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ASSESSMENT OF CHARGED BIOCHAR AND SELECTED ORGANIC FERTILISERS EFFECTS ON SOIL PROPERTIES, NUTRITIONAL QUALITY, AND PROFITABILITY OF LETTUCE

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ABSTRACT

Excessive use of synthetic fertilisers poses soil degradation challenges that partly constrain sustainable vegetable production in many tropical regions. This research aimed at assessing the agronomic and economic potential of organic fertilisers in enhancing lettuce (*Lactuca sativa* L.) soil properties, nutritional quality, and profitability. Specifically, it determined effects of selected organic fertilisers on soil properties, vitamin C, mineral nutrients (N, P, K, Ca, Mg), and net economic benefit (NEB) of lettuce. It was done in a randomized complete block design with six treatments (negative control-soil, positive control-NPK+Urea, charged biochar, compost, poultry and farmyard manures) replicated three times in two seasons from October 2024 to May 2025 on-farm at Egerton University, Kenya. Iceberg lettuce variety used was grown in a nursery bed for five weeks followed by transplanting to permanent experimental plots, measuring 2m x 1.5m and accommodating 30 lettuce plants at 30cm x 30cm spacing. Data was collected pre- and post-production on soil and organic fertilisers, as well as in the 9th week on lettuce fresh weight, nutritional quality components, and net economic benefit. Data was subjected to analysis of variance using JMP Pro 17th edition program. Numerically, application of organic fertilisers resulted in decreased N, P, pH, OC, OM, but increased K, Ca, Mg, CEC, and C:N in soil after lettuce growth. Nonetheless, all treatments had a pH of 6.1 - 6.5, which was optimal for lettuce growth and development. In seasons 1 and 2, lettuce leaf tissue analysis showed significant (P= 0.001; P= 0.048) differences in vitamin C, ranging from 2.0 – 3.2 and 1.0 – 1.4 meg/100 mg. However, there were no significant (P> 0.05) differences in nutritional minerals N, P, K, Mg and Ca. The NEB varied significantly (P= 0.001; 0.011), with poultry manure giving the highest NEB of 543 – 833/=, while biochar (217/=) and compost (224/=) giving the lowest. This study revealed

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that organic fertilisers influence soil properties, lettuce quality and profitability differently. The organic fertilisers significantly enhanced vitamin C and NEB more than no fertilisers. Adoption of poultry manure would serve as a profitable alternative to synthetic fertilisers, while optimizing quality and soil properties. It recommends further research on long-term effects of biochar on soil properties, lettuce quality and profitability.

Keywords: Cost-benefit analysis, Gross margin analysis, Manure, Mineral nutrients, Net economic benefit, Nutrient source, Vitamins

1. INTRODUCTION

Lettuce (*Lactuca sativa* L.) is a salad vegetable crop with high nutritional and economic value. It is usually consumed cooked or raw 'as a salad' without any restriction to daily intake (Das and Bhattacharjee, 2020). In some Sub-Saharan African countries, it is an important component of the human diet with a significant amount of vitamins, minerals and proteins (Das and Bhattacharjee, 2020). In addition, lettuce farming is among the most prevalent agricultural activities, serving as an important source of employment and livelihood for rural people (Abdulai *et al*., 2017; Quansah *et al*., 2020). Successful growth and yield of lettuce heavily depends on soil fertility. Therefore, poor soil fertility and imbalanced pH levels negatively affect lettuce production.

Soil nutrient depletion on smallholder farms causes a decline in food production in Africa (Sanchez *et al*., 1996). Liu *et al*., (2010) noted that the use of synthetic fertilisers has played a crucial role in crop productivity since the advent of the Green Revolution. Contrastingly, Breugem *et al*. (2024) observed that the excessive use of synthetic fertilisers accelerates soil acidification and affects soil micro-organisms, biochemical processes, the environment, and crop production. Similarly, Hernandez *et al*. (2010) stated that excessive use of synthetic fertilisers in agricultural land is an issue of concern, which results in decrease in soil fertility, as well as crop pollutants such as nitrate accumulation in groundwater and plant tissues. Mia *et al.* (2007) observed crop yield decline for many years due to nutrient and organic matter depletion, as well as reduction in soil aggregation.

Some practices that have been proven to increase soil health and fertility include manure application, cover cropping, and zero-tillage (Ding *et al*., 2016). Soil amendments such as rice husk biochar (RHB), poultry manure, compost, and farmyard manure are potential sustainable materials for increasing and maintaining soil health and crop yields (Trupiano *et al*., 2017). This has led to growing interest in use of RHB and other organic fertilisers as a sustainable strategies to improve crop growth, yield, nutrition, as well as soil health. Biochar is an innovative method for enhancing soil health and is gaining popularity as a sustainable alternative to synthetic fertilisers (Crombie *et al*., 2015). The use of RHB in vegetable production has positive effects on yield (Yan *et al*., 2021; Zheng *et al*., 2011). Rombel *et al*. (2022) reported that the use of RHB

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helps to retain nutrients in the soil, making them available for plant growth and development, and paving the way for the reduction of synthetic fertiliser use.

