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Enhancing African leafy vegetable productivity and nutrient levels through manure and fertilizer in Kitui County, Kenya

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Summary: African Leafy Vegetables (ALVs) are crucial components of diet globally due to their significant nutritional value. We conducted a field experiment in October 2022 to assess the effect of fertilizer application rates on the growth and nutritive value of four ALVs (*Solanum nigrum, Cleome gynandra, Amaranthus hybridus*, and *Vigna unguiculata*) at South Eastern Kenya University (SEKU) Teaching and Research Farm. We collected data through a randomized complete block experimental design that comprised four treatments: manure alone (M), fertilizer alone (F), manure + fertilizer (M+F), and a control (C). Once the planted vegetable seeds had been established, we counted their leaves on a weekly basis and averaged after a month. At the end of the experiment, the ALVs leaves were harvested. They were analyzed for retinol, a precursor of vitamin A, iron, calcium and zinc. It was found that manure and fertilizer treatments significantly increased the number of ALVs leaves. Results also showed that the *Solanum nigrum* had the highest number of leaves at 118.5% in M+F treatment as compared to the control. Across all vegetables, a combined treatment (M+F) significantly affected the retinol mean (P=0.0063) while crop type and the interaction between crop type and the treatment had no statistically meaningful impact on any nutrient. This suggests that fertilization effects on retinol are independent of crop type. These results highlight the importance of soil fertilization in influencing vitamin A levels in ALVs.

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Key words: African leafy vegetables, hidden hunger, nutrients, nutritional deficiency, manure application

Introduction

According to the United Nations (2019), the world's population is projected to increase to 9 billion people by 2050. This requires a corresponding increase in the nutrient needs for people and livestock (Manono et al., 2019). To sustain the current dietary patterns up to 2050, food production should increase by 70% (Binder, 2019). Unfortunately, production of proteins from livestock consumes significant amounts of natural resources (Liceaga et al., 2022) while causing tremendous pollution, biodiversity loss and greenhouse gas emissions (Manono, 2016; Ramankutty et al., 2018). Additionally, the changing climate is constraining the resilience of natural systems that food production depends on (Mabhaudhi et al., 2019). This has led to escalating malnutrition rates in developing countries that have been worsened by the combined impact of income inequality and the unaffordability of healthy diets (Chang et al., 2018; FAO et al., 2021). Thus, it is necessary to boost alternative production systems that have less impact on the environment (Imathiu, 2021). Cultivation and use of the locally available and adaptable vegetable crops for diversifying healthy food sources with enriched fertilizers can achieve this diversification goal.

This study focused on four ALV species cultivated in Kenya because of their significant dietary benefits, ease of cultivation, ability to do well in water scarce areas and the ever-ready market. These vegetables were *Solanum nigrum* (garden huckleberry), *Cleome gynandra* (spider plant), *Amaranthus hybridus* (amaranth) and *Vigna unguiculata* (cowpea). *Cleome gynandra*, is an annual, herbaceous plant of Cleomaceae family indigenous to South-East Asia and sub-Saharan Africa. It is highly nutritious with medicinal properties (Moyo & Aremu, 2022). Due to its ability to withstand drought (Mashamaite et al., 2022), it can be grown effectively in water-scarce environments. *Solanum nigrum*, a member of the Solanaceae family, has a high content of micronutrients, medicinal properties and other benefits (Sangija et al., 2021). *Amaranthus hybridus* belongs to the family Amaranthaceae. It is broad leaved with enormous nutrient potential (Waselkov et al., 2018). Its long taproot supported by tertiary roots makes it suitable for cultivation in water deficit environments (Adedibu et al., 2024). *Vigna unguiculata* belongs to the family Foboideae. It is cultivated in dry, semi-arid tropical and subtropical regions as an important supply of proteins and vitamins (Sardar et al., 2024).

