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Variation of Macronutrients in the Stover of Maize Varieties Grown in Western Kenya

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Large scale agricultural activities in Kenya include maize growing. Farmers plant different varieties of the species *Zea mays.* Though seed companies provide seeds based on altitudes, maturing periods and yield predictability, it remains the prerogative of the farmer to make choice. Yields from small scale farms are declining at every harvest despite Governments efforts to provide fertilizers at subsidized prices. Though soil acidity levels could be an accounting factor, the maize varieties planted differ in the amounts of macronutrients they remove from soils and yet next seasons' fertilizer application is uniform. The study sought to determine and compare levels nitrogen, phosphorous, potassium and calcium in stover of maize varieties grown in Lugari, western Kenya. This was with view to inform on macronutrient removal by the different maize varieties. It too was to enable farmers speculate on the possible methods of biomass disposal for some of the methods like burning the stover either as fuel or clearance ignores the need to have an approach that would enable recycling and certainly depletes the soil. Stratified random sampling of both cobs and stalks from farmers in Lugari, western Kenya was done. The samples were dried, milled before wet digestion. The digests were subjected to laboratory analysis using standard AOAC procedures viz avis nitrogen (Kjeldahl's method), phosphorous (Ascorbic acid method) and both potassium and

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calcium (Flame photometry) to establish levels of macronutrients. It was established that maize stalks of any given variety had higher levels macronutrients compared to cobs of the same variety. It was too observed that for both stalks and cobs there was significant differences ($p< 0.05$) between varieties in all macronutrients except phosphorous. The stover from varieties DK, H6213, H614 and pioneer had significantly higher levels than varieties H500, H505, H513 and oduma. It is hoped that the results of this study not only informs of levels of macronutrients retained by the maize stover but also provides basis for sensitization on method of biomass disposal to minimize soil degradation.

Keywords: Maize; yields; biomass disposal; soil degradation.

1. BACKGROUND INFORMATION

Maize (*Zea mays*) growing is a highly relevant activity in developing countries like Kenya due to its importance. It is a dominant food crop [1]. Maize production results from intricate interaction of water, nutrients, weeds, pests and management practices. Total maize production and yield per unit area in growing countries like Kenya has been affected by the different factors. Continued and frequent soil analysis has led to the use of fertilizers to bridge the gap [2]. Despite this, the annual production of the small householders, who form up the majority of the farming community in these countries, have kept on dwindling. Farmers are advised to either practice crop rotation [3] and or do composting of organic matter to enrich the soil. The later would increase cation exchange capacity and reduce nutrients leaching [4]. These measures are not sufficient to convince farmers who change varieties just to get higher yields. Though many factors contribute to the decline in yields, the cumulative effects of macronutrients removal through indiscriminate methods of stover disposal remains a latent cause.

Different parts of maize have significant amounts of the plant nutrients. Corn stover, usually in a ratio 1:2 to maize produce, is the above ground plant excluding corn kernels that has much potential as a biomass feed stalk [5]. It is however of concern where used as animal feed it is usually fed as a whole stalk with leaves without chopping or any kind of treatment resulting in high wastage and very low intake. Maize stover has very low digestibility owing to the high lignin content which inhibits microbial digestion of cellulose/hemicellulose. The low content of nitrogen and deficiency of readily available carbohydrates also limit microbial activity in the rumen. Though treatment using urea or sodium hydroxide or ammonia raises the protein content by 5-7% and increases digestibility by 10 % either has known disadvantages.

While maize cobs have been used on small scale as a fuel for direct combustion in cooking and heating, their use as feed stock for large scale energy production is a more modern concept. Studies on viability of corn cobs as a bio energy feed stock [6] as well as effectiveness of maize cobs powder in controlling weevils in stored maize [7] have been reported. There are concerns associated with crop residues removal from the ground for this contributes to soil organic matter and nutrient depletion [8]. Faced with these competing uses of maize stover farmers have to decide which of the varieties stover has more economic returns. Knowledge of levels of macronutrients in the various maize varieties will not only help make informed decisions on the use of stover but also guide on quantities of fertilizers applied thereafter on new crops.