Apart from biochar, there are other organic fertilisers such as poultry manure, compost and farmyard manure. Khan *et al*. (2023) and Wanikar *et al*. (2024) stated that poultry manure improves soil degradation, organic matter content, as well as essential nutrients. Compost helps to regenerate soil nutrients and maximizes crop production (Zhang *et al*., 2020b). The positive utilization of compost materials in vegetable production leads to the reduction of synthetic fertiliser application to the soil, thus reducing the risks of soil degradation and nutrient leaching, while maintaining soil quality (García-López *et al.,* 2023). Farmyard manure (FYM) is formed from different animal wastes such as dung and urine alongside litter-beddings and leftover materials from fodder fed to animals. Masood *et al*. (2014) reported that FYM improves soil physical and chemical properties. Farmyard manure is not only for improvement of soil nutrient content, cation exchange capacity, or biological aspects of the soil (Zhang *et al*., 2020b), but it is also meant to increase soil-available water (Blanco-Canqui *et al*., 2015).

Production of lettuce is increasing and becoming a profitable venture in the vegetable industry in Kenya (KALRO, 2021a; SNV, 2019). However, lettuce production faces numerous challenges that reduce the NEB among smallholder farmers (Fatty *et al*., 2021; FAO, 2020). Profitability is largely constrained by the high cost of essential inputs such as seeds, fertilisers, pesticides, irrigation, hired labour, and transportation (Wainaina *et al*., 2016; Sheahan and Barret, 2017; Muthini *et al*., 2020; Kassie *et al*., 2025). Organic fertilisers originate from natural materials, whereas synthetic fertilisers are mined or processed in industries. Thus, they tend to be cheaper, as illustrated by costs ranging from 200 to 500 Ksh, compared to synthetic fertilisers, whose cost ranges from 4,000 to 6,000 Ksh per 50 kg bag (AFA, 2023; KALRO, 2021b). Smallholders do not make their own organic fertilisers, but often rely on external sources such as agro-dealers, farmer cooperatives, and commercial waste recyclers to supply them (Wainaina *et al*., 2016; Kassie *et al*., 2025). Use of synthetic fertilisers is more expensive than use of organic fertilisers in crop production due to the more time and skilled labour required when applying amendments to soil before planting crops (AFA, 2023; KALRO, 2021a). In Kenya for instance, labour costs for skilled and unskilled workers are significantly different, ranging from 800 to 1200 KSh and 300 to 500 KSh, respectively (Onyango *et al.,* 2023).

Lettuce production depends on optimum utilization of fertiliser. However, lettuce production farms experience poor soil nutrient management, which hinders meaningful production (Gallo *et al.,* 2022). Therefore, this study compared effects of charged biochar, compost, poultry and farmyard manure in improving lettuce production soil. The findings should provide valuable insights on sustainable agricultural practices that can enhance lettuce quality and profitability. They should demonstrate that eco-friendly farming techniques promote soil properties and long-term

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sustainable agriculture. The amendments should address the porous nature of the soil that persists within lettuce production areas (Breugem *et al.,* 2024; Liu *et al.,* 2010). The results should help stakeholders to make informed decisions and maintain the most sustainable and effective materials by considering environmental, nutritional and economic impacts. Subsequently, the general objective of this study was to contribute to environmental conservation, nutritional security, and income generation through the use of emerging soil amendment techniques in lettuce production. The specific objectives were to determine the effects of charged biochar and selected organic fertilisers on lettuce soil properties, nutritional quality, and net economic benefits.

2.0 MATERIALS AND METHODS

2.1. Experimental Site

The research was conducted in Field-3 at Egerton University, Njoro, Kenya, which lies at latitude 0’23’S, longitude 35’35’E, and 2238 m above sea level (Jaetzold *et al*., 2012). The average minimum and maximum temperatures at the site range from 16 – 22ºC and 5 – 8ºC, respectively, while the total annual rainfall ranges from 1180 – 1400 mm (Jaetzold *et al*., 2012). Mollic Andosols predominantly occupy the experimental site, while the soil type is well-drained and friable, with moderate fertility, low level of phosphorus (0.14%), and an acidic pH, ranging from 5.0 to 6.0 (Jaetzold *et al*., 2012).

2.2. Experimental Design

The experiment was arranged in a randomized complete block design with six treatments and three replications. Each treatment occupied 1.5 m × 2 m (3 m^2) area. The spacing of lettuce was 30 cm × 30 cm, and between replications and beds was 1 m and 50 cm, respectively. The treatments assessed were: negative control (plain soil), positive control (farmer’s practice of 0.06 kg NPK plus 0.03 kg urea), 6 kg charged biochar, 6 kg poultry manure, 6 kg compost, and 6 kg farmyard manure, which were derived from 200 kg/ha NPK plus 100 kg/ha urea, 20 t/ha of either biochar, poultry manure, compost, or FYM (Agyarko *et al.,* 2014; Masood *et al.*, 2014; Blanco-Canqui *et al*., 2015; Ceesay *et al*. 2017; Zhang *et al*., 2020a). The organic fertilisers were incorporated into each plot before transplanting lettuce seedlings. The experiment was done in two seasons, with season 1 of low rainfall spanning from Oct. 2024-Jan. 2025, and season 2 of high rainfall spanning from Feb. to May 2025. The charged biochar, compost, farmyard manure, and poultry manure were sourced from Safi Organic Limited, Griincom Organic Limited, Egerton University Tatton Farm, and Peter Kirui Poultry Farm (0º21’27.7” S 35º57’49.6” E) at Njoro, Kenya, respectively.