ALVs are rich in essential vitamins and micronutrients, which play vital roles in maintaining optimum health (Matthewman & Costa-Pinto, 2023). Globally, zinc and iron are among the most limited micronutrients in human diets (Kihara et al., 2020). Iron and vitamin A deficiencies affect 60% and 70% of the children in sub-Saharan Africa, respectively. In Kenya, a third of children lack vitamin A in their diets (Sawe et al., 2021). Vitamin A deficiency can lead to nutritional blindness, stunted growth, and increased morbidity and mortality rates (WHO, 2025). Iron deficiency is linked to impaired brain development and long-term cognitive performance issues (Theola & Andriastuti, 2025). The 2011 Kenya Micronutrient Survey reported that 83.3% of children under five suffer from zinc deficiency (Ministry of Health, 2011). This contributes to higher risks of diarrhea, pneumonia, malaria, and stunting. In pregnant women, zinc deficiency can result in poor pregnancy outcomes and preterm deliveries (Black, 2014; Kiio et al., 2022). On the other hand, calcium deficiency, can lead to several bone disorders such as rickets in children and osteomalacia in adults (Ciosek et al., 2021). Thus, vegetable consumption can provide an important source of minerals, essential vitamins and proteins (Fageria, 2009; Nyonje et al., 2014). Kenya's Ministry of Public Health and Sanitation recommends taking 3-5 servings of vegetables a day (Theuri et al. 2023). This is hardly achieved because of vegetable scarcity and prices (Stadlmayr et al., 2023). Although the interest in ALVs has increased over time during the past decade (Eric et al., 2024), vegetable production in ASALs has failed to keep pace (Karuma et al., 2015).

In Kitui County, only 1% of the population consumes 400 grams of vegetables as recommended by WHO (Kipkorir et al., 2024). This lag has been attributed to a decline in soil fertility, reduced nutrient absorption and enhanced temperatures' effect on soil moisture, a key ingredient in nutrient absorption (Pareek, 2017). The vegetable producers in Kitui are largely smallholder farmers with limited capital who farm on degraded soils (Owidhi, 2020; Kitavi et al., 2024). In order to maintain soil fertility and subsequently enhance vegetable production, cheaper options like application of organic manures, are indispensable. These manures replace nutrients by supplying the necessary macro and micronutrients during mineralization leading to improved soil's physical and biological properties (Manono et al., 2016). Both manure and artificial fertilizers are widely used as soils' nutrient sources (Abebe et al., 2022). Studies by Maseko et al. (2017) and Mani (2011) have shown that nitrogen and manure application improved production of ALVs. However, the use of manure is indispensable as it is cheaper in replenishing lost nutrients. Thus, this study aims to research for a cheaper alternative soil amendment for the poor vegetable growers in Kitui's degraded soils.

Disparities in nutritional value of vegetables and fruits grown with nitrogen fertilization have been reported (Onyango et al., 2011; Weston & Barth, 1997) with contrasting results. For example, nitrogen fertilizer application decreased vitamin C levels in cauliflower (Lisiewska & Kmiecik, 1996) but increased the beta-carotene content in plant-based foods (Boskovic-Rakocevic et al. 2012; Mozafar, 2008). Hence, the objective of this study was to analyze the effect of different fertilization treatments on the growth and the nutrient levels of ALVs grown in semi-arid Kitui County.

Materials and methods

Study area

The experiment was undertaken at the Teaching and Research Farm of the South Eastern Kenya University (SEKU), situated in Kitui County, Kenya ***(Figure 1)***. South Eastern Kenya University (SEKU) lies within latitudes 0°10'–3°0' S and longitudes 37°50'–39°0' E. The area is classified within the Lower Midland Four (AEZ LM4) agro-ecological zone (Oremo, 2013). The ALVs were planted in October 2022 before the onset of the short rain season which usually begins from October to December. The annual rainfall was 406.9 mm ***(Figure 2)***. The soils in the county have a high moisture-storing capacity and poor nutrient availability; they are well-drained, moderately deep to very deep, dark reddish brown to dark yellowish brown, friable to hard, and sandy clay to clay. Loamy sand to sandy loam makes up the topsoil in most areas (Kitavi et al., 2024).