Macronutrients play an important role in the entire plant cycle. They perform various essential or beneficial activities in plant metabolism as well as protection from biotic and abiotic stresses that include stresses of heavy metals, drought, heat, UV- radiation, diseases and insect attack [9,10]. The macronutrients help to increase crop growth, yield and quality of products [10]. Burning the crop residues either to provide domestic energy or just for disposal has a critical opportunity cost in terms of continued loss of soil carbon and macronutrients. Some crop residues are not desirable for energy supply and are preferentially used for soil fertility improvement. Though agricultural farm biomass have varying components that provide energy (maize cobs (15%), maize stalks (9%), tea prunes (3%) and sorghum stalks (1%)), a rural consumption at 435 kg/person/year would have devastating effects on the farming soils for the corresponding ashes and are hardly applied back to the soils. About 21 % of households' farm residues are used for fuel with rural areas dominating (29 %) compared to urban (0.5 %). It is evident that the use of stover in fuel production is well embedded among the communities.

Different varieties tagged as high or low yielding are on market for farmers to select. Though the varieties may differ in the levels of macronutrients they deplete from soils, households' indiscriminately dispose the stover through provision of fuel, fodder for livestock, burning and minimal composting. Provision of information as to the proportional capacity of soil macronutrient depletion by different varieties of maize would not only guide on quantities of fertilizers to be used for sustained yield but also approaches to stover disposal.

2. MATERIALS AND METHODS

The study involved laboratory analysis that entailed establishing the levels of nitrogen, phosphorous, potassium and calcium in samples of maize cobs and stalks of different maize varieties. Sample stover (maize cobs and stalks) of maize varieties H500, H505, H513, H614, H6213, oduma, pioneer and DK were collected from Lugari Sub County, western Kenya. It is at 0^{o} $41^{1}17^{11}$N, $0^{1}54^{11}$E and lies between altitudes 1300 m and 1800 m above the sea level. It is hilly and rocky towards the east gradually falling into a plain as it progresses towards the south [11]. It experiences equatorial type of climate and rainfall pattern. Temperatures vary between 6 ºC and 23 ºC in the areas as high as 1800 m and between 18 ºC and 24 ºC in the areas as low as 1300 m above sea level. The rainfall pattern experienced is bimodal with long rains usually occurring between March and August while short rains observed in October to November. The months of December to February are normally dry. The annual rainfall received ranges from 1000 mm to 1600 mm with an annual average of about 1300 mm. These conditions favour farming activities that include growing of maize.

Stratified random sampling was used while collecting samples. Farmers within 2 km radius of Lugari market who planted particular maize varieties were visited. Maize stalks were sampled from heaped stakes representing edges and middle parts of the fields. Cobs were selected from heaps where they had been piled after shelling. Samples were further sun dried six hours a day for seven days, milled and packed in labelled envelopes awaiting digestion. A part from sharing the farms for a given maize variety, the sampled cobs and stalks were not necessarily from the same plant. The soil environments of maize plants that generated the maize stover were not considered and may have limited the results. It was also assumed during sample collection that equivalent amounts of fertilizers were used.

Instruments UV-Vis spectrophotometer (Cecil-CE 2041-2000 series) for phosphorous (660 nm) and a flame photometer (Sherwood classic model 410) for calcium (422.7 nm) and potassium (766.5 nm) were used. All the chemical reagents (analar grade) were purchased from Kobian company Ltd, Kenya. Concentrated sulphuric acid (18 M), perchloric acid and the 68 % HNO_3 (15 M) were used as manufactured without dilution. A salt-metal mixture was made by grinding sodium sulphate (20 g) with copper (2 g) in a motor with a pestle. The sodium sulphate was used to raise the boiling points while copper was the catalyst during the digestions. 10 M sodium hydroxide used to drive ammonia from the biomass digest was made by dissolving NaOH (40 g) in 100 cm^3 distilled water. Boric acid (8%) to absorb the ammonia generated was made by dissolving H_3BO_3 (40 g) in 1000 cm^3 of distilled water and warmed with stirring. The lanthanum solution was prepared by dissolving lanthanum oxide (1.727 g) in concentrated HCl (8 ml) and made up to one liter with distilled water.

