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EFFICACY OF FECAL FERTILIZERS ON GROWTH, NUTRIENT UPTAKE AND YIELD OF MAIZE

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ABSTRACT

Maize (*Zea mays* L.) is the most widely cultivated staple food crop in sub-Saharan Africa. However, its production is severely constrained by abiotic and biotic factors of which declining soil fertility is a major contributor. A study was conducted to evaluate the efficacy of fecal matter based organic fertilizers on growth, nutrient uptake, yield and yield components of maize, in two distinct agro-ecological zones. Five fertilizer treatments (control, Diammonium Phosphate (DAP), cow manure, struvite, compost from fecal matter) were tested in a randomized complete block design (RCBD) with four replications per site. Data were collected on crop emergence (%), plant height, number of leaves per plant, leaf area index (LAI), tasseling (%), nutrient uptake and grain yield and yield components. Data were subjected to analysis of variance and treatment means separated using Tukey's HSD test. Results showed that crop emergence in the control treatment, except for struvite, was significantly higher than DAP and fecal matter based organic fertilizer plots in Bahati and Lanet sites. The end-point plant height (9 WAP), LAI and tasseling were significantly ($P<0.05$) influenced by location and organic fertilizer treatments. At the Lanet site, DAP and struvite treatments equally had the tallest maize plants (163 cm) followed by fecal compost (128 cm), manure (121 cm), and the control (79 cm). Similar result trends were recorded in Bahati where struvite (193 cm) had the tallest plants followed by fecal compost (166 cm), DAP (155 cm), manure (151 cm) and the control (98 cm), respectively. A contrasting result was observed at the Egerton University site in which cow manure and the control plots equally had the tallest plants (117-121 cm), followed by DAP and fecal compost (98-99 cm), and struvite (91 cm). The LAI, tasseling and grain yield were significantly influenced by location with struvite and fecal compost treatments producing the highest grain yield (≈8 t/ha) and one thousand (1000)-seed weights (480-560 g) at the Egerton University and Bahati experimental sites. Nitrogen uptake by maize for organic fertilizer treatments was higher than the control at all three locations. However, there was no difference in uptake of phosphorous and potassium between control and organic fertilizer treatments. These findings have demonstrated the potential of fecal matter based organic fertilizers as alternatives to inorganic fertilizers in smallholder agriculture.

Key words: *Zea mays*, fecal compost, struvite, nutrient uptake, manure, Nitrogen, Phosphorus, Potassium

INTRODUCTION

Maize is the main staple in the diet of over 85 percent of the population in Kenya and a per capita consumption of 98-103 kg, which translates to at least 2700 thousand metric tonnes annually [1, 2]. However, productivity amongst smallholder farmers is diminishing in the face of declining land sizes, soil quality, and inadequate use of complementary inputs like fertilizers, water scarcity and drought. This has led to the need for alternative sources of nutrients that will help bridge the gap that has contributed to food insecurity. One source that can be very vital to this approach is sewage sludge and fecal matter. Municipal sewage sludge is highly rich in the relevant components for soil fertilization and plant nutrition [3]. Since it is an organic fertilizer, its addition will help to manage the current state of soil physical, chemical and biological degradation. These properties warrant use of sludge as fertilizer [4]. Traditionally, the agricultural practice of applying nutrients was through organic manures like green manures and farm-yard manure. This was because famers had discovered that organic manure applications enhanced soil physical properties through improved soil aggregation [5] and aggregate stability [6]. The use of both organic and inorganic fertilizers by farmers has been reported to increase yield and withstand soil degradation [7]. The C: N ratio of municipal sludge is 5.68-16.75:1 makes its use acceptable owing to increased N accessibility by plants [8]. The fecal matter fertilizers can be used to replenish nutrients in the soil since they comprise up to 0.7% N (Nitrogen) as a percentage of wet weight [9], which is around 5 to 11 g per day [10]. Pure urine is also used to produce struvite, a slow-dissolving orthophosphate compound, which is a phosphate fertilizer that contains a substantial amount of nitrogen and magnesium ($MgNH_4 PO_4 \cdot 6H_2O$) and is an effective substitute source of rock phosphate to sustain the agricultural production system [11]. The objective of the current study was, therefore, to evaluate the efficacy of fecal matter organic fertilizers on growth, nutrient uptake and yield of maize under different agro-ecological conditions.

