



## OPEN ACCESS

EDITED BY  
Danilo Scordia,  
University of Messina, Italy

REVIEWED BY  
Tyson Tebogo Mokgalabone,  
University of Limpopo, South Africa  
Nagaraj M.,  
Saveetha University, India

\*CORRESPONDENCE  
Janet Tutah  
✉ janettutah@gmail.com

RECEIVED 08 March 2026  
REVISED 25 April 2026  
ACCEPTED 30 April 2026  
PUBLISHED 21 May 2026

## CITATION

Tutah J, Ogindo H, Opala P, Ogello E,  
Outa N and Hoinkis J (2026) Growth and  
yield response of African indigenous  
vegetables to fish effluent water and  
black soldier fly frass in an integrated  
aquaculture-agriculture system.  
*Front. Agron.* 8:1825875.  
doi: 10.3389/fagro.2026.1825875

## COPYRIGHT

© 2026 Tutah, Ogindo, Opala, Ogello,  
Outa and Hoinkis. This is an open-access  
article distributed under the terms of the  
[Creative Commons Attribution License  
\(CC BY\)](https://creativecommons.org/licenses/by/4.0/). The use, distribution or  
reproduction in other forums is  
permitted, provided the original  
author(s) and the copyright owner(s) are  
credited and that the original publication  
in this journal is cited, in accordance  
with accepted academic practice. No  
use, distribution or reproduction is  
permitted which does not comply with  
these terms.

# Growth and yield response of African indigenous vegetables to fish effluent water and black soldier fly frass in an integrated aquaculture-agriculture system

Janet Tutah<sup>1\*</sup>, Harun Ogindo<sup>1</sup>, Peter Opala<sup>1</sup>, Erick Ogello<sup>2</sup>,  
Nicholas Outa<sup>2</sup> and Jan Hoinkis<sup>3</sup>

<sup>1</sup>Department of Crop and Soil Science, Maseno University, Maseno, Kenya, <sup>2</sup>Department of Animal and Fisheries Science, Maseno University, Maseno, Kenya, <sup>3</sup>Center of Applied Research, Karlsruhe University of Applied Sciences, Karlsruhe, Germany

**Introduction:** African indigenous vegetables (AIVs) are important for food and nutrition, yet their production is constrained by soil infertility.

**Methodology:** The effects of fish effluent water (FEW) and black soldier fly frass (BSFF) on the growth and yield of AIVs were evaluated in a splitplot factorial experiment at the PrAEctiCe Living Lab-1, Kisumu, Kenya. Three AIVs; spider plant, kale, and African nightshade, were assigned to the main plots, while three nutrient sources; fish effluent water (FEW), BSFF combined with non-effluent water (BSFF+NEW), and non-effluent water (NEW), were allocated to the subplots. Crop type, nutrient source, and their interaction significantly ( $p < 0.05$ ) influenced plant height and leaf number, whereas crop type and nutrient source significantly influenced biomass.

**Results:** There was progressive increase in plant height and number of leaves over time across all treatments, with spider plant recording the highest values (87.3 cm and 50) in season 1, followed by African nightshade (38.4 cm and 45) and kale (14.4 cm and 16). Similarly, BSFF +NEW produced the tallest plants and the highest number of leaves (52.3 cm and 48, respectively) in the fifth week, followed by FEW (49.3 cm and 37.6, respectively) and NEW (39 cm and 24.7, respectively). In season 2, nutrient sources had no significant effect on growth parameters in kale. However, FEW and BSFF+ NEW produced comparable growth parameters in African nightshade and spider plant relative to NEW alone. In season 1, fresh biomass was highest in spider plant ( $12.5 \text{ t ha}^{-1}$ ) compared to African nightshade and kale ( $10.2 \text{ t ha}^{-1}$  and  $10.8 \text{ t ha}^{-1}$ , respectively). However, kale produced the greatest biomass in season 2. In both seasons, the BSFF+NEW application produced the highest biomass, with season 1 recording fresh and dry biomass of  $14.9 \text{ t ha}^{-1}$  and  $2.1 \text{ t ha}^{-1}$ , respectively, followed by FEW ( $12.1 \text{ t ha}^{-1}$  and  $1.8 \text{ t ha}^{-1}$ ) and NEW ( $6.5 \text{ t ha}^{-1}$  and  $0.9 \text{ t ha}^{-1}$ ).

**Discussion:** These findings demonstrate that FEW and BSFF are effective nutrient sources for enhancing the growth and yield of AIVs, underscoring their potential application in sustainable IAAs.

## KEYWORDS

African indigenous vegetables, black soldier fly frass, fish effluent water, growth, integrated aquaculture-agriculture systems, yield

## Introduction

The rapid growth of the global population continues to exert increasing pressure on food production systems, necessitating approaches that simultaneously enhance productivity and safeguard environmental sustainability (IFAD, 2021; Mugwe et al., 2020). The global population is projected to reach approximately 9.7 billion by 2050, with a corresponding surge in food demand (Rodias et al., 2021). Meeting this demand will inevitably require the intensified use of primary production resources, such as water and nutrients. However, unsustainable intensification has been associated with ecosystem degradation and climate-related stresses, including rising temperatures, erratic rainfall patterns, increased incidences of pests and diseases, and recurrent droughts and floods (Chepkoech et al., 2018; Rodias et al., 2021). These challenges are particularly pronounced in developing countries, where agriculture remains a cornerstone of economic development and food security.

In many developing countries, agriculture directly or indirectly supports more than 80% of the rural population through employment, income generation, and livelihood security. Beyond providing food, the sector contributes to foreign exchange earnings and plays a critical role in alleviating poverty and hunger (Alila and Atieno, 2006). In this context, African indigenous vegetables (AIVs) have gained increasing recognition for their contribution to food and nutrition security. AIVs are rich sources of essential nutrients, including vitamins A and C, iron, calcium, and protein. In addition, certain species, such as spider plant (*Cleome gynandra*) and African nightshade (*Solanum scabrum*), possess medicinal properties (Abukutsa-Onyango, 2007). Growing consumer awareness and rising demand for AIVs in urban centers, such as Kisumu City in Kenya, have further created income opportunities for smallholder farmers through their production, processing, and marketing (Bokelmann et al., 2022; Krause et al., 2019).

Despite their nutritional and economic importance, the productivity of African indigenous vegetables in western Kenya has declined substantially. In Kisumu County, current yields range between 1 and 3 t ha<sup>-1</sup>, far below the potential yields of 20–40 t ha<sup>-1</sup>. This decline has been largely attributed to declining soil fertility and increasing water scarcity (Abukutsa-Onyango, 2010; Hayombe et al., 2018). AIV production continues to face multiple constraints, including climate variability, drought and famine, soil nutrient depletion, and increasing incidences of pests and diseases (Chepkoech et al., 2018). Poor agronomic and land management practices, such as inadequate fertilizer application, continuous cropping, crop residue removal, and frequent tillage, have accelerated land and ecosystem degradation, further undermining soil fertility (Mugwe et al., 2020).

Although synthetic fertilizers are widely used to improve soil fertility, their escalating costs limit their accessibility among smallholder farmers, making it increasingly difficult to apply the appropriate fertilizer rates (Bunde, 2017). Concurrently, climate change-induced erratic rainfall patterns and heightened competition for water among domestic, industrial, and agricultural users have intensified water scarcity, further constraining AIV production. Moreover, agronomic research and technological development targeting African indigenous vegetables have historically been limited, partly due to their perception as wild or subsistence

crops. As a result, critical information on their nutrient and water requirements remains inadequate (Kodzwa et al., 2023).

Integrated Aquaculture–Agriculture Systems (IAAS) have been proposed as a sustainable way to address nutrient and water limitations in smallholder farming systems. IAAS integrates aquaculture and crop production components to enhance resource-use efficiency, promote system synergies, and minimize waste (Melaku and Natarajan, 2019). A key feature of IAAS is the reuse of fish effluent water (FEW) for crop irrigation and nutrition, thereby contributing to soil fertility enhancement and improved farm sustainability (Diatta et al., 2023). Fish effluent water is typically rich in plant-available nutrients, such as nitrogen and phosphorus, which originate from fish excreta and the microbial decomposition of organic waste. Previous studies have demonstrated that FEW can significantly enhance crop productivity by providing readily available nutrients, improving soil fertility and nutrient uptake (Da et al., 2020; Fruscella et al., 2023; Mulokozi et al., 2021; Rasowo and Auma, 2006). Despite this potential, empirical evidence on the agronomic effectiveness of fish effluent water as both an irrigation source and nutrient input remains limited, and uncertainties persist regarding the quantity of nutrients supplied to crops.

Within IAAS, black soldier fly (*Hermetia illucens*) larvae have emerged as an innovative and cost-effective protein source for aquaculture feed. The bioconversion of organic waste by black soldier fly larvae generates frass, a nutrient-rich byproduct with considerable potential as an organic fertilizer. Black soldier fly frass (BSFF) contains substantial amounts of macro- and micronutrients, including nitrogen, phosphorus, and boron, and often exhibits higher organic matter content than conventional composts and manures (Nakitare and Kollongei, 2023). In addition, BSFF harbors beneficial microorganisms, such as nitrogen-fixing and nitrifying bacteria, which enhance nutrient availability and plant uptake (Choi and Hassanzadeh, 2019). Previous studies have demonstrated the ability of BSFF to enhance crop growth, biomass, and soil health in various crops (Chavez et al., 2025; Kawasaki et al., 2020; Klammer et al., 2020; Santos et al., 2026). The simultaneous production of larval biomass for animal feed further strengthens the circularity and sustainability of the system (Lopes et al., 2024).

Despite the demonstrated potential of IAAS and BSFF, their adoption in developing countries such as Kenya remains limited due to inadequate information and low awareness. Farmers engaged in black soldier fly production have primarily focused on its use as a protein source for livestock, with minimal utilization of frass as a soil fertility amendment. Furthermore, limited empirical evidence exists on the combined use of FEW and BSFF for vegetable production, particularly for AIVs. The objective of this study was, therefore, to evaluate the effects of FEW and BSFF within an Integrated Aquaculture–Agriculture System on the growth and yield of selected AIVs.

