers on fertilizer subsidized programme. The study sampled sub- locations/wards that are predominantly growing Maize and also those that are currently manned with extension workers. The samples were stratified according to soil pH level, Organic content (SOM %), farm and family characteristics.

2.1.1 **Maize Sample Collection**

Structured data collection tools (closed ended questionnaire) and check lists was used to collect quantitative data from Heads of Departments, staff, and stakeholders in the small scale and large scale production systems, small and large scale/commercial farms. Maize samples about 250 grams were collected at the time of interview, the samples were put labeled Ziplocs and transported at room temperature to KEBS laboratory for selenium analysis. The samples were collected according to the sampling frame work (table 2)

Table 1: Maize Grain Sampling Frame Work

County	Criteria	Sub-Counties	No. Locations	No. Sub-locations	No. Villages	No. of Maize Samples
Trans Nzoia	High Response	1	2	2	4	10
	Low Response	1	2	2	4	10
Uasin Gishu	High Response	1	2	2	4	10
	Low Response	1	2	2	4	10
Kakamega	High Response	1	2	2	4	10
	Low Response	1	2	2	4	10
Kisii	More people less erosion	2	4	2	4	40
TOTAL						**100**

2.1.2 Soil Sample Collection

Soil samples were taken using soil augers at the depth of 0- 30 centimeters in the month of March to April 2014. The composite sample was made out of sub-samples taken. Each sample of about 0.5 kilogram from composite was taken using a shovel put in labelled Ziploc and transported at room temperature to KARI (NARL) Laboratory at Kabete for analysis. Samples from farms in the village formed a batch. The soil parameters of each sample in a batch were analyzed and the means of each batch calculated.

2.2 Laboratory Analysis of Maize and Soil Samples

2.2.1 Estimation of Selenium Levels in the Maize Grains

The maize selenium level was analyzed by method suggested by William *et al.,* (2008) , and Mitoko *et al*., (1979). The selenium level was determined by Atomic Absorption spectrophotometry after making appropriate dilutions as follows; approximately 0.250grams of maize samples were accurately weighed and put in graduated tube it was mixed with hydrogen peroxide followed by digestion in perchloric acid to remove the organic matter. Nitric Acid (0.75ml) and 2.25ml Hydrochloric Acid (HCl) which were measured and carefully was added. The contents were thoroughly mixed with test tube shaker. The mixture was heated at 80 degrees centigrade for one hour on Aluminum heated block, it was allowed to cool. Approximately 11.5ml of distilled water was added, mixed thoroughly and allowed to settle. A portion of the solution was centrifuged for AAS (Perkin Elmer A analyst 300,Germany).The standards were prepared from TITRISOL stock solutions with same amount of acids i.e. 1ppm concentration of solution equals 30ppm in sample.

2.2.2 Estimation of soil pH levels

The pH levels were measured in a soil-water suspension. About 50 ml of distilled water was added to a glass beaker containing 10 grams of sediments. The suspension was stirred using a glass rode and then left to equilibrate for 16 hours. The pH was measured using a pH electrode model 520A pH meter, Orion Research inc., Boston, MA, USA.

2.2.3 Determination of Cation Exchange Capacity (CEC)

The determination of Cation exchange in ammonium acetate at pH 7 was done in three steps as suggested by Van Ranst *et al*.,1999 follows;

The adsorption complex was saturated with ammonium acetate ions (NH_4^+). This extracted the bases. The soil was washed by alcohol to eliminate the excess ammonium solution they filled the pores. The qualitative analysis was done of the ammonium after adsorption with Potassium ions (K^+).The exchange reaction was accomplished by successive extraction, equilibration centrifugation and decantation.

2.2.5 Measuring of Electrical Conductivity of the Soil (Measure of Dissolved Salts)

It is measured by conductrimetric cell composed of two electrodes having a 1 cm sq. surface area, separated by 1 cm. The relationship between dissolved salts and conductivity is proportional i.e. mS/cm =meq/L.

Procedure: A 50ml of distilled water was added to 250 mL Erlenmeyer flask containing 10.0 grams sediment. This was put in a shaker for 1 hour, after which it was filtered. The EC (Eh) was measured from filtrate. The Eh varies in order of 0.01 to 10mS/cm. Below 2 mS/cm the effect of Eh is negligible, but above 16mS/cm very few crops are able to tolerate.

3.0 Data Analysis

Regression analysis was used to determine the effect of soil chemical characteristics on selenium level in *Zea mays* grains. In the model the quadratic effect of the independent variables, pH, CEC, Eh, and Total carbon on dependent variable, grain selenium concentration is determined.