2.3. Lettuce Establishment and Maintenance

The iceberg lettuce variety used was purchased from Safari Seeds Limited, Kenya. It is adaptable to different climatic conditions and has a low bolting ability and crispier texture (Gumisiriza,

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2023). A nursery bed was prepared one week before sowing by tilling with a hoe to a fine tilth and levelling. Sunken beds were prepared and irrigated with a hose pipe on a daily basis. The day before planting, plots were harrowed to loosen the soil particles and then flattened to avoid burying seeds too deeply into the soil, which could cause poor germination. Furrow lines were made at 10 cm apart, seeds dropped in gently and covered lightly with soil. After sowing, irrigation and shade were applied immediately. After germination in 5 – 7 days post-sowing, seed beds were weeded as necessary to avoid competition for growth resources. Subsequently, permanent beds were prepared for seedling transplanting at a different site.

2.4. Experimental Land Preparation

The experimental land was ploughed with a hoe and leveled to a fine tilth, after which permanent beds were demarcated using a tape measure and pegs at a spacing of 1.5 m by 2 m each. A total of 18 beds were prepared and materials added as per treatment. The experimental materials were incorporated into each assigned bed before transplanting seedlings. Lettuce seedlings were carefully uprooted and transplanted into each bed when five-weeks-old post-sowing. Irrigation was done immediately using a hose pipe and repeated daily in the morning and evening to maintain moist beds throughout the growing seasons. Weeding commenced two weeks after transplanting and continued on bi-weekly basis for nine weeks when the lettuce was harvested.

2.5. Data Collection and Analysis

Data values were collected on soil, organic fertilisers, lettuce yield and tissue samples. Seven soil samples were collected randomly using a zigzag method in the whole experimental field and analysed for nutrient and other properties present before demarcation of permanent beds. An auger was used to scoop soil from 0-20 cm depth. The collected samples were mixed and composite sample taken to the laboratory for air-drying at room temperature, followed by sieving through a 2-mm sieve to remove foreign materials. Samples were also collected from organic fertilisers before application to the treatment plots. The properties measured were: pH, organic carbon, cation exchange capacity (CEC), and mineral nutrients (nitrogen, phosphorus, potassium, calcium and magnesium). The electrometric and ammonium acetate procedures were used to measure pH and CEC, respectively (Gillman and Sumpter, 1986). Total nitrogen was measured using Kjeldahl method (Bremner *et al*., 1960). Standard methods and procedures were used to analyze phosphorous, potassium, calcium, and magnesium in the samples (Hinga *et al*., 1980; Okalebo *et al*., 2002). Organic carbon measurement used Walkley-Black method (Matus *et al*., 2009). After harvest, soil samples were collected from experimental plots for analysis of properties mentioned above.

Nutritional quality was based on vitamin C and selected mineral nutrients (N, P, K, Ca, and Mg) in lettuce leaf tissue. Three randomly selected lettuce plants per treatment were used. The second

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and fourth leaves were gently cut-off with a knife from sampled plants and used in determination of vitamin C and mineral nutrient contents. Determination of vitamin C used redox titration method (Reische *et al*., 2008). The mineral nutrient contents were determined using the previously mentioned procedures.

A simplified net economic benefit (NEB) analysis was performed and expressed in Kenyan shillings (Ksh). The NEB was represented by the difference between output (lettuce income) and input costs. The NEB was calculated using the data recorded on fresh weight of lettuce that was sold to generate income, and the costs of inputs (biochar, compost, farmyard manure, poultry manure, NPK, urea, labour) used in production. The costs of land, machinery, water and other inputs that were held constant were not included as they were beyond the scope of this study.

The fresh weight yield was determined by harvesting and weighing the total biomass of three lettuce plants per treatment, followed by calculating the average weight of lettuce (AFWTL). Fresh weight was recorded once on whole, mature lettuce plants aged 66 days post-transplanting. Fresh weight yield was expressed in g/plant. Total fresh weight of lettuce (TFWTL) heads per treatment was calculated by multiplying the average fresh weight of lettuce for each treatment by the 30 lettuce heads per treatment.

Thus, TFWTL (g/bed) = AFWTL x 30 lettuce heads Equation 1.

The total income of lettuce (IOL) per treatment was calculated as (total fresh weight of lettuce/average fresh weight of lettuce) x price of AFWTL. In this regard, the sale price of KSh 25 per head of lettuce (average fresh weight of lettuce) was obtained from Nakuru farmers' market in Kenya.

Thus, IOL = (TFWTL/AFWTL) x Ksh. 25 Equation 2.

The cost of seeds, NPK and urea were set by the Agrovet shop where they were purchased. The cost for organic fertilisers was set by the various sellers who provided the materials. The costs per treatment was as follows: lettuce seeds (Ksh 22.23), NPK and urea (Ksh 16.5), biochar (Ksh 360), compost (Ksh 240), poultry manure (Ksh 156), and farmyard manure (Ksh 90).

Thus, these costs were derived from bulk costs as: seeds 400/18 treatments (=22.23), NPK (200/kg)*0.06 kg (=12) + urea (150/kg)*0.03 kg (=4.5), biochar (3,000/50 kg)*6 kg (=360), compost (2,000/50 kg)*6 kg (=240), poultry manure (1,300/50 kg)* 6 kg (= 156), and farmyard manure (750/50 kg) * 6 kg (=90) Equations 3.