## Materials and methods

### Study area description

The experiment was conducted at the Kisumu County–PrAECTiCe Lab-1 site in Nyalenda, located approximately 2 km

southeast of Kisumu City center, Kenya. The site is situated at a latitude of 00°07'36.012" S, a longitude of 34°45'27.0216" E, and at an elevation of 1,142 m above sea level. The soils in Nyalenda are predominantly Vertisols, characterized by a high clay content with marked shrink–swell properties arising from seasonal moisture fluctuations (Jonkman et al., 2019). The area experiences a modified equatorial climate, with mean maximum annual temperatures ranging from 25 to 33 °C and minimum temperatures between 16 and 18 °C. Average annual rainfall ranges from 1,000 to 1,800 mm during long rains (March to May) and 450–600 mm during short rains (September to November) (Climate, 2023). Farming systems in Nyalenda are predominantly urban-based, with the majority of households engaged in vegetable production and small-scale livestock keeping as key livelihood activities (Jonkman et al., 2019).

### Experimental design

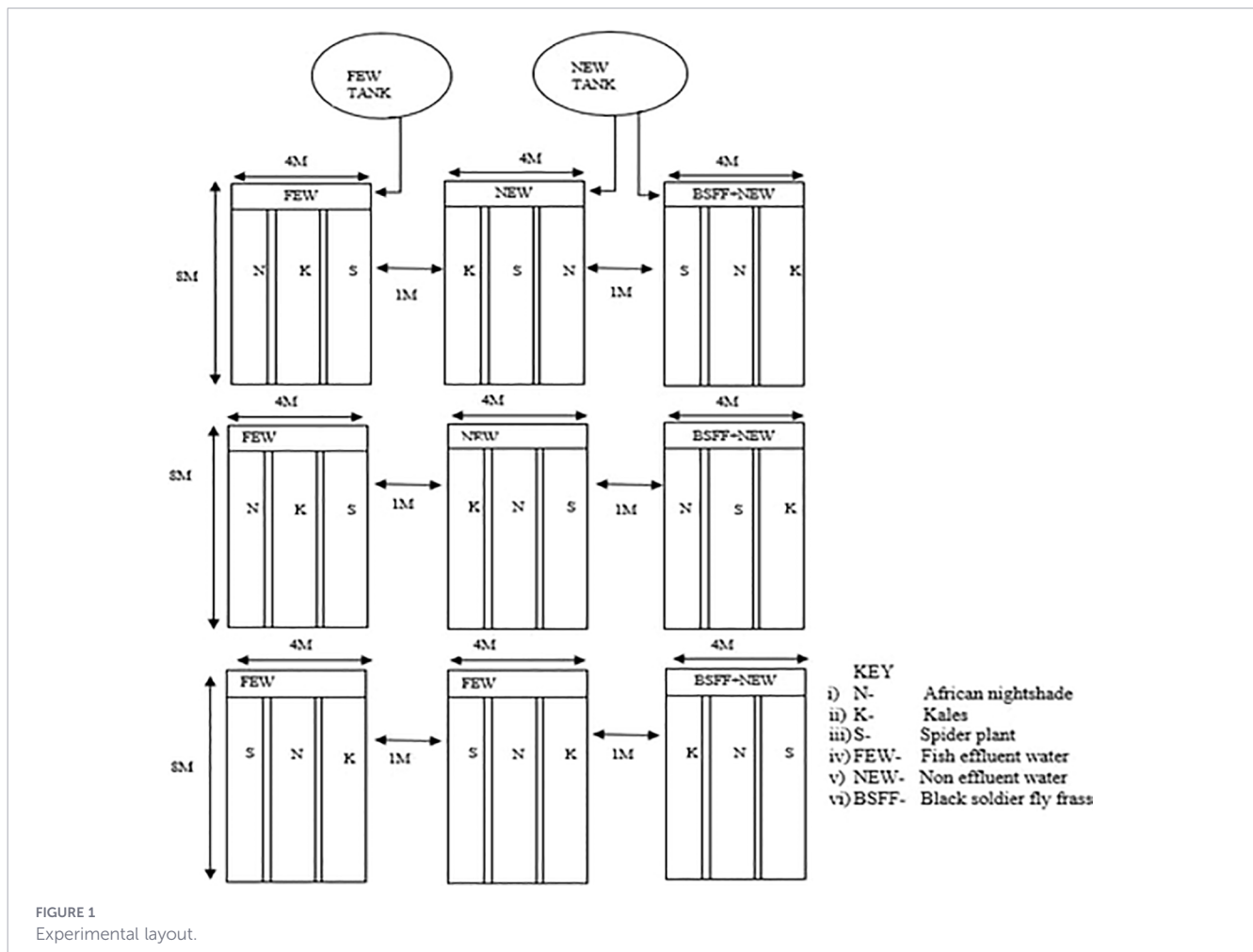
The experiment was laid out in a split-plot factorial experimental design with three replications. The main plot factor comprised three levels of AIVs: spider plant (*Cleome gynandra*), kale (*Brassica oleracea* var. *acephala*), and African nightshade (*Solanum scabrum*). The subplot factor consisted of three levels of nutrient sources: FEW, BSFF+non-effluent water (NEW), and NEW. Each experimental plot measured 8 m × 4 m, with a 1-m-wide pathway

separating adjacent plots, as illustrated in Figure 1. Each subplot measured 8 m × 1 m, with a 0.5-m-wide pathway separating adjacent subplots. The AIVs were planted at a spacing of 45 cm × 15 cm to achieve optimal plant population density and uniform crop establishment across treatments.

FEW used for irrigation was sourced from raised fish ponds located adjacent to the experimental site. The NEW was obtained from treated sewage water supplied by the Nyalenda sewage ponds through an on-site membrane bioreactor (MBR) system, which purified and sanitized the sewage water through a combination of aerobic biological treatment and ultrafiltration using membranes with a nominal pore size of 35 nm. This process ensured that the irrigation water was free from pathogenic organisms prior to use.

### Crop establishment and management

Seedlings of African indigenous vegetables (AIVs) were raised under greenhouse conditions using a containerized nursery system at the experimental site. Seeds were sown in 200-cell seedling trays filled with cocopeat as the growth medium. Two seeds were placed per cell to ensure adequate germination. Irrigation was applied immediately after sowing and then maintained once daily in the evening using a fine spray.



Two weeks after emergence, an organic foliar fertilizer containing NPK was applied to enhance early vegetative growth. The seedlings were thinned to one per cell by removing the weaker individuals to ensure uniformity and vigor. Pest and disease management was undertaken using appropriate pesticides, such as nimerdicine, and fungicides, such as neem oil, to control common nursery challenges, including cutworms and damping-off. During the third week, the seedlings were subjected to a hardening-off process to acclimate them to field conditions prior to transplanting.

The experimental field was laid out into nine plots, each measuring 8 m × 4 m, with 1 m buffer pathways between plots. Plot demarcation was carried out using measuring tapes and ropes. A drip irrigation system was installed by laying the mainline along the designated field layout, followed by the connection of lateral lines aligned with the planting rows. Emitters were installed on the lateral lines after completion of tillage operations. Two water storage tanks, designated for FEW and NEW, respectively, were installed adjacent to the experimental field.

Primary tillage was conducted to loosen the soil, followed by secondary tillage to achieve a fine tilth suitable for planting. Raised beds were then formed as ridges and furrows above ground level, and drip lines were installed along the ridges. The irrigation system was tested prior to transplanting to ensure uniform water distribution.

Prior to transplanting, the plots were irrigated to field capacity. Transplanting was carried out early in the morning on the 28<sup>th</sup> day after germination, with seedlings placed along the ridges adjacent to the drip lines. Black soldier fly frass was applied once at planting as a single application to designated plots at a rate equivalent to 60 kg N ha<sup>-1</sup> prior to irrigation with non-effluent water. The application rate of 60 kg N ha<sup>-1</sup> was selected based on nutrient requirements for AIVs and previous studies demonstrating optimal growth and yield under a moderate nitrogen supply (Abukutsa-onyango and Karimi, 2016). Treatments receiving FEW and NEW were irrigated through the drip system according to the specifications of each treatments.

Irrigation scheduling was based on the soil moisture depletion approach, in which irrigation was applied when 20% of the available soil water had been depleted. Soil moisture content was determined using the gravimetric method and validated using *in situ* soil moisture sensors installed at a depth of 1 m. Irrigation was applied

uniformly across all treatments during both cropping periods. An automatic weather station located adjacent to the experimental site provided rainfall data throughout the study period (Figure 2).

Harvesting of AIVs was conducted at 56 days after transplanting.

## Soil, frass, and water sampling and analysis

For baseline soil characterization, composite samples were obtained by randomly sampling multiple points across the experimental field using a soil auger at a depth of 0–20 cm. The samples were air-dried, gently crushed by hand, and foreign materials, such as plant residues and stones, were removed. The processed soil was passed through a 2-mm sieve to obtain fine soil for laboratory analysis. The soil samples were analyzed for selected physical and chemical properties using standard analytical procedures (Okalebo et al., 2002) (Table 1).

Samples of BSFF derived from organic waste substrates were collected, air-dried, and analyzed for their physical and chemical properties using standard methods (Okalebo et al., 2002) (Table 2). FEW and NEW were collected from their respective tanks. The samples were transferred into clean plastic bottles, properly labeled, and transported to the laboratory for chemical analysis. The results of the analysis are presented in Table 3.

## Data collection

### Growth and biomass measurements

Plant height was determined weekly, up to the fifth week after transplanting (WAT), by measuring the distance from the soil surface at the base of the plant to the terminal bud on three randomly selected and tagged plants per subplot. The same tagged plants were used throughout the study, and the mean height was calculated and recorded as the plant height per subplot.

Leaf number was determined weekly from 1 to 5 WAT by counting fully expanded leaves on the same tagged plants. The mean leaf number per subplot was calculated and recorded.