Se = α + β₁ pH + β₂CEC + β₃Eh + β₄TCarbon

4.0 Results and Discussion

4.1 Selenium Levels in Maize Grains

4.1.1 The Mean Selenium Levels in the Zea Mays Grains

The mean selenium levels in *Zea mays* grains varied from 1.82±0.76 mg/kg in Batch 3 to 2.11±0.86 mg/kg in Batch 4 with overall mean being 1.938mg/Kg (table 3).No significant difference in selenium levels in the maize grains were observed between the batches {χ (df = 76) = 26.04, p = 1.000}.

As shown in the table 5, in a multivariate analysis, no significant relationship was found between the selenium concentration in the grains and the four independent variables {$F_{(4, 91)}$ =).721, p= 0.579}.The mean value of selenium in the *Zea mays* grain in all batches was slightly higher than those earlier reported in Malawi by Chilima *et al*., (2011), but is lower than those reported by Funwe *et al*., (2012).

How ever the values are consistent with those reported by Otieno *et al.,* (2014a). These levels likely reflect availability of the more soluble selenates (SeVI) species in the soil.

The selenium uptake by *Zea mays* roots depend on soil conditions (Funwe.,2012,Zhang *et al*.,2010, Mayland *et al*.,2007) which includes the pH, CEC, total carbon and environmental temperature and which in turn determines the selenium speciation and mobility in the soil. Plants tend to absorb selenates (SeVI) via sulphate transporters. Lie *et al*.,(2010) reported that lower levels of sulphur in the soil tend to up regulate the uptake of selenium by stimulating manufacture of sulphate transporters in the roots which increases uptake of the selenate (SeVI).Since most soil parameters were not significantly different in the study sites (p >0.05) table 5, hence could not therefore affect the selenium uptake by the *Zea mays* it is likely that the soil was deficient of sulphur hence the high level of selenium in the grains.

4.2 Soil Chemical Characteristics and Selenium levels in *Zea Mays* Grains

4.2.1 Effect of the pH Levels of the Soil on Mean Selenium in Grains

As shown in table 3, the mean soil pH varied from 5.43 ± 0.58 in Batch 5 to 5.85 ± 0.32 in Batch 2 , overall mean pH being 5.559 ± 0.768. No significant differences in pH between the five batches were noted $\{\chi \text{ (df =21)} = 32.05, p = 0.058\}$.There was negative but insignificant correlation between the soil pH and the selenium concentration in the maize grains (Table 5) $\{,t= (1, N= 97) = -1.465 , p= 0.162, \beta = -0.202, R = -0.143\}$.The result suggests that only 14.3% of all change in selenium content in the grain in the study area is explained by the change in pH of the soil.

The soil pH is the logarithmic measure of acidity and alkalinity of soil (and in a scale of 1 to 14) tends to have the greatest effect on selenium speciation (Mayland *et al*.,2007). The pH of the soil is generally derived from the parent rock from which the soil is derived. Inorganic fertilizers have also been reported to acidify the soils hence lower the pH,(Yolanda *et al*.,2014) these groups include ammonium nitrates, the ammonium sulphates with the sulphur coated urea having the greatest acidifying effect in soil. In low pH (< 3) the predominant selenium species is selenites (SeIV) which are insoluble and tend to be tightly adsorbed to soil particles (Neal *et al*., 1987, Mayland *et al*.,2007),hence not readily absorbed from the soil by *Zea mays* roots.

The observation from this study tends to suggest that application of inorganic fertilizers in the study counties had no significant effect as the mean pH, of the soils in these counties were neutral to slightly acidic. Chilima *et al*.,2011, and Zhang *et al.,* (2007) reported that at pH 3-10 selenium tends to be reduced to selenates (SeVI) under these conditions, but it also coincides with optimum absorption of selenites (SeIV) by *Zea mays* roots, which supports our observation in this study, high level of selenium in grains in all batches.

4.2.2 Cat Ion Exchange Effects

The mean of cat-ion-exchange varied from 23.84 ± 7.28 me% in Batch One to 12.99 ± 6.03me % in Batch three (Table 3) with overall mean in all the batches being 20.305 ± 9.8 me %. No significant difference in the cat-ion exchange was observed between all the batches of soil sampled (p > 0.05).In the model positive but in significant co-relation between CEC and selenium in maize grains was observed $\{t (1 , N=95) = 0.743, p = 0.743 , \beta = 0.003\}$ which indicates that it exerted positive but insignificant effect on the uptake of selenium by *Zea mays* roots in the study site (Figure 2).

Higher CEC tends to suggest high levels of adsorption of selenates and is consistent with other observations by Walker and Bernal (2008), Van Djik., (1991).,Singh *et al*., 1981 that the level of CEC varies with carbon content of the soil which in turn affects the pH. In this study site low level to medium levels of CEC perhaps made it insignificant in the speciation of selenium in the soil, hence absorption of selenium by *Zea mays*.

