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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—Selenium is an-antioxidant which is important for human health enters food chain through 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. Several soil factors are known to have antagonistic effects on selenium speciation hence the uptake by *Zea mays*. There are no studies in Kenya that has been done to determine the effects of soil characteristics (pH, Tcarbon, CEC, Eh) affect accumulation of selenium in *Zea mays* grains in Maize Belt in Kenya.

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.

The mean selenium in *Zea mays* grains varied from 1.82 ± 0.76 mg/Kg to 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), and 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.

It can be concluded that the soil chemical characteristics in the study site did not significantly affect the accumulation of native selenium in *Zea mays* grains.

Keywords—Maize, native, soil, selenium.

I. Introduction

SELENIUM is essential for human health [1], [8], [12]. It occurs naturally in metalloid form and is needed in traces for human health [4]. Selenium plays important role in body anti oxidation system [9] in the process protect the body cells from free radicals. It is therefore protective against cancer, cardiovascular diseases. It is also important in thyroid hormone metabolism, inhibits HIV virulence and reduces development of AIDS from complications associated with asthma

Selenium occurs in various oxidative states in the environment, which include Selenites (SeIV), selenides, selenates (SeVI), and organic selenium (SeMet, SeCyst). These various oxidative forms determine the forms available to crops in the soil. Selenates are easily taken up by the crops due to similarity of its oxidative state with sulphur, through sulphur transporters [2], [14] Selenites are strongly adsorbed to soils and the uptake is thought to be through phosphate transporters [5].

Selenium uptake by crops depends on a number of bio-physical characteristics of the soil [10]. These include the soil pH, redox potential, speciation, organic matter, soil texture and presence of competitive ions, soil weathering and climate. These factors therefore determine the availability of selenium in the food chain [3], [13].

Relationship between soil selenium and plant selenium has been reported. A strong correlation between soil selenium and plant selenium (R^2 = 0.82) while it has been reported in some studies a correlations (R^2 between 0.66 and 0.78) among vegetation grown in seleniferous soils.

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

II. Materials and Methods

A. 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.

1. Maize Sample Collection

Structured data collection tools (closed ended questionnaire) and check lists was used to collect quantitative data from the key informants which included Heads of Departments, staff, and stakeholders in the small scale and large scale production systems, small and large scale/commercial farms. Maize samples (Table I) 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 II).

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TABLE I
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. Soil Sample Collection

Soil samples were taken using soil augers a 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 labeled 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

B. Laboratory Analysis of Maize and Soil Samples

1. Estimation of Selenium Levels in the Maize Grains

The maize selenium level was analyzed by Atomic Absorption Spectophotometry. 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 to 80 degrees centigrade for one hour on aluminum heated block, it was then 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. 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.

3. Determination of Cation Exchange Capacity (CEC)

The determination of Cation exchange in ammonium acetate at pH 7 was done in three steps as follows;

The adsorption complex was saturated with ammonium acetate ions (NH4+). This extracted the bases. The soil was washed by alcohol to eliminate the excess ammonium solution 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.

4. Estimation of Organic Matter (OM) /Total Carbon

The organic matter was determined by ashing as follows; Labeled crucibles were dried in oven at 100 degrees centigrade for one hour. They were put in an excicator to cool down. Three grams air dried soil were put in the crucibles and weighed in analytical balance and a shed for 2 hours in a muffle furnace at 550 degrees centigrade. The crucibles were allowed to cool down in an excicator and reweighed using analytical balance. The difference in weight before and after gave the ashing which represents the organic matters content of the sample was taken. The results were expressed in organic matter percent.

5. Measuring of Electrical Conductivity of the Soil (Measure of Dissolved Salts)

It is measured by conducmetric 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.

III. DATA ANALYSIS

The mean selenium levels (in mg/kg) and those of other variables were calculated.