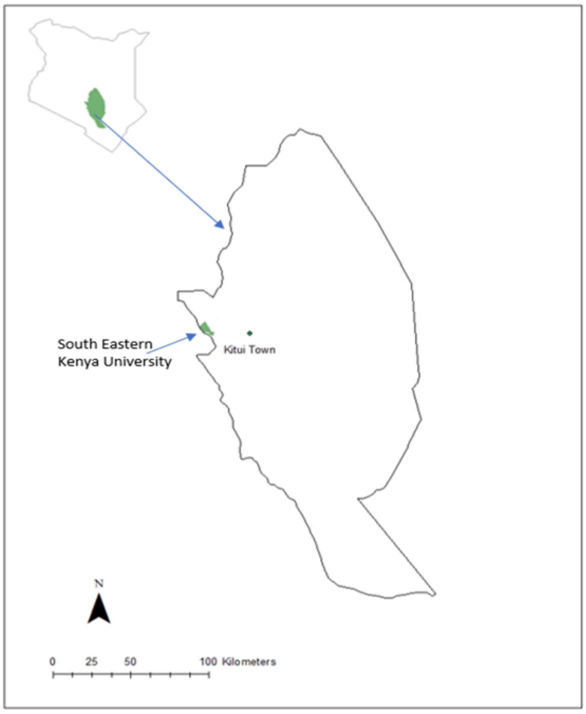

Figure 1. Location of South Eastern Kenya University (SEKU) in Kitui County, Kenya.

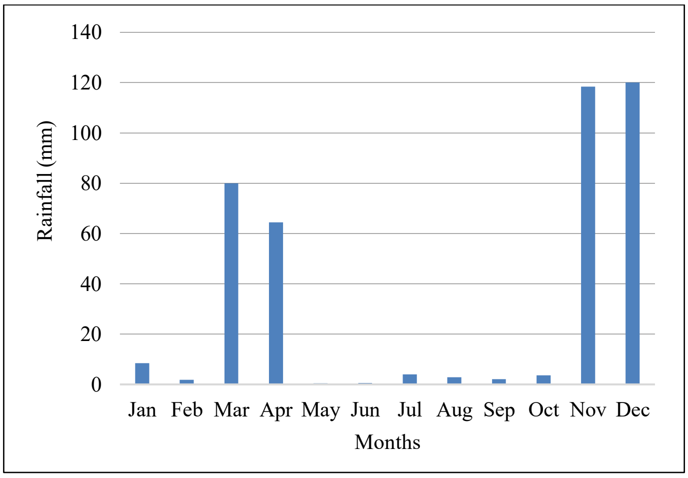

Figure 2. Rainfall in mm during the ALVs growing period in 2022 at South Eastern Kenya University, Kenya.

Experimental design

We used randomized complete block design comprising of 48 experimental plots (3 plots of four treatments with four vegetables). Each plot measured 2 m × 2 m, with plants spaced 0.15 m between rows and 0.1 m within rows as described by Onyango et al. (2011). Four African Leafy Vegetables (ALVs) namely garden huckleberry (*Solanum nigrum*), spider plant (*Cleome gynandra*), Amaranthaceae (*Amaranthus hybridus*), and cowpeas (*Vigna unguiculata*) were planted. Certified ALVs seeds were obtained from the Kenya Agricultural and Livestock Research Organization (KALRO), Katumani Research Station in Machakos County. Varieties suited to the Semi-Arid conditions of Kitui County were selected. Four treatments were applied (i) fertilizer only (F), (ii) manure only (M), (iii) manure and fertilizer combined (M + F) and (iv) control (C). Manual application of farmyard manure was carried out at the rate of 30 t/ha in all plots. Calcium ammonium nitrate (CAN) fertilizer was applied at 275 kg/ha. For the combined treatment, 7.5 t/ha of farmyard manure was applied with 150 kg N/ha of CAN (Ng'etich et al., 2014). Drip irrigation was applied based on soil moisture requirements according to procedures described by Bittelli (2011). Weeding was manually done before canopy closure.

Plant growth assessment

Plant growth was assessed by weekly leaf counts. The weekly leaf counts were then averaged at the end of the month. In each replicate, six plants were sampled, and the mean number of leaves was calculated. Ten fresh leaf samples were collected per treatment and transported in cool boxes to the International Livestock Research Institute (ILRI) laboratory located in Nairobi, Kenya for nutrient analysis. Samples were stored at -80 °C. Because exposure to light degrades vitamins (Failloux et al., 2004), the stored samples were freeze dried for 7 days in the dark. They were then ground into a fine powder for chemical analysis.