The cost of labour at KSh 500 per 8 hours per person was obtained from people searching for short-term labour within the research site. A fraction of this amount was paid when a person worked for fewer hours per day.

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Thus, total labour = land preparation (Ksh 300 per 4 hours) + incorporating amendments (KSh 250 per 4 hours) + transplanting (Ksh 250 per 4 hours) + weeding (Ksh 270 per 4 hours x 3 times) + harvesting (Ksh 250 per 4 hours) = Ksh 1,860/18 treatments, giving 103.3 Ksh/treatment

Equation 4.

Subsequently, the total cost of inputs (COI) for each treatment was arrived at by totaling the cost of individual inputs for each treatment as shown below.

Treatment (Source of nutrients)	COI per treatment	Costing values	Costing formula per 3 m^2	Equation
Farmyard manure	215.6	90+22.23+103.3	FYM+S+L	Equation 5
Negative control (Soil)	125.6	0+22.23+103.3	N+S+L	Equation 6
Biochar	485.6	360+22.23+103.3	B+S+L	Equation 7
Poultry manure	281.6	156+22.23+103.3	PM+S+L	Equation 8
Compost	365.6	240+22.23+103.3	C+S+L	Equation 9
Positive control (NPK + urea)	142.1	16.5+22.23+103.3	NPK&Urea+S+L	Equation 10

Where: FYM = Farmyard manure, S = Seeds, L = Labour, N = Nil, B = Biochar, PM = Poultry manure, C = Compost

Ultimately, the net economic benefit (NEB) was derived from the difference between the income of lettuce (IOL) and the cost of inputs (COI).

Thus, NEB = IOL – COI Equation 11.

The data for quality parameters and NEB was subjected to analysis of variance (ANOVA) using JMP Pro Version 17 statistical software. The Tukey's test at $\alpha = 0.05$ was used to separate means.

3. RESULTS AND DISCUSSION

3.1. Effects of Charged Biochar and Organic Fertilisers on Soil Properties

In trial 1, the laboratory analysis results showed a variation of nutrients and other properties such as pH and cation exchange capacity (CEC) pre- and post-lettuce production (Table 1). The pre-production soil sample had a slight neutral pH of 7.15, low total nitrogen (0.15%), phosphorus (67.4 ppm), and organic carbon (1.26%). The pre-production CEC was relatively low (4.29 meq/100g), thereby indicating poor soil fertility. The pre-production C: N ratio of 8.40 was within the moderate range. Poultry manure and farmyard manure showed significantly higher organic matter (27.03% and 12.83%), phosphorus (994.8 and 909.2 ppm), and nitrogen content (1.47% and 2.83%), respectively, pre-production. Poultry manure had the highest CEC (69.43 meq/100g) pre-production, suggesting that it had a potential to improve and maintain soil fertility (Table 1).

In trial 1 post-production, there was an increase in CEC compared to the pre-treatment level, with the highest CEC content observed in the biochar treated bed (24 meq/100g) (Table 1). Soil organic matter increased in all treated beds, with farmyard manure showing the highest value (4.24%). The nutrient levels, particularly phosphorus and potassium, were also enhanced (Table 1). The biochar treated soil had the highest phosphorus (169 ppm), followed by compost (134 ppm) and poultry manure (129 ppm). Notably, poultry manure and compost also increased the pH of the soil to near-neutral (Table1).

The laboratory analysis conducted for trial 2 showed a visual variation in nutrient content and physicochemical properties across different treatments after lettuce production (Table 1). The post-production soil assessments revealed major changes in soil properties in season 2, as in season 1. The highest pH was observed in the positive control bed and the negative control had the lowest. All organically amended beds, including biochar, compost, and poultry manure, maintained a moderately acidic pH of 61-6.2. The nitrogen content was higher for positive control (0.35%), while compost (0.26%) had the lowest content (Table 1).

Available phosphorus concentration varied across treatments, ranging from a low of 23.05 ppm in the negative control to a high of 52.46 ppm in poultry manure treated bed. The concentration of potassium was higher in poultry manure (45.49 ppm), followed by biochar (43.72 ppm), while the least was observed in compost (27.79 ppm) treated bed. Negative control had the highest magnesium concentration (74.16 ppm), while poultry manure had the lowest concentration (18.06 ppm). Calcium was high in positive control (569.77 ppm), while negative control (481.14 ppm) had the lowest concentration (Table 1). The soil organic carbon was higher in compost and poultry manure with the same concentration of 3.32%, while biochar had the least of 2.83%. Farmyard manure had the highest concentration of CEC (32.67 meq/100g), while positive control had the lowest CEC concentration (28.67 meq/100g). The soil organic matter was higher in poultry manure and compost with the same quantity (5.72%), while biochar (4.88%) had the lowest. Carbon to nitrogen ratio was higher in poultry manure (10.06), while the lowest observed was for biochar (8.58) treated beds (Table 1).