The stock solution reagents for colour development molybdate and the ascorbic acid solutions were made. Ammonium molybdate (6.2 g) was dissolved in de-ionized water (80 ml) and heated to 60^{o} C. It was maintained at 60^{o} C for five minutes and allowed to cool to room temperature. To the cooled solution antimonyl potassium tartrate (0.7 g) was added before thorough mixing. The flask with its contents was placed in an ice bath before slowly adding concentrated sulphuric acid (70 ml). Upon cooling the mixture was diluted to 250 ml and stored in brown bottles at 4^{o} C. The ascorbic acid stock solution was made by dissolving ascorbic acid (10.56 g) in 75 ml distilled water and diluted to 100 ml. The mixture was equally stored at 4^{o} C. Phosphorous colour developing working solution was made by mixing acid molybdate stock solution (20 ml), the ascorbic acid stock solution (10 ml) and 800 ml of de-ionized water. The resulting solution was thoroughly mixed before dilution with de-ionized water to 1 litre.

Potassium, Calcium and Phosphorous ions stock solutions were prepared too. Potassium chloride (0.1 g) was dissolved in de-ionized water (50 ml) to constitute 1000 ppm stock solution. A 2.5 ml of this solution, 100 ml de-ionized water and 10 ml of concentrated hydrochloric acid were thoroughly mixed before topping up to 250 ml with de-ionized water raising a 20 ppm working solution. Calcium carbonate (4.00 g) was reacted with 1 M HCl before topping up to 50 ml with water to obtain the stock solution. Phosphorous stock solution was prepared by dissolving KH_2PO_4 (0.23 g) in 50 ml water.

Aliquots of 5, 10, 15, 20 and 25 ml of the stock solutions were separately diluted to 50 ml with deionized water to obtain the working solutions with concentration range 1.30 mg to 10 mg ion per 50 ml of the solution. Absorbances of the solutions were recorded at 766.5 nm (potassium), 422.7 nm (calcium) and 660 nm (phosphorous). The data obtained was used in drawing calibration curves. Limit of detection of each element was calculated from calibration curves.

The AOAC, [12] procedures as outlined in the laboratory manual [13] were followed in the determination of total nitrogen, potassium, calcium and phosphorous.

Total mass of nitrogen (mg/100g),

$$DM = \frac{140{,}000x\ V_a x T}{M_O\ x\ M_S}$$

Where

V_a =volume of the acid used
T_a = molarity of the acid used
M_o =% moisture
M_s = mass of the sample used.

Calibration curves were used to obtain corresponding concentrations in the samples. The data generated was analysed by SPSS version 21.0. The mean levels of potassium, nitrogen, phosphorous and calcium in the samples were determined. Analysis of variance (ANOVA) was used to determine the effects of sample variety on levels of macronutrients. A post hoc analysis assuming Duncun's equal variances was done to help separate and identify the causes of variations. T-tests were done to compare macronutrients in cobs and stalks.

3. RESULTS AND DISCUSSION

3.1 Calibration Equations

Regression equations were used to determine the levels of macronutrients. They were generated out of plots of absorptions against concentration of standard solutions. The equations obtained (Table 1) had positive slopes, viz avis 0.121 (P), 1.47 (K) and 0.032 (Ca). This implied that a unit increase in the biomass accounted for the increase in the concentration. The coefficient of determination values (R^2) of the plots were 0.998 (P), 0.995 (K) and Ca (0.989) meaning that 99.8 %, 99.5% and 98.9% of the variations in the absorbance could be explained by variations in concentrations. The closeness of the R^2 to 1 showed that in determination of the macro elements absorbance were linearly correlated to the concentration of the ions [14]. The regression equations therefore expressed direct proportionality between the instrument response and the concentration.

Table 1. Methods regression equations

Analyte	Calibration Equation R^2	%
Phosphorous	y = 0.121x – 0.001	0.998
Potassium	y = 1.474x + 0.408	0.995
Calcium	y = 0.032x – 0.045	0.989

3.2 Macronutrient Levels in Maize Stover

Average levels of total nitrogen, phosphorous, potassium and calcium in maize cobs and stalks of different maize varieties from different farms were recorded (Table 2).