Analysis of iron, calcium and zinc

Analysis was performed using Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) for iron, calcium and zinc. The samples were analyzed according to AOAC method 985.01 (Bukomarhe et al., 2023). Half a gram (0.5 g) of finely powdered vegetable samples was weighed in duplicate into 50 mL microwave digestion tubes, after which 8.0 mL of concentrated nitric acid and 2.0 mL of 30% hydrogen peroxide were added. Digestion was carried out using an Anton Paar Multiwave GO Plus microwave digestor (Graz, Austria). Samples were heated to 100 °C for 10 minutes, then ramped to 180 °C at 10 °C per minute and held for an additional 10 minutes. The digested samples were transferred into 25 mL volumetric flasks and brought up to the mark with 2% of HNO_3. The resulting extracts were analyzed using the Perkin Elmer Avio 550 Max ICP-OES instrument. For determination of Fe, Zn, and Ca, ICP-OES mixed standard (Cat. No. 43843; Sigma-Aldrich, Buchs, Switzerland) was employed. Serial dilutions of the standard were prepared with 2% HNO_3 to obtain calibration solutions at concentrations of 80, 320, 800, and 1600 µg/L. Quantification was performed using the external standard calibration method, with calibration carried out through Perkin Elmer Syngistix™ software version 5.1. The measured data were subsequently used to calculate the concentration of each element in mg/100 g by applying the appropriate formula in Microsoft® Excel® (2018).

$$X = (C - B) \times V \times 100 / W \times 1000$$

Where:
X denotes the amount of individual elements (Fe, Zn, Ca) expressed in mg/100 g of the sample.
C is the concentration of the individual elements of iron, zinc, and calcium, µg/L after external calibration.
B denotes the concentration of the reagent blanks, µg/l used in the extraction.
V is the volume digest peak topped up to 25 mL.
100 is the conversion factor to mg/100 g dilution factor after extraction with 1% HNO_3.
W is the weight of the sample used; 1000 is the conversion factor from µg/l to mg/l.

The results were adjusted for moisture content and expressed on a dry weight (dw) basis. For quality control (QC), after every batch of 30 samples, a QC sample (T18106QC, infant formula) obtained from Fera Science Ltd., Sand Hutton, York, YO41 1LZ, UK, was processed through the entire analytical procedure in duplicate.

Determination of retinol in the ALVs

The analysis was performed with high performance liquid chromatography with diode array detection (HPLC-DAD). The procedure recommended by the Center for Disease Control and Prevention [CDC] (2008) was followed as outlined below.
1. The sample preparation and analysis were performed in a laboratory setup fitted with yellow light to prevent white light exposure and maintain sample integrity.
2. Triplicate 0.5 g powdered samples were placed in 25 mL borosilicate tubes. Each sample was mixed with 6 mL of ethanol containing 0.1% BHT and homogenized for 1 minute, after which 120 µL of 80% (w/v) potassium hydroxide was added. After vortexing, the samples were incubated at 85 °C for 5 minutes and then rapidly cooled in an ice bath. Subsequently, 4 mL of deionized water and 5 mL of hexane were added, mixed by vortexing, and centrifuged at 3000 rpm for 5 minutes. The upper hexane layer was collected, and the extraction was repeated three additional times using 4 × 3 × 3 mL of hexane. The pooled hexane extract underwent another centrifugation with 5 ml deionized water before the final hexane layer was collected and evaporated to dryness under nitrogen stream.

The dried residue was reconstituted in 1 ml methanol: tetrahydrofuran (85:15 v/v), vortexed, sonicated for 30 seconds and 0.8 ml was transferred into amber vials for analysis. Individual standards (retinol) were diluted in ethanol, with concentrations verified using a UV-VIS spectrometer via Beer-Lambert's law. Following the CDC Laboratory Manual (NHANES 2005–2006), a multi-component standard mix was prepared by serial dilution to develop an external calibration curve for quantification.

Statistical analysis

The data collected were subjected to analysis of variance (ANOVA). This method used the Agricolae package (version 1.3-5) implemented in R software version 4.2.0. Fisher's protected least significant difference (LSD) test at a significance level of $p \leq 0.05$ was used to compare the treatment means. Tukey's Honest Significant Difference (HSD) post-hoc test was applied to evaluate differences among treatments on the nutrient composition of the ALVs.