MATERIALS AND METHODS

Experimental Sites

Three field agronomic experiments were conducted during the long rains (April to October 2016) in representative on-farm sites (Lanet and Bahati) and on-station at Egerton University in two (2) distinct agro-ecological zones (AEZs) in Nakuru County, Kenya. The two on-farm trials were located in Lanet (near Lanet Military Barracks: -$0^0$29'S and $36^0$15'E; altitude: 1883 metres above sea level (masl); AEZ: Lower highland (LH2)] and Bahati [Bahati Forest Station: -0°15'S and 36°12'E; 1912 masl; AEZ: Upper highland (UH2)] sub-counties. The on-station field experiment was set up at Egerton University (Horticulture Teaching and Research Field: 0°22'S and 35°56'E; altitude: 2238 masl; AEZ: LH2). The mean annual rainfalls at the experimental sites are 900, 1012, and 937 mm for Lanet, Bahati and Egerton University sites, respectively [12]. The soil types at the experimental sites were Mollic Oxisol, Latosol and Mollic Oxisol for Lanet, Bahati and Egerton University sites, respectively [12].

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Experimental Layout and Crop Management

The field experiments were set up in April 2016 and laid out in a randomized complete block design (RCBD) arrangement replicated four times per site. A hybrid maize variety H628 was planted in plots measuring 3.75 m by 3.0 m at spacing of 0.75 m and 0.3 m for inter- and intra-row spacing, respectively, and one (1) seed planted per hill. A total of five treatments consisting of three (3) fecal matter organic fertilizers (struvite, compost, and cow manure), inorganic fertilizer, Diammonium phosphate (DAP) and an untreated control were evaluated. The rate of application for fecal matter organic fertilizers was as follows: compost at 5 t/ha (≈ 92 kg N/ha and 16 kg P/ha), cow manure at 5 t/ha (≈ 75 kg N/ha and 20 kg P/ha) and struvite at 222 kg/ha (equivalent to 18 kg N/ha and 58 kg P/ha). The positive control, DAP at the recommended rate of 180 kg/ha (equivalent to 30 kg N and 80 kg P_2O_5/ha) and an untreated control were included as treatments.

Three (3) hand weeding operations were performed at 3, 6 and 10 weeks after planting (WAP) and Tremor® 0.05 GR (Active ingredient: Beta-cyfluthrin 0.5g/Kg) was applied 5-6 WAP at the rate of 6 kg/ha to control stem borers in the experimental plots. Data were collected on crop growth parameters (plant height, number of leaves, leaf area index (LAI) and percent tasseling), nutrient uptake (N, P and K) and yield and yield components as described below.

Experimental variables and data collection

(a) Growth parameters

Five plants were randomly sampled from each of the three middle rows and used for plant height measurements and number of leaves per plant. Maize plant height (cm) was measured from the soil surface to the highest point of the arch (the uppermost leaf whose tip is pointing down). Plant height data were recorded after 2, 4, 6, 8 and 10 WAP. Similarly, the number of leaves was counted and recorded 2, 4, 6, 8 and 10 WAP. Data on percent tasseling and the leaf area index (LAI), on the other hand, were collected 60 days after planting from the entire experimental plot (5 rows of maize). The percent tasseling and LAI were computed as shown in equations 1 and 2 below:

$$\text{Tasseling (\%)} = \frac{\text{No.of plants tasseled in plot}}{\text{Total number of plants in plot}} \qquad \text{Eq.1}$$

$$\text{LAI} = \frac{\text{Ground area}}{\text{L * W * K}} \qquad \text{Eq. 2}$$

Where L= leaf length, W= leaf maximum width and K= constant (0.74).