Above-ground biomass was determined at harvest. Spider plant (*Cleome gynandra*) and African nightshade (*Solanum* spp.) were harvested at 7 WAT, while kale (*Brassica oleracea* var. *acephala*) was harvested at 8 WAT to account for differences in maturity. All plants within each subplot were harvested by cutting at the soil

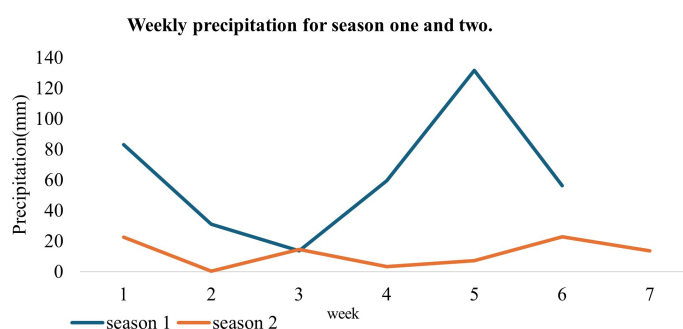


FIGURE 2  
Weekly precipitation.

TABLE 1 Initial soil physical and chemical properties.

| Physicochemical properties               | Values | Optimum value                       |
|--|--------|-------------------------------------|
| pH (H <sub>2</sub> O, 1:2.5 soil: water) | 4.4    | 6.0-7.5 (FAO, 2021)                 |
| Organic Carbon, %                        | 1.4    | 1.5-3% (Okalebo et al., 2002)       |
| Organic Matter, %                        | 2.41   | 2-4% (Biernbaum, 2012)              |
| Total Nitrogen, %                        | 0.027  | 0.12-0.25% (Okalebo et al., 2002)   |
| Phosphorus (P), ppm                      | 9.69   | 25-50 ppm (Horneck et al., 2011)    |
| Potassium (K), ppm                       | 353.17 | 50-175ppm (Okalebo et al., 2002)    |
| Calcium (Ca), ppm                        | 79.04  | 1000-1600ppm (Okalebo et al., 2002) |
| Zinc (Zn), ppm                           | 34.34  | 1.5 ppm (Horneck et al., 2011)      |
| Iron (Fe), ppm                           | 379.05 | 10 ppm (Sakal et al., 1984)         |
| Copper (Cu), ppm                         | 2.82   | 0.6 ppm (Horneck et al., 2011)      |

surface, and fresh biomass was measured using a weighing balance. A representative subsample from each subplot was oven-dried at 70 °C to a constant weight to determine dry biomass.

## Statistical analysis

The data were analyzed using analysis of variance (ANOVA) for a split-plot design in a randomized complete block with three replications using GENSTAT Discovery Edition 3 (VSN International Ltd., UK). Crop type was assigned to main plots and nutrient source to subplots. Replications were treated as random effects, while crop type and nutrient source were treated as fixed effects. Treatment means were compared using the least significant difference (LSD) test at the 5% probability level ( $p \leq 0.05$ ) when significant differences were detected.

TABLE 2 Physical and chemical properties of black soldier fly frass.

| Parameter               | Unit                | Value |
|-------------------------|---------------------|-------|
| pH                      |                     | 7.51  |
| Electrical conductivity | mS cm <sup>-1</sup> | 7.15  |
| Dry matter              | %                   | 88.3  |
| Organic Carbon          | %                   | 39.8  |
| Total Nitrogen          | %                   | 3.82  |
| Potassium               | %                   | 1.15  |
| Phosphorus              | %                   | 2.13  |
| Calcium                 | %                   | 3.68  |
| Magnesium               | %                   | 0.93  |
| Sulfur                  | %                   | 0.41  |
| Manganese               | ppm                 | 401   |
| Iron                    | ppm                 | 4400  |
| Zinc                    | ppm                 | 221   |
| Copper                  | ppm                 | 419   |
| Boron                   | ppm                 | 34.5  |
| Sodium                  | ppm                 | 1910  |
| C/N ratio               |                     | 10.4  |

TABLE 3 Physical and chemical properties of FEW and NEW.

| Parameter               | Unit               | FEW    | NEW    |
|-------------------------|--------------------|--------|--------|
| pH                      |                    | 8.35   | 7.19   |
| Electrical conductivity | mScm <sup>-1</sup> | 0.70   | 0.75   |
| Ammonium                | ppm                | 4.89   | < 0.01 |
| Calcium                 | ppm                | 20.4   | 33.3   |
| Magnesium               | ppm                | 6.81   | 8.74   |
| Potassium               | ppm                | 37.7   | 34.2   |
| Phosphorus              | ppm                | 2.76   | 9.34   |
| Total Nitrogen          | ppm                | 38.3   | 36.0   |
| Nitrate N               | ppm                | 25.6   | 35.9   |
| Nitrate                 | ppm                | 113    | 159    |
| Sulfur                  | ppm                | 9.64   | 9.84   |
| Sulphate                | ppm                | 28.9   | 29.5   |
| Iron                    | ppm                | 0.013  | < 0.01 |
| Manganese               | ppm                | < 0.01 | < 0.01 |
| Zinc                    | ppm                | < 0.01 | < 0.01 |
| Boron                   | ppm                | 0.027  | 0.032  |
| Copper                  | ppm                | < 0.01 | < 0.01 |
| Molydenum               | ppm                | < 0.01 | < 0.01 |
| Sodium                  | ppm                | 80.9   | 81.5   |
| Chloride                | ppm                | 86.9   | 74.0   |
| Bicarbonate             | ppm                | 83.2   | 60.8   |
| Silicon                 | ppm                | 18.6   | 20.3   |
| SAR                     |                    | 3.96   | 3.25   |
| Hardness                | Ppm                | 78.9   | 119    |
| Turbidity               | NTU                | 495    | 2.35   |

## Results

### Plant height

There was no significant interaction between crop type and nutrient source on plant height in season 1. However, crop type significantly influenced plant height, whereas the effect of nutrient source varied over the weeks, as illustrated in Table 4. Plant height increased progressively over the weeks in all treatments, with spider plant consistently recording the highest plant height, followed by African nightshade and kale. In week 1, spider plant and African nightshade did not differ significantly in plant height (12.2 and 11.5 cm, respectively), although both produced significantly taller plants than kale (5.8 cm). Nutrient source had no significant effect on plant height. In week 2, spider plants recorded significantly taller plants than African nightshade, whereas kale had the shortest plants. This trend was consistently observed from week 2 to week 5, with the highest height recorded in spider plant (87 cm), followed by African nightshade (38.4 cm) and kale (14.4 cm). Application of black soldier fly frass combined with non-effluent water (BSFF +NEW) produced significantly taller plants (14.1 cm) than those treated with NEW (11.5 cm) in the second week. However, no significant differences were observed between BSFF+NEW and

TABLE 4 Effect of crop type and nutrient source on plant height (cm) in season 1.

| Season 1<br>Crop type               | Nutrient source week 1. |             |              |            | Nutrient source week 2 |             |              |             | Nutrient source week 3 |             |             |            |
|-------------------------------------|-------------------------|-------------|--------------|------------|------------------------|-------------|--------------|-------------|------------------------|-------------|-------------|------------|
|                                     | NEW                     | FEW         | BSFF<br>+NEW | Mean       | NEW                    | FEW         | BSFF+NEW     | Mean        | NEW                    | FEW         | BSFF+NEW    | Mean       |
| Kale                                | 5.2 ± 0.9               | 6.2 ± 2.3   | 5.8 ± 0.6    | 5.7 ± 0.5  | 6.4 ± 1.1              | 7.7 ± 1.7   | 7.5 ± 1.1    | 7.2 ± 0.7   | 7.0 ± 1.5              | 9.5 ± 1.0   | 8.6 ± 0.2   | 8.4 ± 1.3  |
| African nightshade                  | 9.9 ± 0.9               | 11.5 ± 1.5  | 13.1 ± 2.0   | 11.5 ± 1.6 | 13.0 ± 2.2             | 14.0 ± 2.0  | 15.5 ± 2.7   | 14.2 ± 1.5  | 15.1 ± 1.5             | 21.4 ± 4.3  | 19.1 ± 4.0  | 18.5 ± 3.2 |
| Spider plant                        | 12.1 ± 1.7              | 11.8 ± 1.7  | 12.5 ± 1.5   | 12.1 ± 0.4 | 14.9 ± 2.3             | 16.3 ± 2.1  | 19.4 ± 1.0   | 16.9 ± 2.3  | 23.4 ± 11.3            | 29.6 ± 8.5  | 39.8 ± 2.1  | 30.9 ± 8.3 |
| Mean                                | 9.1 ± 3.5               | 9.8 ± 3.2   | 10.5 ± 4.1   | 9.8        | 11.4 ± 4.5             | 12.7 ± 4.5  | 14.1 ± 6.1   | 12.8        | 15.2 ± 8.2             | 20.2 ± 10.1 | 22.5 ± 15.9 | 19.3       |
| LSD <sub>0.05</sub> crop type       | 1.60                    |             |              |            | 1.82                   |             |              |             | 4.97                   |             |             |            |
| LSD <sub>0.05</sub> nutrient source | NS                      |             |              |            | 1.82                   |             |              |             | 4.97                   |             |             |            |
| LSD <sub>0.05</sub> interaction     | NS                      |             |              |            | NS                     |             |              |             | NS                     |             |             |            |
| CV%                                 | 16.4                    |             |              |            | 14                     |             |              |             | 25.8                   |             |             |            |
|                                     | Nutrient source week 4  |             |              |            | Nutrient source week 5 |             |              |             |                        |             |             |            |
| Crop type                           | NEW                     | FEW         | BSFF<br>+NEW | Mean       | NEW                    | FEW         | BSFF<br>+NEW | Mean        |                        |             |             |            |
| Kale                                | 10.4 ± 2.0              | 13.7 ± 1.7  | 13.1 ± 0.2   | 12.4 ± 1.8 | 11.9 ± 1.5             | 15.9 ± 1.9  | 15.5 ± 2.4   | 14.4 ± 2.2  |                        |             |             |            |
| African nightshade                  | 21 ± 6.0                | 32.0 ± 8.5  | 29 ± 3.1     | 27.3 ± 5.7 | 31.1 ± 11.1            | 44.1 ± 14.5 | 41.5 ± 3.8   | 38.9 ± 6.9  |                        |             |             |            |
| Spider plant                        | 44.1 ± 20.0             | 55.4 ± 15.8 | 70 ± 8.2     | 56.5 ± 13  | 74.1 ± 27.6            | 88.0 ± 16.5 | 99.8 ± 9.9   | 87.3 ± 12.9 |                        |             |             |            |
| Mean                                | 25.2 ± 17.2             | 33.7 ± 20.9 | 37.4 ± 29.4  | 32.1       | 39.0 ± 31.8            | 49.3 ± 36.3 | 52.3 ± 43.2  | 46.9        |                        |             |             |            |
| LSD <sub>0.05</sub> crop type       | 8.49                    |             |              |            | 11.25                  |             |              |             |                        |             |             |            |
| LSD <sub>0.05</sub> nutrient source | 8.49                    |             |              |            | NS                     |             |              |             |                        |             |             |            |
| LSD <sub>0.05</sub> interaction     | NS                      |             |              |            | NS                     |             |              |             |                        |             |             |            |
| CV%                                 | 26.5                    |             |              |            | 24.0                   |             |              |             |                        |             |             |            |

FEW, Fish effluent water; NEW, Non-effluent water; BSFF, Black soldier fly frass; NS, Not significant; LSD, least significant difference.