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Table 1: Physicochemical characterization of experimental materials

Material (Source of nutrients)	N (%)B	NA	ND	P (ppm)B	PA	PD	K (ppm)B	KA	KD	Mg (ppm)B	MgA	MgD	Ca (ppm)B	CaA	CaD
Season 1															
Biochar	0.70	0.19	-0.51	777	169	-608	0.26	42.1	41.8	0.04	169	169	0.01	799	799
Compost	0.65	0.17	-0.48	485	134	-351	0.04	45.1	45.1	0.04	197	197	0.01	802	802
Farmyard manure	2.83	0.17	-2.66	909	120	-789	0.30	2.0	1.73	0.05	193	193	0.01	168	168
-ve control (Soil)	0.15	0.19	0.04	67	91	23.2	0.26	45.0	44.7	0.05	190	190	0.01	803	803
+ve control (NPK+urea)		0.22	NA		102	NA		46.8	NA		200	NA		794	NA
Poultry manure	1.47	0.19	-1.28	995	129	-866	0.05	39.8	39.8	0.05	196	196	0.01	803	803
Season 2															
Biochar	0.70	0.33	-0.37	777	31	-746	0.26	43.7	43.5	0.04	48	48	0.01	551	551
Compost	0.65	0.26	-0.39	485	28	-456	0.04	27.8	27.8	0.04	72	75	0.01	556	556
Farmyard manure	2.83	0.31	-2.52	909	38	-871	0.30	36.7	36.4	0.05	35	35	0.01	548	548
-ve control (Soil)	0.13	0.30	0.17	67.6	23	-44.6	0.24	30.3	30.1	0.05	74	74	0.03	481	481
+ve control (NPK+urea)		0.35	NA		26	NA		35.6	NA		65	NA		570	NA
Poultry manure	1.47	0.33	-1.14	995	53	-942	0.05	45.5	45.4	0.05	18	18	0.01	561	561

Table 1: (Continued)

Material (Source of nutrients)	pHB	pHA	phD	OC (%)B	OCA	OCD	CEC (meq/100g B	CECA	CECD	OM (%)B	OMA	OMD	C: N B	C:NA	C:ND
Season 1															
Biochar	6.86	6.3	-0.58	3.27	2.29	-0.98	22.0	24.0	2.0	5.64	3.95	-1.69	4.67	12.1	7.38
Compost	8.27	6.3	-1.97	3.97	2.43	-1.54	13.1	19.3	6.2	6.84	4.15	-2.69	20.20	14.3	-5.93
Farmyard manure	7.54	6.5	-1.05	7.44	2.46	-4.98	31.7	20.0	-11.7	12.8	4.24	-8.59	2.63	14.1	11.50
-ve control (Soil)	7.15	6.3	-0.81	1.26	2.1	0.84	4.3	20.0	15.7	0.82	3.62	1.45	8.40	11.1	2.65
+ve control (NPK+urea)		6.1	NA		2.33	NA		20.0	NA		4.02	NA		10.6	NA
Poultry manure	8.98	6.4	-2.58	15.70	2.28	-13.4	69.4	22.7	-46.8	27.0	3.93	-23.1	10.70	12.0	1.33
Season 2															
Biochar	6.86	6.2	-0.66	3.27	2.83	-0.44	22.0	29.2	7.20	5.64	4.88	-0.76	4.67	8.58	3.91
Compost	8.27	6.2	-2.07	3.97	3.32	-0.65	13.1	30.7	17.53	6.84	5.72	-1.12	20.22	12.77	-7.45
Farmyard manure	7.54	6.1	-1.44	7.44	2.93	-4.51	31.7	32.7	0.96	2.17	5.05	2.88	2.63	9.45	6.82
-ve control (Soil)	7.13	6.0	-1.13	1.21	2.87	1.66	4.12	29.3	25.18	2.09	4.95	2.86	9.30	9.57	0.27
+ve control (NPK+urea)		6.3	NA		3.03	NA		28.7	NA		5.22	NA		8.66	NA
Poultry manure	8.98	6.2	-2.78	15.6	3.32	-12.28	69.4	30.7	-38.76	27.00	5.72	-21.28	10.67	10.06	-0.61

Key: B = Pre-production content, A = Post-production content, D = Difference (A-B), NA = Not applicable, -ve = Negative, +ve = Positive

The analysis of soil in both seasons showed nutrient-deficiency in the experimental site. This scenario was consistent with many tropical agricultural production fields, which exhibit low organic matter, poor nutrient levels, and limited nutrient holding capacity (Adekiya *et al*., 2019a). The application of organic fertilisers improved soil fertility, which was similar to the observations made by Brady and Weil (2016). Among the organic fertilisers, poultry manure emerged as the most nutrient-dense material, particularly in phosphorus and organic matter content that contributed substantially to soil fertility improvement. Its high organic matter as well as C: N ratio likely facilitated rapid mineralization and nutrient release, which agreed with past research findings conducted by Ayoola and Makinde (2007), who stated that poultry manure is effective in improving soil fertility in a short period of time. Adekiya *et al.* (2020) also noted that poultry manure's efficacy improved and enhanced soil health and promoted plant growth.

Farmyard manure also presented a balanced nutrient profile with exceptionally low C: N ratio of 2.63, which then supported fast decomposition and nutrient release. It had higher nitrogen and second in phosphorus content, compared to compost and biochar, making it a viable alternative to poultry manure for soil fertility improvement (Havlin *et al.*, 2014). Biochar was comparatively lower in nitrogen and organic matter; however, it has potential to improve soil phosphorus, CEC, as well as nutrient retention. Biochar has shown promising level of organic carbon as well as C: N ratio, which indicate that it may have long-term effects in improvement of soil properties and organic carbon sequestration (Lehmann and Joseph, 2015). Compost had the highest C: N ratio, which can support and improve soil nutrient retention (Zubair *et al*., 2021). Bernal *et al*., (2009) reported that compost contributes valuable humus formation and nutrient retention over time.