(b) Nutrient uptake by maize

Fresh maize leaf samples were randomly obtained from the experimental plots at the tasseling stage and transported to the laboratory within 6 hours (h). The samples were cleaned using distilled (deionized) water to remove any surface impurities before being oven-dried (Oven model: Model Wiseven WOF-105) for 24 h at 105 ºC. The oven-dried leaf samples were ground into fine a powder and sieved through a 2-mm sieve before

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being used for plant tissue analysis. The dry powdered samples were used for N, P and K content of maize leaves as described below:

i) **Nitrogen (N)**

Dry plant powder (0.3 g) sample was digested in a Kjeldahl digestion procedure using a digestion mixture comprising of hydrochloric acid (HCl), nitric acid (HNO_3), selenium (Se) and copper sulphate ($CuSO_4$). The temperature of the heating block was maintained at 360 ^oC for 2 h after which the samples were left to cool and transferred into a 50ml volumetric flasks and the sample volume made to the mark by adding deionized. The solution in the volumetric flask was allowed to settle, and 5 ml aliquots measured into a distillation bottle where 10 ml of 40% sodium hydroxide (NaOH) was added. The sample in the volumetric flask was then steam-distilled into a 5-ml 1% boric acid containing 4 drops of mixed indicator for 2 minutes from the time the indicator turned green. The distillate was titrated using 0.01M HCl. The end-point of the titration was reached when the titer turned green through grey to definite pink. A blank experiment was prepared using the same procedure [13]. The maize tissue content of nitrogen (% N) was computed as shown in equation 3 below [14]:

$$N\,(\%) = \frac{(A - B)xCxDx0.014x100}{WxQ} \qquad \text{Eq. 3}$$

Where A= the titer of the sample, B= the titer of the blank, C= Concentration of the HCL acid, D= Dilution volume, W= weight of the soil and Q= volume of the aliquot.

ii) **Potassium**

Dry plant powder (0.3 g) sample was digested in digestion tubes using a digestion mixture comprising HCl, HNO_3, hydrogen fluoride (HF) and boric acid (H_3BO_3). The temperature of the heating block was maintained at 360 ^oC for 2 h after which the samples were left to cool and then transferred to 50 ml volumetric flasks and volume made to the mark. Calibration was done using certified standards. Samples were analyzed using Varian spectra AA10 AAS machine. The level of absorbance was recorded. The amount of potassium (%) was calculated as shown in equation 4 below [14]:

$$K\,(\%) = \frac{GR\ x\ Vx\,100}{Wx1000000} \qquad \text{Eq. 4}$$

Where GR= graph reading, V= Total volume after dilution and W= weight of the soil measured.

iii) **Phosphorous**

Dry plant powder (0.3 g) sample was digested in digestion tubes using a digestion mixture comprising of HCl, HNO_3, Se and $CuSO_4$. The temperatures in the heating block maintained at 360 ^oC for 2 h after which the samples were left to cool and transferred into 50-ml volumetric flasks and volume made to the mark. Aliquots (5 ml) were transferred into sample bottles where 1 ml of developing color solution (Ammonium vanadate: H_4NO_3V and Ammonium molybdate: $(NH_4)_2MoO_4$ in the ration of 1:1) was

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added. The samples were left to stand for 30 minutes after which they were transferred to cuvettes. Readings (absorbance) were taken using a spectrophotometer (210 VGP) at 430 wavelengths. Calibration was done using certified standards. The percent P in the plant tissue was calculated using equation 5 below [14]:

$$P\,(\%) = \frac{GR \text{ x } V\text{x}\,100}{W\text{x}DV\text{x}1000000} \qquad \text{Eq. 5}$$

Where GR= graph reading, V= Total volume after dilution, W= weight of the soil measured and DV=Developing color volume used.

(c) Yield and yield components
At physiological maturity, the maize was hand-harvested within the three central rows of each experimental plot, representing a harvested area of 6.75 m^2. The maize cobs were de-husked, shelled, and the kernels weighed and recorded as maize grain yield (kg) per plot. For each experimental plot, four (4) replicates of 1000 seed samples were obtained from the shelled grains and thousand seed weights (TSW) (g) recorded. Maize grain yield (kg ha^{-1}) was calculated using equation 6 [15]:

$$\text{Grain Yield (kg/ha)} = \frac{[\text{Plot weight (kg) x } 10{,}000\text{ m}^2/\text{ha x } (100 - \text{AMC})]}{[\text{HA x } (100 - \text{SMC})]} \qquad \text{Eq. 6}$$

Where AMC = actual grain moisture content at harvest, HA= plot harvest area (m^2) and SMC= recommended storage moisture content.