Results

Effects of treatment on the number of leaves of the ALVs

The findings of the study showed that the treatments used had a significant effect on the number of leaves as presented in ***Table 1***. The highest leaf count was observed in plants treated with a combination of manure and fertilizer, whereas the control had the lowest. Fertilizer only had higher leaf growth compared to manure only. *Solanum nigrum* had the highest increase of 97.7% in manure only treatment compared with the control while *Cleome gynandra*, increased the least with 34.8%. *Amaranthus hybridus* recorded the highest number of leaves (94.3) under the fertilizer-only treatment. In contrast, *Solanum nigrum* recorded the highest number of leaves (118.5) under the manure and fertilizer (M+F) treatment as compared with the control.

Table 1. Effect of the different fertilizer treatments on the number of ALVs leaves.

Varieties	Treatments			
	M	**F**	**M+F**	**Control**
V. unguiculata	5.16Cc	6.82Bb	8.96Aa	3.46Db
S. nigrum	8.56Aa	6.66Bb	9.46Aa	4.33Ca
A. hybridus	5.66Cc	7.83Ba	8.57Aa	4.03Da
C. gynandra	6.90Ab	8.60Aa	8.66Aa	5.12Da
P value	0.04			
F value	2.29			
LSD	1.64			

Key: Treatments: M = Manure; F = Fertilizer; M+F = Manure +Fertilizer; C = Control.
Means in each row followed by capital letters (A–D) and means in each column followed by lowercase letters (a–g) indicate significant differences at $p < 0.05$.

Effect treatment on nutritive performance on African leafy vegetables (ALVs)

The ALVs proximate analysis under different fertilizer treatments revealed variations in their nutrient composition. For *Vigna unguiculata*, retinol (vitamin A precursor), content was highest under fertilizer treatment (1.07 mg/kg). Iron levels were highest under manure (83.00 mg/kg) and lowest under fertilizer (69.23 mg/kg). Calcium content peaked under manure + fertilizer (41811.5 mg/kg), suggesting improved mineral uptake. The nutrient profiles of the four ALVs under each treatment are shown in ***Table 2.***

In *Solanum nigrum*, retinol levels were relatively low across treatments, peaking in control (0.52 mg/kg). Iron content increased with fertilizer (100.86 mg/kg) and manure + fertilizer (108.73 mg/kg) treatments. Calcium content peaked under manure + fertilizer (35848.7 mg/kg). Zinc levels were slightly higher in the manure + fertilizer treatment (24.8 mg/kg) compared to control (22.9 mg/kg).

For *Amaranthus hybridus*, the highest retinol, concentration was recorded under fertilizer (0.93 mg/kg). Iron content was relatively stable across treatments. Calcium was highest in the manure + fertilizer treatment (34035.1 mg/kg). Zinc content was notably highest in manure treatment (52.6 mg/kg) compared to the lowest levels in fertilizer (32.3 mg/kg).

In *Cleome gynandra*, retinol, content was highest in the fertilizer treatment (0.63 mg/kg). Iron levels varied widely, with fertilizer treatment yielding the highest concentration (89.94 mg/kg), and manure + fertilizer the lowest (57.33 mg/kg). Calcium levels were highest in the manure treatment (25056.7 mg/kg), while zinc content peaked under manure + fertilizer (50.2 mg/kg). Overall, manure and manure + fertilizer treatments tended to enhance mineral content, particularly iron, calcium, and zinc, while fertilizer treatment improved retinol content. This suggests that an integrated approach to treatments could optimize the nutritive value of ALVs.

A one-way ANOVA analysis revealed that retinol was the only nutrient significantly affected by treatments ($p = 0.0058$). Other nutrients, i.e. iron, calcium, and zinc did not show significant variations. The Tukey HSD post-hoc test further confirmed that the use of both manure and fertilizer (M+F) resulted in a significant increase in retinol content. This was relative to the control group ($p = 0.0319$) and the fertilizer-only treatment ($p = 0.0150$). The ANOVA analysis results supports these findings. This indicates that the combination of manure and fertilizer had a significant effect on the retinol levels ($p = 0.0063$). Therefore, neither the crop type nor the interaction between crop type and treatment had a significant effect on the nutrients *(**Table 3**)*. This indicates that the treatment effects on retinol are independent of crop type.