3.3 Macronutrient Levels in Maize Cobs

The average level of total nitrogen in the maize cobs was 258.170±136.316 mg/100 g DM. They were in the range 89.90 - 436.48 mg/100 g. This result is in close agreement with a value of 220 mg/100 g reported by Knox and Geoff, [15] in a study on the estimation of nutrients in baled corn stalks. The amounts of nitrogen found in the tested varieties were significantly different (p=0.015). The variety DK showed the highest amount of nitrogen, averaging 424.030±10.790 mg/100g DM. This was closely followed by variety H614 that in general accumulated 389.660±4.790 mg/100g. The other varieties had lower values with the least being variety H513 that showed an accumulated average of 94.48 mg/100g.

Table 2. Mean mass of total N, P, K and Ca in maize cobs and stalks

Variety	Mean ± Std. Dev. (mg/100g), DM							
	Total Nitrogen in		Phosphorous in		potassium in		Calcium in	
	Cobs	Stalks	Cobs	Stalks	Cobs	Stalks	Cobs	Stalks
H6213-F_1	326.290±10.616^{b}	541.74±12.09^{c}	36.446±0.154	49.329±0.950^{a}	529.22±68.83^{a}	737.52±4.93	195.909±0.281^{a}	458.387±21.575
H6213-F_2	327.580±19.969^{b}	549.35±14.16^{c}	39.190±1.239	72.006±0.190^{a}	595.46±15.11^{a}	335.51±10.37	153.299±0.196^{a}	458.387±21.575
H6213-F_3	323.360±8.091^{b}	453.11±12.96^{c}	31.685±1.399	62.445±1.210^{a}	493.00±15.49^{a}	635.51±9.35	187.157±0.614^{a}	507.387±11.975
H614-F_1	395.100±2.976^{a,b}	747.33±10.05^{b}	36.815±1.088	54.533±0.820^{a,b}	393.00±25.19^{a,b}	606.53±10.52	147.801±1.089^{a,b}	354.743±20.999
H614-F_2	387.840±13.658^{a,b}	775.44±12.86^{b}	42.411±3.292	69.123±1.010^{a,b}	595.52±37.08^{a,b}	636.65±50.09	170.538±0.531^{a,b}	364.092±10.942
H614-F_3	386.050±10.906^{a,b}	654.62±21.91^{b}	46.739±3.112	23.104±0.120^{a,b}	495.02±17.08^{a,b}	549.35±14.48	151.527±1.778^{a,b}	351.190±10.178
DK-F_1	436.480±5.052^{a,b}	907.93±12.41^{a}	70.793±1.263	53.069±0.680^{a,b}	426.96±26.05^{a,b}	717.82±3.29	166.801±1.233^{a,b}	461.584±10.834
DK-F_2	418.300±6.569^{a,b}	986.94±12.72^{a}	28.097±1.008	36.083±3.640^{a,b}	572.85±28.83^{a,b}	447.18±8.39	152.878±0.798^{a,b}	474.235±8.264
DK-F_3	417.320± 5.177^{a,b}	735.55±22.82^{a}	29.297±1.022	42.641±4.050^{a,b}	447.45±24.15^{a,b}	552.52±3.80	176.411±1.170^{a,b}	266.411±11.402
Oduma–F_1	215.030±15.078^{c}	504.46±22.14^{c}	46.236±1.703	54.113±1.790^{a,b}	383.31±21.21^{b}	485.55±16.78	140.383±0.753^{b,c}	369.948±21.535
H513-F_1	89.904±0.8728^{c}	398.82±9.74^{c}	27.285±0.256	45.612±1.210^{a,b}	405.15±10.52^{b}	535.42±7.86	136.159±1.841^{c,d}	301.020±14.801
H513-F_2	92.859± 2.944^{c}	332.24±11.58^{c}	23.698±1.641	48.911±1.090^{a,b}	425.09±.12.13^{b}	517.69±31.33	128.776±1.684^{c,d}	199.220±11.301
H513-F_3	103.870±8.124^{c}	353.43±14.20^{c}	20.644±1.047	44.133±0.800^{a,b}	410.29±23.83^{b}	539.48±6.42	91.445±1.510^{c,d}	249.671± 20.998
Pioneer-F_1	364.06±8.612^{a,b}	964.06±4.67^{a}	61.873±0.680	31.873±0.680^{c}	518.56±15.39^{a,b}	618.56±15.39	187.203±0.874^{a}	467.203±10.874
H505-F_2	115.52±2.418^{c}	595.52±23.47^{c}	29.123±1.710	49.103±1.710^{a,b}	382.27±10.49^{ab}	185.808±11.30	81.808±2.307^{d}	185.808±11.302
H505-F_3	109.86±6.845^{c}	409.86±18.34^{c}	23.104±0.120	24.204±0.120^{a,b}	376,22±11.09^{a,b}	365.808±16.30	95.008±1.302^{d}	365.808±16.302
H500-F_1	177.33±1.220^{c}	477.33±11.72^{c}	33.119±0.680	33.119±0.680^{c}	221.54±21.00^{c}	311.54±21.00	121.165±0,891^{c,d}	233.165±10.891
H500-F_2	96.48±5.036^{c}	396.48±22.03^{c}	36.183±3.640	26.183±3.640^{c}	242.73±9.07^{c}	342.73±9.07	103.768±0,622^{c,d}	253.768±20.622
H500-F_3	122.04±1.862^{c}	372.04±21.06^{c}	34.103±1.790	44.103±1.790^{c}	248.45±10.56^{c}	308.45±10.56	111.943±1.227^{c,d}	248.943±21.227
Overall	**258.170±136.316**	**587.17±211.89**	**36.676±11.92**	**45.46±14.08**	**429.570±111.21**	**525.22±138.62**	**142.104±34.459**	**345.730±103.337**
P- Value	**0.015**	**0.000**	**0.902**	**0.203**	**0.007**	**0.039**	**0.033**	**0.015**