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

$$Se = \alpha + \beta 1\ pH + \beta 2CEC + \beta 3Eh + \beta 4TCarbon$$

IV. RESULTS AND DISCUSSION

A. Selenium Levels in Maize Grains

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 III). 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 Table V, 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 [1], but is lower than those reported. However, the values are consistent with those reported in Kenya [12]. 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 [10], [16] 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. Lower levels of sulphur in the soil tend to up regulate the uptake of selenium by stimulating manufacture and increase of sulphate transporters in the roots which increases uptake of the selenate (SeVI) [9]. Since most soil parameters were not significantly different in the study sites (p >0.05) Table V, hence could not therefore affect the selenium uptake by the *Zea mays* it is likely that the soil was deficient in sulphur hence the high the level of selenium in the grains.

2. Soil Chemical Characteristics and Selenium Levels in *Zea mays* Grains

a. Effect of the pH Levels of the Soil on Mean Selenium in Grains

As shown in Table III, 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 {χ (df =21) = 32.05, p = 0.058}. There was no correlation between the soil pH and the selenium concentration in the maize grains (Table V) {t= (1, N= 97) = -1.465, p= 0.162, β = -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 [10]. 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, [15] 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, [10], 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, as the soils in these counties were neutral to slightly acidic. It has been [7], [15] 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.

b. 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 III) with overall mean in all the batches being 20.305±9.8 me %. No significant difference in the cat-ion exchange was observed in all the batches of soil sampled (p > 0.05). Positive but insignificant correlation between CEC and selenium in maize grains was observed {t (1, N=95) = 0.743, p = 0.743, β = 0.003} which indicates that it exerted positive but insignificant effect on the uptake of selenium by *Zea mays* roots in the study site (Fig. 1).

Higher CEC tends to suggest high levels of adsorption of selenates and is consistent with other observations by [16] that 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*.

c. Effects of Organic Matter Content

The mean value of total carbon in the soil samples varied from 2.43± 0.66% in Batch One to 1.49± 0.73% in Batch Four, (Table III) with over all mean being 1.913±0.764% however there was no significant difference between batches (p>0.05).

As shown in Table V no significant correlations were observed between selenium concentration and carbon level in the soil {t (1, N = 95), = -0.215, p =0.830, β = -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 Fig. 2, perhaps reflect the fact that no farmer reported applying manure in their farms in the previous five years.

Total carbon in the soil (Soil Organic Matter) is defined as the summation of plant and animal residues in various stages of decomposition. 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 [2], [6]. This is reflected in the negative coefficient (Table VI) observed in between total carbon and selenium levels in the soil in this study.