The initial phosphorus content was highest in experimental plots amended with poultry manure, consistent with its enrichment potential as reported by other research findings (Hue and Silva, 2000; Eghball *et al.*, 2004). However, final results from both production seasons showed that biochar treated plots had the highest phosphorus compared to poultry manure. This observation showed that biochar has the ability to absorb, retain enhance and reduce phosphorus leaching losses (Lehmann and Joseph, 2015; Glaser *et al*., 2015; Ye *et al*., 2020; Isitekhale and Osemwota, 2010). Biochar can also act as a slow-release phosphorus source, thereby maintaining plant available P in the rhizosphere over time (Xu *et al*., 2016).

The slight decrease of pH across all treatments is a common phenomenon in organically amended soils due to microbial decomposition, nitrification, and root exudate activity (Manna *et al*., 2005; Zaman *et al.,* 2010). Despite this occurrence, soil pH values remained within the acceptable range for optimal lettuce growth and development (5.5 – 6.5), ensuring that macro- and micro-nutrients remained bio-available (Fageria, 2012; Havlin *et al.*, 2014).

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The soil organic carbon and organic matter levels declined at post-production stage in all treatments. This trend might be due to mineralization processes and microbial activity that convert organic inputs into bio-available nutrients (Bationo *et al.*, 2007; Agegnehu *et al.,* 2016). In addition, organic carbon may be utilized by plant roots and soil microbes or lost as CO_2 through respiration (Liang *et al.*, 2006). The observed reductions also suggest that effective decomposition and nutrient cycling took place.

Apparent increases in exchangeable potassium, magnesium, and calcium soil contents were observed in all treatments. This increase might be as a result of cation exchange capacity of the organic fertilisers enhancing the soil nutrient holding capacity (Agyarko *et al.*, 2014). Organic fertilisers are known for their high buffering capacity that improves base saturation, particularly in highly weathered tropical soils (Palm *et al.*, 2001). However, total nitrogen content declined in all treatments post-production in this research. This reduction may be attributed to several factors, including volatilization, leaching losses whenever it rained, and high plant demand during the peak vegetative growth and development stages, all of which have been observed and reported in various other studies (Giller and Cadisch, 1997; Sakala *et al*., 2000; Murphy *et al*., 2007; Jaetzold *et al*., 2012).

3.2. Effect of Charged Biochar and Organic Fertilisers on Lettuce Quality

There were significant differences ($P = 0.001$; $P = 0.048$) among the vitamin C contents in both production seasons (Figure 1). In season 1, there was a significant variation between poultry manure (3.2 mg/100 g) and the rest of the treatments. Farmyard manure, biochar, compost, positive and negative controls had 2.0, 2.5, 2.0, 2.0, and 2.3 mg/100 g, respectively (Figure 1). In season 2, farmyard manure (1.4 mg/100 g) had the highest amount, while poultry manure (1.0 mg/100 g) had the lowest. However, no significant differences occurred among farmyard manure and other treatments, including: compost (1.2), biochar (1.2), positive (1.1) and negative control (1.1) mg/100 g. Similarly, there were no significant differences between poultry manure and biochar, compost, positive and negative control (Figure 1).

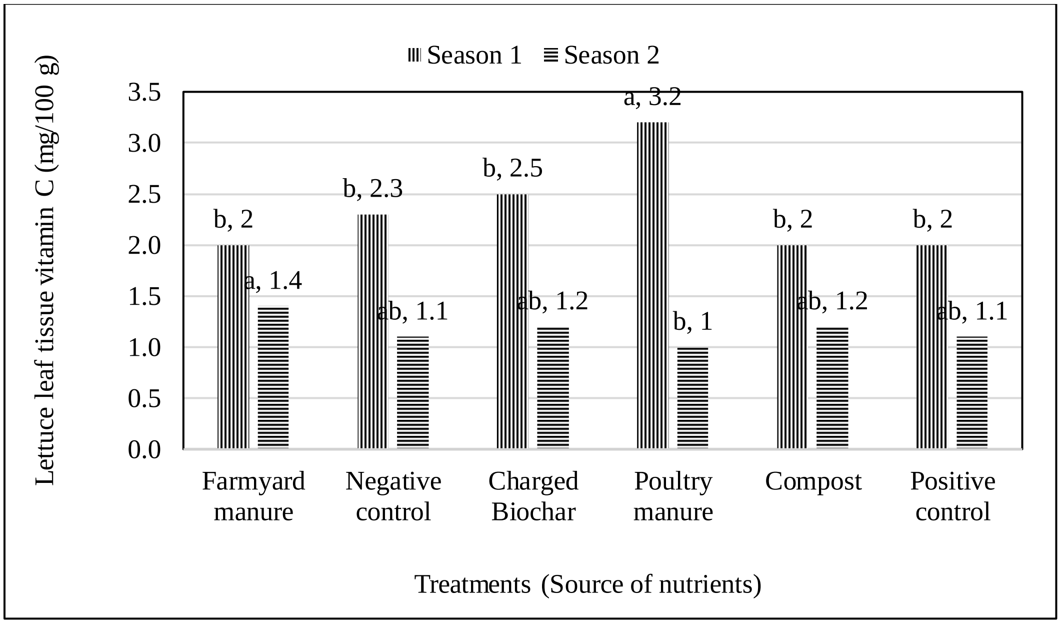

Figure 1: Graph of vitamin C (mg/100 g) versus source of nutrients (treatments)

Season 1 (P=0.0006) and season 2 (P=0.048). Means with the same letter(s) within a season are not significantly different at P = 0.05 by Tukey's t-test.