FEW, nor between FEW and NEW. In weeks 3 and 4, BSFF+NEW and FEW did not differ significantly; however, they produced significantly taller plants than NEW did.

There was a significant interaction between crop type and nutrient source on plant height in season 2, except in week 2, as illustrated in Table 5. There was no significant difference in the plant height of kale among the nutrient sources (BSFF+NEW, FEW, and NEW). However, in African nightshade, the application of BSFF+NEW and FEW produced significantly taller plants than NEW, although BSFF+NEW and FEW did not differ significantly. In spider plant, application of FEW resulted in significantly taller plants than NEW; however, there was no significant difference between BSFF+NEW and FEW or between BSFF+NEW and NEW. In week 2, nutrient source and crop type had a significant effect on plant height. Spider plant had significantly taller plants (13.3 cm) than African nightshade (9.9 cm), while kale had the shortest plants (5.8 cm). Application of BSFF+NEW and FEW did not differ significantly; however, they resulted in significantly taller plants (11.6 and 10.8 cm, respectively) than NEW (6.6 cm). There was no significant difference in the plant height of kale among the nutrient sources (BSFF+NEW, FEW, and NEW) from the third to the fifth week. However, the application of FEW in African nightshade resulted in significantly taller plants than NEW in the third week, although there was no significant difference between FEW and BSFF+NEW or between BSFF+NEW and NEW. In spider plant, application of FEW resulted in significantly taller plants than BSFF+NEW, whereas BSFF+NEW produced taller plants than NEW. In week 4, application of FEW produced significantly taller plants in African nightshade than BSFF+NEW and NEW, although BSFF+NEW and NEW were statistically similar. However, in spider plant, application of FEW and BSFF+NEW resulted in significantly taller plants than NEW; however, FEW and BSFF+NEW did not differ significantly. In week 5, application of FEW produced significantly taller plants in African nightshade compared to BSFF+NEW and NEW, although BSFF+NEW and NEW did not differ significantly. However, in spider plant, application of FEW and BSFF+NEW produced significantly taller plants than NEW; however, FEW and BSFF+NEW did not differ significantly.

## Number of leaves

There was no significant interaction between crop type and nutrient source on leaf number in season 1, except in week 3, where the interaction was significant, as presented in Table 6. However, crop type had a significant effect on leaf number across all weeks, whereas nutrient source had a significant effect in all weeks except week one. There was a progressive increase in the number of leaves among the crops over the weeks, with spider plant producing the highest number of leaves, followed by African nightshade and kale. In week 1, African nightshade (6.3) had a significantly higher number of leaves compared to spider plant (5.2), whereas kale had the lowest (4.1). In week 2, spider plant and African nightshade had a higher leaf number compared to kale; however, they did not differ significantly. A similar trend was observed from week three to week five, where spider plant and African nightshade recorded leaf numbers of 50 and 45, respectively, whereas kale attained a leaf number of 16. Application of BSFF+NEW produced

a significantly higher number of leaves (9.0) compared to FEW and NEW (6.6 and 6.6, respectively), although no significant differences were observed between FEW and NEW in week 2. In week 3, nutrient sources (BSFF+NEW, FEW, and NEW) had no significant effect on the number of leaves in kale and African nightshade. However, the application of BSFF+NEW resulted in a significantly higher number of leaves compared to FEW and NEW. In week 4, BSFF+NEW and FEW produced a significantly higher number of leaves in spider plant compared to NEW alone; however, BSFF+NEW and FEW were statistically similar. In week 5, application of BSFF+NEW resulted in a significantly higher number of leaves compared to NEW alone; however, no significant differences were observed between BSFF+NEW and FEW, nor between FEW and NEW.

The interaction between crop type and nutrient source had a significant effect on leaf number, except in week 1, as illustrated in Table 7. In week 1, crop type and nutrient source had a significant effect on the number of leaves. Spider plant had a significantly higher number of leaves (5.3) compared to African nightshade (4.4), whereas kale had the lowest number (3.8). Application of BSFF+NEW and FEW produced a significantly higher number of leaves compared to NEW alone; however, no significant differences were observed between BSFF+NEW and FEW. In week 2, nutrient sources (BSFF+NEW, FEW, and NEW) had no significant effect on the number of leaves in kale. A similar trend was observed in kale from week three to week five. However, the application of BSFF+NEW and FEW produced a higher leaf number in African nightshade and spider plant compared to NEW in week 2, although BSFF+NEW and FEW did not differ significantly. In week 3, application of FEW resulted in a significantly higher number of leaves in African nightshade compared to NEW alone; however, no significant differences were observed between BSFF+NEW and FEW, nor between BSFF+NEW and NEW. A similar trend was observed in African nightshade in weeks 4 and 5. In contrast, application of FEW resulted in a significantly higher number of leaves in spider plant compared to BSFF+NEW, while NEW had the lowest number of leaves in week 3. A similar trend was observed in spider plant in week 4. In week 5, application of BSFF+NEW and FEW resulted in a significantly higher number of leaves compared to NEW alone; however, no significant differences were observed between BSFF+NEW and FEW.

## Biomass

The interaction between crop type and nutrient source had no significant effect on either fresh or dry biomass in season 1. However, nutrient source significantly influenced both fresh and dry biomass, whereas crop type had a significant effect only on fresh biomass, as presented in Table 8. Spider plant exhibited significantly higher fresh biomass (12.5 t ha<sup>-1</sup>) compared to African nightshade and spider kale plant (10.2 t ha<sup>-1</sup> and 10.8 t ha<sup>-1</sup>, respectively). Application of BSFF+NEW resulted in significantly greater fresh biomass (14.9 t ha<sup>-1</sup>) compared to FEW (12.1 t ha<sup>-1</sup>), whereas NEW had the lowest yield (6.5 t ha<sup>-1</sup>). However, the application of BSFF+NEW and FEW resulted in significantly higher dry biomass (2.1 t ha<sup>-1</sup> and 1.8 t ha<sup>-1</sup>, respectively) compared to NEW (0.9 t ha<sup>-1</sup>), although BSFF+NEW and FEW did not differ significantly.

In season 2, the interaction between crop type and nutrient source had no significant effect on fresh and dry biomass. However,

TABLE 5 Effect of crop type and nutrient source on plant height (cm) in season 2.

| Season 2<br>Crop type               | Nutrient source <sub>week 1</sub> |             |              |             | Nutrient source <sub>week 2</sub> |             |              |             | Nutrient source <sub>week 3</sub> |             |              |             |
|-------------------------------------|-----------------------------------|-------------|--------------|-------------|-----------------------------------|-------------|--------------|-------------|-----------------------------------|-------------|--------------|-------------|
|                                     | NEW                               | FEW         | BSFF<br>+NEW | Mean        | NEW                               | FEW         | BSFF<br>+NEW | Mean        | NEW                               | FEW         | BSFF<br>+NEW | Mean        |
| Kale                                | 3.3 ± 0.4                         | 4.3 ± 0.1   | 4.1 ± 0.2    | 3.9 ± 0.5   | 4.0 ± 0.8                         | 6.9 ± 0.7   | 6.5 ± 0.5    | 5.8 ± 1.6   | 5.4 ± 0.7                         | 11.2 ± 0.8  | 9.2 ± 0.4    | 8.6 ± 2.9   |
| African nightshade                  | 5.2 ± 0.5                         | 7.2 ± 0.3   | 7.7 ± 2.2    | 6.7 ± 1.3   | 6.0 ± 1.2                         | 12.4 ± 0.8  | 11.3 ± 5.1   | 9.9 ± 3.4   | 9.0 ± 1.2                         | 19.5 ± 1.1  | 13.8 ± 16.6  | 14.1 ± 5.3  |
| Spider plant                        | 4.6 ± 0.7                         | 6.2 ± 0.8   | 5.2 ± 0.4    | 5.3 ± 0.8   | 9.7 ± 3.5                         | 15.6 ± 3.3  | 14.6 ± 0.4   | 13.3 ± 3.2  | 20.9 ± 7.6                        | 51.1 ± 6.2  | 39.7 ± 7.2   | 37.2 ± 15.3 |
| Mean                                | 4.4 ± 1.0                         | 5.9 ± 1.5   | 5.6 ± 1.8    | 5.3         | 6.6 ± 2.9                         | 11.6 ± 4.4  | 10.8 ± 4.1   | 9.7         | 11.8 ± 8.1                        | 27.3 ± 21.1 | 20.9 ± 16.4  | 20.0        |
| Lsd <sub>0.05</sub> crop type       | 0.43                              |             |              |             | 1.62                              |             |              |             | 4.27                              |             |              |             |
| Lsd <sub>0.05</sub> nutrient source | 0.43                              |             |              |             | 1.62                              |             |              |             | 4.27                              |             |              |             |
| Lsd <sub>0.05</sub> interaction     | 0.74                              |             |              |             | NS                                |             |              |             | 7.39                              |             |              |             |
| CV%                                 | 8                                 |             |              |             | 16.8                              |             |              |             | 21.4                              |             |              |             |
|                                     | Nutrient source <sub>week4</sub>  |             |              |             | Nutrient source <sub>week5</sub>  |             |              |             |                                   |             |              |             |
| Crop type                           | NEW                               | FEW         | BSFF<br>+NEW | Mean        | NEW                               | FEW         | BSFF<br>+NEW | Mean        |                                   |             |              |             |
| Kale                                | 8.8 ± 1.5                         | 14.9 ± 1.2  | 13.5 ± 1.0   | 12.4 ± 3.2  | 15.1 ± 1.0                        | 25.9 ± 2.2  | 20.8 ± 1.1   | 20.6 ± 5.4  |                                   |             |              |             |
| African nightshade                  | 15.3 ± 3.8                        | 35.6 ± 2.1  | 24.6 ± 26.4  | 25.2 ± 10.2 | 29.4 ± 9.1                        | 52.8 ± 4.4  | 36.4 ± 33.7  | 39.5 ± 12.0 |                                   |             |              |             |
| Spider plant                        | 36 ± 10.1                         | 76.4 ± 8.5  | 68.6 ± 5.5   | 60.3 ± 21.4 | 50.7 ± 9.6                        | 99.1 ± 20.0 | 90.3 ± 9.2   | 80 ± 25.8   |                                   |             |              |             |
| Mean                                | 20 ± 14.2                         | 42.3 ± 31.3 | 35.6 ± 29.1  | 32.6        | 31.7 ± 17.9                       | 59.3 ± 37.0 | 49.2 ± 36.5  | 46.7        |                                   |             |              |             |
| Lsd <sub>0.05</sub> crop type       | 5.84                              |             |              |             | 9.83                              |             |              |             |                                   |             |              |             |
| Lsd <sub>0.05</sub> nutrient source | 5.84                              |             |              |             | 9.38                              |             |              |             |                                   |             |              |             |
| Lsd <sub>0.05</sub> interaction     | 10.1                              |             |              |             | 17.03                             |             |              |             |                                   |             |              |             |
| CV%                                 | 17.9                              |             |              |             | 21.1                              |             |              |             |                                   |             |              |             |