Discussion

Crops differ in their response to the availability of the different plant nutrients in the soil depending on the root system distribution and density (Van Averbeke et al., 2012). This study confirmed this observation since plant leaf numbers showed significant differences according to fertilization treatments. The propensity of organic manures to positively influence the availability of essential plant nutrients was demonstrated. These concur with findings by Ullah et al. (2008). In the Bangladesh study, the application of organic manure and inorganic fertilizer affected both brinjal yield and soil properties (Ullah et al. 2008). The findings also concur with Motladi (2024)'s where the combined application of manure and chemical fertilizer had a positive effect on crop performance and significantly improved leaf growth parameters. Unlike our study, the effect between the two (manure and fertilizer) was not statistically different in Motladi (2024)'s study. However, our findings agree with those of Gonye et al. (2017); Kipkosgei et al. (2003) and Adjogboto et al. (2023). These studies reported an increase in plant growth when a combination of manure and fertilizer was used. This could be attributed to enhanced nutrient availability (Roe & Cornforth, 2000).

The observation where fertilizer only had higher leaf growth compared to manure only would be attributed to slow release of nutrients from organic manures (Fonge et al. 2016; Manono et al. 2019). Hence, over the long term, manure treatment would have higher leaf growth compared to fertilizer. Our study, however, contrasted with that of Mavengahama et al. (2006) where the application of fertilizer had no significant differences from those treated with manure. A study by Onyango et al. (2012) also supports these findings, showing that fertilizer application resulted in a higher leaf count compared to manure and the control.

Table 2. Effect of different fertilizer treatments on nutritive performance of ALVs (mg/kg ±SD).

Vegetable type	Treatment	Retinol (mg/kg)	Iron (mg/kg)	Calcium(mg/kg)	Zinc (mg/kg)
V. unguiculata	M	0.70±0.21	83.00±18.29	40188±1326.29	28.4±1.41
	F	1.07±0.50	69.23±26.23	35041.8±169.56	17.1±2.5
	M+F	0.80±0.15	78.16±24.86	41811.5±179.18	26.0±20.6
	C	0.77±0.31	75.22±19.60	39472.8±117.19	20.8±11.1
S. nigrum	M	0.36±0.18	93.65±27.03	31723.5±125.65	21.3±6.7
	F	0.41±0.02	100.86±37.95	34024.6±131.71	20.5±10.2
	M+F	0.34±0.22	108.73±23.25	35848.7±1101.23	24.8±6.5
	C	0.52±0.36	94.57±26.76	30809.2±104.19	22.9±7.4
A. hybridus	M	0.62±0.21	61.80±29.96	31588.3±106.11	52.6±17.1
	F	0.93±0.68	66.20±11.58	32779.2±158.53	32.3±9.9
	M+F	0.52±0.14	64.58±45.11	34035.1±165.24	46.6±22.8
	C	0.67±0.84	62.89±22.84	32155.3±150.13	47.6±16.6
C. gynandra	M	0.42±0.14	82.1±53.61	25056.7±114.07	44.3±11.6
	F	0.63±0.24	89.94±19.91	22333.4±133.54	41.5±5.8
	M+F	0.39±0.09	57.33±35.41	22418.5±166.49	50.2±8.5
	C	0.49±0.78	76.65±40.34	24713.7±175.85	42.8±8.5

Key: Treatments: M = Manure; F = fertilizer; M+F = Manure and fertilizer; C = Control

Table 3. Tukey HSD post-hoc test for retinol content.

Group 1	Group 2	Mean Difference	P-Value	Lower Bound	Upper Bound
Control	Fertilizer	-0.0637	0.900	-0.3617	0.2343
Control	Manure + Fertilizer	0.3798	0.0319	0.0248	0.7348
Control	Manure	0.2336	0.1715	-0.0644	0.5316
Fertilizer	Manure + Fertilizer	0.4435	0.0150	0.0676	0.8194
Fertilizer	Manure	0.2973	0.0808	-0.0254	0.6200
Manure + Fertilizer	Manure	-0.1462	0.7056	-0.5221	0.2297

Nitrogen availability is known to have a considerable effect on plant yields. For example, nitrogen enhances the yield of Amaranth (Makus, 1986; Onyango et al., 2012). On the other hand, the addition of manure had no effect on cow pea (Turan & Sevimli, 2005; Adediran et al. 2005). Our study could confirm the assertion that manure activates living organisms to release phyto-hormones that stimulate plant growth and absorption of nutrients (Arisha et al., 2003). The low leaf growth in the control could be because of lack of soil fertility improvement products that were used in the other treated plots. Similar observations have been reported by Muthama et al. (2024).