Data on counts were first subjected to appropriate angular transformation before performing analysis of variance (ANOVA), regressions and treatment means separated using Turkey's HSD test [16, 17].

RESULTS AND DISCUSSION

a. Growth parameters, Yield and Yield Components
Results showed that crop emergence in the control treatment, except for struvite, was significantly higher than the emergence in the DAP and organic fertilizer treated plots at the Bahati and Lanet sites (Table 1). The control and struvite treated plots equally had the highest emergence (90-92%) followed by the manure (83.5-88.5%), fecal compost (74-84.5%) and DAP (30.5-47.0%) treated plots in order of decreasing percent emergence. At the Egerton site, the cow manure had highest emergence (95%) followed by struvite, fecal compost and control (77.5-81.5%) and DAP (72%).

There were no significant differences ($P<0.05$) in the number of maize leaves at Lanet and Bahati for DAP, struvite, compost and manure with an exception of the control (8.26±0.76; 7.80±0.71), respectively (Fig. 1). At the Egerton University experimental site, there was a significant difference ($P<0.05$) between the control and the three other treatments (DAP, struvite and compost). In retrospect, there was no significant difference between the control and manure treatments in the number of leaves per plant at the Egerton University site.

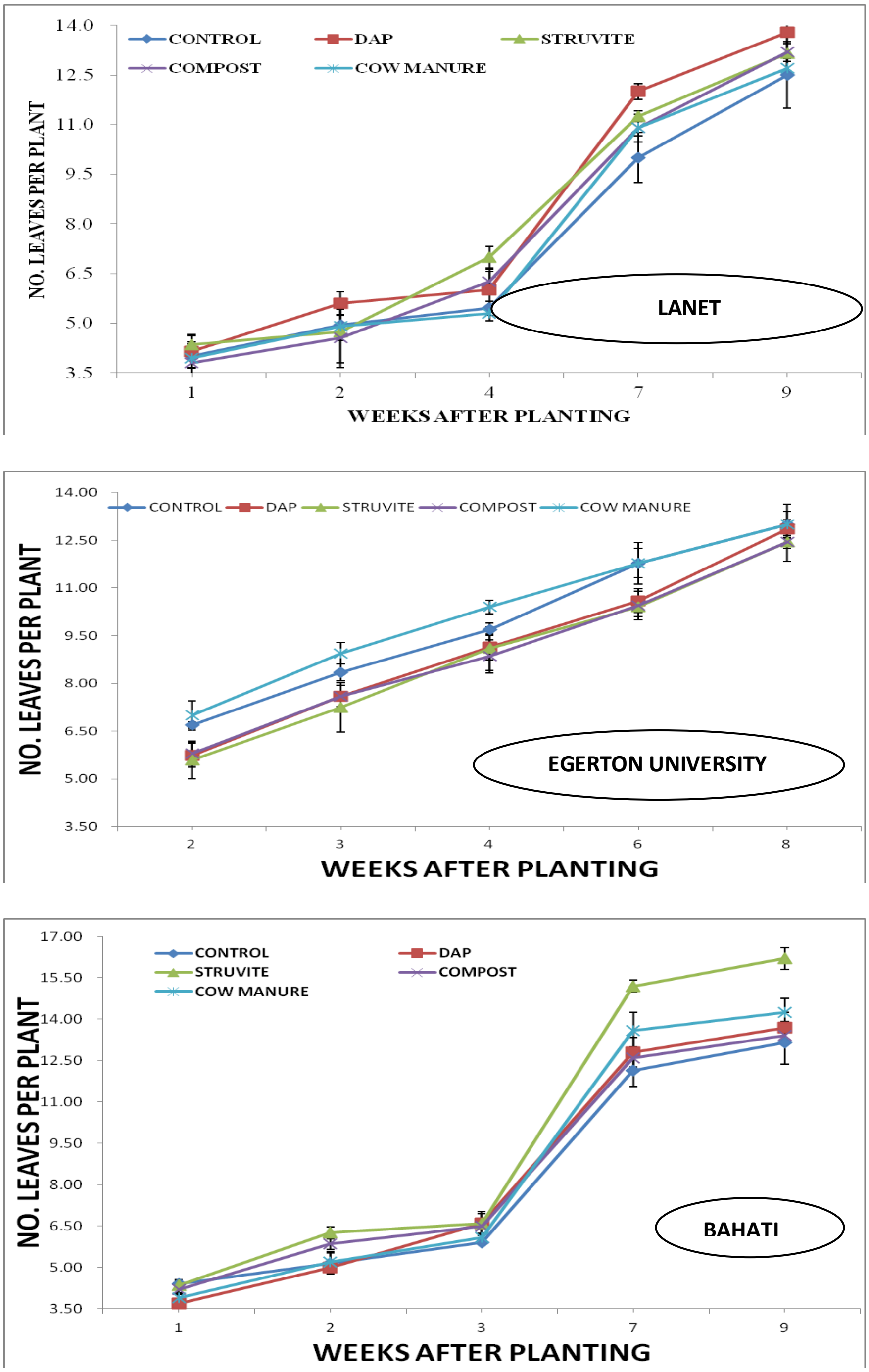

Figure 1: Effect of fecal matter fertilizers on number of leaves per maize plant in Lanet, Egerton University, and Bahati areas in Nakuru County

Results showed that the end-point plant height, 9 weeks after planting (WAP), LAI and tasseling were significantly (P<0.05) influenced by location and fertilizer treatment (Table 2). At the Lanet site DAP and struvite treatments (163 cm) equally had the tallest maize plants followed by fecal compost (128 cm), manure (121 cm) and the control (79

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cm). Similar result trends were recorded in Bahati, where struvite (193 cm) had the tallest plants followed by fecal compost (166 cm), DAP (155 cm), manure (151 cm) and the control (98 cm), respectively. A contrasting result was observed at the Egerton University site in which cow manure and the control plots equally had the tallest plants (117-121 cm), followed by DAP and fecal compost (98-99 cm) and struvite (91 cm).

The LAI and tasseling were significantly influenced by location and fertilizer treatment. There were location-specific responses, in which maize at the Egerton University site recorded the highest mean percent tasseling of 41.7% followed by Bahati (35.9%) and Lanet (25.4%), respectively (Table 3). The struvite treatment consistently had the highest percent tasseling (38.4-48.8%) across all the three experimental sites. A similar trend in results was observed for LAI, where the maize plants at the Egerton University site had the highest mean LAI of 4.82 followed by Bahati (4.73) and Lanet (3.95). Diammonium phosphate (DAP) treated plots consistently had the highest LAI values across the locations followed by struvite, fecal compost, manure, and the control, respectively.