FEW, Fish effluent water; NEW, Non-effluent water; BSFF, Black soldier fly frass; NS, Not significant; LSD, least significant difference.

TABLE 6 Effect of crop type and nutrient source on the number of leaves in season 1.

| Season 1<br>Crop type               | Nutrient source Week 1 |             |             |            | Nutrient source Week 2 |             |             |             | Nutrient source Week 3 |             |             |            |
|-------------------------------------|------------------------|-------------|-------------|------------|------------------------|-------------|-------------|-------------|------------------------|-------------|-------------|------------|
|                                     | NEW                    | FEW         | BSFF+NEW    | Mean       | NEW                    | FEW         | BSFF+NEW    | Mean        | NEW                    | FEW         | BSFF+NEW    | Mean       |
| Kale                                | 3.9 ± 0.5              | 4.2 ± 0.4   | 4.1 ± 0.2   | 4.1 ± 0.2  | 5.2 ± 0.2              | 5.2 ± 0.7   | 6 ± 0.0     | 5.5 ± 0.5   | 6 ± 1.0                | 7.4 ± 0.2   | 6.9 ± 0.5   | 6.8 ± 0.7  |
| African nightshade                  | 6.2 ± 1.2              | 6 ± 0.9     | 6.8 ± 0.8   | 6.3 ± 0.4  | 7.9 ± 2.3              | 8 ± 3.4     | 9.8 ± 1.8   | 8.6 ± 1.1   | 14.7 ± 7.6             | 23.1 ± 10.8 | 17.6 ± 3.2  | 18.4 ± 4.3 |
| Spider plant                        | 4.9 ± 1.3              | 4.9 ± 1.0   | 5.8 ± 0.4   | 5.2 ± 0.5  | 6.8 ± 1.9              | 6.4 ± 2.0   | 11.3 ± 2.5  | 8.2 ± 2.7   | 14.9 ± 7.1             | 19.8 ± 7.2  | 31.3 ± 4.1  | 22 ± 8.4   |
| Mean                                | 5 ± 1.2                | 5.0 ± 0.9   | 5.6 ± 1.4   | 5.2        | 6.6 ± 1.4              | 6.5 ± 1.4   | 9.0 ± 2.7   | 7.4         | 11.9 ± 5.1             | 16.9 ± 8.3  | 18.6 ± 12.2 | 15.7       |
| Lsd <sub>0.05</sub> crop type       | 0.78                   |             |             |            | 1.83                   |             |             |             | 5.03                   |             |             |            |
| Lsd <sub>0.05</sub> nutrient source | NS                     |             |             |            | 1.83                   |             |             |             | 5.03                   |             |             |            |
| Lsd <sub>0.05</sub> interaction     | NS                     |             |             |            | NS                     |             |             |             | 8.71                   |             |             |            |
| CV%                                 | 15                     |             |             |            | 24.7                   |             |             |             | 32                     |             |             |            |
|                                     | Nutrient source Week 4 |             |             |            | Nutrient source Week 5 |             |             |             |                        |             |             |            |
| Crop type                           | NEW                    | FEW         | BSFF+NEW    | Mean       | NEW                    | FEW         | BSFF+NEW    | Mean        |                        |             |             |            |
| Kale                                | 7.3 ± 0.3              | 9.6 ± 0.8   | 8.4 ± 1.0   | 8.4 ± 1.2  | 8.3 ± 0.7              | 29.1 ± 31.1 | 10.4 ± 1.2  | 15.9 ± 13.2 |                        |             |             |            |
| African nightshade                  | 25.1 ± 15.6            | 40 ± 17.6   | 43.7 ± 4.9  | 36.3 ± 9.8 | 32.4 ± 17.2            | 36.6 ± 31.7 | 65.9 ± 7.6  | 45 ± 20.7   |                        |             |             |            |
| Spider plant                        | 27.1 ± 10.3            | 41.7 ± 9.1  | 54.2 ± 11.2 | 41 ± 13.6  | 33.2 ± 12.9            | 47.2 ± 12.9 | 69.7 ± 13.7 | 50 ± 15.9   |                        |             |             |            |
| Mean                                | 19.9 ± 10.9            | 30.4 ± 18.1 | 35.4 ± 24.0 | 28.6       | 24.6 ± 14.2            | 37.6 ± 9.1  | 48.7 ± 33.2 | 37          |                        |             |             |            |
| Lsd <sub>0.05</sub> crop type       | 8.32                   |             | 17.52       |            |                        |             |             |             |                        |             |             |            |
| Lsd <sub>0.05</sub> nutrient source | 8.32                   |             | 17.52       |            |                        |             |             |             |                        |             |             |            |
| Lsd <sub>0.05</sub> interaction     | NS                     |             | NS          |            |                        |             |             |             |                        |             |             |            |
| CV%                                 | 29.2                   |             | 47.4        |            |                        |             |             |             |                        |             |             |            |

FEW, Fish effluent water; NEW, Non-effluent water; BSFF, Black soldier fly frass; NS, Not significant; LSD, least significant difference.

TABLE 7 Effect of crop type and nutrient source on the number of leaves in season 2.

| Season 2<br>Crop type               | Nutrient source <sub>week 1</sub> |             |              |             | Nutrient source <sub>week 2</sub> |             |              |             | Nutrient source <sub>week 3</sub> |             |              |             |
|-------------------------------------|-----------------------------------|-------------|--------------|-------------|-----------------------------------|-------------|--------------|-------------|-----------------------------------|-------------|--------------|-------------|
|                                     | NEW                               | FEW         | BSFF<br>+NEW | Mean        | NEW                               | FEW         | BSFF<br>+NEW | Mean        | NEW                               | FEW         | BSFF<br>+NEW | Mean        |
| Kale                                | 3.3 ± 0.3                         | 4 ± 0.3     | 4 ± 0.0      | 3.8 ± 0.4   | 4.2 ± 0.7                         | 5.9 ± 0.4   | 5.8 ± 0.5    | 5.3 ± 1.0   | 5.3 ± 0.3                         | 7.9 ± 0.5   | 7.2 ± 0.2    | 6.8 ± 1.3   |
| African nightshade                  | 3.8 ± 0.2                         | 4.8 ± 0.7   | 4.7 ± 1.9    | 4.4 ± 0.6   | 4.9 ± 0.2                         | 8 ± 0.3     | 7.8 ± 4.4    | 6.9 ± 1.7   | 6.2 ± 0.5                         | 13.6 ± 0.5  | 10.6 ± 11.7  | 10.1 ± 3.7  |
| Spider plant                        | 4.3 ± 0.0                         | 6.1 ± 0.5   | 5.4 ± 0.5    | 5.3 ± 0.9   | 6.2 ± 0.5                         | 13.9 ± 2.0  | 13.2 ± 2.9   | 11.1 ± 4.3  | 12 ± 4.1                          | 36.2 ± 7.0  | 29 ± 4.1     | 25.7 ± 12.4 |
| Mean                                | 3.8 ± 0.5                         | 5 ± 1.1     | 4.7 ± 0.7    | 4.5         | 5.1 ± 1.0                         | 9.3 ± 4.1   | 8.9 ± 3.8    | 7.8         | 7.9 ± 3.6                         | 19.2 ± 15.0 | 15.6 ± 11.7  | 14.2        |
| Lsd <sub>0,05</sub> crop type       | 0.39                              |             |              |             | 1.12                              |             |              |             | 2.79                              |             |              |             |
| Lsd <sub>0,05</sub> nutrient source | 0.39                              |             |              |             | 1.12                              |             |              |             | 2.79                              |             |              |             |
| Lsd <sub>0,05</sub> interaction     | NS                                |             |              |             | 1.93                              |             |              |             | 4.83                              |             |              |             |
| CV%                                 | 8.8                               |             |              |             | 14.4                              |             |              |             | 19.6                              |             |              |             |
|                                     | Nutrient source <sub>week 4</sub> |             |              |             | Nutrient source <sub>week 5</sub> |             |              |             |                                   |             |              |             |
| Crop type                           | NEW                               | FEW         | BSFF<br>+NEW | Mean        | NEW                               | FEW         | BSFF<br>+NEW | Mean        |                                   |             |              |             |
| Kale                                | 7.1 ± 1.1                         | 11.1 ± 1.3  | 8.9 ± 0.2    | 9.0 ± 2.0   | 10.8 ± 2.2                        | 15.1 ± 1.6  | 11.3 ± 1.0   | 12.4 ± 2.4  |                                   |             |              |             |
| African nightshade                  | 11 ± 1.8                          | 23.9 ± 3.9  | 18.2 ± 18.0  | 17.7 ± 6.5  | 17.1 ± 3.9                        | 40.9 ± 5.1  | 28.8 ± 26.6  | 28.9 ± 11.9 |                                   |             |              |             |
| Spider plant                        | 25.8 ± 6.7                        | 54.4 ± 13.0 | 44.0 ± 8.6   | 41.4 ± 14.5 | 34.8 ± 3.7                        | 75.3 ± 16.9 | 70.2 ± 19.3  | 60.1 ± 22.1 |                                   |             |              |             |
| Mean                                | 14.6 ± 9.9                        | 29.8 ± 22.2 | 23.7 ± 18.2  | 22.7        | 20.9 ± 12.4                       | 43.8 ± 30.2 | 36.8 ± 30.2  | 33.8        |                                   |             |              |             |
| Lsd <sub>0,05</sub> crop type       | 5.08                              |             |              |             | 9.83                              |             |              |             |                                   |             |              |             |
| Lsd <sub>0,05</sub> nutrient source | 5.08                              |             |              |             | 9.83                              |             |              |             |                                   |             |              |             |
| Lsd <sub>0,05</sub> interaction     | 8.80                              |             |              |             | 17.03                             |             |              |             |                                   |             |              |             |
| CV%                                 | 22.4                              |             |              |             | 22.5                              |             |              |             |                                   |             |              |             |