The results showed positive effects of organic fertilisers, particularly poultry manure, which enhanced nutritional quality of lettuce in terms of vitamin C accumulation. The statistically significant differences of vitamin C concentration in lettuce tissues was associated with nutrient concentration and rapid mineralization which improves the bioavailability of essential compounds involved in ascorbic acid biosynthesis (Chowdhury *et al.*, 2014). Vitamin C serves as a potent antioxidant in plant tissues and its concentration is often influenced by nutrient availability, especially nitrogen and potassium, which are associated with secondary metabolite synthesis (Lal and Singh, 2017; Smirnoff, 2018). The differences in vitamin C contents of season 1 and season 2 were attributed to changes in seasonal climatic conditions, including light, temperature and rainfall, similar to findings of Phillips *et al.,* (2018).

The ANOVA showed no statistically significant difference among mineral nutrient contents in lettuce leaf tissue in all treatments. However numerically, there were variations observed among the treatments in both production seasons (Table 2). In season 1, N content ranged from 2.92% in the negative control to 3.72% in the compost treated bed. Farmyard manure, biochar, and compost tended to enhance N accumulation compared to the control. The P levels were highest in the positive control (5.11%) and compost (4.99%), with other treatments showing similar values. Potassium showed visible variability, ranging from 3.35% (negative control) to 3.94% (farmyard manure). Magnesium and calcium showed similar contents. All the treatments had similar values

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for magnesium. Calcium showed little difference, with biochar having slightly higher (0.28%) content, while the least value was observed for farmyard manure and negative control that had the same values of 0.23% (Table 2).

In season 2, similar trend was observed as for the first production season across all treatments. The nitrogen concentrations ranged from 2.44% to 2.96% (positive control and farmyard manure, respectively). Phosphorus ranged from 0.30 to o.43%, while potassium concentrations had similar amount (3.28-3.86%) in all treatments. Biochar and farmyard manure had the highest value (3.86%), while negative control had the lowest value (3.28%). Farmyard manure and compost had the least value of magnesium, while poultry manure and negative control had little bit higher value of 0.23% compared to the other treatments. Farmyard manure had slight lower value of 0.21% compared to the rest of the treatments, although a slightly higher value was observed for biochar treated bed (Table 2).

Table 2: Mineral nutrients in lettuce leaf tissue

	Season 1					Season 2				
Treatment (Nutrient source)	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	N (%)	P (%)	K (%)	Mg (%)	Ca (%)
Farmyard manure	3.40	4.85	3.94	0.22	0.23	2.96	0.30	3.86	0.21	0.21
Negative control	2.92	4.34	3.35	0.21	0.23	2.48	0.42	3.28	0.23	0.25
Biochar	3.59	4.03	3.67	0.22	0.28	2.73	0.42	3.86	0.22	0.28
Poultry manure	3.20	4.54	3.70	0.22	0.25	2.69	0.38	3.58	0.23	0.23
Compost	3.72	4.99	3.63	0.22	0.26	2.71	0.43	3.47	0.21	0.25
Positive control	3.24	5.11	3.69	0.22	0.24	2.44	0.38	3.61	0.22	0.23
P-value	0.52	0.61	0.84	0.77	0.25	0.78	0.42	0.56	0.32	0.44
S E	0.36	0.59	0.29	0.008	0.02	0.46	0.43	0.23	0.008	0.02
CV (%)	20.8	17.8	20.3	12.3	5.7	25.7	18.2	10.9	6.2	15.7

*Means with the same letter(s) within a column are not significantly different at $P = 0.05$ by Tukey's test

Whereas mineral nutrient contents did not show any statistically significant variations among the treatments, numerical differences observed showed that compost and biochar had high values of nitrogen uptake. The present findings are consistent with several studies indicating that organic fertilisers can improve the nutritional quality and overall yield of vegetables through improved soil properties (Adekiya *et al.*, 2019b; Arancon *et al.*, 2004). Organic fertiliser effects are documented to be more on the improvement of soil structure, aeration, and overall health than on accumulation in plant tissues. Additionally, they may work through long-term rather than short-term impacts. These findings are in agreement with those in previous studies (Johnson and Lee, 2020; Smith *et al.*, 2018). The trend of visual differences indicated that the organic fertilisers slightly enhanced mineral nutrient accumulation in lettuce leaf tissues. Garg *et al.* (2017) and Muhammad *et al.* (2019) reported that organic fertilisers improve nutrient content and absorption by plants, which impacts crop yield and quality. In contrast, biochar has been used to improve soil physical

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properties, as well as health, which might have long-term beneficial effects even if its immediate effects are not noticeable (Zhang *et al.*, 2020a).