Results showed that maize grain yield and 1000-seed weights significantly ($P<0.05$) differed across experimental locations and the type of fertilizer applied. Struvite and fecal compost treatments produced the highest grain yield (≈8 t ha^{-1}) and 1000-seed weights (480-560 g) at the Egerton and Bahati trial sites (Fig. 2). The highest yield responses were produced by DAP, fecal compost and manure (7.7-8.2 t ha^{-1}) whereas at Bahati, struvite, fecal compost, and manure had the highest yields (7.7-8.0 t ha^{-1}). The Lanet site contrastingly had low yields of 4.0-5.5 t ha^{-1} for struvite and fecal compost treatments. Except for the Lanet site, there were no significant differences in 1000-seed weight at the Egerton and Bahati sites for all the fecal-based organic fertilizers tested.

The findings of this research show that application of inorganic (DAP) and organic fertilizers (fecal compost and manure) results in reduced maize crop emergence. The results also revealed that organic fertilizers (struvite and fecal compost) produced the highest growth and grain yield. The organic fertilizers resulted in 30-45% increase in grain yield of maize over the control. The observed reduced crop stands points towards the possibility of direct contact between the seed and fertilizer. These findings are consistent with previous studies which observed that the rate and method of fertilizer application influenced growth and yield of maize [18]. The fact that organic fertilizers (struvite, fecal compost, and manure) produced crop performance (growth and yield) comparable to inorganic fertilizer, DAP, holds good promise for organic fertilizers especially fecal matter-based fertilizers as a viable alternative to synthetic fertilizers. This is further corroborated by other studies that detected no significant difference between inorganic and manure fertilizers in their long-term effects on crop production, and yet noted that the contribution of organic manure to the development of the vegetative organs of maize [19, 20]. These results, therefore, highlight the importance that should be attached to the use of organic fertilizers in modern agriculture for sustainable higher crop yields, improved soil water retention and mineralization of soil nutrients. The location-specific variation in crop performance is attributable partially to agro-ecological and micro-climatic conditions. The three experimental sites had differences in precipitation, altitude, topography, vegetation cover and temperature, which agree well with recent studies on the potential causes of varied crop performance [21].