FEW, Fish effluent water; NEW, Non-effluent water; BSFF, Black soldier fly frass; NS, Not significant; LSD, least significant difference.

TABLE 8 Effect of crop type and nutrient source on fresh and dry biomass (t ha<sup>-1</sup>) in season 1.

| Season 1<br>Crop type                | Nutrient source fresh biomass |            |              |            | Nutrient source Dry biomass |           |              |           |
|--------------------------------------|-------------------------------|------------|--------------|------------|-----------------------------|-----------|--------------|-----------|
|                                      | NEW                           | FEW        | BSFF<br>+NEW | MEAN       | NEW                         | FEW       | BSFF<br>+NEW | MEAN      |
| Kale                                 | 5.7 ± 0.3                     | 11.5 ± 1.2 | 15.3 ± 0.9   | 10.8 ± 4.8 | 0.7 ± 0.1                   | 1.6 ± 0.4 | 2.1 ± 0.4    | 1.5 ± 0.7 |
| African nightshade                   | 5.4 ± 0.4                     | 12.2 ± 2.4 | 13.0 ± 2.8   | 10.2 ± 4.2 | 0.7 ± 0.1                   | 1.8 ± 0.7 | 1.9 ± 0.3    | 1.5 ± 0.7 |
| Spider plant                         | 8.5 ± 0.6                     | 12.7 ± 1.2 | 16.4 ± 1.0   | 12.5 ± 4.0 | 1.2 ± 0.3                   | 2.0 ± 0.5 | 2.4 ± 0.6    | 1.9 ± 0.6 |
| Mean                                 | 6.5 ± 1.7                     | 12.1 ± 0.6 | 14.9 ± 1.7   | 11.2       | 0.9 ± 0.3                   | 1.8 ± 0.2 | 2.1 ± 0.3    | 1.6       |
| LSD <sub>0.005</sub> crop type       | 1.37                          |            |              |            | NS                          |           |              |           |
| LSD <sub>0.005</sub> nutrient source | 1.37                          |            |              |            | 0.41                        |           |              |           |
| LSD <sub>0.05</sub> interaction      | NS                            |            |              |            | NS                          |           |              |           |
| CV%                                  | 12.2                          |            |              |            | 26                          |           |              |           |

FEW, Fish effluent water; NEW, Non-effluent water; BSFF, Black soldier fly frass; NS, Not significant; LSD, least significant difference.

nutrient source significantly influenced both fresh and dry biomass, whereas crop type had a significant effect only on fresh biomass, as illustrated in Table 9. Kale had significantly greater fresh biomass (16.7 t ha<sup>-1</sup>) compared to African nightshade and spider plant (11.8 t ha<sup>-1</sup> and 11.3 t ha<sup>-1</sup>, respectively). Application of BSFF+NEW produced significantly greater fresh biomass (17.1 t ha<sup>-1</sup>) compared to FEW and NEW (13.5 t ha<sup>-1</sup> and 9.2 t ha<sup>-1</sup>, respectively). However, FEW and NEW had similar yields. Application of BSFF+NEW and FEW resulted in significantly higher biomass dry yield (2.5 t ha<sup>-1</sup> and 2.0 t ha<sup>-1</sup>, respectively) compared to NEW (1.2 t ha<sup>-1</sup>); however, BSFF+NEW and FEW did not differ significantly.

## Discussion

The results showed that the crop type, nutrient source, and their interaction significantly influenced growth and yield. Spider plant and African nightshade produced taller plants and more leaves compared to kale. In terms of biomass production, spider plant and kale recorded the greatest biomass in season 1 and season 2, respectively. These variations in growth and yield among the crops can be attributed to inherent differences in growth habits

and structural characteristics. Spider plant and African nightshade exhibit upright growth with stem elongation, whereas kale tends to have a compact growth habit. These findings are consistent with previous studies (Masuka et al., 2012; Wasonga et al., 2015; Kim et al., 2018), which reported similar morphological differences among these crops. Spider plant and African nightshade are characterized by extensive lateral branching and dense canopy production, which results in increased leaf production and biomass. However, kale exhibits a rosette growth habit with large leaf size and high biomass production. Mosenda (2020) attributed the number of leaves in a spider plant to its branching pattern. Similarly, Ochieng et al. (2017) demonstrated that enhanced branching in African nightshade leads to increased leaf formation. Carlos et al. (2022) attributed variations in plant height, plant branching, and biomass production of spider plant to morphological traits.

Regarding nutrient application, black soldier fly frass combined with non-effluent water (BSFF+NEW) and FEW produced significantly taller plants with more leaves and greater biomass than NEW. Black soldier fly frass and FEW contain essential nutrients, such as nitrogen, which promote vegetative growth and biomass accumulation. These findings are consistent with those of Phiri et al. (2025) and Beesigamukama et al. (2020), who reported increased crop productivity following BSFF application. Comparable results

TABLE 9 Effect of crop type and nutrient source on fresh and dry biomass (t ha<sup>-1</sup>) in season 2.

| Season 2<br>Crop type               | Nutrient source fresh biomass |            |              |            | Nutrient source Dry biomass |           |              |           |
|-------------------------------------|-------------------------------|------------|--------------|------------|-----------------------------|-----------|--------------|-----------|
|                                     | NEW                           | FEW        | BSFF<br>+NEW | MEAN       | NEW                         | FEW       | BSFF<br>+NEW | MEAN      |
| Kale                                | 13.2 ± 2.0                    | 14.3 ± 1.7 | 22.7 ± 2.5   | 16.7 ± 5.2 | 1.6 ± 0.3                   | 1.9 ± 0.1 | 3.2 ± 0.9    | 2.2 ± 0.9 |
| African nightshade                  | 7.2 ± 1.0                     | 12.6 ± 1.6 | 15.6 ± 0.7   | 11.8 ± 4.3 | 0.9 ± 0.1                   | 1.8 ± 0.3 | 2.3 ± 0.5    | 1.7 ± 0.7 |
| Spider plant                        | 7.3 ± 2.6                     | 13.5 ± 4.7 | 13.2 ± 2.2   | 11.3 ± 3.5 | 1.0 ± 0.2                   | 2.2 ± 1.0 | 1.9 ± 0.5    | 1.7 ± 0.6 |
| Mean                                | 92.2 ± 3.4                    | 13.5 ± 0.9 | 17.2 ± 4.9   | 13.3       | 1.2 ± 0.4                   | 2.0 ± 0.2 | 2.5 ± 0.7    | 1.9       |
| LSD <sub>0.05</sub> crop type       | 2.36                          |            |              |            | NS                          |           |              |           |
| LSD <sub>0.05</sub> nutrient source | 2.36                          |            |              |            | 0.53                        |           |              |           |
| LSD <sub>0.05</sub> interaction     | NS                            |            |              |            | NS                          |           |              |           |
| CV%                                 | 17.8                          |            |              |            | 28.6                        |           |              |           |

FEW, Fish effluent water; NEW, Non-effluent water; BSFF, Black soldier fly frass; NS, Not significant; LSD, least significant difference.

were reported by Ademola et al. (2019); Cerozi et al. (2022), and Ulas et al. (2022) when FEW was applied to crops. Additionally, BSFF and FEW contribute to improving soil health and stimulating microbial activity, which enhances nutrient availability and uptake. These findings align with those of Gurung et al. (2024) and Jupesta et al. (2025), who reported a concurrent increase in crop productivity and improvement in soil health when using BSFF. Samuel et al. (2021) and Fruscella et al. (2023) reported increased crop productivity and improved soil health following FEW application.

However, the lack of a significant effect of the nutrient source on plant growth during the early stages can be linked to the delayed mineralization and nutrient availability associated with organic nutrient sources, such as BSFF+NEW and FEW. This delay in nutrient availability often results in limited growth responses during initial stages, as observed in similar studies (Orangi et al., 2020; Zondo et al., 2025). Furthermore, organic inputs typically require microbial decomposition before nutrients become plant-available, explaining the delayed response.