4.2.3 Effects of organic Matter Content

The mean value of total carbon in the soil samples varied from $2.43\pm 0.66\%$ in Batch One to $1.49\pm 0.73\%$ in Batch Four,(table 3) with over all mean being $1.913\pm0.764 \%$ however there was no significant difference between batches (p>0.05).

As shown in table 5 no significant correlations were observed between selenium concentration and carbon level in the soil $\{t (1, N = 95), = -0.215, p =0.830, \beta = -0.031\}$ suggesting that although level of carbon negatively affected selenium accumulation in the grains, the effect was not statistically significant.

This observation which is shown in figure 3, perhaps reflect the fact that no farmer reported applying manure in their farms in the previous five years and is consistent with reports by Larney *et al* .,2000.

Total carbon in the soil which refers to Soil Organic Matter (SOM) is defined by Brady and Weil,(1999) as the summation of plant and animal residues in various stages of decomposition, with no significant carbon content difference between the batches ($p > 0.05$), the most likely source of carbon could be decaying stovers from the maize harvests since the farmers mainly applied inorganic fertilizers. The residual soil organic matter therefore together with soil micro-organisms tend to act as reservoir of acidity, hence continuously acidify the soils (anti-lime index) through slow release of carbon dioxide. By lowering the soil pH the SOM tends to lead to secondary micronutrient deficiency including selenium in the soil through continuous speciation in the soil to insoluble forms like selenite which are tightly bound to soil particles and metallic complexes (Johnson.,1991, Dhillon *et al*.,2011).This is reflected in the negative coefficient (table 6) observed in between total carbon and selenium levels in the soil in this study.

5.0 Conclusion

5.1 Using the native selenium accumulation in *Zea mays* grains as proxy-indicator of selenium speciation in the soil, it can be concluded that the agricultural intensification through use of inorganic fertilizer did not significantly affect the mobility of available selenium species in the study site.

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Table 2: Mean Selenium in Zea mays grains

	Se mg/kg	N
Batch1	1.88±0.98	19
Batch 2	1.90±1.07	11
Batch 3	2.11±0.86	19
Batch 4	1.82±0.76	19
Batch 5	1.97±0.99	29

Table 3: Mean level of Biogeochemistry of the Soil

	pH	CEC me%	Eh mS/cm	TCarbon%	N
Batch 1	5.55±0.47	23.84±7.28	0.09±0.05	2.43±0.66	19
Batch 2	5.85±0.32	15.42±4.45	0.04±0.02	2.12±0.82	11
Batch 3	5.77±0.43	12.99±6.03	0.07±0.04	1.65±0.95	19
Batch 4	5.71±0.55	22.40±10.89	0.06±0.02	1.49±0.73	19
Batch 5	5.43±0.58	24.60±9.45	0.092±0.05	1.99±0.29	29

Table 4: ANOVA Grain Selenium and Soil Biochemistry

Model	SSQ	Df	Mean Sq	F	P value
Regression	2.483	4	0.621	0.721	0.579
Residual	78.301	91	0.860		
Total	80.784	95			

Table 5: The Coefficients

Model	B	SE	t- value	P value
pH	-0.202	0.138	-1.465	0.146
CEC	-0.003	0.011	-0.329	0.743
Eh	2.575	2.397	1.074	0.286
Carbon	-0.013	0.146	-0.215	0.830
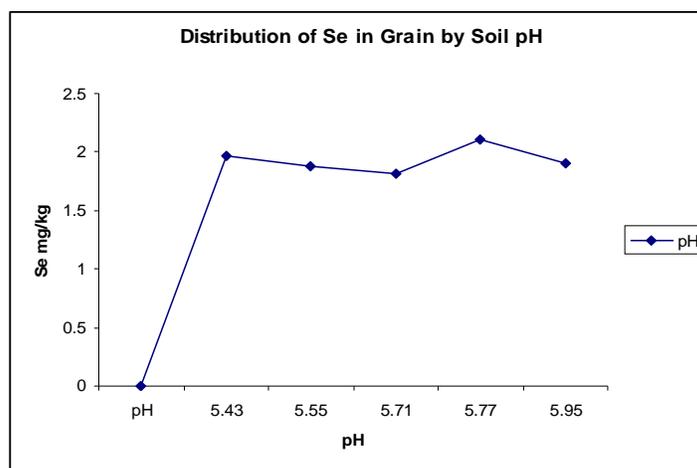
Distribution of selenium in Zea mays grains by soil chemical characteristrics