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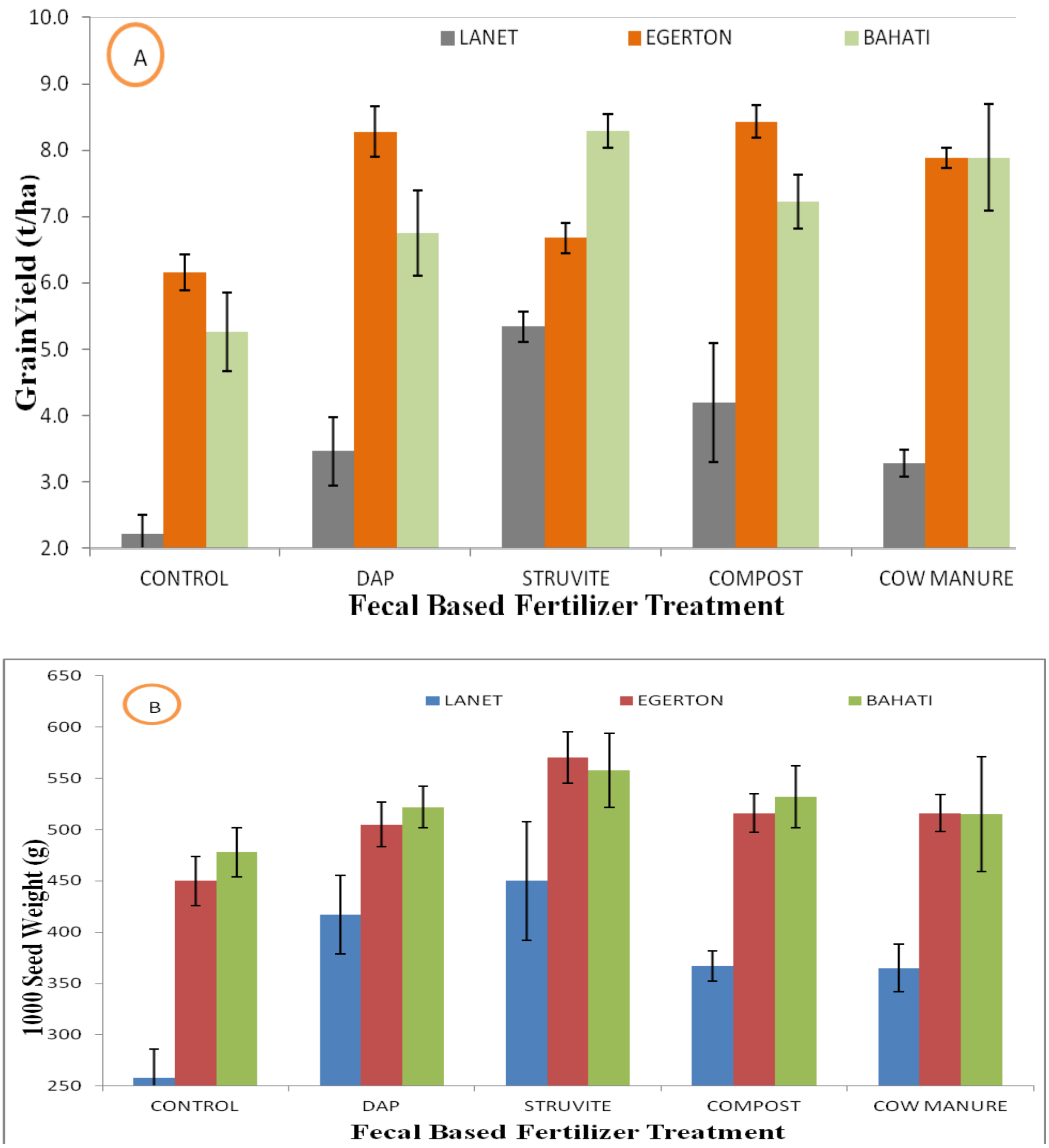