Despite the presence of interaction between crop type and nutrient source on plant height and the number of leaves, the nutrient source (BSFF+NEW, FEW, or NEW) had no significant effect on kale. This observation can be attributed to the genetic makeup of kale, which governs its compact rosette growth habit. Pipan and Neji (2024) reported that genetic differences among kale varieties influence morphological characteristics, such as plant height and leaf traits. Furthermore, the slow mineralization of organic inputs may have delayed nutrient availability, reducing their immediate impact on kale growth. Similar findings have been reported by Beesigamukama et al. (2020) and Shaji et al. (2021). In contrast to the present study, Abiya et al. (2022) reported increased plant height and a higher number of leaves in kale treated with black soldier fly frass compared to NPK fertilizer. According to Jones et al. (2025) and Haris et al. (2024), the application of nutrients in kale resulted in higher crop productivity. This suggests that plant responses may vary depending on the cultivar and type of nutrient applied.

However, the application of FEW and BSFF+NEW to African nightshade and spider plant resulted in taller plants with more leaves compared to NEW alone. The application of organic nutrient sources in spider plant and African nightshade improves nutrient availability and uptake efficiency, leading to increased vegetative growth. Similar results have been reported by Chemutai (2019), Tellen and Mbiseh (2020), and Njukeng et al. (2017), who reported increased productivity in African nightshade following organic nutrient application. Similarly, studies by Gonye et al. (2017); Maniaji (2018), and Mutoro et al. (2019) have demonstrated that application of organic nutrient sources improves spider plant productivity.

## Conclusion

The findings of this study demonstrate that crop type, nutrient source, and their interaction had a significant effect on growth and yield. Spider plant attained the highest plant height and leaf number (87.3 cm and 50, respectively), followed by African nightshade (38.4 cm and 45, respectively) and kale (14.4 cm and 16, respectively).

Furthermore, spider plant and kale recorded the greatest biomass (12.5 t ha<sup>-1</sup> and 16.7 t ha<sup>-1</sup>, respectively) in season 1 and season 2, respectively. These differences in growth and yield are attributed to variations in crop growth habits and their responses to nutrient application. Black soldier fly frass (BSFF+NEW) and FEW produced comparable plant growth and yield relative to NEW alone. This observation indicates that both black soldier fly frass and fish effluent water contain readily available nutrients, such as nitrogen and phosphorus, for plant uptake, resulting in increased growth and yield.

However, nutrient availability to crops may largely depend on the nutrient composition of FEW, which is primarily influenced by fish species, feed type, and management practices. Additionally, the use of FEW may be constrained to farmers engaged in aquaculture, limiting its broader applicability. Similarly, the nutrient content of BSFF is highly dependent on the substrate used for larval rearing, leading to variability in its composition. Furthermore, the relatively slow mineralization rate of BSFF may delay nutrient release and availability to crops.

Future research should focus on characterizing the nutrient composition of FEW under varying aquaculture conditions, including fish species, feeding regimens, and management practices, and assessing their implications for crop productivity. For BSFF, further studies are needed to evaluate the influence of different rearing substrates on nutrient composition and crop response. In addition, long-term studies are recommended to assess the cumulative effects of repeated applications of FEW and BSFF on soil nutrient dynamics, soil health, and the sustained productivity of African indigenous vegetables.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Author contributions

JT: Writing – original draft, Formal analysis, Methodology, Investigation, Conceptualization. HO: Visualization, Supervision, Writing – review & editing. PO: Investigation, Supervision, Writing – review & editing. EO: Supervision, Writing – review & editing. NO: Supervision, Writing – review & editing, Validation. JH: Funding acquisition, Resources, Writing – review & editing.

## Funding

The author(s) declared that financial support was received for this work and/or its publication. This study was funded by the European Commission under the project titled “Potentials of Agroecological Practices in East Africa with a focus on Circular Water – Energy-Nutrient Systems” (PrAEctiCe), under project call ref: HORIZON-CL6-2022-FARM2FORK-01–12 and Grant No. 101084248.

## Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

The author(s) declared that generative AI was not used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial

intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

## Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

## References

- Abiya, A. A., Kupesa, D. M., Beesigamukama, D., Kassie, M., Mureithi, D., Thairu, D., et al. (2022). Agronomic performance of kale (*Brassica oleracea*) and swiss chard (*Beta vulgaris*) grown on soil amended with black soldier fly frass fertilizer under wonder multistorey gardening system. *Agronomy*, 12 (9), 2211. doi: 10.3390/agronomy12092211
- Abukutsa-Onyango, M. (2007). The diversity of cultivated African leafy vegetables in three communities in Western Kenya. *Afr. J. Food Agric. Nutr. Dev.* 7, 01–15. doi: 10.18697/ajfand.14.ipgr1-3
- Abukutsa-Onyango, M. O. (2010). African indigenous vegetables in Kenya : Strategic repositioning in the horticultural sector volume 2 of inaugural lecture. Available online at: [https://www.researchgate.net/publication/235323508\\_African\\_indigenous\\_vegetables\\_in\\_Kenya\\_strategic\\_repositioning\\_in\\_the\\_horticultural\\_sector](https://www.researchgate.net/publication/235323508_African_indigenous_vegetables_in_Kenya_strategic_repositioning_in_the_horticultural_sector) (Accessed December 1, 2025).
- Abukutsa-onyango, M. O., and Karimi, J. (2016). Effects of nitrogen levels on growth and yield of broad-leafed african nightshade (*solanum scabrum*). *Acta horticulture* 745, 379–386. doi: 10.17660/ActaHortic.2007.745.23
- Ademola, T., Kabir, B., Babangida, I., Nasir, A., and Wagini, H. (2019). Co - production and biomass yield of amaranthus (*Amaranthus hybridus*) and tilapia (*Oreochromis niloticus*) in gravel - based substrate filter aquaponic. *Int. J. Recycl. Org. Waste. Agric.* 8, 255–261. doi: 10.1007/s40093-019-00297-5
- Alila, P. O., and Atieno, R. (2006). Agricultural policy in Kenya : Issues and processes 20–22.
- Beesigamukama, D., Mochoge, B., Korir, N. K., Fiaboe, K. K. M., Nakimbugwe, D., Khamis, F. M., et al. (2020). Exploring black soldier fly frass as novel fertilizer for improved growth, yield, and nitrogen use efficiency of maize under field conditions 11. doi: 10.3389/fpls.2020.574592
- Biernbaum, J. (2012). Organic matters : Feeding the soil and building soil quality 1–7.
- Bokelmann, W., Huyskens-keil, S., Ferenczi, Z., Stöber, S., and Kennedy, G. (2022). The role of indigenous vegetables to improve food and nutrition security : Experiences from the project HORTINLEA in Kenya, (2014 – 2018) 6, 1–19. doi: 10.3389/fsufs.2022.806420
- Bunde, M. A. (2017). Integrated soil fertility management in vegetable production systems : A potential for improved food security in Kenya 2–7.
- Carlos, A., Id, H., Achigan-dako, E. G., Sogbohossou, E. O. D., Id, E. S., Odindo, A. O., et al. (2022). Phenotypic variation in biomass and related traits among four generations advanced lines of cleome (*Gynandropsis gynandra* L. (Briq.)). 17, 1–26. doi: 10.1371/journal.pone.0275829
- Cerozi, B. S., Arlotta, C. G., and Richardson, M. L. (2022). Fish effluent as a source of water and nutrients for sustainable urban agriculture. *Agric. Switz.* 12, 10–15. doi: 10.3390/agriculture12121975
- Chavez, M. Y., Villa Ignacio, A., Craver, J. K., and Bousset, J. (2025). Investigating black soldier fly larval (*Hermetia illucens*) frass applications as a partial peat replacement and liquid fertilizer in brassicaceae crop production. *Agrochemicals* 4, 10–20. doi: 10.3390/agrochemicals4020008
- Chemutai, F. (2019). Effects of farmyard manure on growth and performance of *solanum nigrum* in embu county.
- Chepkoech, W., Mungai, N. W., Stöber, S., Bett, H. K., and Lotze-Campen, H. (2018). Farmers' perspectives: Impact of climate change on African indigenous vegetable production in Kenya. *Int. J. Clim. Change Strat. Manage.* 10, 551–579. doi: 10.1108/IJCCSM-07-2017-0160
- Choi, S., and Hassanzadeh, N. (2019). BSFL frass: a novel biofertilizer for improving plant health while minimizing environmental impact. *Candian. Sci. Fair. J.* 2, 41–46. doi: 10.18192/csrf.v2i220194146
- Climate, F. L. (2023). Kisumu county participatory climate risk assessment report financing locally-led climate action (FLLoCA) program.
- Da, C. T., Tu, P. A., Livsey, J., Tang, V. T., Berg, H., and Manzoni, S. (2020). Improving productivity in integrated fish-vegetable farming systems with recycled fish pond sediments. *Agronomy* 10. doi: 10.3390/agronomy10071025
- Diatta, A. A., Manga, A. G. B., Bassène, C., Mbow, C., Battaglia, M., Sambou, M., et al. (2023). Sustainable production of tomato using fish effluents improved plant growth, yield components, and yield in northern Senegal. *Agronomy* 13. doi: 10.3390/agronomy13112696
- Food and Agriculture Organization of the United Nations. (2021). *Standard operating procedure for soil pH determination*. Rome.
- Fruscella, L., Kotzen, B., Paradelo, M., and Milliken, S. (2023). Investigating the effects of fish effluents as organic fertilisers on onion (*Allium cepa*) yield, soil nutrients, and soil microbiome. *Sci. Hortic.* 321, 112297. doi: 10.1016/j.scienta.2023.112297
- Gonye, E., Kujjeka, G. T., Edziwa, X., Ncube, A., Masekesa, R. T., Icishahayo, D., et al. (2017). Field performance of spider plant (*Cleome gynandra* L.) under different agronomic practices. *Afr. J. Food Agric. Nutr. Dev.* 17, 12179–12197. doi: 10.18697/ajfand.79.15985
- Gurung, S. K., Mickan, B. S., Middleton, J. A., Singh, P. K., Jenkins, S. N., Rengei, Z., et al. (2024). Manure-derived black soldier fly frass enhanced the growth of chilli plants (*Capsicum annum* L.) and altered rhizosphere bacterial community. *Appl. Soil Ecol.* 105606.
- Haris, A., Nontji, M., Robbo, A., Akbar, A., and Berlian, A. A. (2024). Optimizing the growth and yield of kale (*Brassica oleracea* var. *acephala*) by providing eggshell liquid fertilizer and water hyacinth bokashi. *Jurnal. Agronomi. Tanaman. Tropika. Juatika.* 6, 735–748. doi: 10.36378/juatika.v6i3.3678
- Hayombe, P. O., Owino, F. O., and Awuor, F. O. (2018). Planning and governance of food systems in Kisumu City. *Urban. Food. Syst. Gov. Poverty. Afr. Cities. - Open. Access.* 116–127. doi: 10.4324/9781315191195
- Horneck, D. A., Sullivan, D. M., Owen, J. S., and Hart, J. M. (2011). Soil test interpretation guide.
- IFAD (2021). Stock-take report on agroecology in IFAD operations: An integrated approach to sustainable food systems.
- Jones, A., Naroju, S. P., Nandwani, D., Witcher, A., and Chowdhary, S. (2025). Impact of nitrogen fertilizer application rates on plant growth and yield of organic kale and swiss chard in vertical farming system. *Horticulturae* 11, 1–17. doi: 10.3390/horticulturae11070827
- Jonkman, N. T. R. J. M., Daniëlle Kooijman, E., Kalbitz, K., Rosa Maria Pouw, N., and Jansen, B. (2019). Women's agricultural practices and their effects on soil nutrient content in the Nyalenda urban gardens of Kisumu, Kenya. *Soil* 5, 303–313. doi: 10.5194/soil-5-303-2019
- Jupesta, J., Permana, I., and Sahari, B. (2025). Sustainable agriculture through black soldier fly larvae frass : Impacts on soil properties, shallot crop productivity, and cost analysis. 1, 8. doi: 10.53941/ubs.2025.100008
- Kawasaki, K., Kawasaki, T., Hirayasu, H., Matsumoto, Y., and Fujitani, Y. (2020). Evaluation of fertilizer value of residues obtained after processing household organic waste with black soldier fly larvae (*Hermetia illucens*). *Sus. Switz.* 12. doi: 10.3390/SU12124920
- Kim, Y. R., Mascarini, L., Lorenzo, G. A., and González, M. N. (2018). Planting density and its effect on plant height and rosette quality in ornamental cabbages for cutting 50, 49–64.