Across all vegetables, the combination of manure and fertilizer produced the highest mean nutrient levels. These findings suggest that a balanced approach to treatment, incorporating both organic and inorganic elements may be most effective for nutrient optimization. The mean retinol content is higher when both manure and fertilizer were used in comparison to the control group. These ALVs findings show that combining manure and fertilizer (M+F) is notably effective for enhancing retinol levels. A similar observation was also demonstrated by Gonye et al. (2017) and Kipkosgei et al. (2003). In their study, vitamin A content was associated with a combination of manure and fertilizer treatment.

Application of nitrogen has been reported to improve beta carotene content in other crops such as *Solanum nigrum* (Murage, 1990) and spinach (Fritz & Habben, 1973). This could be attributed to nitrogen facilitating the formation of chloroplasts that are rich in beta -carotene (Kipkosgei et al., 2003). This also points to the fact that a combination of treatments influences nitrogen availability and improves the nutritive value of vegetables (Gonye et al., 2017). Interestingly, no significant differences were found in our study. This implies that neither fertilizer nor manure alone significantly impacts retinol levels.

The calcium levels were highest in the manure treatment compared to other treatments. This contrasts with Gonye et al. (2017)'s study where the treatments that were used had no significant effect on the calcium content of *C. gynandra* (spider plant). According to Gonye et al. (2017), *Cleome gynandra* has a C4 pathway that is associated with high rates of photosynthesis and efficient use of water and fertilization treatments. A study in India showed that calcium and zinc content in *Amaranthus tricolor* L. grown under fertilizer was significantly lower than the one planted in manure (Aparna, 2011). This was attributed to organic manure's improvement of the soil components such as moisture retention, water absorption, and soil structure. Interestingly, the mean iron in manure grown *Amaranthus tricolor* L. was significantly lower compared to fertilizer grown *Amaranthus tricolor* L. in the same study. According to Hutchinson (2011), fertilizer application did not significantly alter calcium levels in *Solanum villosum*, *Amaranthus caudatus*, *Solanum aethiopicum*, or *Solanum macrocarpon*. Zinc concentrations were not significantly influenced by the use of fertilizers on *Solanum villosum*, *Solanum nigrum* and *Amaranthus caudatus*. Similar results have also been reported for iron (Hutchinson, 2011). This might be because of the immobility of calcium in the phloem and therefore may have accumulated in the young tissues. This means that the availability of some minerals in the leafy vegetables is dependent on mineral availability from the soil.

Given the lack of significant variation in other nutrients apart from retinol, factors such as soil quality, environmental conditions, or crop genetics might play a more substantial role. This is because, the plant's nutritional value can vary with the soil fertility, environment, plant type, plant age and the production techniques used (Mishra et al. 2011). The findings highlight the importance of using a combined manure and fertilizer approach to optimize retinol content in ALVs. This could have substantial implications for agricultural practices aimed at enhancing the nutritional value of crops.

Conclusions

ALVs production and consumption can be used to alleviate food insecurity and micronutrient deficiencies. Treatments significantly led to an increase in leaf numbers across all varieties. Leaf mineral contents (Fe, Ca, and Zn) were significantly influenced by the application of manure and fertilizers. This observation could be attributed to the ability of manure to supply nutrients that improve the soil's physical and the chemical properties and its ability to release nutrients gradually to the soil. Thus, the study demonstrates that a combined approach of using both manure and fertilizer is more effective in increasing retinol content.

Since the treatment did not significantly affect the other nutrients, there is need to research on the influence of other factors such as soil quality, climate conditions and genetic factors. Further, there is need for further studies to determine the effects of anti-nutrients such as oxalates and phenols on the bioavailability of these nutrients on ALVs.

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