Figure 2: Effect of fecal matter-based fertilizers on (A) yield and (B) 1000-seed weight of maize in Nakuru County, Kenya

In the present study, different fecal-based organic manure and an inorganic fertilizer were used in determining the yield and yield components of maize in three different sites in Nakuru County. Organic manure and/or chemical fertilizer benefit only soil productivity and not soil quality [20]. This implies that the relative buildup of soil nutrients, particularly N and P, shown by the apparent nutrient uptake evidenced by the results and is postulated to emanate from long-term use of organic fertilizers relative to inorganic fertilizers. In spite of this, sustainable and stability in production of maize, which is the

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staple food in Kenya, is heavily reliant on the continued upgrading of both the soil productivity and soil quality.

Clearly, organic fertilizers have advantage over inorganic fertilizers in improving the soil permeability by alleviating the inconsistency between scarce water resources and high water demand resulting in better grain yield. In a study to determine the effect of organic manure on yield of maize and water productivity in Arid and Semi-Arid regions of China [22], it was reported that soil organic manure increased significantly over time, and the soil improved in production and productivity when using organic manure relative to inorganic fertilizers. Long-term application of organic manure to the soil significantly increased yield of maize by 7.4 % steadily, over a period of 4 years [22]. This finding is in agreement with the current study and affirms the theory of organic fertilizers resulting in better soil permeability hence, higher yields.

b. Nutrient (NPK) uptake by maize

The N uptake by maize for the fertilizer treatments was higher (2.95-3.73%) than the control (2.15%) at all the three locations (Table 4). Except for the P uptake at Egerton University, there were no significant differences in uptake of the other nutrients (P and K) between the control and organic fertilizer treatments and among the fertilizer treatments. At the Egerton University site, DAP had the highest P uptake of 0.50% followed by the control (0.44%), struvite (0.43%), manure (0.40%), and fecal compost had lowest uptake at 0.15%, respectively.

This study showed a positive response of nutrient uptake (NPK) by maize to fertilizer application (both inorganic and organic) compared with the control. These findings revealed that lack of fertilizer application leads to low nutrient uptake, especially the macronutrients, which are limiting factors of production. The level of P observed in the compost at the Egerton site is capable of limiting the availability of N, P and K required by the plant [23]. The indifference in nutrient uptake between the control and organic fertilizer treatments in Bahati and Egerton can be attributed to the soils at those sites, which have fairly adequate levels of N, P and K. The variations recorded in treatments across the three sites might be due to other factors such as soil properties, environmental conditions and nutrient interactions [24, 25].

CONCLUSION

The results obtained from this study showed that organic fertilizer application significantly influences the performance of maize as evidenced by increased growth and yield of maize. The fecal compost increased maize yield by up to 45% in comparison with the control. Hence, the use of organic fertilizers as a potential alternative to inorganic fertilizers in maize production in terms of anticipated soil productivity and crop returns.

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Table 1: Effect of different fecal organic fertilizers on the emergence of maize in Lanet, Egerton and Bahati

	Percent Maize Emergence		
Treatments	Lanet	Egerton	Bahati
1. CONTROL	90.50±4.20	77.50±9.00	91.00±2.52
2. DAP	30.50±10.50	72.00±14.45	47.00±5.69
3. STRUVITE	90.50±3.09	81.50±12.12	92.00±2.45
4. FECAL COMPOST	74.00±7.87	81.00±11.21	84.50±3.20
5. COW MANURE	83.50±2.50	95.00±1.00	88.50±3.20

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Table 2: Effect of different fecal-based organic fertilizers on height of maize over time (weeks) in Lanet, Egerton and Bahati