F_1, F_2 and F_3 represents farms that had designate variety; ^{a,b,c} and ^{d} post hoc analysis placement

Phosphorous in the maize cobs averaged 36.676±11.92 mg/100 g DM ranging from 23.104±0.120 to 70.793 mg/100g (Table 2). The mean value of phosphorous in this study is much greater than 40 ppm (4 mg/100g) reported in an earlier study on analysis of biogas generated from maize wastes (cobs) and carrot leaves [16]. In a separate study it was reported too that an accumulation of phosphorous by maize as a result of reduction in the potassium fertilizer averaged 50 mg/100 g [17].

The variation of phosphorous in maize cobs of different varieties was insignificant (p=0.902). Unlike nitrogen there was no particular variety that out rightly showed low or high levels. Phosphorous in large quantities of cereal grains is mostly associated with phytic acid and its salts. The season, method and quantity of fertilizer application determine the phosphorous content. In a study on phosphorous concentration by two varieties of corn it is reported that with correct variety selection, fertilizer application in dozes is better than mixing fertilizers with the soil at sowing [18]. Phosphorous application during winter and spring on wheat showed contrasting observations in the study on the effect of applied mineral elements on content and yield of cereals and potatoes in Finland [19]. The report showed that phosphorous content of the grains was not affected by the fertilizer treatment of wheat, barley and rye during spring but was in winter.

Many other factors determine levels of phosphorous in plants, including interaction of phosphorous and calcium that causes desorption, the pH range, amount of organic matter and proper placement of fertilizer-phosphorous [20]. The dissolution of $H_2PO_4^-$ and HPO_4^{2-} depends on the pH range. The $H_2PO_4^-$ dissolves at low pH while the later dissolves at high pH. There is a marked increase in phosphorous uptake in the presence of ammonium – nitrogen than nitrate nitrogen [21].

Potassium in maize cobs of varieties sampled averaged 429.57±111.21 mg/100 g. The values ranged from 221.54 – 595.46 mg/100 g (Table 2). A separate study that investigated biogas generation from maize wastes (cobs) and carrot leaves, reported potassium levels as 320 mg/100 g [16]. Given that potassium soil requirements is estimated to be 3 mg/100 g [16] and that the recommendation for crops like corn is 22.68-34.02 kg/acre for those soils with very low levels [22], 65 kg of maize cobs can sufficiently be a supplementary source of potassium per acre. There was significant variation (p=0.007) in potassium between maize varieties' cobs.