- Klammsteiner, T., Turan, V., Juárez, M. F. D., Oberegger, S., and Insam, H. (2020). Suitability of black soldier fly frass as soil amendment and implication for organic waste hygienization. *Agronomy* 10. doi: 10.3390/agronomy10101578
- Kodzwa, J. J., Madamombe, G., Masvaya, E. N., and Nyamangara, J. (2023). Optimization of African indigenous vegetables production in sub Saharan Africa : a review. *CABI. Agric. Biosci.* 4, 1–10. doi: 10.1186/s43170-023-00184-0
- Krause, H., Fafé, A., and Grote, U. (2019). Welfare and food security effects of commercializing African indigenous vegetables in Kenya. *Cogent. Food. Agric.* 5. doi: 10.1080/23311932.2019.1700031
- Lopes, I. G., Wiklicky, V., Vinnerås, B., Yong, J. W. H., and Lalander, C. (2024). Recirculating frass from food waste bioconversion using black soldier fly larvae: Impacts on process efficiency and product quality. *J. Environ. Manage.* 366. doi: 10.1016/j.jenvman.2024.121869
- Maniaji, B. (2018). Growth response of spider plant (*Cleome gynandra* L.) on plant population and phosphorus levels. *Asian Res. J. Agric.* 9, 1–11. doi: 10.9734/arja/2018/43396
- Masuka, A., Goss, M., and Pleasant, M. (2012). Morphological characterization of four selected spider plant (*Cleome gynandra* L.) morphs from morphological characterization of four selected spider plant (*Cleome gynandra* L.) morphs from 2, 646–657. doi: 10.22004/ag.econ.198011
- Melaku, S., and Natarajan, P. (2019). Status of integrated aquaculture-agriculture systems in Africa. *Int. J. Fish. Aquat. Stud.* 7, 263–269.
- Mosenda, E. (2020). Assessment of agronomic traits of selected spider plant (*Cleome gynandra* L.) accessions 9, 222–241. doi: 10.7275/n1wf-6y77
- Mugwe, J., Ngetich, F., and Otieno, E. O. (2020). Integrated soil fertility management in sub-Saharan Africa: Evolving paradigms toward integration 435–446. doi: 10.1007/978-3-319-95675-6\_71
- Mulokozi, D. P., Berg, H., Tamatamah, R., Lundh, T., and Onyango, P. (2021). Assessment of pond and integrated aquaculture (Iaa) systems in six districts of Tanzania. *J. Agric. Rural Dev. Tropics. Subtropics.* 122, 115–126. doi: 10.17170/kobra-202105253965
- Mutoro, K., Mwijita, M. R., Ndenga, C., and Mabele, I. (2019). Effects of nitrogen levels on growth and yield of spider plant in Kenya 7, 1–6. doi: 10.46882/IJHF/1082
- Nakitare, G. N., and Kollongei, N. (2023). Black soldier fly frass for improved soils, crop yields and environment among smallholders-mixed farming system in Kenya. *J. Agric. Forestry. Res.* 2, 11–24.
- Njukeng, N. J., Ngome, F. A., Efombagn, I. B. M., and Temegne, C. N. (2017). Response of African nightshade (*Solanum* sp.) to cassava peel-based manure in the humid forest zone of Cameroon. *Afr. J. Agric. Res.* 12, 1866–1873. doi: 10.5897/ajar2017.12315
- Ochieng, O. H., Opiyo, A. M., and Saidi, M. (2017). Different agronet covers influence physiological traits, growth and yield of African nightshade (*Solanum scabrum* Mill.) and spiderplant (*Cleome gynandra* L.) 15, 1–12. doi: 10.9734/IJPSS/2017/32620
- Okalebo, J. R., Gathua, K. W., and Woome, P. L. (2002). "A working manual," in *Laboratory methods of soil and plant analysis*, vol. 2. Nairobi, Kenya: TSBF-CIAT and Sacred Africa, 29–68.
- Orangi, B., Otiato, D. A., and Abukutsa-onyango, M. O. (2020). Effect of nitrogen source on growth, yield, quality, and nitrogen use efficiency of african nightshade varieties (*Solanum* spp.) grown in Kenya. doi: 10.7275/xh5s-z970
- Phiri, A. T., Zhang, H., and Mnthambala, F. (2025). Comparative effects of black soldier fly frass fertilizer and vermicompost on crop performance, soil organic carbon, and nutrient dynamics. doi: 10.1007/s44378-025-00095-8
- Pipan, B., and Neji, M. (2024). Genetic diversity of kale (*Brassica oleracea* L. var acephala) using agro - morphological and simple sequence repeat (SSR) markers. *Genet. Resour. Crop Evol.* 71, 1221–1239. doi: 10.1007/s10722-023-01686-6
- Rasowo, J., and Auma, E. O. (2006). "On farm trials with rice-fish cultivation in the west kano rice irrigation scheme, Kenya," in *NAGA, WorldFish Center Quarterly*, 29, 36–41. Available online at: [http://www.worldfishcenter.org/resource\\_centre/on-farm.pdf](http://www.worldfishcenter.org/resource_centre/on-farm.pdf) (Accessed November 14, 2025).
- Rodias, E., Aivazidou, E., Achillas, C., Aidonis, D., and Bochtis, D. (2021). Water-energy-nutrients synergies in the agrifood sector: A circular economy framework. *Energies* 14, 1–17. doi: 10.3390/en14010159
- Sakal, R., Singh, B. P., and Singh, A. P. (1984). Determination of threshold value of iron in soils and plants for the response of rice and lentil to iron application in calcareous soil. *Plant Soil* 82, 141–148. doi: 10.1007/BF02220778
- Samuel, O., Ifeoma, I., and Patrice, O. (2021). Impact of fish pond effluent on the physicochemical characterization of soil, growth and yield of maize crop 02, 221–238.
- Santos, C. C. J., Dannon, E. A., Bougna Tchoumi, H. H., Mbokou, S. F., Etchiha Afoha, S. A. P., Mignouna, D., et al. (2026). Black soldier fly frass as a sustainable organic fertilizer: enhancing productivity of leafy vegetables and soil health in Benin. *Front. Plant Sci.* 16. doi: 10.3389/fpls.2025.1663593
- Shaji, H., Chandran, V., and Mathew, L. (2021). Organic fertilizers as a route to control release of nutrients. In: F. B. Lewu, T. Volova, S. Thomas and R. K. R. Rakhimol, (Eds.), *Controlled Release Fertilizers for Sustainable Agriculture*. Academic Press, pp 231–345. doi: 10.1016/B978-0-12-819555-0.00013-3
- Tellen, V. A., and Mbiseh, S. (2020). Effectiveness of fortified liquid organic manure and inorganic fertilizer on the growth, physiological and pesticidal response of african nightshade (*Solanum scabrum*) 21, 30–46. doi: 10.9734/JAERI/2020/v21i1730155
- Ulaş, A., Yücel, Y. C., and Ulaş, F. (2022). The application of fish wastewater to improve the plant growth, development and yield of lettuce (*Lactuca sativa* L.). *Int. J. Agric. Environ. Food. Sci.* 6, 100–107. doi: 10.31015/jaefs.2022.1.14
- Wasonga, D. O., Ambuko, J. L., Chemining'wa, G. N., Odeny, D. A., and Crampton, B. G. (2015). Morphological characterization and selection of spider plant (*Cleome gynandra*) accessions from Kenya and South Africa. *Asian J. Agric. Sci.* 7 (4), 36–44.
- Zondo, N., Ntuli, N. R., Mavengahama, S., and Van Jaarsveld, C. M. (2025). Improving growth and yield of Cucurbita argyrosperma with goat manure. *Front. Plant Sci.* 16. doi: 10.3389/fpls.2025.1658365