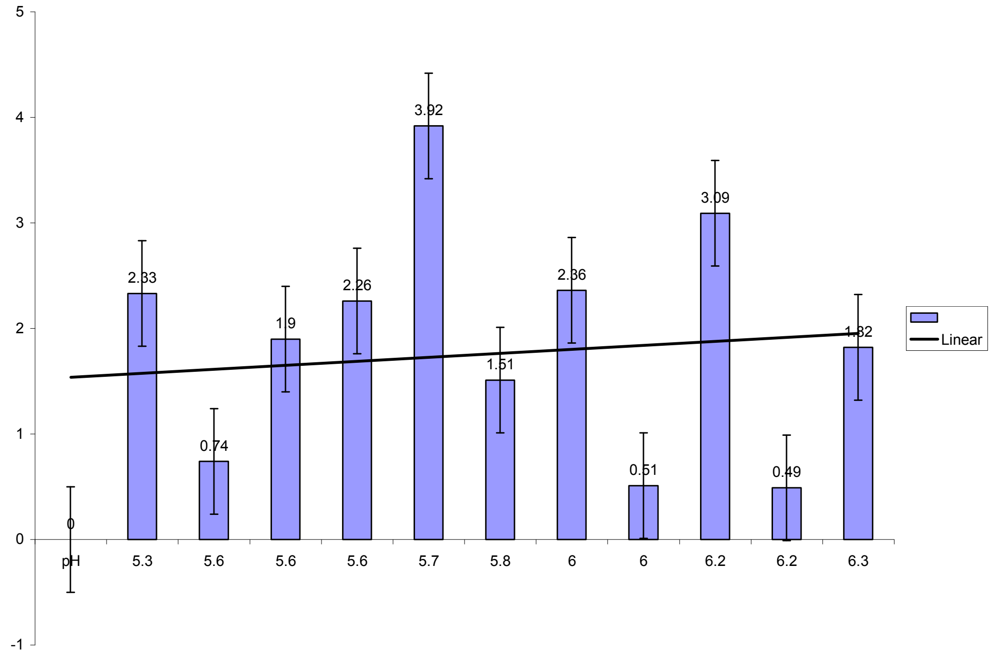

Fig. 1 Variation of soil selenium by soil pH

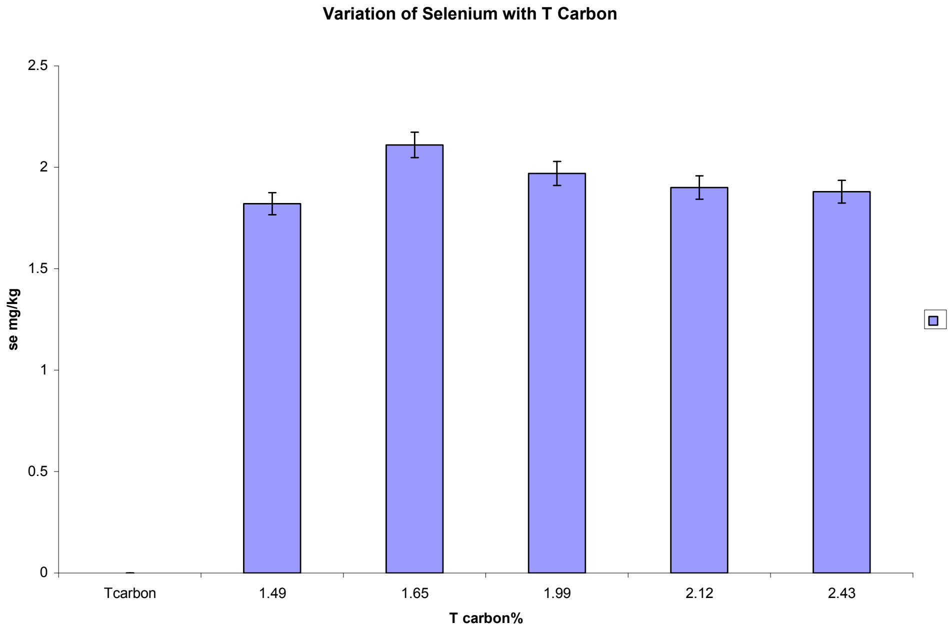

Fig. 2 Variation of Selenium by Carbon

V. Conclusion

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.

Selenium is an essential micronutrient to the human health and normally enters the food chain through crops. *Zea mays spp* is eaten by about 96% of all Kenyans hence form important route through which selenium can be consumed in Kenya. On average an adult eats about70 - 100 grams of maize meal per day, which translates to 70 µgm - 90 µgm selenium. Processing the maize grains leads to reduction of 10-20% of selenium in cereals (which is about 40 µgm) [3]. It can, therefore, be concluded from this study that the intake of selenium in the study site was between 30 µgm - 150 µgm per day. This may be adequate for daily requirement, depending on frequency of eating and inter-household food distribution, but may not be sufficient in therapeutic supplementation.

TABLE II
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 III
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 IV
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 V
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

VI. RECOMMENDATION

The study shows that selenium levels in maize grown under intensive agronomic practices in Uasin Gishu, Trans Nzoia, Kakamega and Kisii counties meets DRI as recommended by USDA for healthy living. An earlier study [11] has shown that there is a deficiency of selenium in foods in the in Nyanza region. Further, [12] established that this deficiency is correlated to HIV/AIDS, in Nyanza region. From this study therefore it can be recommended that in order to address the selenium deficiency in parts of Kenya including the Nyanza Region, there should be targeted distribution of maize grown in these counties for consumption in the selenium deficient regions. The approaches including policy intervention like improving access through establishment of marketing infrastructure such as maize depots, access roads, and the use of marketing strategies by farmers like mobile phones, targeting where there is selenium deficiency in the diet.

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