Calcium levels averaged 142.104±34.459 mg/100 g in a range from 81.808 mg/100 g in the variety H505F_2 to 195.909 mg/100 g levels in variety H6213F_1. In a study on the feeding and economic value of maize cob meal for broiler chickens, the level of calcium reported was 110 mg/100 g [23]. The Ochetim's value and that found in this study however significantly differs from 25 mg/100 g found in the investigation of biogas generation from maize wastes (cobs) and carrot leaves [16]. The levels of calcium in maize cobs from different cultivars varied significantly (p=0.033). Calcium influences the division of meristematic cells and their subsequent extension, which is necessary for the growth of both roots and stems [23]. Calcium concentrations in the cell cytosol are sensitive to different signals such as light, biotic stress, hormones and any small changes results in specific physiological response which significantly affects the plant growth rate [24].

Calcium level in maize is tissue based, decreasing in the order leaves, stems, cobs covering leaves and cobs. The decrease in calcium concentration in the vegetative tissues implies its high mobility from the cobs core and cob covering leaves to developing kernels considered as a final sink. In general plant's variety and its environment play an important role in accumulation of nutrients [25]. The composition of maize cobs has also been reported to be affected by stage of maturity, climate, soils and production method [26].

3.4 Macronutrients Levels in Maize Stalks

Maize stalks of different maize varieties from different farms were analyzed for total nitrogen, phosphorous, potassium and calcium. The mean ± standard deviations of the levels (mg/100 g, DM) were recorded as in Table 2.

The levels of macronutrients in maize stalks of eight maize cultivars analysed averaged 587.17±211.89 mg/100 g (N), 45.46±14.08 mg/100 g (P), 525.22±138.62 mg/100 g (K) and 345.730±103.337 mg/100 g (Ca). Analysis of variance (ANOVA) indicated that at 95% confidence, levels of macronutrients total nitrogen (p=0.000), potassium (p=0.039) and calcium (p=0.015) significantly varied with maize varieties. Phosphorous levels insignificantly varied with varieties (p = 0.203). Phosphorous accumulation is not necessarily dependent on the varieties [19].

The results compare well with levels reported in other studies. In the determination of total nitrogen levels in maize stalks 997 mg/100 g [15], 448 mg/100 g [17] and 750 mg/100 g [27] have been reported. Phosphorous in maize stalks too has been reported in earlier studies as 158 mg/100 g [15] and 69.0 mg/100 g [28]. Camberato, [29], Hoskinson *et al*., [27], Darwish, [30] and Knox and Geoff; [15] reported potassium levels as 430 mg/100 g, 998.4 mg/100 g, 102 mg/100 g and 1204 mg/100 g respectively. Hoffman *et al*., [31] reported an average of 1810 mg/100 g calcium in maize stalks. The variation in levels of macronutrients in plants are affected by plant variety [32], soil environment [33,25] inputs including fertilizer application [34].

Paired samples statistical comparison between levels of macronutrients (T-tests) in cobs and stalks showed significant difference as was p=0.003 (N), p=0.037 (P), p=0.006 (K) and p= 0.000 (Ca). Stalks had higher levels of macronutrients than cobs. In a study of accumulation of nitrogen, phosphorous and potassium in mature maize under variable rates of mineral fertilization, Krzysztof *et al*., [35] reported that phosphorous concentration in the maize organs significantly decreased in the order grain > stems > leaves > husks > cob cores, explaining the role of phosphorous in a plant development.

4. CONCLUSION AND RECOMMENDATION

Levels of macronutrients N, K and Ca in maize stover of different maize varieties significantly differed. The maize cobs and stalks of high yielding varieties like H6213, H614 characterized with massive stalk sizes compared to the less yielding ones like H500, H505, H513 and Oduma had higher levels. The stover from H6213, H614, DK and pioneer varieties retain high levels of macronutrients and so recycling through composting or animal feeding is recommended. It was further observed that stalks had more macronutrients than cobs though in either phosphorous did not vary with varieties.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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