3.3. Effect of Charged Biochar and Selected Organic Fertilisers on Lettuce Net Economic Benefit

ANOVA revealed a highly statistically significant difference in net economic benefit among treatments in both production seasons, with season 1 $P = 0.001$ and season 2 $P = 0.011$. In season 1, the highest net economic benefit was observed under the positive control (Ksh 778), followed by poultry manure (Ksh 543) and farmyard manure (Ksh 523), while biochar recorded the lowest benefit (Ksh 217) that was significantly lower than that for all other treatments. In season 2, poultry manure yielded the highest net economic returns of Ksh 833 that surpassed the positive control with Ksh 716 and biochar (Ksh 298), while compost had the least profit (Ksh 224) (Table 3).

Table 3: Net economic benefit of lettuce produced in two seasons

Treatment (Nutrient source)	Season 1 (Ksh/3m^2)	S1 FWT (g/plant)	Season 2 (Ksh/3m^2)	S2 FWT (g/plant)
Farmyard manure	523^{ab}	622.00^{ab}	476^{ab}	479.78^{ab}
Negative control	363^{bc}	411.00^{b}	339^{ab}	322.22^{b}
Biochar	217^{c}	591.33^{ab}	298^{b}	543.89^{ab}
Poultry manure	543^{ab}	694.00^{a}	833^{a}	773.33^{a}
Compost	401^{bc}	645.67^{ab}	224^{b}	408.89^{b}
Positive control	778^{a}	774.33^{a}	716^{ab}	595.67^{ab}
P value	0.001*	0.010*	0.011*	0.019*
SE	60.9	50.70	105.0	69.60

*Means with the same letter(s) within a column are not significantly different at $P = 0.05$ by Tukey's test. S1 = Season 1, S2 = Season 2, FWT = Fresh weight.

These findings underscore the critical role of input type in determining the profitability of lettuce production. In season 1, the positive control produced the highest net economic benefit, which agrees with existing literature on the high responsiveness of lettuce to synthetic fertiliser that provides readily available nutrients particularly nitrogen known to be crucial in rapid vegetative growth (Palm *et al.*, 2001). In season 2, poultry manure yielded higher NEB than all the other treatments, namely: positive control, farmyard manure, biochar, compost, and negative control. This indicated that poultry manure had the cumulative benefit of improved nutrient mineralization dynamics that promoted high lettuce yields (Agegnehu *et al*., 2016). The high yields translated into high income that surpassed the cost of inputs, hence generating highest net economic benefit (profitability).

Poultry manure consistently ranked among the top treatments in both lettuce production seasons. This could be because it is rich in nitrogen and phosphorus and fast in mineralization rate, making nutrients readily available to plants. In contrast, biochar had the lowest net economic benefit in

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season 1, and this might be due to high input cost during lettuce production and also its low immediate nutrient availability and immobilization potential that hides its long-term effect on soil health benefits (Lehmann and Joseph, 2015). Apparently, negative control outperformed biochar and compost in both production seasons; this might be due to high initial cost of biochar and compost used in the experiment. Additionally, biochar and compost have slow release of mineral nutrients for utilization by plants, leading to low yields and hence low income (Nziguheba *et al*., 2010).

4. CONCLUSIONS

This study revealed that organic fertilisers significantly enhance soil properties, nutrient uptake, growth and yield of lettuce grown in a typical tropical production system. The initial soil conditions, characterized by low organic matter, poor nutrient availability, and limited moisture retention, were notably improved by the application of organic fertilisers. Among the organic fertilisers, poultry manure emerged as the most effective amendment, providing high concentrations of readily mineralizable nutrients, particularly nitrogen and phosphorus. Biochar demonstrated consistent benefits across seasons by improving soil cation exchange capacity and phosphorus retention. Farmyard manure and compost showed intermediate performance and sustained benefits in soil fertility improvement. All treatments maintained a soil pH within the optimal range for lettuce plant growth, despite slight acidification due to organic matter decomposition. Economic analysis indicated that poultry manure provided the highest net economic benefit among the organic fertilisers, making it a cost-effective and sustainable alternative to synthetic fertilisers. Although biochar and compost had lower short-term profitability, they may contribute to the sustainability of soil health management through residual benefits on a long-term basis.

5. RECOMMENDATIONS

Poultry manure should be promoted as a primary organic amendment and alternative to synthetic fertilisers in tropical lettuce production due to its high nutrient value, rapid mineralization, and profitable economic (income) performance. Poultry manure is also recommended for lettuce production due to its high profitability and nutrient availability. Compost and farmyard manure should be carefully integrated into soil fertility programmes due to their slow nutrient mineralization. They may be incorporated into soil fertility programmes to support microbial activity, as well as sustain soil health over time. Biochar effects should be studied further in integrated soil fertility management and long-term soil improvement strategies targeting improvement of soil structure, aeration, nutrient retention, and long-term stability. Further research should investigate the long-term residual effects of organic fertilisers under diverse climatic and soil conditions to enhance system resilience. Detailed study and analysis of quality and net economic benefit of lettuce using organic fertilisers on a large-scale is recommended. Agricultural policies and extension services should support the adoption of organic fertilisers, particularly poultry manure and biochar, through training and offering of incentives or subsidies to farmers in order to reduce heavy utilization of synthetic fertilisers which result in soil degradation.

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