Treatment	HEIGHT (CM; WEEKS AFTER PLANTING)				
	LANET				
	1	3	5	7	9
1. CONTROL	8.50±0.24	17.05±1.91	61.40±6.99	64.65±5.86	78.75±5.98
2. DAP	7.86±1.09	25.80±4.84	93.20±4.08	100.00±3.46	163.85±29.91
3. STRUVITE	9.99±0.56	35.95±3.14	99.80±5.56	105.65±6.12	163.05±18.69
4. COMPOST	7.35±0.38	26.80±2.43	71.45±2.18	80.70±3.32	128.15±10.59
5. MANURE	7.63±0.69	22.50±0.96	65.95±5.89	74.60±4.97	121.35±25.29
	EGERTON				
	1	3	5	7	9
1. CONTROL	23.50±1.34	31.66±2.04	44.60±0.91	100.15±3.70	116.89±1.74
2. DAP	21.93±1.36	27.33±1.61	42.36±3.30	80.33±8.09	98.35±7.94
3. STRUVITE	21.67±2.46	23.51±3.40	39.60±4.66	76.25±10.49	91.06±11.71
4. COMPOST	23.26±0.82	25.55±2.76	41.42±1.83	79.50±3.82	98.94±7.64
5. MANURE	25.33±1.79	37.67±1.97	46.80±3.11	111.10±14.10	121.12±15.26
	BAHATI				
	1	3	5	7	9
1. CONTROL	5.59±0.77	18.71±1.67	39.59±11.88	60.95±8.42	97.70±8.37
2. DAP	6.84±0.89	25.91±1.31	72.05±5.19	93.45±0.72	155.35±7.12
3. STRUVITE	7.21±0.24	27.98±1.54	80.95±5.71	134.48±4.11	193.38±13.55
4. COMPOST	5.89±0.52	23.01±0.26	58.70±3.17	91.20±5.31	165.90±5.93
5. MANURE	4.98±0.81	15.49±1.97	53.65±2.54	87.35±3.64	151.40±8.22

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Table 3: Effect of different fecal-based organic fertilizers on leaf area index (LAI) and Tasseling (%) in Lanet, Egerton and Bahati

Treatment	LANET		EGERTON		BAHATI	
	LAI	Tasseling	LAI	Tasseling	LAI	Tasseling
1. CONTROL	3.51±0.33	16.25±3.26	5.00±0.12	41.5±1.28	4.74±0.24	36.00±2.18
2. DAP	4.37±0.12	17.00±2.32	5.22±0.21	39.25±1.05	4.92±0.46	47.50±2.89
3. STRUVITE	4.15±0.36	38.35±0.88	4.17±0.45	41.5±1.20	4.82±0.20	48.75±3.14
4. COMPOST	3.97±0.36	28.00±1.51	4.55±0.10	43.5±0.77	4.55±0.12	26.5±4.79
5. MANURE	3.73±0.52	27.5±1.81	5.17±0.35	42.75±1.78	4.63±0.24	20.5±3.33

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Table 4: Effect of different fecal-based organic fertilizers on nutrient uptake (N, P and K levels) in Lanet, Egerton and Bahati

Treatment	N (%)			P (%)			K (%)		
	Lanet	Egerton	Bahati	Lanet	Egerton	Bahati	Lanet	Egerton	Bahati
1. CONTROL	2.15±0.57	2.93±0.98	3.75±0.83	0.54±0.05	0.44±0.06	0.49±0.03	1.49±0.14	1.27±0.18	1.51±0.26
2. DAP	3.73± 0.42	3.79±0.62	4.28±0.85	0.53± 0.51	0.50±0.06	0.4±0.1	1.83±0.73	1.36±0.40	1.63±0.21
3. STRUVITE	3.37± 0.59	3.40±0.84	3.60±0.64	0.52± 0.03	0.43±0.14	0.49±0.02	1.50±0.13	1.43±0.20	1.38±0.43
4. COMPOST	2.95±0.35	3.95±0.73	3.45±0.39	0.50±0.01	0.15±0.02	0.48±0.06	1.75±0.02	1.43±0.32	1.39±0.42
5. MANURE	3.70±0.22	3.83±0.34	3.8±0.34	0.48±0.06	0.40±0.17	0.36±0.09	1.62±0.37	1.29±0.19	1.73±0.21

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